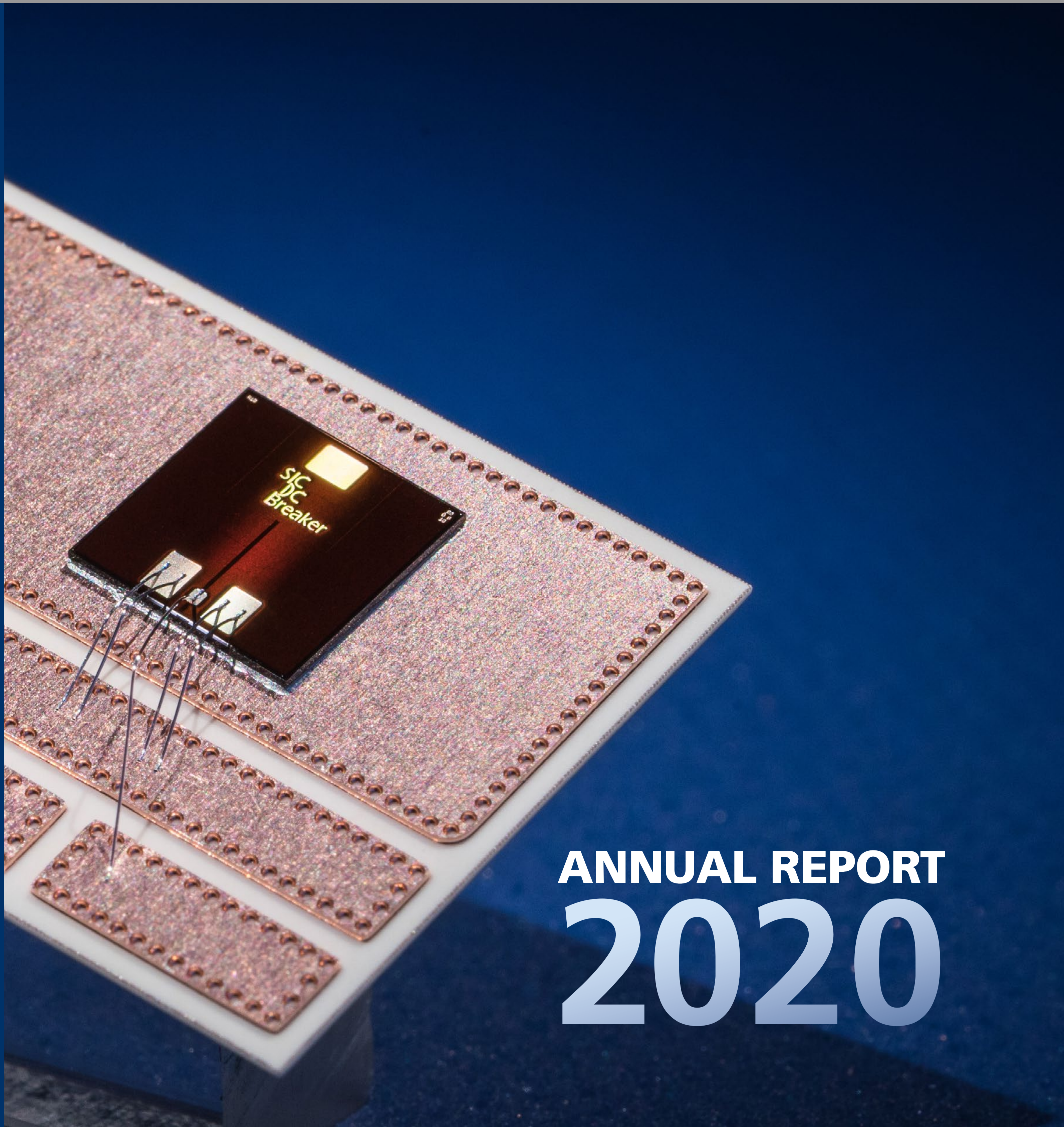
Fraunhofer

IISB

FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

Fraunhofer Institute for Integrated Systems and Device Technology IISB

Annual Report 2020



ANNUAL REPORT 2020

Imprint

Published by:
Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie IISB
Schottkystrasse 10
91058 Erlangen, Germany

Editors:
Martin März
Thomas Richter

Layout and Setting:
Betül Pineci
Thomas Richter

Printed on Recycled Paper

Climate-neutral Print Product

Klimaneutral
Druckprodukt
ClimatePartner.com/12518-1907-1001

Cover Photo:
Novel Circuit Breaker Chip from Fraunhofer IISB, Soldered and Bonded on Copper Substrate.
© Thomas Richter / Fraunhofer IISB

Backside Photo:
DC Grid Manager from Fraunhofer IISB in a Typical DC Distribution Panel.
© Anja Grabinger / Fraunhofer IISB

Note to the Chapter „Names and Data“

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

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

It includes the following contents:

- Guest Scientists
- Patents
- Publications
- PhD Theses
- Master Theses
- Bachelor Theses

ACHIEVEMENTS AND RESULTS

ANNUAL REPORT 2020

FRAUNHOFER INSTITUTE FOR

INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

Director (acting):
Prof. Dr.-Ing. Martin März

Fraunhofer IISB
Schottkystrasse 10
91058 Erlangen, Germany

Phone: +49 (0) 9131 761-0
Fax: +49 (0) 9131 761-390

E-Mail: info@iisb.fraunhofer.de
Web: www.iisb.fraunhofer.de

PREFACE


2

1

We are looking back on a year full of challenges and changes, which brought bitter constraints for all of us and massively affected our way of living and working. However, also many positive developments have been triggered or accelerated, offering new possibilities for our everyday work and communication, and underlining the significance of cohesion, team spirit, and mutual support. In that sense, Fraunhofer IISB continues its pioneering research on intelligent power electronic systems and technologies in close cooperation with our partners.

The institute consistently pursues its strategy of exploring seminal issues in the fields of materials, electron devices, packaging, and elaborate electronic systems, always having a look at the specific application and the overall systemic correlations. With an extensive modular toolkit for all kinds of electric vehicles, we support automotive and aviation industry in competitively creating the mobility of the future. I am very proud that in the past year the prestigious Joseph von Fraunhofer Prize was awarded to researchers of IISB for the first time, for developing a new generation of light, compact, and highly efficient DC/DC converters for fuel cell vehicles.

In general, hydrogen technology plays an increasingly substantial role in our research activities, with IISB contributing its huge experience in complex energy systems comprising a multitude of conversion, storage, and grid components. In addition, our comprehensive offer of silicon carbide technologies allows reaching new dimensions in energy efficiency, sensing quality, and performance.

This year, I am particularly grateful to my colleagues at our institute. With outstanding dedication, flexibility, and prudence, they substantially contributed to Fraunhofer IISB having weathered the global COVID crisis in very good shape so far. Pulling together with such terrific commitment, I am very optimistic for the hurdles to come. I also thank our partners in industry and all our funding authorities, especially the Bavarian Ministry of Economic Affairs, Regional Development and Energy as well as the German Federal Ministry of Education and Research for their lasting support.

Now let me commend our annual report to you and invite you to find out more about the latest work of Fraunhofer IISB. Let yourselves be inspired!

Sincerely yours,
Prof. Dr. Martin März (Erlangen, January 2021)

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

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

TABLE OF CONTENTS

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

It includes the following contents:

- Guest Scientists
- Patents
- Publications
- PhD Theses
- Master Theses
- Bachelor Theses

PROFILE AND HISTORY

PROFILE

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

The institute is located in Erlangen, Germany, and has branches in Nuremberg and Freiberg. As one of the 75 institutes of the Fraunhofer-Gesellschaft, the IISB does contract research for industry and public authorities. Moreover, it closely cooperates with the University of Erlangen-Nürnberg. The IISB has more than 280 employees plus numerous students working as research assistants. The institute is equipped with high-class laboratories, such as a test center for electric cars and an application center for DC grid technology. Together with the University, it operates 1500 m^2 of cleanroom area for semiconductor technology on silicon and silicon carbide.

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

HISTORY

The Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen is an important center of applied R&D for 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 sibling institute IIS-A, today's Fraunhofer Institute for Integrated Circuits IIS. In 2003, IIS and IISB became completely independent from each other as two individual Fraunhofer institutes. From 1985 until 2008, Prof. Heiner Ryssel was the head of the IISB. From 2008 to 2018, Prof. Lothar Frey was director and currently Prof. Martin März leads the institute. From the beginning, the IISB has been closely cooperating with the University of Erlangen-Nürnberg (FAU). In 2015, IISB together with IIS and FAU founded the "Leistungszentrum Elektroniksysteme" (LZE).

ADVISORY BOARD 2020

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

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

Dr. Helmut Gassel
Infineon Technologies AG

Dr. Christina Hack
Brose Fahrzeugteile GmbH & Co. KG

Thomas Harder
European Center for Power Electronics (ECPE)

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

Dr. Gabriel Kittler
X-Fab Global Services GmbH

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

Petra Mönius
Conti Temic microelectronic GmbH

Dr. Andreas Mühe
PVA TePla AG

Dr. Martin Schrems
i-conel GmbH

Dr. Thomas Stockmeier
ams AG

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

ORGANIZATIONAL CHART 2020

DIRECTOR

M. März (acting)

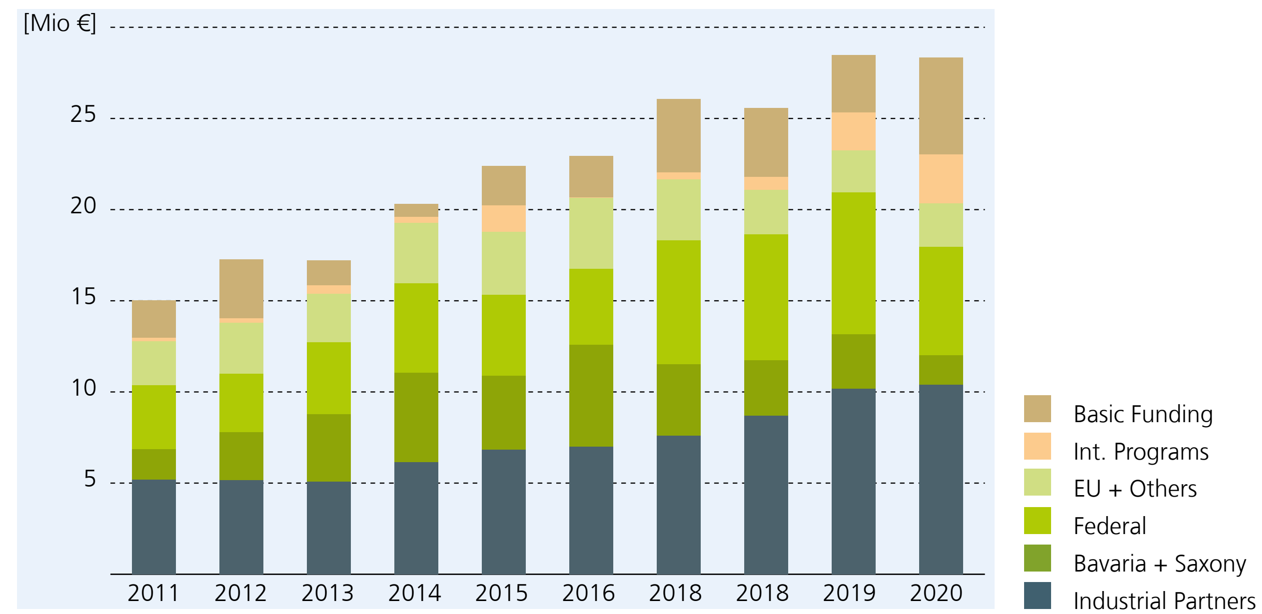
H. Hermes – ADMINISTRATION	J. Schöneboom – INFRASTRUCTURE
B. Fischer – STRATEGY & PR	G. Ardelean – IT

MODELING & ARTIFICIAL INTELLIGENCE J. Lorenz	MATERIALS J. Friedrich	TECHNOLOGY & MANUFAC-TURING A. Bauer	DEVICES & RELIABILITY A. Schletz	VEHICLE ELECTRONICS B. Eckardt	INTELLIGENT ENERGY SYSTEMS V. Lorentz
DOPING & DEVICES P. Pichler	SILICON C. Reimann	DEVICE PROCESSING V. Häublein	DEVICES T. Erlbacher	DRIVES & MECHATRONICS M. Hofmann	INDUSTRIAL POWER ELECTRONICS M. Billmann
STRUCTURE SIMULATION E. Bär	SILICON CARBIDE P. Berwian	THIN-FILM SYSTEMS M. Jank	ADVANCED POWER MODULES H. Rauh	AC/DC CONVERTERS S. Zeltner	BATTERY SYSTEMS V. Lorentz
LITHOGRAPHY & OPTICS A. Erdmann	NITRIDES E. Meißner	NANO TECHNIQUES M. Rommel	PACKAGING C. Bayer	DC/DC CONVERTERS S. Matlok	DC GRIDS B. Wunder
AI-AUGMENTED SIMULATION A. Roßkopf	ENERGY MATERIALS U. Wunderwald J. Heitmann	MANUFACTU-RING CONTROL M. Pfeffer	TEST & RELIABILITY A. Schletz	RF POWER & EMC B. Eckardt	ENERGY TECHNOLOGIES R. Öchsner
	MATERIAL QUALIFICATION F. Beyer			GRID INTERFACES S. Endres	DATA ANALYTICS M. Schellenberger
	EQUIPMENT SIMULATION J. Friedrich			AEROSPACE ELECTRONICS F. Hilpert	
				MEDIUM VOLTAGE ELECTRONICS T. Heckel	

NUMBERS

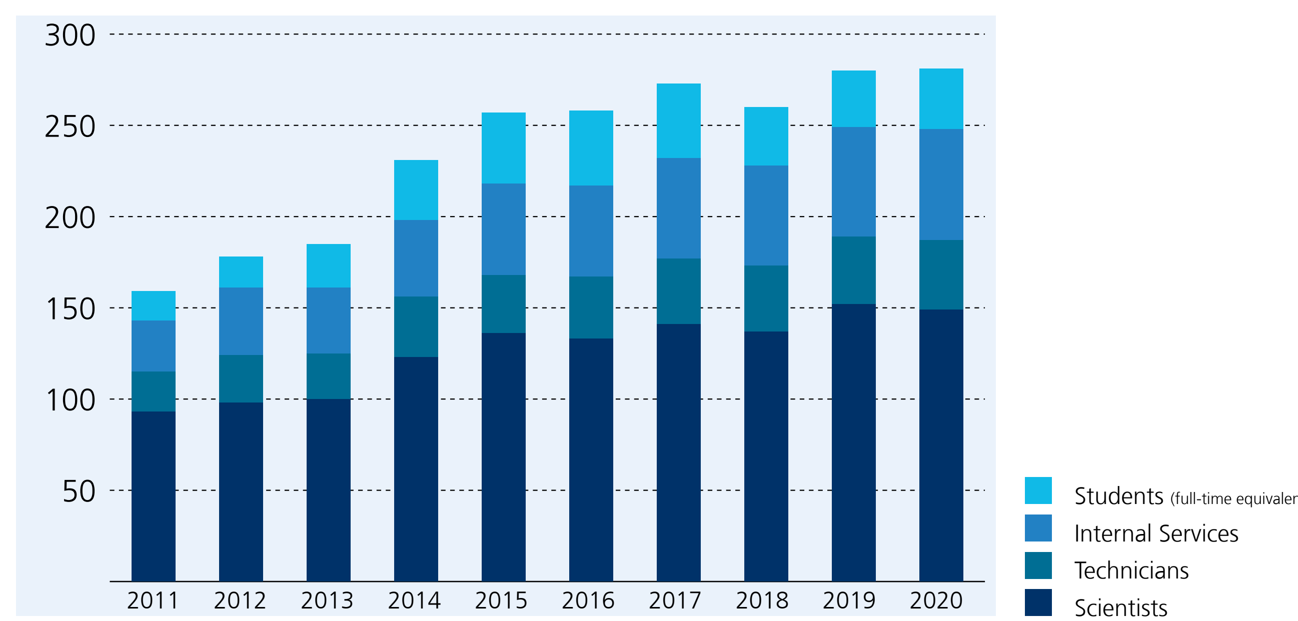
OPERATING BUDGET

28.32 Mio. € in 2020



STAFF DEVELOPMENT

281 Employees in 2020



RESEARCH AREAS

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 up to complete systems for application in mobility and energy technologies, with power electronics as a continuous backbone of the institute.

MATERIALS

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

TECHNOLOGY & MANUFACTURING

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

MODELING & ARTIFICIAL INTELLIGENCE

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

DEVICES

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

PACKAGING & RELIABILITY

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

VEHICLE ELECTRONICS

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

INTELLIGENT ENERGY SYSTEMS

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

ENERGY INFRASTRUCTURE TECHNOLOGIES

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

LOCATIONS

HEADQUARTERS OF FRAUNHOFER IISB ERLANGEN

Schottkystrasse 10, 91058 Erlangen

The headquarters of Fraunhofer IISB in Erlangen are located close to the University of Erlangen-Nürnberg. About 10,000 m² of laboratories and office area allow research and development on a broad range of power electronics, semiconductor technology, and materials development. A test center for electric cars, a medium-voltage application hall, an application center for DC grid technology, and extensive cleanroom area for semiconductor technology on silicon and silicon carbide, which is partly operated together with the Chair of Electron Devices of the University, are part of the available infrastructure.

BRANCH LABS OF FRAUNHOFER IISB

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

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

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

The THM is a joint department of Fraunhofer IISB and Fraunhofer ISE. It supports industry in technologies for the production of innovative semiconductor materials to be used in microelectronics, optoelectronics, and photovoltaics. The IISB part of the THM comprises 650 m².

NETWORK AND PARTNERS

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

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

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

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

NETWORK AND PARTNERS

CHAIR OF POWER ELECTRONICS (LEE), UNIVERSITY OF ERLANGEN-NÜRNBERG (FAU)

Since September 1, 2016, Prof. Dr. Martin März, acting director at Fraunhofer IISB, is heading the Chair of Power Electronics (LEE). The chair 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. LEE is part of the Energie Campus Nürnberg (EnCN) in the Fürther Strasse in Nuremberg, and the first chair grown out of the EnCN.

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

The Fraunhofer IISB and the Chair of Electron Devices (German abbreviation: LEB) of the University of Erlangen-Nürnberg are both currently headed by Prof. Martin März as acting director.

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

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

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

Dr. Anton Bauer
- Colloquium on Semiconductor Technology and Metrology

Dr. Bernd Eckardt
- Electrical Energy Storage Systems

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

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

Dr. Jochen Friedrich
- Course on Crystal Growth

Dr. Michael Jank
- Introduction to Printable Electronics
- Nanoelectronics

Dr. Jürgen Lorenz
- Process and Device Simulation

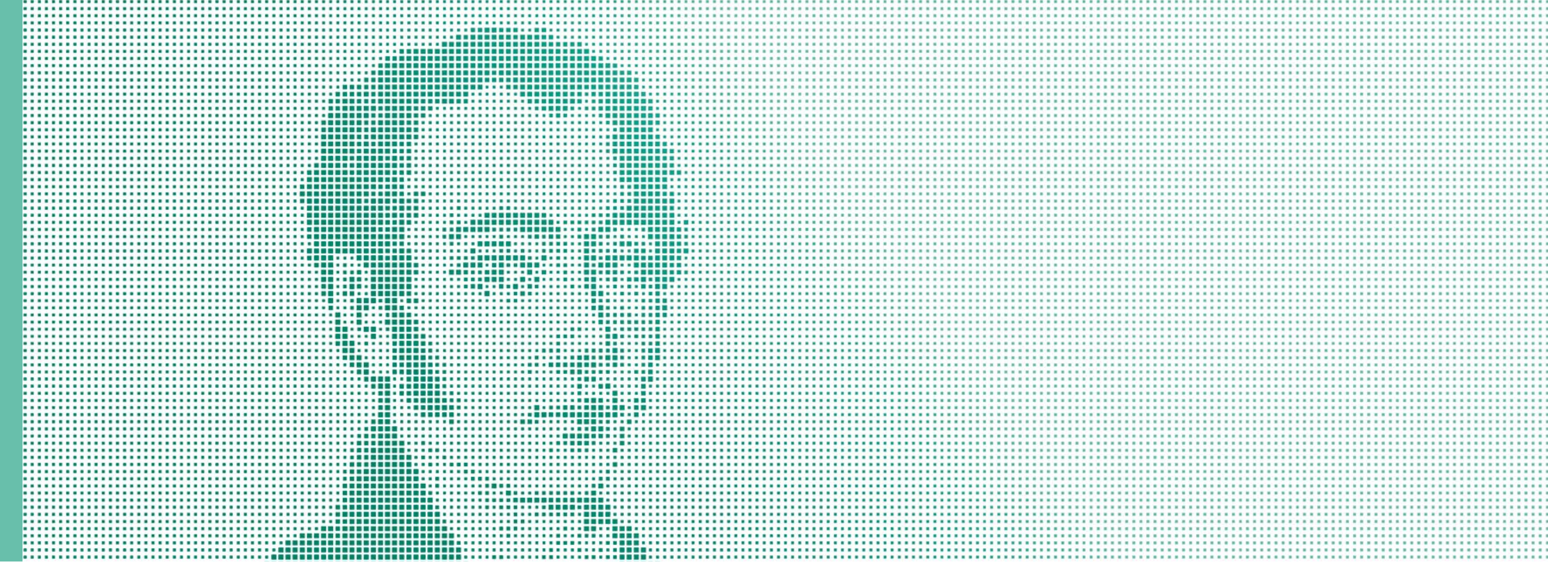
Prof. Dr. Martin März
- Power Electronics
- Power Electronics Colloquium
- Power Electronics for Decentralized Energy Supply - DC Grids
- Thermal Management for Power Electronics

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

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

THE FRAUNHOFER-GESELLSCHAFT

1



2

The Fraunhofer-Gesellschaft, headquartered in Germany, is the world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. Fraunhofer is a pioneer and catalyst for groundbreaking developments and a model of scientific excellence. As a source of inspirational ideas and sustainable scientific and technological solutions, Fraunhofer provides science and industry with a vital base and helps shape society both now and in the future.

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work with partners from industry and government to turn novel ideas into innovative technologies, to coordinate and realize key research projects with systemic relevance, and to strengthen the German and European economy with a commitment to value creation that is based on ethical principles. International collaboration with outstanding research partners and companies from around the world brings Fraunhofer into direct contact with the key regions that drive scientific progress and economic development.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 75 institutes and research units throughout Germany. The majority of the organization's 29,000 employees are qualified scientists and engineers who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros is generated through contract research. Around two thirds of Fraunhofer contract research revenue is derived from industry contracts and from publicly funded research projects. The remaining one third comes from the German federal and state governments in the form of base funding. This enables our institutes to work on solutions that are likely to become vital for industry and society in the coming years.

Applied research also has a knock-on effect that is felt way beyond the direct benefits to the customer. Our institutes boost industry's performance and efficiency, promote the acceptance of new technologies within society and help train the future generation of scientists and engineers that the economy so urgently requires.

We have a highly motivated staff working at the cutting edge of research. They are the key factor for our success as a scientific organization. Fraunhofer offers its researchers the opportunity to undertake independent, creative and, at the same time, targeted work. We provide our employees with a chance to develop the professional and personal skills that will enable them to take up positions of responsibility within Fraunhofer itself or at universities, in industry or in society. Students who work on projects at Fraunhofer Institutes have excellent career prospects in industry on account of the practical training they enjoy and the early experience they acquire in dealing with contract partners.

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

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

RESEARCH FAB MICROELECTRONICS GERMANY

Forschungsfabrik Mikroelektronik Deutschland

RESEARCH FAB MICROELECTRONICS GERMANY

ONE-STOP-SHOP: FROM BASIC RESEARCH TO CUSTOMER-SPECIFIC PRODUCT DEVELOPMENT

Since April 2017, Fraunhofer IISB and 12 other member institutes have formed the cross-site collaboration Research Fab Microelectronics Germany (FMD). With over 2000 scientists from the Fraunhofer Group for Microelectronics and the Leibniz institutes FBH and IHP, this research association is the largest and world-leading R&D group for applications and systems in micro- and nanoelectronics.

Consolidating the FMD

The FMD, with the aim to conduct research and development in Germany across several locations, was in its inauguration phase until 2020, supported by the Federal Ministry of Education and Research (BMBF) with around 350 million euros. This mainly involved modernising the research equipment of the 13 participating institutes of the Fraunhofer-Gesellschaft and the Leibniz Association. With a new concept for sustainable operation, the FMD is now entering the productive phase after the initial project period.

Versatile cooperation opportunities

In addition to the range of services for its customers from industry, FMD also offers a wide variety of cooperation opportunities for its partners in science. Among the highlights are services that aim directly at processing research questions cooperatively, for example through collaborative work in joint projects and the operation of so-called Joint Labs. In addition, it is possible to commission FMD institutes to test basic research concepts in the institutes' facilities with regard to their suitability in more application-oriented environments. Good examples of cooperation between FMD and universities as well as other institutions of higher education include the ASCENT+ project, the "iCampμs" research collaboration and the SmartBeam-Lab Joint Lab in Duisburg.

FMD at Fraunhofer IISB

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

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

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

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

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

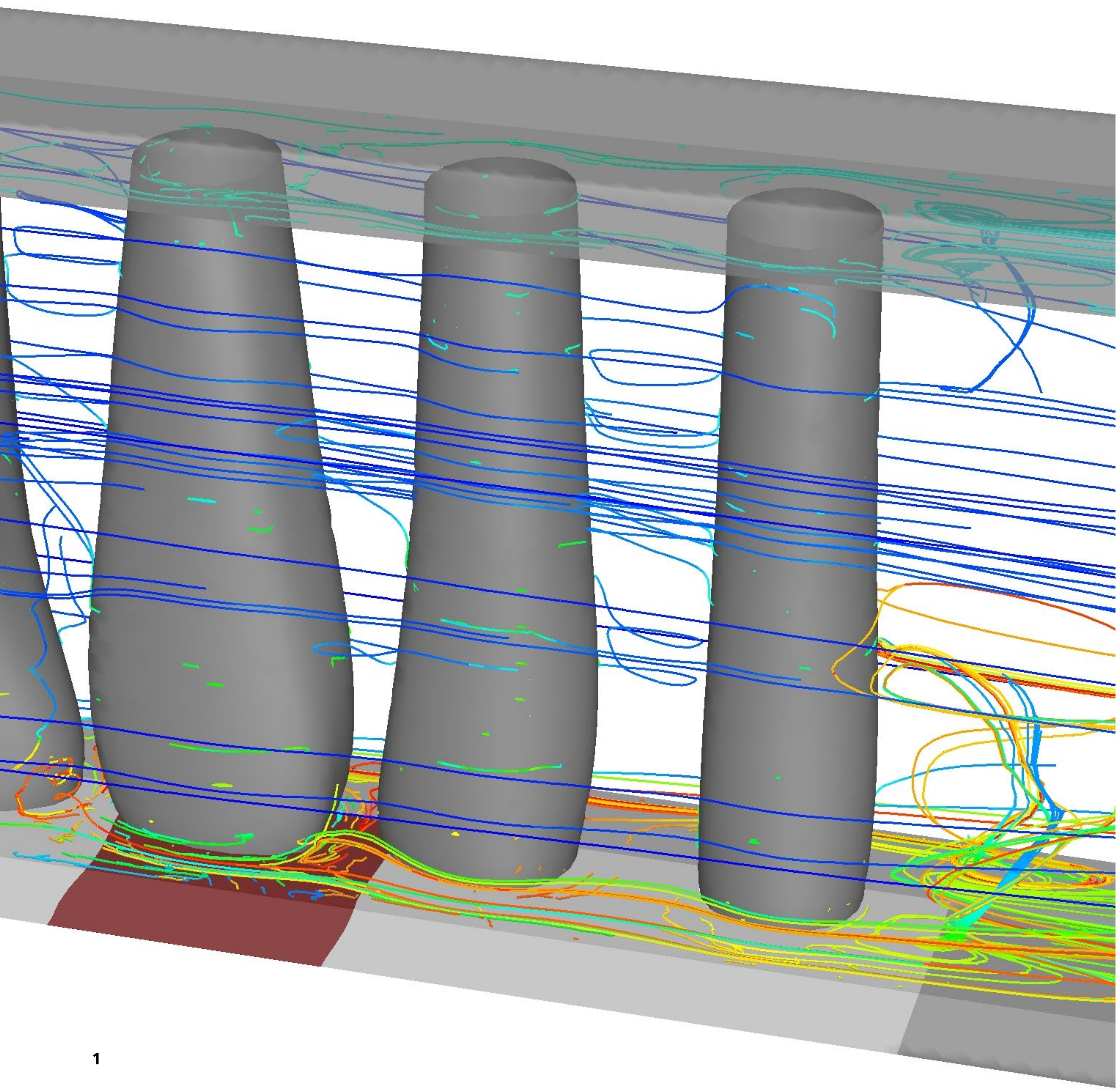
Find more information about the Research Fab Microelectronics Germany at https://www.forschungsfabrik-mikroelektronik.de/

1 *Previous double page: Line for backend of line processing for silicon carbide (SiC) at Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

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

MODELING AND ARTIFICIAL INTELLIGENCE

2



1

Modeling and simulation has during the last decades established itself as indispensable for the development and optimization of technologies and applications in most industrial areas. This also holds for the semiconductor area. Here, simulation methods range from first-principle calculations on the atomic or molecular scale through multiphysics simulations to large-area simulations using heuristic models which do not solve detailed physical equations but employ simplified analytical expressions and elaborated methods for extraction of the parameters required. At IISB, currently numerical methods are complemented by approaches from data science, known as Artificial Intelligence (AI).

In micro- and nanoelectronics, the simulation of semiconductor fabrication processes, devices, circuits, and systems (the so-called Technology-Aided Design TCAD) has a great share in the reduction of development costs in the semiconductor industry. The department "Modeling and Artificial Intelligence" contributes to this by developing physical models and programs for the simulation and optimization of semiconductor fabrication processes and equipment. Furthermore, it supports the characterization and optimization of lithography (incl. masks, materials, and imaging systems) and other processes, devices, circuits, and systems by providing and applying its own and third-party simulation and optimization tools. Whereas the research effort on the modeling and simulation of processes for aggressively scaled devices has since the foundation of the institute been the core of the activities of the department, the activities of the department have been strongly extended into the area of "More than Moore", which consists of fields such as analog / RF, low-power electronics, power electronics, and microsystems technology. These fields of application in particular often require the combination of heterogeneous competencies, because thermal, mechanical, optical, and chemical effects also occur in addition to electronic effects. Moreover, the use of advanced semiconductor materials such as silicon carbide or novel materials in lithography for photomasks and for photoresists enables important innovations in technology and products and poses new challenges for simulation. This gives rise to an additional demand for research in the areas of the department.

Addressing scaling of nanoelectronic devices

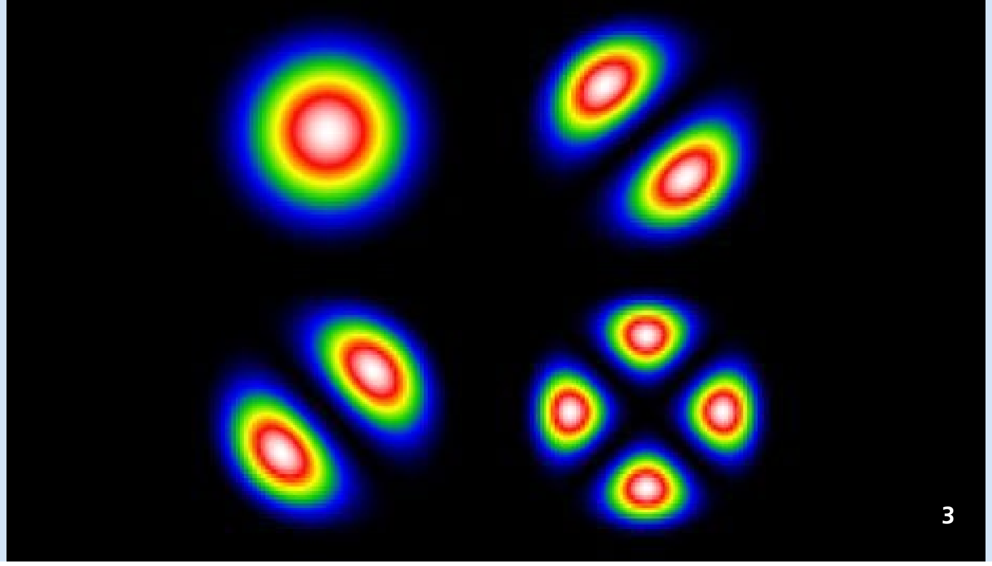
The department continues to make important contributions to support the further scaling of advanced nanoelectronic devices. These activities have been mainly carried out in four cooperative projects on the European level, funded by the European Commission and in some cases also by the member states:

The traditionally optics-driven resolution improvements through extreme ultraviolet (EUV) lithography have been addressed in the ECSEL KET pilot lines "Technology Advances for Pilotline of Enhanced Semiconductors for 3 nm (TAPES3) and "Pilot Integration of 3 nm Semiconducter Tech-

1 *Pin fin heat sink geometry with optimized heat transfer for a heat source located in the base plate, calculated based on a free shape optimization.*

2 *Dr. Jürgen Lorenz, head of the Modeling and Artificial Intelligence department. © Kurt Fuchs / Fraunhofer IISB*

MODELING AND ARTIFICIAL INTELLIGENCE



nology" (PIn3S). The main objective of TAPES3, started in October 2018, is to discover, develop and demonstrate lithographic, metrology, EUV mask technology, devices and process modules enabling 3 nm node technology. The PIn3S project, started in October 2019, aims to launch a pilot production line of 3-nanometer semiconductor technology. The focus is on optimizing process integration, and developing new lithography, mask repair and metrology tools. These key lithography projects are carried out by large consortia of companies, research institutes, and universities, coordinated by ASML, the leading vendor of lithography steppers. For both projects, the German part is coordinated by Zeiss. The department contributes with the extension and especially with the application of its leading-edge lithography simulator Dr.LiTHO. The activities of the department in the field of lithography are not limited to challenges in imaging, but beyond that include several optical and mechanical aspects of photomask and photoresist materials, and have partly led to groundbreaking results, presented e.g. in leading SPIE conferences and journals. Most research is carried out in close cooperation with industry, which frequently also funds the actions.

Novel and very innovative device architectures are required to continue the scaling of nanoelectronic devices which for several years now does no more refer to mere size ("More Moore") but to overall functionality, namely "Power-Performance-Area-and-Cost" (PPAC) scaling. In consequence, the most appropriate device architecture increasingly depends on the application in question. The Horizon 2020 project "Ion-irradiation-induced Si Nanodot Self-Assembly for Hybrid SET-CMOS Technology" (IONS4SET), coordinated by the Helmholtz Zentrum Dresden-Rossendorf, has aimed at merging of single electron transistors, granting low-power consumption, and CMOS technology, providing speed, performance and integrability. Here, the department has used simulation to assess technological options and device performance. This project has very successfully been completed towards the end of 2020. Within the project "Modeling Unconventional Nanoscaled Device Fabrication" (MUNDFAB), funded by the EC from January 2020 to December 2022 within the Horizon 2020 Programme, a consortium of European research institutes, universities and the semiconductor company STMicroelectronics, coordinated by IISB, develops atomistic models for dopants in novel architectures needed for PPAC (see the more detailed article below).

Furthermore, the department also earns license fees for software developed within "More Moore" projects. Our solid expertise gained in the field of "More Moore", for instance regarding tailored numerical methods for model implementation, provides a sound basis for the development and application of simulation in other fields, such as "More than Moore".

Software engineering and Artificial Intelligence

Software engineering techniques are developed and applied in various areas of the institute, among others for smart battery management, which is an important research topic in power electronics. Genetic algorithms, neural networks and hierarchical modeling approaches are utilized for component and system optimization. Multiphysics simulations that include electrical, mechanical, and/or thermal effects on a case-by-case basis are employed for applications especially in the power electronics area. Methods based on Artificial Intelligence have been increasingly used to enhance traditional approaches for modeling, simulation, and optimization, especially on system level. Key information hidden in large data sets including signals and pictures can be extracted in a largely automated and parallelized way to describe and optimize systems at all levels. The challenge and approach is not to replace physics-based modeling and simulation by data science based predictions, but to combine and utilize the strengths of these two complementary approaches. This is also highlighted by the department name "Modeling and Artificial Intelligence" which was newly introduced at the beginning of 2019, as well as by its group "AI-Augmented Simulation" in which this approach is implemented and exploited especially for the optimization of power electronic systems. Among others, the department pursues this approach in the project "Simulationsbasiertes Maschinelles Lernen für Design und optische Charakterisierung von Nanostrukturen" (simLOpt), which is being carried out since the beginning of this year together with the Chair of Electron Devices of the University of Erlangen-Nuremberg and the Zuse Institute Berlin, and funded by the BMBF within its programme "Mathematik für Innovation".

Conclusions and Outlook

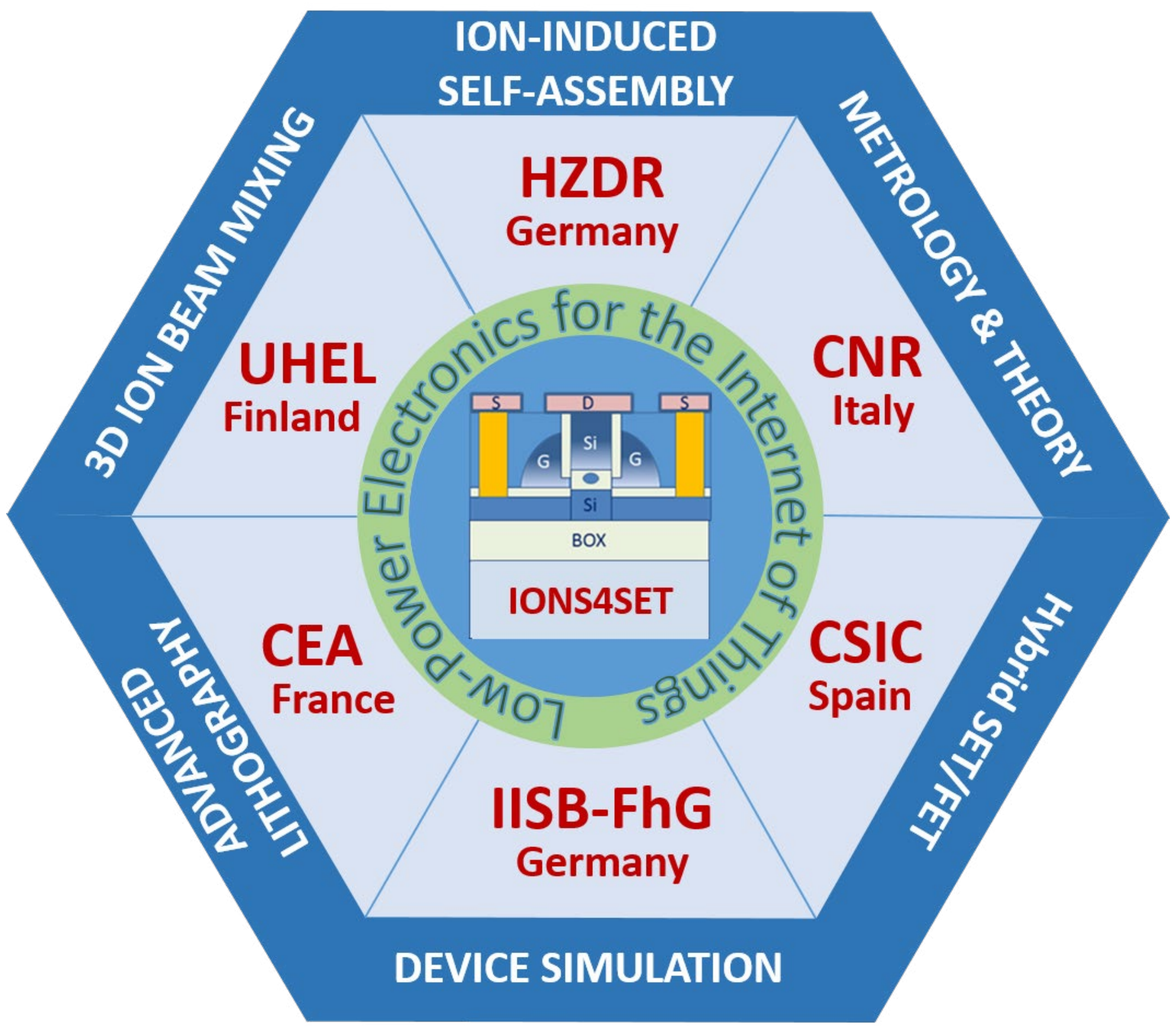
In the various areas of "More Moore", "More than Moore" and Power Electronics, the expertise gained or expanded in publically funded cooperative projects also provides the foundation for several research and development projects directly commissioned and financed by industry, e.g., for the optimization of processes and materials in lithography.

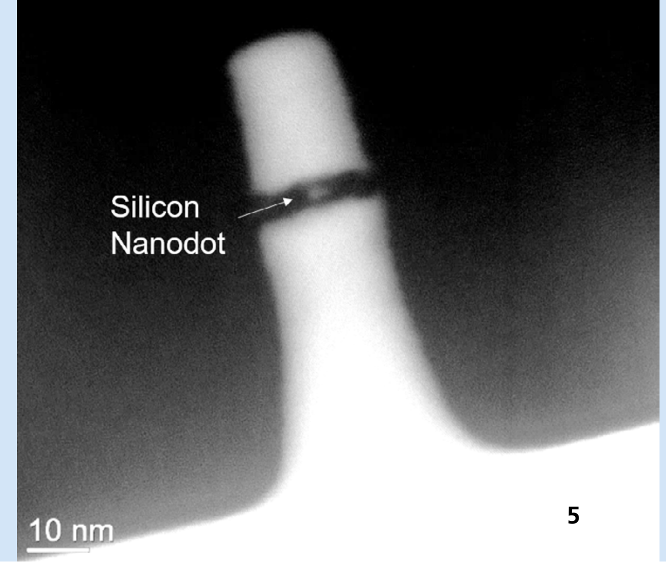
The department will continue its approach to performing focused work on physical models and algorithms in order to develop the necessary skills and tools on the one hand and to transfer these results to applications in industry on the other. Especially, the combination of physical understanding with the additional capabilities of data science implemented in AI approaches has considerably extended the capabilities of the department to provide promising research results and valuable support to industry. Here, a close and trustful cooperation based on sharing work according to the individual competencies and requirements of the partners has been a key element of the success achieved for many years.

3 *Square of quantum mechanical wave function for particle in a circular well (example from IISB in project IONS4SET): Ground state (upper left) and three exited states.*

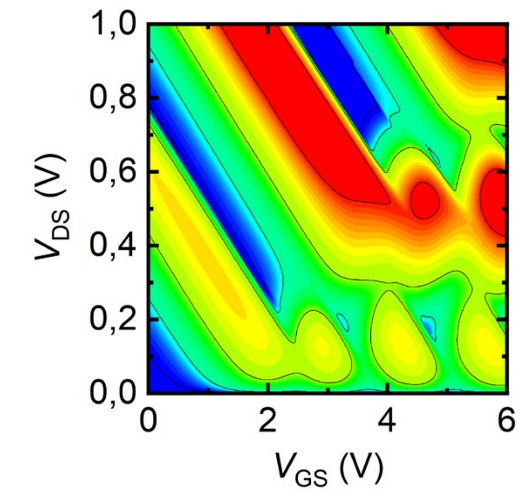
MODELING AND ARTIFICIAL INTELLIGENCE

TCAD in the Era of Equivalent Scaling and Beyond





5



6

TCAD IN THE ERA OF EQUIVALENT SCALING AND BEYOND

The very successful extension of Moore's law beyond the approach of mainly geometrical scaling during the last decade has been based on the utilization of novel materials, stress engineering, and especially on novel advanced device architectures to replace or complement traditional planar CMOS transistors. This has raised various new challenges on the models and tools for Technology Computer Aided Design, especially for process and device simulation. IISB continues to contribute to the worldwide endeavor to meet these challenges. Among others, it has initiated and currently coordinates the European project MUNDFAB on the development of process simulation models and tools needed especially for the three-dimensional stacking of transistors.

Equivalent Scaling

The traditional scaling of transistor sizes by about 0.7 within about two years, which has been very successful since the frist publication of Moore's law in 1965, could not go on forever because they started to approach atomic dimensions. This first happened around 2005 when the electrical gate oxide thickness was reduced to 1 nm and below, about 20 atomic layers or less. Silicon dioxide layers that thin were no longer reliable and had to be replaced by deposited dielectrics with a higher dielectric constant k, and, indirectly proportional to this, an electrical oxide thickness smaller than the geometrical one. This was the end of the era of the so-called "happy scaling" and the begin of the era of "equivalent scaling" and beyond that of "Power-Performance-Area-and-Costs" (PPAC) scaling, where performance improvement of transistors or interconnects was obtained by introducing advanced materials like SiGe to complement or replace silicon, buried oxide in so-called depleted SOI ("silicon-on-insulator") transistors, gate dielectrics with a higher or lower k to replace silicon dioxide for gate dielectrics or for interconnect barrier layers, respectively, or by stress engineering to increase carrier mobility along the transistor channel. A further key development has been the utilization of truly three-dimensional transistor architures starting from the so-called FinFETs to stacked nanowires or three-dimensional sequential fabrication and integration of transistor layers. Moreover, specific applications require the combination of different transistor architectures.

Equivalent scaling has raised and continues to raise the challenges for the generality, accuracy and efficiency of models and tools for process and device simulation. The institute has made and

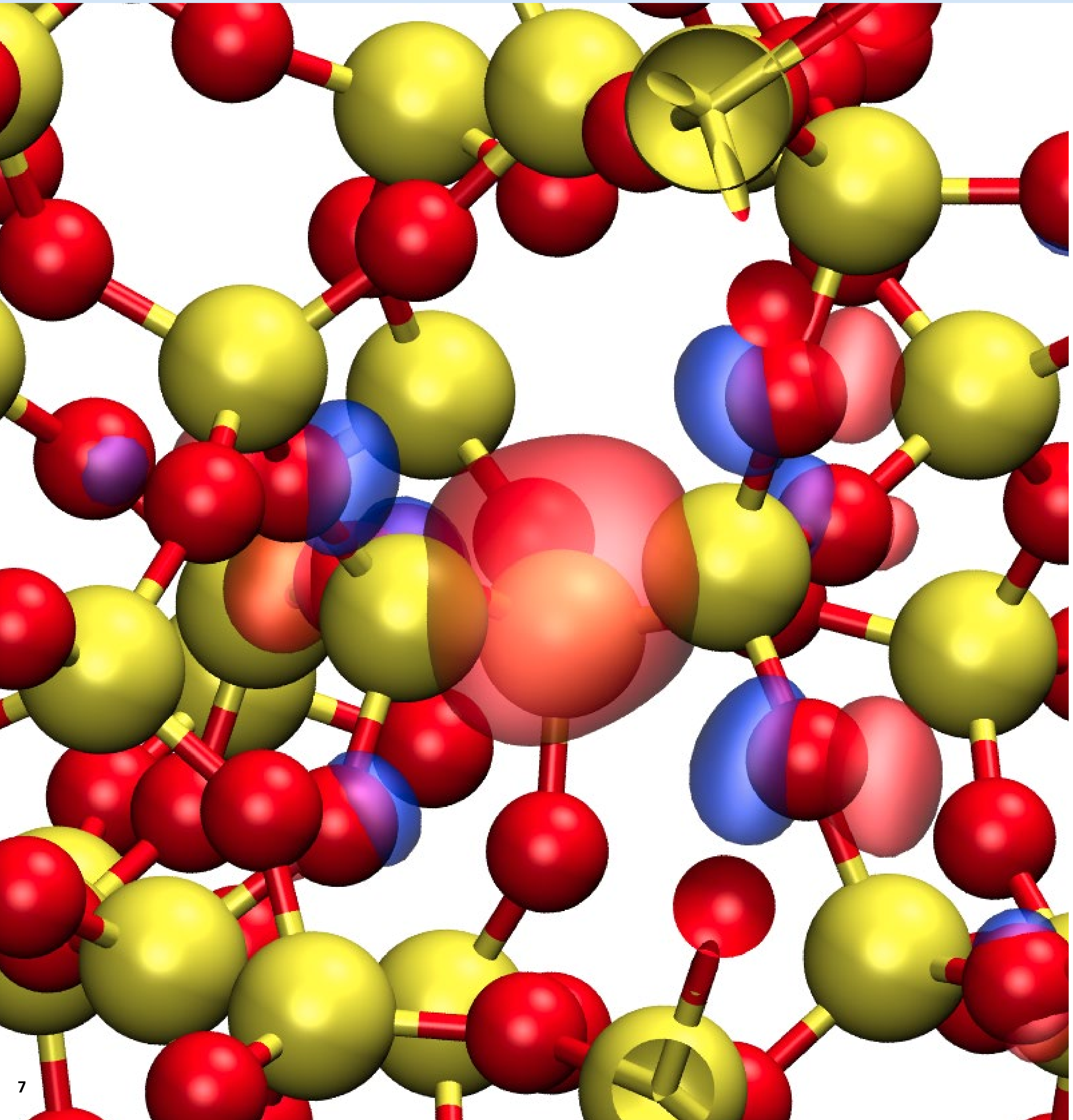
4 *Organization of the IONS4SET project.*

5 *Energy Filtered Transmission Electron Microscope image of a stacked Si/SiO_2/Si nanopillar with a single Si quantumdot embedded in the oxide from the IONS4SET Newsletter #1 available via www.ions4set.eu.*

6 *Typical IV characteristics of a SET with features resulting from the Coulomb blockade from F.J. Klüpfel, IEEE Access 7, 84053 (2019).*

MODELING AND ARTIFICIAL INTELLIGENCE

TCAD in the Era of Equivalent Scaling and Beyond



7

continues to make various contributions to address these challenges. Two recent activities are outlined below.

Hybrid integration: The Horizon 2020 project IONS4SET

It is well-known that Single Electron Transistors (SETs) are extremely low-energy dissipation devices. CMOS and SETs are complementary: SET is the champion of low-power consumption while CMOS advantages like high-speed, driving etc. compensate exactly for SET's intrinsic drawbacks. Unrivalled integration with high performance is expected for hybrid SET-CMOS architectures. Manufacturability is the roadblock for large-scale use of hybrid SET-CMOS architectures.

The HORIZON 2020 project "Ion-irradiation-induced Si Nanodot Self-Assembly for Hybrid SET-CMOS Technology" (IONS4SET, see www.ions4set.eu) carried out from February 2016 to July 2020 by a consortium of six European partners (see Figure 4) and coordinated by the Helmholtz-Zentrum Dresden-Rossendorf explored the fabrication of low-energy gate-all-around SET nanotransistor devices. These devices are based on electron tunneling via a single silicon quantum dot embedded in the silicon dioxide layer of a stacked nanopillar (see Figure 5). To assure room temperature operation, single dots with diameters below 3 nm have to be fabricated with tunnel distances of 1.2 nm and less to the source and drain electrodes. Formation of the nanodot was based on an innovative ion irradiation process. Within IONS4SET, among others the fabrication of a hybrid SET/FET device has been performed, which confirmed the possibility to combine SET fabrication with other device technologies which may include FETs, ASICs or mixed-modules. Besides nanocharacterization work carried out within its department Technology and Manufacturing, IISB has especially applied state-of-the-art first principle device simulation programs for the assessment and optimization of the SET structures (see Figure 6 for an example), and developed and published a novel compact model for electron tunneling through an Si nanodot in a stacked nanopillar that can be used for circuit simulations with SPICE or similar programs.

TCAD for 3D integration: The H2020 project MUNDFAB

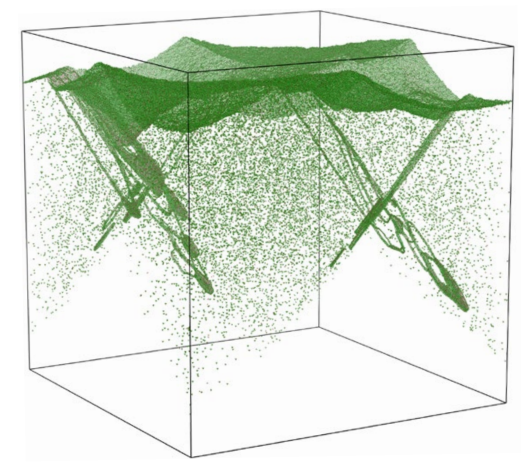
Because of power, energy, and cost reasons, a further development of big data and mobility applications as well as the Internet of Things will require continued Power-Performance-Area-and-Cost (PPAC, formerly More Moore) scaling. Already now, 3D sequential integration schemes play a major role in the research roadmaps of the leading semiconductor companies and research institutes. However, such integration schemes drastically limit the thermal budget for the thermal processes still needed e.g. for layer growth and dopant activation.

While particularly the early stages of industrial research and development in micro- and nanoelectronics are hardly conceivable now without the support by TCAD, we face the situation that the

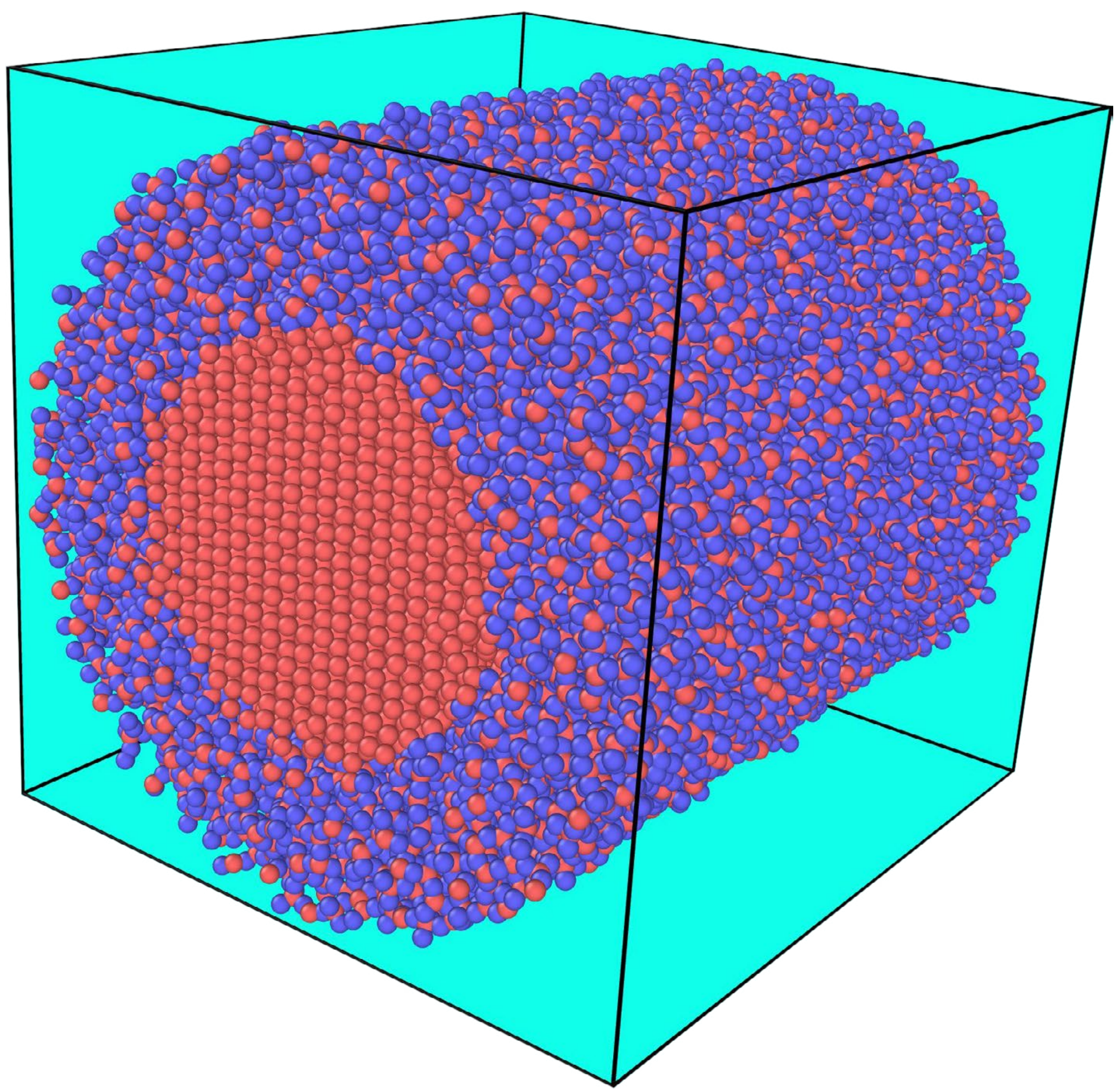
7 *Schematics of one of the three most prominent point defects in amorphous silicon dioxide: The oxygen vacancy.*
© Institute for Microelectronics, TU Wien

MODELING AND ARTIFICIAL INTELLIGENCE

TCAD in the Era of Equivalent Scaling and Beyond



9



8

mostly continuum-based tools available do no longer capture the basic trends in the low-temperature fabrication of nanoscaled electron devices, because key processes needed were so far hardly considered in simulation: 3D sequential integration limits the processing temperatures to a maximum of 500 to 600 °C. The majority of the processing steps for 3D sequential integration and the fabrication of unconventional nanoscaled devices imply growth processes and phase changes which are crystal-orientation dependent. The incomplete activation of dopants aggravates in nanosized electronic structures because of the small thermal budgets admissible during growth or annealing, or simply because interface sites with reduced activation make out a major part of the volume.

The overall objective of the project “Modeling Unconventional Nanoscaled Device FABrication” (MUNDFAB), funded by the EC within its Horizon 2020 programme, is to develop the missing atomistic TCAD process (Kinetic Monte Carlo, KMC, and Lattice Kinetic Monte Carlo, LKMC – see Figure 9 for an example) methodologies and models, and to integrate them into full TCAD workflows on the basis of Sentaurus Process and Sentaurus Device with external tools used only when the commercial software does not provide the required functionality. The project is carried out by a consortium consisting of Fraunhofer IISB (coordinator), the French partners STMicroelectronics, CEA/Leti and CNRS/LAAS, the Italian partner CNR-IMM, the Polish partner Łukasiewicz – IMiF, and TU Wien (Austria). The main scientific contributions of IISB include the investigation of models for the accumulation of damage during heated implants and the solid-phase epitaxial regrowth, the calibration of LKMC epitaxy models and of models for activation and interface segregation of dopants in epitaxially grown layers during annealing processes, optics simulations of the power dissipation in nanostructured materials during laser annealing, molecular dynamics simulations of thermal transport properties (see Figure 8 for an example), and TCAD workflows including the integration of external tools.

In spite of the early stage of the project and experimental delays caused by the COVID-19 pandemia 6 open access papers were published from MUNDFAB already in 2020, see the MUNDFAB home page (www.mundfab.eu).

8 *Atomic arrangement for the study of the radial heat transport in a cylindrical nanowire with a length of 10 nm. Radius of the nanowire is 2.6 nm, the nanowire side wall is covered by 2 nm of silicon dioxide.*

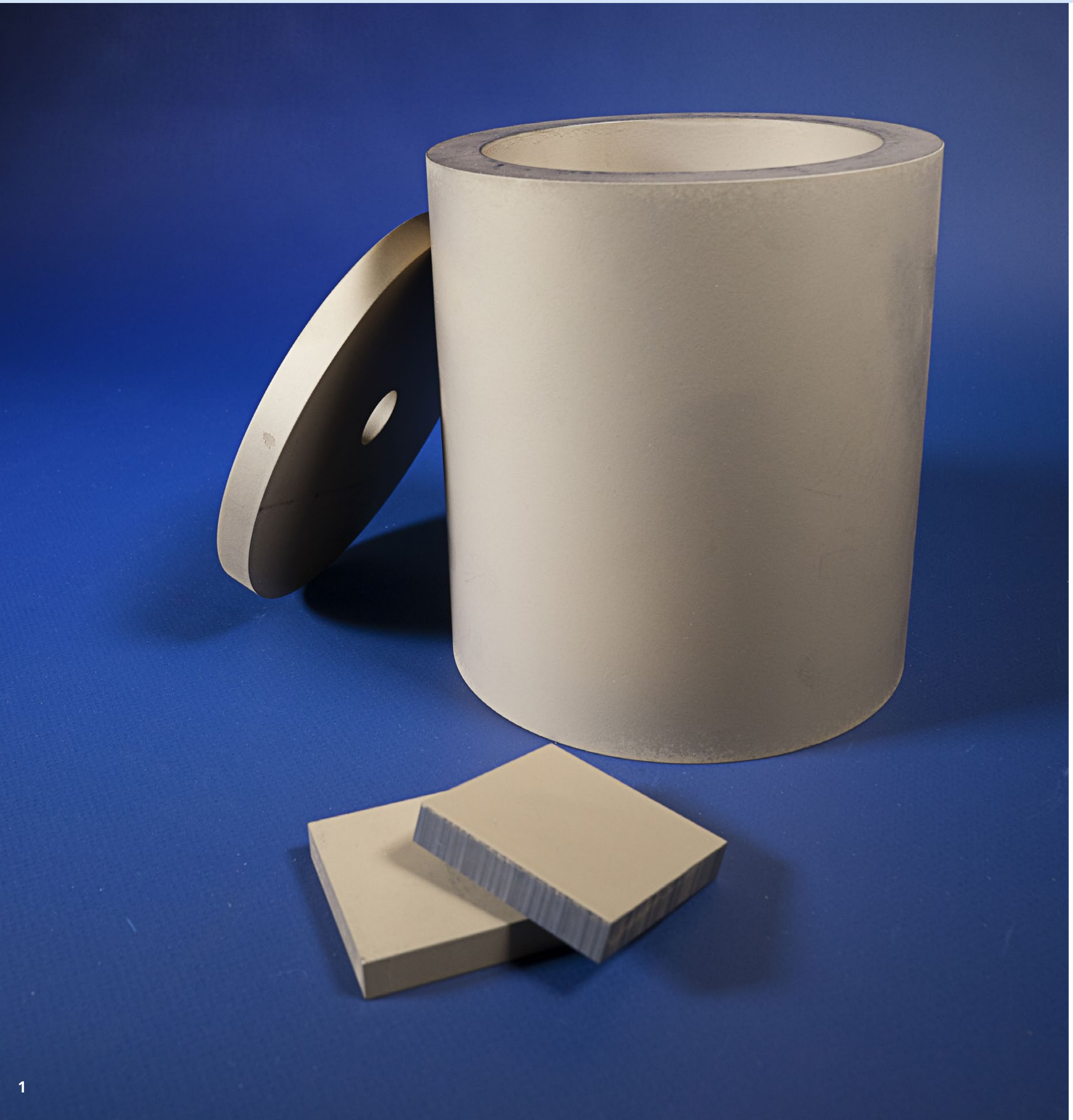
9 *Snapshot of an LKMC simulation of 3C-SiC epitaxial growth process obtained with the CNR LKMC tool developed within the H2020 project CHALLENGE and used within MUNDFAB.*

Contact

Dr. Jürgen Lorenz
Phone: +49 (0) 9131 761-210
juergen.lorenz@iisb.fraunhofer.de

MATERIALS


2


1

Our mission

We support material, device, and equipment manufacturers and their suppliers by delivering scientific-technological solutions in the field of production and characterization of crystals, epitaxial layers, and devices. For that purpose, we develop and improve equipment, processing, modelling, and characterization techniques. Our main focus is on semiconductors, but we are also experienced with optical, laser, and scintillator crystals. We pioneer novel ultra-wide band gap, quantum, and battery materials. Our customers' benefits are new products at reduced costs, higher yield, better quality, and improved device reliability.

Our strategy

Our strategy is the optimization of the manufacturing processes through a combination of thorough experimental process analysis, tailored characterization techniques, and numerical modeling. For that purpose, we have a well-suited infrastructure at hand, which consists of R&D type furnaces and epitaxial reactors, state-of-the-art metrology tools for the investigation of the physical, chemical, electrical, and structural material properties as well as powerful simulation programs well suited for heat and mass transport calculations in high temperature equipment.

Main areas

Silicon: We perform specific research on growth of silicon by the Czochralski technique mainly for power electronics and photovoltaics application with respect to higher yield and improved material quality. In the field of directional solidification, emphasis is put on innovative crucible and coating materials to reduce harmful defects and impurities. Numerical modeling gives us a deeper insight into the heat and mass transport phenomena occurring during growth. We offer individual services such as specific crystal growth experiments and characterization of silicon.

Silicon Carbide & Diamond: We develop the SiC epitaxy process with emphasis on improved material quality. State-of-the-art metrology tools such as UV-PL or XRT together with the possibility to process complete devices allow us to correlate the properties of the epilayer and the substrate with electrical device parameters. Based on these findings solutions are demonstrated how to overcome harmful defects. In addition, the potential of SiC and diamond for quantum applications is explored. In this area we investigate especially how color centers in SiC and diamond can be generated.

GaN & AlN: We develop the HVPE growth of GaN crystals. The process is optimized towards a high uniform V/III ratio along the growing interface by comparing in-situ process data, ex-situ determined properties of the crystal with results from numerical modeling of the growth process.

1 *Coated graphite samples used for SiC PVT reactor.* *© Anja Grabinger / Fraunhofer IISB*

2 *Dr. Jochen Friedrich, head of the Materials department.* *© Kurt Fuchs / Fraunhofer IISB*

MATERIALS

Advanced Coating Technologies @ IISB

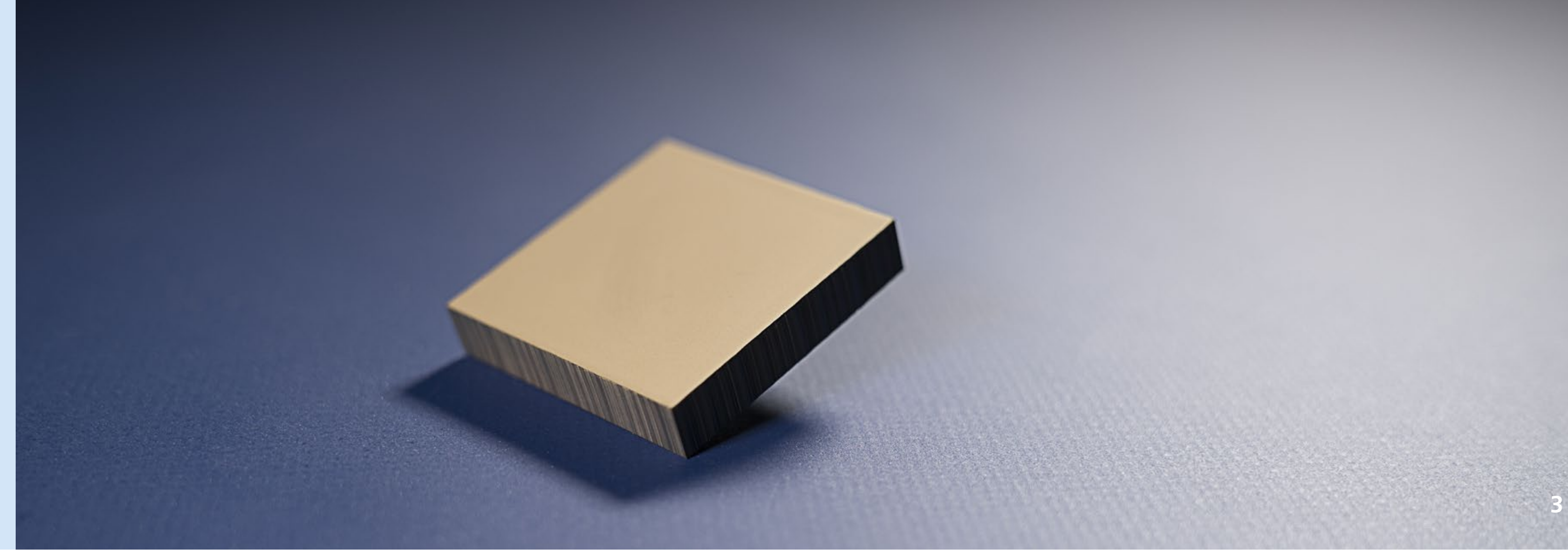
We pioneer the PVT growth of AlN crystals with the focus of deeper understanding of growth mechanisms and upscaling towards larger crystal diameters. In our wafering line we explore advanced GaN and AlN crystal preparation and characterization technologies for epi-ready wafers.

Other Crystal Materials: We are well experienced in the growth and characterization of a variety of other semiconductor materials (Ge, GaAs, InP, CdTe) as well as of optical, laser, and scintillator crystals (sapphire, oxides (LSO, YVO_4, Y_2O_3) or halides (CaF_2, $CeBr_3$) by different melt and solution growth techniques. We support our customers in the development of new crystal growth and epitaxy equipment and processes based on our broad material expertise and by using numerical simulation. Furthermore, we offer specific characterization services of crystal and wafer material.

Material qualification & test devices: We are experienced with the characterization of the electrical, structural, physical, and chemical properties of different crystal, wafer, and epi materials. This includes, e.g., specific techniques like x-ray topography, various atomic force microscopy methods, and electrical and optical defect spectroscopy. Furthermore, we utilize a customized design of test devices, which are processed in a fully CMOS equipped cleanroom facility. This allows a systematic correlation of the material properties to device performance and the identification of device critical defects.

Energy Materials: We analyze rechargeable aluminum-ion battery systems as future long-term alternative of lithium-ion batteries. Therefore, we develop new cathode materials and electrolytes. The materials are assembled into battery test cells and characterized with respect to their electrochemical behavior. Furthermore, we develop technologies to recycle silicon from sawing waste and to reuse the recycled silicon for thermoelectric generators, as anode material for lithium batteries, and for precursors for 3D printing of high strength, lightweight AlSi alloys.

Equipment Simulation: We support the development of high-temperature equipment and processes by our expertise in numerical modeling of the heat and mass transport phenomena. Specific expertise is available for crystal growth and epitaxial processes. But we are also experienced with thermal treatment of wafers and CVD applications. We provide solutions for furnace modifications in order to optimize the process equipment and we give new insights into the processes, especially for parameters that are hardly accessible via measuring techniques like species distributions or convection pattern.



3 *Coated graphite plate. © Anja Grabinger / Fraunhofer IISB*

ADVANCED COATING TECHNOLOGIES @ IISB

Coatings can have a wide range of application. They are very versatile and there are many different methods of applying them. Coatings may also be described as “hidden champions”, which are useful for many technical solutions. The water-based powder spray coating technology developed at Fraunhofer IISB is a cost-effective alternative to conventional methods, such as the deposition from the gas phase by Chemical-Vapour-Deposition (CVD) or others. The IISB coating technology is flexible in terms of size and geometry of the component and can be used also for part refurbishment.

Coatings for solar application

In principal, protective functions can be achieved with coatings very well. For example, they can protect against reactive gases and mechanical abrasion or serve as barriers against contaminations. In this way, we have successfully improved the purity of the crystal material in the production of silicon crystals for solar cells. The trick here is a high-temperature-resistant Si_3N_4 based coating for the SiO_2 ceramic crucible in which the solar silicon crystals are produced. These Si_3N_4 coatings have to withstand temperatures up to 1600 °C and interact with aggressive SiO vapour which is evaporating from the free silicon melt surface. These Si_3N_4 coating can be functionalized in different directions. First by e.g. modifying the surface roughness of the coating or placing special seed particles to influence the microstructure of the Si ingot. This leads to an improved quality of the multicrystalline silicon ingot towards a low content of harmful dislocation clusters. Second by e.g. applying an intelligent layer stack of different materials so that the diffusion of impurities from the crucible into the Si ingot can be suppressed. These results obtained within the SYNERGIE Project, funded by Federal Ministry for Economic Affairs and Energy, gave a guidance for industrial semiconductor crystal manufacturer, especially in the area of silicon photovoltaics, to judge which crystalline material quality results by using different kind of auxiliary materials.

Coatings for space

Based on this knowledge Fraunhofer IISB has developed a novel technology for ultra-high-temperature-resistant protective coatings for application temperatures exceeding 2000 °C for space applications. In the framework of the upcoming HOSSA project, funded by the German Space Agency, high-melting refractory metal compounds are the key to make rocket engines even more efficient and to improve the durability of thermal protection structures. The HOSSA project is based on IISB’s research work to apply ceramic protective coatings to fibre-reinforced composites using powder coating technology. The aim is to make the advantages of fibre-reinforced composite components, such as high elongation at fracture, high cracking resistance and dynamic load capacity, available for new applications by increasing heat and oxidation resistance as well

MATERIALS

Aluminum Ion Batteries as a Low Cost Lithium-free Electrical Storage

4

5

as increased mechanical abrasion resistance. The patented technology offers a considerable cost advantage over conventional coating processes and is also suitable for component repair.

High temperature resistant coatings for semiconductor processes

It is well known, that also in the areas of semiconductor processes harsh conditions can occur in which protective coatings could perform beneficial. Especially if one looks at the emerging SiC market, where SiC crystals were grown after the Physical-Vapour-Transport (PVT) method at temperatures well above 2000 °C under aggressive atmospheric conditions for more than one week process time. These harsh conditions lead to high production costs due to the needed exchange of graphite based furnace parts, especially in the hot-zone area. These graphite parts are with 30-40% cost share, one of the cost drivers for SiC crystal production. A doubling of the use-time of the graphite parts would lead to up to 20% cost reduction. Here the IISB coating technology could be one solution to increase run-to-run process reproducibility, to stabilize the growth conditions and to bring down the production costs for SiC wafers.

ALUMINUM ION BATTERIES AS A LOW COST LITHIUM-FREE ELECTRICAL STORAGE

Aluminium-ion batteries (AIB) employing natural graphite cathodes are promising alternatives to Li-ion systems due to their low-cost and sustainability because of highly abundant materials, as well as a high charge/discharge rates, stable long-term cycle life with non-toxic and non-flammable materials. The theoretical volumetric capacity of an Aluminium metal anode is four times higher than that of metallic Li. The focus of basic research for AIBs is currently on the development of suitable, inexpensive electrolytes in contrast to commonly used ionic liquid based electrolytes, like different deep eutectic solvents (DES, also known as ionic liquid analogues, ILA). At the same time, the advancement for the manufacturing of optimized graphite cathodes is required. In combination with inexpensive natural graphite (NG) as cathode material and the Al current collector as likewise anode material, the overall costs of this alternative electrical storage system can be considerably reduced.

In the IISB battery lab at Fraunhofer THM in Freiberg, Saxony (Figure 5) special lab cells (ELCells®) are used for investigations to improve the cell performance by better understanding the influence of electrode material properties and interaction with different electrolytes (Figure 7).

4 *Spray coating of a solar crucible.* *© Kurt Fuchs / Fraunhofer IISB*

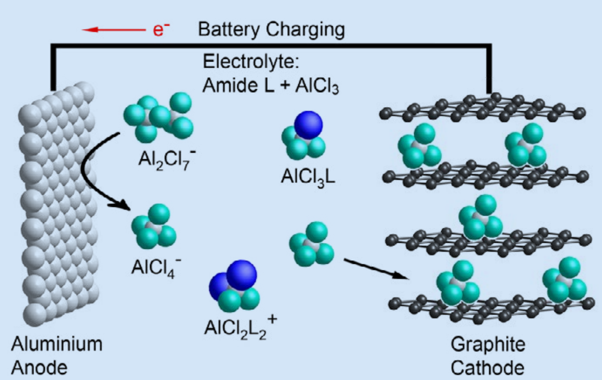
5 *IISB battery lab at Fraunhofer THM.* *© Kurt Fuchs / Fraunhofer IISB*

MATERIALS

Aluminum Ion Batteries as a Low Cost Lithium-free Electrical Storage

The cell chemistry of Al ion batteries

AIBs employ an Aluminium anode and typically a graphite cathode. The electrolyte is a type I deep eutectic solvent (DES), commonly called an ionic liquid (IL), or a type IV DES, also known as an ionic liquid analogue (ILA). Typically, AIB ILs are based on dialkylimidazolium chloride and ILAs on urea or acetamide, which form an eutectic solution when mixed with $AlCl_3$. Both ILs and ILAs contain the anionic species $AlCl_4$- and Al_2Cl_7-. The charging mechanism is given by the oxidative intercalation of AlCl4- into the graphite cathode, followed by Al deposition as Al_2Cl_7- is reduced at the anode forming Al and $AlCl_4$- (see Figure 6). In addition to the anionic species, DES contain cationic $[AlCl_2L_n]$+ and neutral $[AlCl_3L]$ species (L = amide ligand), which influence viscosity and conductivity of ILAs and hence the capacity and voltage efficiency of the AIBs.

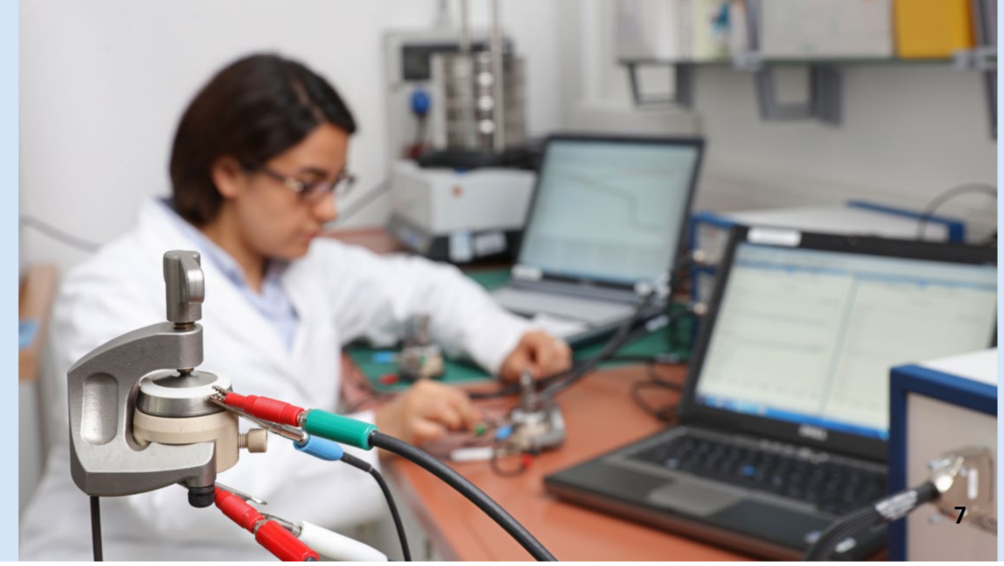


6

6 *Schematic representation of electrochemical processes during charging of an Al || $AlCl_3$/amide || graphite battery system (L = amide).*

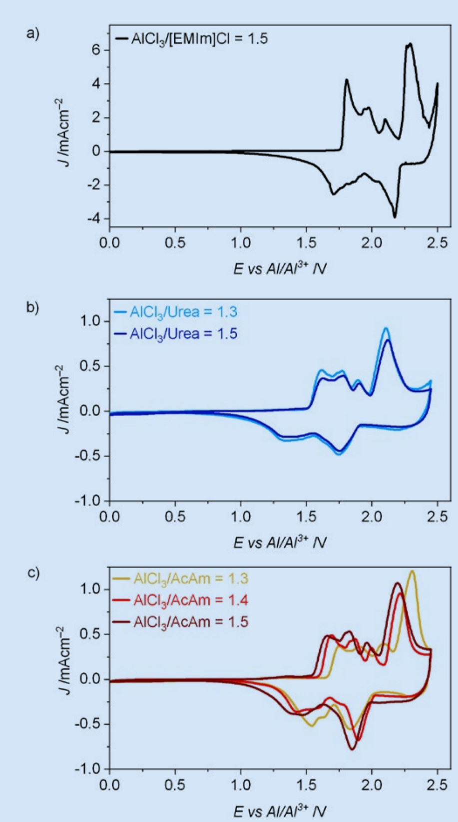
Investigation of alternative cost efficient electrolytes

Type V DES made of $AlCl_3$ and urea, acetamide (AcAm), or their derivatives are significantly cheaper than the commonly used dialkylimidazolium chloride based electrolytes. The systematic electrochemical investigations of AIB with urea and AcAm DES of varied compositions allow for a correlation between Al speciation in the electrolyte and resulting battery performance. One further advantage of DES electrolytes in comparison to commonly used ILs is the smaller corrosive effect, which could simplify battery case design in future applications. However, this requires additional effort for anode activation: In contrast to typical ILs such as $AlCl_3$/[EMIm]Cl, $AlCl_3$/urea and $AlCl_3$/AcAm electrolytes only slightly dissolve the passivating Al_2O_3 layer. Constant current cycling of Al-pyrolytic graphite cells with modified anode materials and electrolytes indicated that polishing the Al surface prior to use is sufficient to solve this issue. Hence, the same cost-efficient Al material can be used and no additives are necessary.

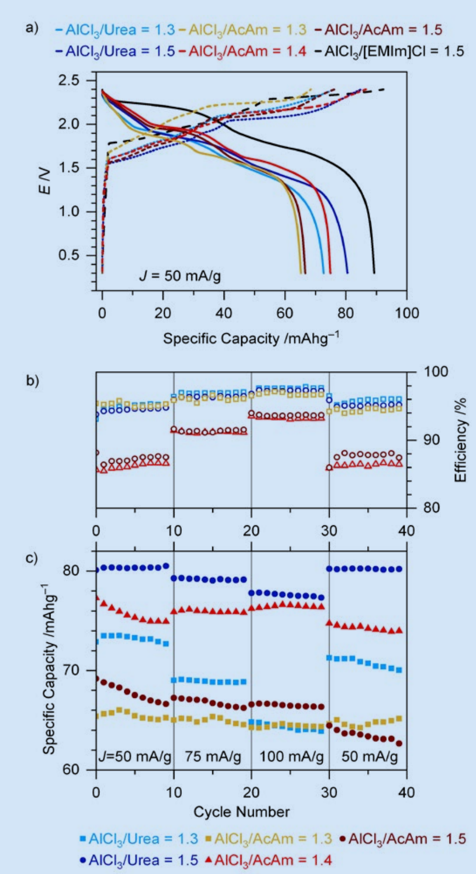

7

7 *Lab cell configuration (ELCell®) for investigation of Al-graphite cells. © Kurt Fuchs / Fraunhofer IISB*

The experiments were carried out using a freshly polished Al anode, pure electrolytes, and natural graphite (NG) cathodes. Cyclic voltammetry (CV) experiments of Al-NG cells were performed with the following electrolyte compositions: DES with $AlCl_3$/urea ratios of 1.3 and 1.5; DES with $AlCl_3$/AcAm ratios of 1.3, 1.4, and 1.5; and an IL with a $AlCl_3$/[EMIm]Cl ratio of 1.5. In all electrolytes similar redox processes were occurring (Figure 8), namely intercalation and deintercalation of $AlCl_4$- in graphite. In comparison to the imidazolium electrolyte, redox signals of AIBs with DES electrolytes were shifted to lower potentials and also varied slightly with $AlCl_3$ content. This Nernstian shift indicates different concentrations of anionic Al species within the electrolytes, which will be further investigated below.



8



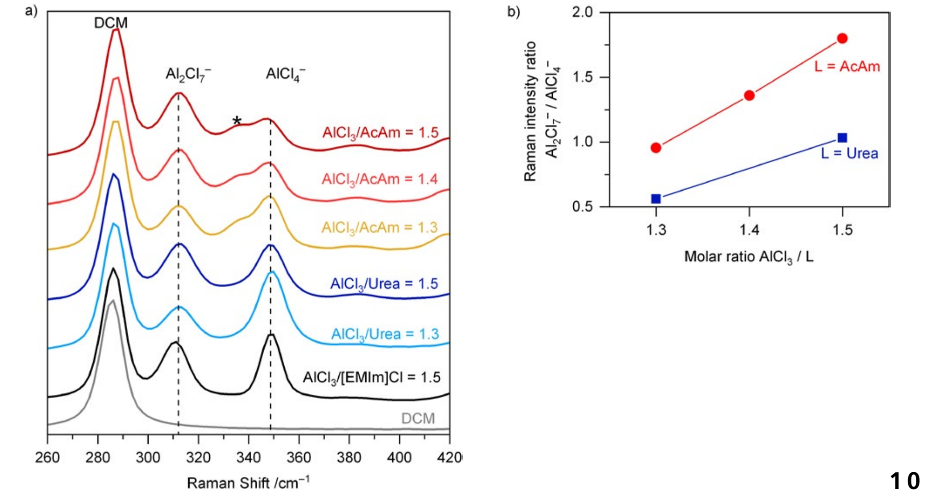
9

8 *Cathodic CVs of Al-NG battery cells employing different IL and DES electrolytes (scanrate 1 mV/s).*

9 *Constant current charge-discharge cycles of Al || electrolyte || NG cells. a) Charge and discharge curves. b) Coulomb efficiencies. c) Specific discharge capacities.*

MATERIALS

Aluminum Ion Batteries as a Low Cost Lithium-free Electrical Storage



10

Constant current cycling experiments confirmed that the electrochemical properties were strongly dependent on electrolyte type (Figure 9). The shifted CV redox signals correspond to lower potential plateaus during charging and discharging for cells employing DES electrolytes in comparison to those with $AlCl_3$/[EMIm]Cl electrolyte (Figure 9a). Best results regarding specific capacities and Coulomb efficiencies are observed for cells with an $AlCl_3$/urea ratio of 1.5 (Figure 9b,c): i.e. a constant specific capacity of 80 mAh/g for different current rates, which does not differ significantly from the observed values for an IL electrolyte tested with the same experimental setup (90 mAh/g). With energy densities of 135 Wh/kg (referred to graphite material and based on a mean nominal voltage of 1.7 V) the $AlCl_3$/urea electrolyte is a valid alternative to $AlCl_3$/[EMIm]Cl with 170 Wh/kg (mean nominal voltage 1.9 V).

The $AlCl_3$/urea electrolyte (ratio of 1.3) with lower $AlCl_3$ content yields significantly reduced specific capacities and cycling stability. The cycling results seem less clear for cells employing AcAm electrolytes: $AlCl_3$/AcAm ratios of 1.3 and 1.5 exhibit similar specific capacities, which are lower compared to cells with urea electrolytes. In contrast, cells using $AlCl_3$/AcAm (ratio 1.4) yield significantly higher specific capacities of ca. 78 mAh/g, which is similar to the $AlCl_3$/urea (ratio 1.5) electrolyte.

Structural analysis of alternative electrolytes

In order to examine influences of anionic, neutral, and cationic Al species in $AlCl_3$-based DES, key complexation equilibria need to be considered. The formation of ion pairs by heterolytic cleavage of Al_2Cl_6 (dimeric form of $AlCl_3$), as well as the equilibria between ions and neutral molecules was described for a 1:1 mixture of $AlCl_3$ and amide (L) as follows:

$$2\ AlCl_3 + 2\ L \rightarrow AlCl_4^- + [AlCl_2L_2]^+ \leftrightarrows 2\ [AlCl_3L] \qquad (1)$$

A higher $AlCl_3$ content, such as in the $AlCl_3$/amide electrolyte with ratio 1.3, may yield a higher fraction of $AlCl_4^-$ (eq. 1) or the formation of dimers according to:

$$AlCl_4^- + [AlCl_2L_2]^+ + AlCl_3 \rightarrow Al_2Cl_7^- + [AlCl_2L_2]^+ \leftrightarrows [AlCl_3L] + [Al_2Cl_6L] \qquad (2)$$

Amounts of the respective species found in a DES with a ratio $AlCl_3$/L > 1 are greatly influenced by the amide type L, since the amides' tendency for heterolytic cleavage of Al_2Cl_6 varies. The examination of the Al species in the tested DES electrolytes were carried out by Raman and IR spectroscopy. Raman spectra exhibit the typical bands of $AlCl_4^-$ and $Al_2Cl_7^-$ independently of the electrolyte mixture (Figure 10a).

For examination of concentration differences of both chloroaluminate anions the $Al_2Cl_7^-$/$AlCl_4^-$ intensity ratio is a powerful tool since it is proportional to the respective molar ratio:

$$\frac{I\ (Al_2Cl_7^-)}{I\ (AlCl_4^-)} = K \cdot \frac{[Al_2Cl_7^-]}{[\ AlCl_4^-]} \qquad (3)$$

where K is the cross section ratio of both species.

As expected from eq. 2, the intensity ratio $Al_2Cl_7^-$/$AlCl_4^-$ within each electrolyte increases for higher $AlCl_3$ contents (Figure 10b). Interestingly, the intensity ratio increases more significantly for AcAm electrolytes than for urea mixtures. Thus, for AcAm eutectics, increasing the $AlCl_3$ content yields more pronounced formation of $Al_2Cl_7^-$ dimers from $AlCl_4^-$ (eq. 2) than additional heterolytic cleavage (eq. 1). In contrast, urea electrolytes form higher amounts of additional ionic species (eq. 1) as well as dimerization (eq. 2), which can be deduced from the weakly increasing $Al_2Cl_7^-$/$AlCl_4^-$ intensity ratio. This indicates a higher overall anion concentration for $AlCl_3$/urea in comparison to $AlCl_3$/AcAm mixtures with the same $AlCl_3$ content. A tentative evaluation of intensities is based on measurements of imidazolium IL: $AlCl_3$/urea eutectics exhibit a [$Al_2Cl_7^-$]/[$AlCl_4^-$] molar ratio close to one for $AlCl_3$/urea = 1.5, while the 1.3 mixture exhibits an unbalanced ratio with a much smaller $Al_2Cl_7^-$ fraction. This explains the lower specific capacities for the latter. Correlation between chloroaluminate ratio and electrochemical results is less clear for AcAm eutectics: the obtained molar ratios for $AlCl_3$/AcAm = 1.3 and $AlCl_3$/urea = 1.5 are very similar, but specific capacities are much poorer for the AcAm eutectic. Instead, a mixture of $AlCl_3$/AcAm = 1.4 exhibiting a ratio of [$Al_2Cl_7^-$]/[$AlCl_4^-$] > 1 showed the best electrochemical results. This indicates, that besides the [$Al_2Cl_7^-$]/[$AlCl_4^-$] ratio further electrolyte properties affect electrochemical processes. For eutectic mixtures, the fraction of cationic and neutral Al species is an important variable. Even if these species do not actively participate in AIB redox processes, they will influence the ion concentration via the fragile chloroaluminate equilibra (eq. 1 and 2).

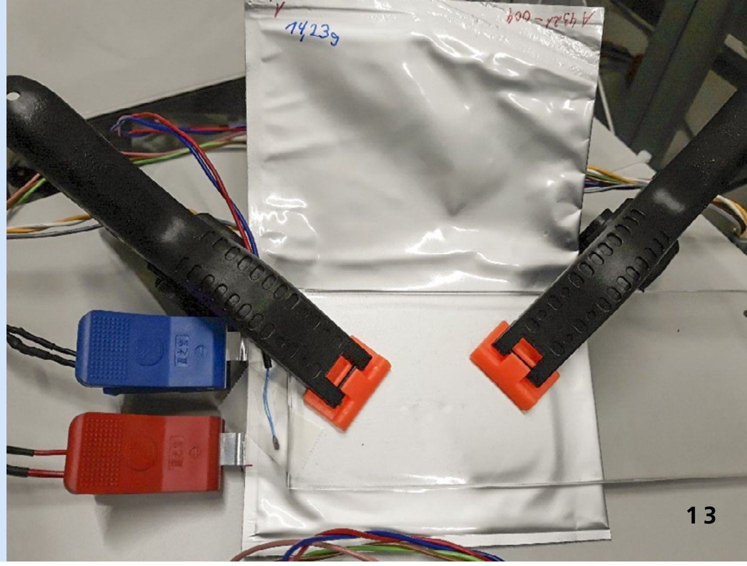
Analysis of the $Al_2Cl_7^-$/$AlCl_4^-$ Raman intensity ratio as well as the sum of both Raman bands points towards a higher anion concentration in urea eutectics than in AcAm melts. This and the high exchange rates between neutral an anionic species might yield higher capacities of Al-graphite batteries employing $AlCl_3$/urea electrolytes in comparison to most AcAm melts.

AcAm based electrolytes exhibit an additional Raman band at 336 cm^{-1} (Figure 10a), which is tentatively assigned to neutral [Al_2Cl_6L]. This additional [Al_2Cl_6L] Raman band is not observed for $AlCl_3$/urea melts, again hinting towards a lower concentration of these neutral Al species in urea eutectics than in AcAm based melts.

10 a) Raman spectra of IL and DES electrolytes, diluted with and normalized to DCM (CH_2Cl_2). Bands of $AlCl_4^-$ and $Al_2Cl_7^-$ occur at 312 and 348 cm^{-1}. The band at 336 cm^{-1} for AcAm electrolytes is assigned to [Al_2Cl_6L] (marked with an asterisk).
b) Dependence of the Raman intensity ratio $Al_2Cl_7^-$/$AlCl_4^-$ on the $AlCl_3$ content of DES for different amides L.

MATERIALS

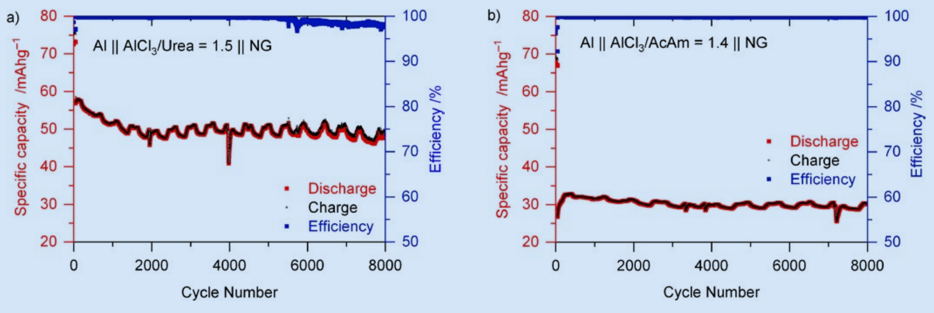
Aluminum Ion Batteries as a Low Cost Lithium-free Electrical Storage



The similar complexation of Al to the amide ligands trough the carbonyl oxygen for both amide types is confirmed by IR spectra of $AlCl_3$/urea and $AlCl_3$/AcAm. The stronger Lewis acidity of the carbonyl oxygen in urea yields a higher tendency for heterolytic cleavage of Al_2Cl_6 in comparison to acetamide, explaining the higher ion concentration. Thus, differences in Al-graphite battery properties mainly result from differing molar fractions of Al species within the electrolytes, rather than from differing structures.

Long term stability

The long term stability of Al-graphite batteries employing $AlCl_3$/urea and $AlCl_3$/AcAm electrolytes was tested with cycling experiments under real-life conditions with high specific current rates of 2 A/g (i.e. a complete charge-discharge cycle in ca. 3 minutes for $AlCl_3$/urea) and without the protective atmosphere of a glove box or any thermal regulations (Figure 11). Batteries with both electrolytes ran for more than 8000 cycles exhibiting Coulomb efficiencies >95 % as well as 80 and 90 % capacity retention for urea and AcAm electrolytes respectively. Temperature-dependency is observed with acceptable capacity variations of less than 10 % for changes of 15 K. More important, the long term stability is not compromised by the varying temperature.



11

Conclusion and outlook

The improvement of the performance of the Aluminum ion battery demands the systematical investigation of the active species and their electrochemical properties.

For the Al-graphite battery the DES electrolytes $AlCl_3$/urea and $AlCl_3$/AcAm with various ratios can be cost-efficient electrolytes. It has been shown that the Al speciation correlated to these in the eutectics. Whereas type and structure of Al species are similar for all examined eutectics, the molar fractions vary greatly. Three main factors resulting in high specific capacities were identified: ion concentration is a critical factor for eutectic mixtures which also contain neutral species. Additionally, high exchange rates of the equilibria between ionic and neutral species might improve capacities. Since both anionic chloroaluminates are involved in electrochemical processes, a balanced ratio of these two species enhances the battery performance. With these concepts, the superior performance of $AlCl_3$/urea = 1.5 and $AlCl_3$/AcAm = 1.4 can be understood. Additional investigations regarding viscosity and conductivity require further research. With energy densities of 135 Wh/kg (referred to graphite active material and based on a mean nominal voltage of 1.7 V) the $AlCl_3$/urea = 1.5 electrolyte is a valid alternative to imidazolium-based ILs using cheaper and non-toxic raw materials.

The practical application of low-cost Al-graphite batteries employing urea and AcAm eutectics was proven by a long term stability of more than 8000 cycles in the lav cell configuration of ELCells®.

With the first proof of function of CR2032 coin cells (Figure 12) statistic investigations of various material and cell configuration are possible to increase the experimental data availability and the evaluation of the optimal cell components.

Behind the further investigations on the physical properties of DES based electrolytes to improve the conductivity of charged species and on the optimized structural properties of graphite particles as active cathode material the development of application-relevant cell configuration takes center stage for the IISB battery group at Fraunhofer THM. Therefore first prototypes of Al-graphite pouch cells (electrolyte $AlCl_3$/urea = 1.5) were tested (Figure 13) and showed the same specific capacity as the lab cells (about 80 mAh/g). Furthermore the implementation of AIB pouch cells into a real battery module is the aim of ongoing and planned research projects.

11 *Long-term cycling experiments of a) Al || $AlCl_3$/urea = 1.5 || NG und b) Al || $AlCl_3$/AcAm = 1.4 || NG cells with a constant current rate of 2 A/g.*

12 *Similar electrochemical characterization testing of AIB coin cells, dimension CR2032. © Maximilian Wassner / Fraunhofer IISB*

13 *Cycling of first prototypes of AIB pouch cells, dimension 6 x 9 cm². © Lars Esmezian, CUSTOMCELLS GmbH / Fraunhofer IISB*

Contact

Dr. Jochen Friedrich
Phone: +49 (0) 9131 761-270
jochen.friedrich@iisb.fraunhofer.de

TECHNOLOGY AND MANUFACTURING

Technology and manufacturing at Fraunhofer IISB mean above all research, development, and prototype manufacturing in the field of power electronic devices mainly on 4H-silicon carbide (SiC) but as well as on silicon (Si). In particular the service sector is set up in a separate organizational unit called π-Fab, to meet the requirements of our external and internal customers better. π-Fab is intended for the fabrication of custom-tailored prototype electron devices, mainly for power electronic application, and it is ISO 9001:2015 certificated for this.

For this purpose, IISB and the Chair of Electron Devices of the University of Erlangen-Nürnberg operate joint cleanroom facilities of 1500 m^2 (primarily class 10) with CMOS-compatible equipment. This allows the implementation of important process steps on silicon wafers with diameters of up to 200 mm and on SiC wafers with diameters of up to 150 mm. An industrial CMOS process transferred to IISB and constantly adapted for research and development purposes is used as a reference and as the basis for developing advanced process technologies.

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

All of this allows the department to strengthen its competence in manufacturing high-voltage power devices. By now, IISB has developed its resources and expertise to the point where it can perform nearly all manufacturing steps on SiC substrates according to an industrial standard. The devices currently under development include diodes and merged pin diodes in the voltage ranges from 1.2 kV up to 4.5 kV, as well as MOSFET devices such as vertical or lateral DMOS. A trench technology for vertical diodes and MOSFET as well as sensor and high-temperature CMOS devices are in progress. For the development of novel process steps in the field of dielectrics and metallization, IISB operates advanced sputter and chemical vapor deposition tools on the basis of ALD that are used for the deposition of high-k and metallic layers.

Furthermore, special activities focus on ion implantation technologies. At IISB, implantation tools with acceleration voltages ranging from a few eV up to 800 keV are available. Special implantations for CMOS as well as for power semi-conductors have been established (for example,

1 *Partial view of the processing line for silicon carbide (SiC) at Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

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

TECHNOLOGY AND MANUFACTURING

Advanced Electrical Characterization of 4H-SiC Material, Power Devices and Circuits

commercial tools have been modified to be able to implant several wafer diameters and manifold elements at elevated temperatures).

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

Furthermore, from nanotechnology to printable macro-electronics, the Technology and Manufacturing department is your contact for the realization and characterization of single process steps up to prototype devices.

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

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

A core competence of the Manufacturing Control group is contamination control in advanced CMOS processing. The IISB analysis laboratory for micro and nanotechnology with various chemical, physical-chemical, and physical test methods is essential for a conclusive and comprehensible assessment.

Several working groups at Fraunhofer IISB contribute their expertise in Advanced Process Control, manufacturing science, productivity, contamination control, and yield control aspects to the running ECSEL projects "Productive4.0" and "iDev40". With 109 partners involved, Productive4.0 is Europe's biggest research project in the field of Digital Industry. By interlinking development processes, logistics, and production with Industry 4.0 technologies, iDev40 achieves a disruptive step towards speedup in time to market.

3 Operator loading a 100 mm SiC epiwafer in an UV excited photoluminescence scanner (UVPL) at Fraunhofer IISB. @ Thomas Richter / Fraunhofer IISB

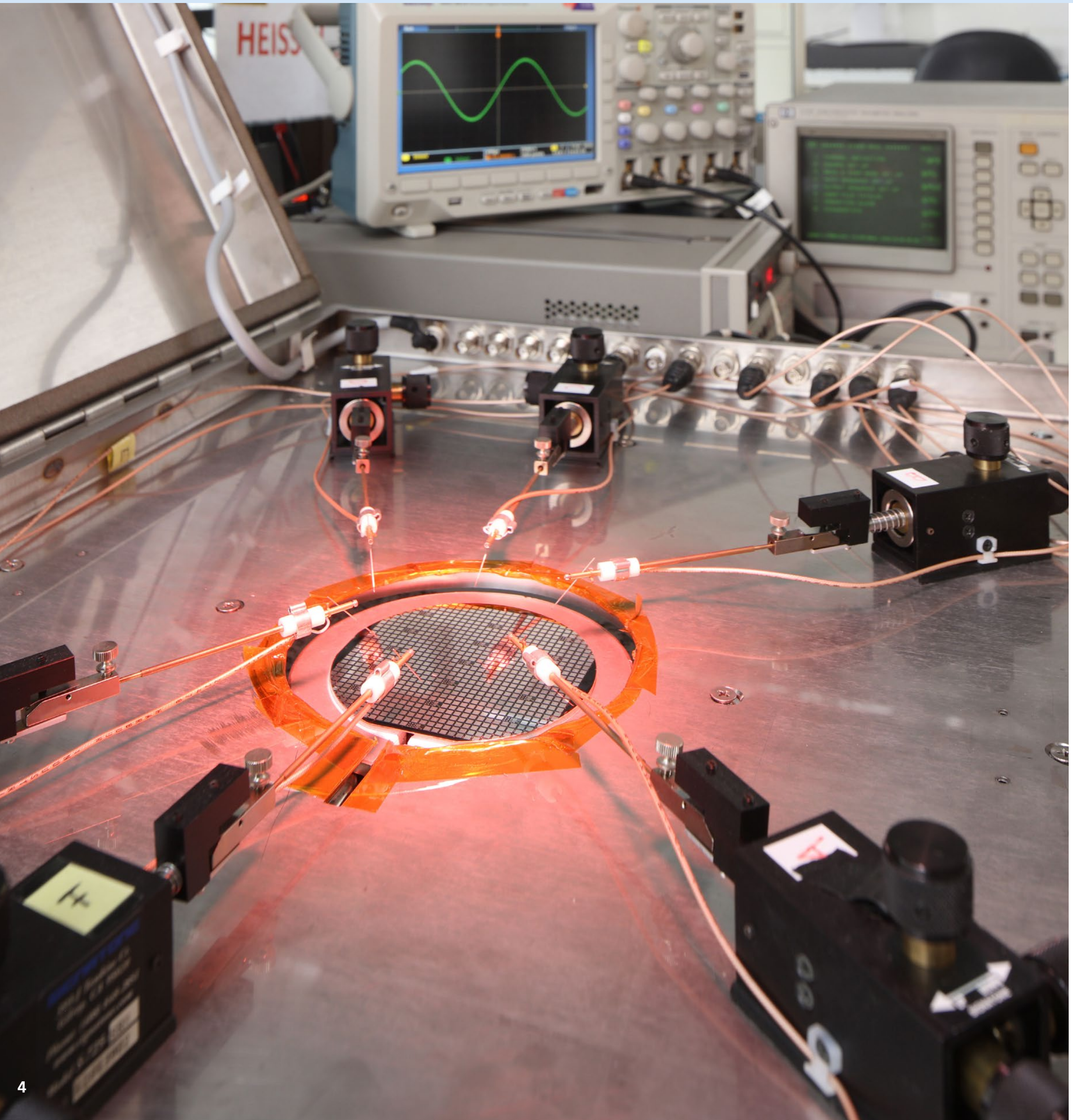
ADVANCED ELECTRICAL CHARACTERIZATION OF 4H-SIC MATERIAL, POWER DEVICES AND CIRCUITS

Since more than 25 years, Fraunhofer IISB is working both in fundamental research and on the establishment of a 4H silicon carbide (4H-SiC) process technology for state-of-the-art device fabrication. Today, IISB's competence covers the full process chain from growth of epitaxial layers over a 150 mm wafer process line up to packaging of single devices. The device portfolio ranges from power VDMOS devices (typically 1.2 kV or 3.3 kV) over high temperature CMOS logic circuits to optical sensors and even quantum devices. However, IISB not only serves as a one-stop partner for small scale device fabrication but also as service provider for single process steps or process sequences. Such process-related work is strongly supported by profound expertise in device design and simulation of process technology, electrical device performance as well as thermal behavior of dies and packaged devices.

Conforming to a ISO9001 certified quality management system, control of the individual process steps during the fabrication is being performed at IISB and is mandatory for high overall processing yield. Unfortunately, the results of some key processes such as doping by ion implantation and subsequent annealing or the reliability of gate dielectrics cannot be measured directly after the relevant processes due to lack of according metrology. For this purpose, IISB adds optimized test structures on the chip design for specifically assessing such process results which can also be used for root cause evaluation in case of non-ideal device characteristics. For the exemplarily mentioned doping process, e.g., so-called TLM (transmission line method) structures are being used with optimized design for automated wafer level measurements which also enable the assessment of the quality of the ohmic contacts on such doped regions.

TECHNOLOGY AND MANUFACTURING

Advanced Electrical Characterization of 4H-SiC Material, Power Devices and Circuits



4

Even more detailed information on the electrical characteristics of doped layers can be obtained from temperature dependent Hall effect measurements on dedicated test structures such as Van-der-Pauw structures or Hall bar structures. Apart from temperature dependent free carrier concentration and carrier mobility (channel mobility in case of MOS test structures), according Hall measurements can be used to obtain important parameters such as compensation ratio for aluminum implanted p-type regions which in turn need to be considered during device design and simulation. For such measurements, IISB's Hall measurement setup offers very fast measurements for a temperature range from 80 K up to ~700 K. Additional customized or device specific test structures can easily be integrated in the design or properly considered for electrical characterization. Such measurements, however, will be performed on die level (see Figure 3).

Another aspect which needs to be considered when evaluating the overall process yield is that 4H-SiC substrates exhibit higher crystal defect density compared to e.g., silicon substrates. To a lower extent this is also true for homoepitaxially grown 4H-SiC layers. Several of such crystal defects lead to higher leakage currents or even failure of the final device even for ideal processing. Therefore, dedicated wafer inspection before actual processing using specific photoluminescence characterization can be applied at IISB with a full wafer defect UV excited photoluminescence scanner (UVPL, see Fig. 4) to determine the density of crucial electrically active extended crystal defects, and, consequently, to predict to a certain extent the maximum possible yield for the particular substrate and the targeted device design.

Especially for future bipolar 4H-SiC devices, carrier lifetime will be of utmost importance and, thus, needs to be monitored and considered. One possibility is the measurement of effective carrier lifetimes using dedicated diode test structures at the end of the overall process. But as long as no metal structures are present on the wafer, effective carrier lifetime can also be monitored on wafer scale using so-called microwave detected conductivity decay (µ-PCD) with UV laser excitation: Starting with epitaxy layer characterization, the suitability to determine the influence of several process steps on the change in carrier lifetime (such as dedicated lifetime engineering processes) has been demonstrated. Note though, that this requires rather thick epitaxial layers or lightly doped concentrations of the layer. As carrier lifetime strongly depends on the concentration of point defects, most prominent carbon vacancies, more detailed and sensitive characterization of such defects is very important for e.g. the development of dedicated lifetime improvement processes for future device generations. Here, IISB offers deep level transient spectroscopy (DLTS) for the detection and quantification of point defects (for a temperature range from ~30 K up to ~ 750 K, see Fig. 5).

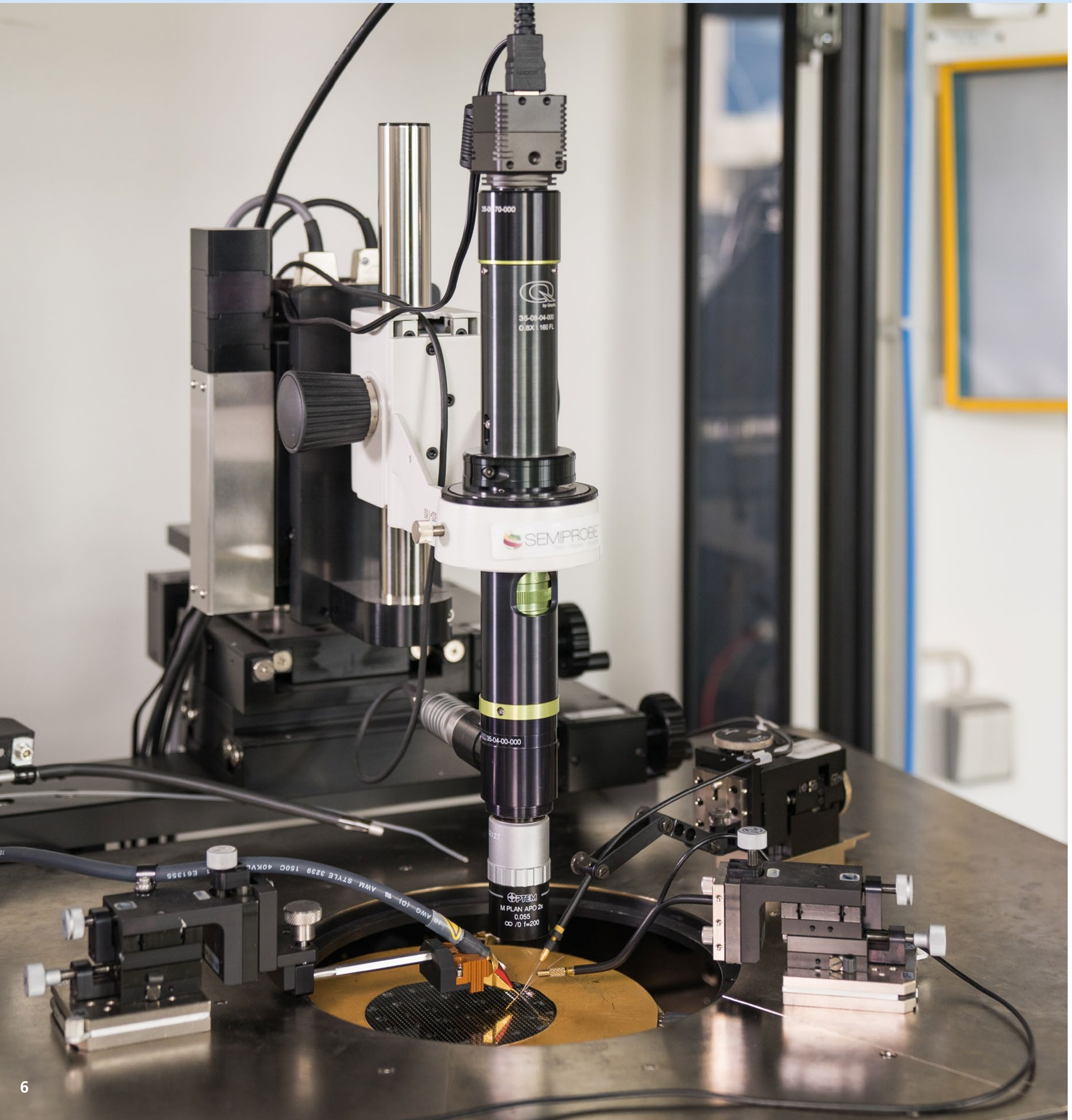
At the end of the process flow, fabricated devices will be judged by their electrical performance (on wafer level or as packaged device) which decides about the quality of the overall process including simulation supported design of the devices and process flow. For this purpose, IISB

4 *Manual probe station for dedicated high temperature characterization of 4H-SiC devices.*
© Kurt Fuchs / Fraunhofer IISB

5 *Components of DLTS (deep level transient spectroscopy) measurement setup for the detection and quantification of point defects in 4H-SiC.*
© Anja Grabinger / Fraunhofer IISB

TECHNOLOGY AND MANUFACTURING

Advanced Electrical Characterization of 4H-SiC Material, Power Devices and Circuits



offers automated measurements on wafer level (up to 200 mm) on two wafer probe stations. Standardized measurement routines exist for typical current voltage (IV) characteristics such as transfer or output characteristics for VDMOS devices or for determining standard device parameters (e.g., threshold voltage, maximum operating voltage or drain-source on-resistance). IISB's dedicated equipment offers such wafer level characterization including statistical evaluation for voltages up to 10 kV (using in-house developed automated application of insulation liquids) and pulsed currents up to 1500 A for measurement temperatures ranging from -60 °C to 300 °C (see Fig. 6). Based on IISB's know-how, measurement procedures and sequences can easily be adapted to customized needs and chip designs. Several manual probe stations, on the other hand, allow even more flexible and specific measurements, including high temperature AC and DC measurements (up to 500 °C, see Fig. 7) for e.g. high temperature CMOS circuits.

6 *Silicon carbide (SiC) wafer with contacted test structures for electrical characterization in the high voltage, high current wafer probe station.*
© Thomas Richter / Fraunhofer IISB

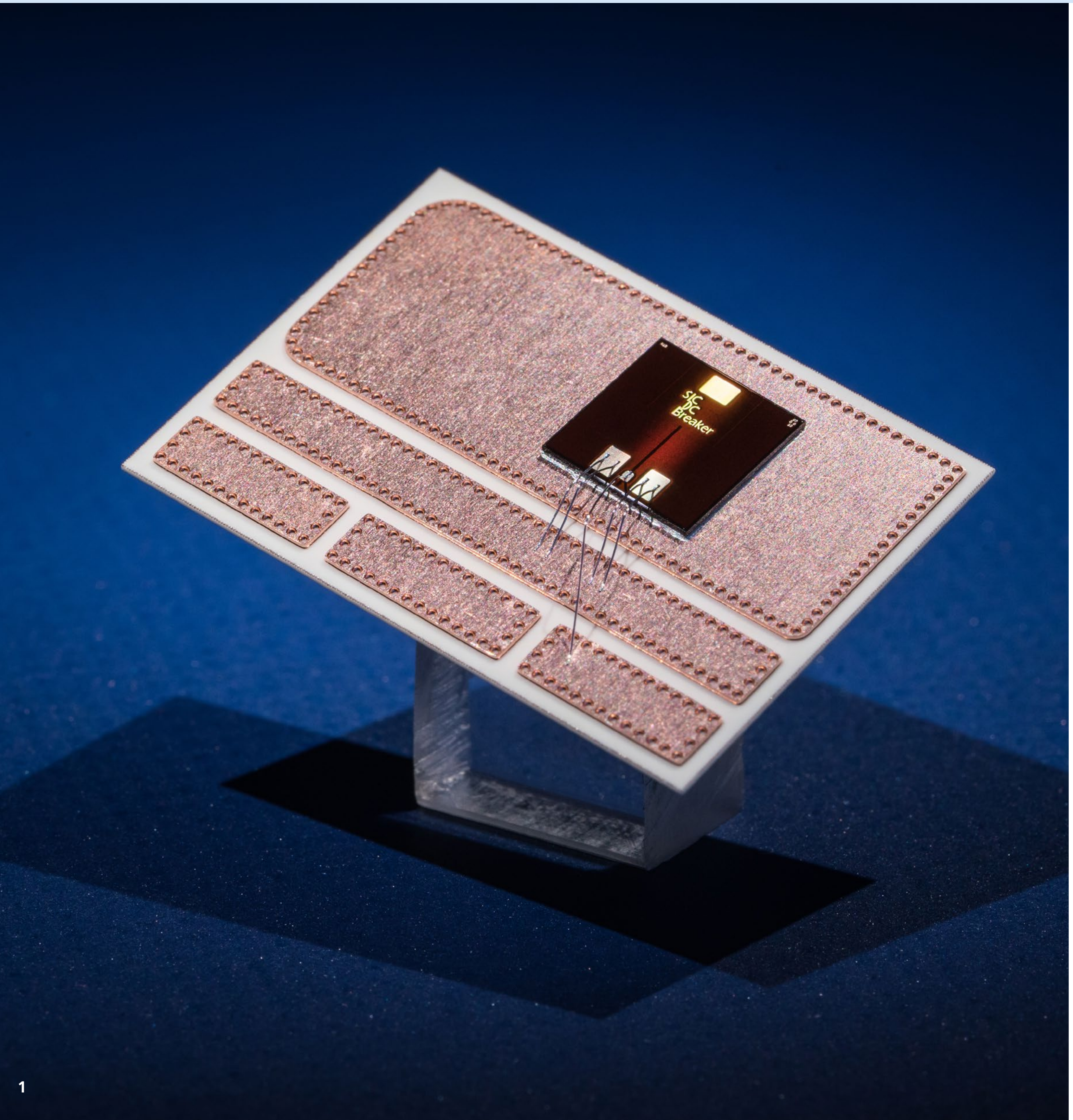
7 *High voltage, high current wafer probe station for measurements up to 10 kV (DC) and 1500 A (pulsed).*
© Thomas Richter / Fraunhofer IISB

Contact

Dr. Anton Bauer
Phone: +49 (0) 9131 761-308
anton.bauer@iisb.fraunhofer.de

DEVICES AND RELIABILITY

2



1

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

With the increased demands and inquiries regarding the silicon carbide device development, the last year has seen extended effort to increase the quality and throughput in our unit process steps. A modular processing approach and the implementation of baseline processes enables device prototyping in a reasonable timeframe despite the continuously increasing demand for silicon carbide development services.

Together with the National Institute for Nanomaterials Technology in Pohang, Republic of Korea, Fraunhofer IISB completed the fabrication of 1200 V TrenchMOS devices in its first technology generation. This achievement extends our capability of prototyping a wide range of silicon carbide power devices using our 150 mm processing line. This project will subsequently move into the final two-year stage. The focus for the next two years will shift towards process integration for SiC-based superjunction device structures.

Regarding our SiC CMOS baseline technology for high-temperature capable circuits, the start of the EU- and BMBF-funded iRel4.0 project is marking a new stage towards the investigation of reliability-related technology aspects. Suitable process modules will enable operational amplifiers and sensors rated at temperatures well beyond 250 °C.

The high-voltage silicon capacitor technology has achieved a new milestone with the availability of early-access prototypes (900 V RC-snubbers for power modules). These devices are available in reasonable R&D quantities for all of our partners through the LZE workshop.

In September 2020, the new research group "Innovative Power Modules" was founded in the area of devices and reliability, in which all relevant competences around the power module are bundled. The group specially takes care of power modules for WBG semiconductors and optimised module properties as well as new module concepts. Thus, the group represents a bridging function between packaging technologies and power electronic systems. The competences of the new group in the areas of power module concepts, characterisation & modelling as well as prototyping enable the rapid transfer of packaging technologies into power electronic system applications.

A novel SiC demonstrator module with 1200 V SiC mosfets for up to 100 A is a first result of these research activities. Minimal switching and conduction losses as well as optimised EMC behaviour

1 *Novel circuit breaker chip soldered and bonded on copper substrate.*
© Thomas Richter / Fraunhofer IISB

2 *Andreas Schletz, head of the Devices and Reliability department.*
© Kurt Fuchs / Fraunhofer IISB

DEVICES AND RELIABILITY

were achieved through a high degree of integration of the load and control path. The functional integration of ceramic capacitors in the power module in conjunction with the integration of the gate control close to the chip make a significant contribution to the optimal module properties. Innovative design concepts were realised, among other things, using multilayer substrates.

Ongoing development of silicon carbide processing technology for power devices is focused on the implementation of self-aligned process steps since 2019. This technology extends the manufacturing capabilities towards shorter device channels in VDMOS transistors beyond the limitations imposed by photolithography.

In the joint collaboration with the National Institute for Nanomaterials Technology in Pohang, Republic of Korea, Fraunhofer IISB has started the implementation of trench etching processes towards a baseline TrenchMOS technology. Results can be expected throughout 2022. The project has moved right into the second two-year stage. Close collaboration between both institutions and significant exchange of staff was continued towards the establishment of subsequent joint R&D activities in Korea and Germany.

The SiC CMOS baseline technology for high-temperature capable circuits was moved forward with the next round of process batches. Presently, the work focuses on process optimization and implementation of analog circuits like high-temperature amplifiers.

Further work towards RC-snubbers suitable for switching speed enhancement in SiC-based 1200 V power modules has been carried out to implement the feasibility of technology transfer to an external silicon foundry. Additionally, together with the Leistungszentrum Elektroniksysteme (LZE), efforts are ongoing to identify and address more use cases for this technology.

In the field of packaging, new research projects have been started. Power4re, sponsored by the Fraunhofer Association, was kicked off in the early year of 2020. PREPARE projects serve the purpose of demanding, cross-institutional preliminary research in preparation for new business fields. These projects intend to lay the foundation for a longer-term alliance between the institutes IISB, IWES, IMWS, ISE, and IZM. Within the Power4re project, reliable converters for regenerative energy supply and compact power module concepts for harsh environments are being researched and developed. The task is to achieve a deep understanding of humidity-driven corrosive lifetime issues in a wide range of power electronic applications like windmill inverters. This project goes hand in hand with the whole packaging and reliable power modules strategy followed in this working group.

Furthermore, we established a new coating process within the packaging laboratories to integrate a clear organic coating for narrow gaps and highly integrated power modules. This Parylene coating system is transferred from military or aircraft microelectronic applications to power electronic modules.

Besides new technologies for coating systems, new partners were found for starting a joint lab within the packaging clean room in the Fraunhofer IISB. Palomar technologies placed a vacuum soldering machine there. Boschman introduced the newest sintering press in our laboratories, both working under defined atmospheric constraints for void and oxide-free solder or sinter interlayers. Our fully equipped packaging manufacturing line serves as a demonstration lab for industry and an up-to-date research showroom within these joint lab activities.

At the end of the year 2020, the packaging technologies were officially rewarded by the Fraunhofer IISB award for excellent research work regarding direct bonding as a novel interconnection technology for power electronic modules. Zechun Yu, as an operating scientist, was honored to receive this award for her research and development activities.

Finally, the first steps for further fruitful and growing collaboration were made. A student program was started with Heraeus company. Moreover, an online workshop and packaging conference started the collaboration between the electro-technical institute of the Xi'an university in China and the union on research projects with the Suganuma lab at Osaka University in Japan continued.

The research activities concerning testing and reliability led to supporting activities for the semiconductor business field. One example is the work on the Si RC snubber device. A market acceptance is needed to make the step from research to prototypes, which are provided in small volumes. Thanks to the LZE project, a test strategy was developed, accompanied by several lifetime tests in order to get a good confidence into IISB's snubber technology. The test results are promising. Design optimizations of the end of line test could be achieved.

The topic of thermo-mechanic lifetime simulation made great progress thanks to the public funded project HELENE, supported by the Federal Ministry of Education and Research (BMBF). The-state-of-the-art rainflow algorithms were studied to take out weak points. In addition, these results were compared to the thermo-mechanical simulation of power cycling mission profiles. The results show superiority of the material based lifetime estimation. Geometrical design optimizations are now possible.

In addition to the variety of publicly funded projects, there were a huge number of joint industrial projects in all research fields. The topics range from assistance and consulting to large feasibility studies and process and technology developments for devices, packaging, and testing. The

DEVICES AND RELIABILITY

A Monolithically Integrated and Self-Controlled SiC Circuit Breaker

3

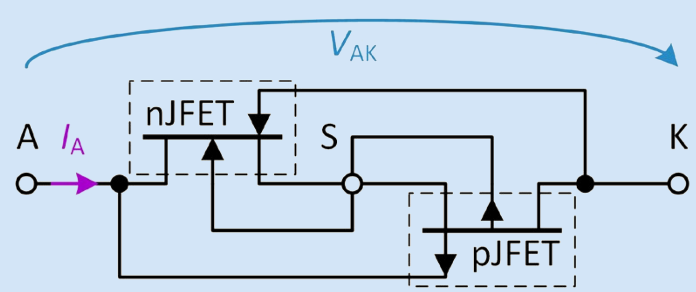
applied research within the department is financed by an industrial budget contribution of well above forty percent. This perfectly achieves the Fraunhofer target.

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

A MONOLITHICALLY INTEGRATED AND SELF-CONTROLLED SIC CIRCUIT BREAKER

Power electronic DC applications like smart grids and automotive drive trains for electric cars pushed the development of circuit breakers to an advent of a variety of different approaches. This includes hybrid breakers utilizing thyristors and mechanical switches. However, state-of-the-art solutions for DC applications up to 900 V supply voltage use micro controller based circuitries employing current sensors and enhancement-mode SiC MOSFETs. The fundamental requirement to all approaches is the capability to turn off excessive current by switching from a low-resistive on-state to a high-resistive off-state. The discovery of the "thyristor dual" function in 1999, paved the way for additional efforts to fulfil this requirement with a single self-triggered device.

The elementary "thyristor dual" implementation utilizes an n-channel JFET (nJFET) and a p-channel JFET (pJFET) as shown in Figure 4. In this configuration, the drain-source voltage of one JFET is equal to the gate-source voltage of the other JFET.



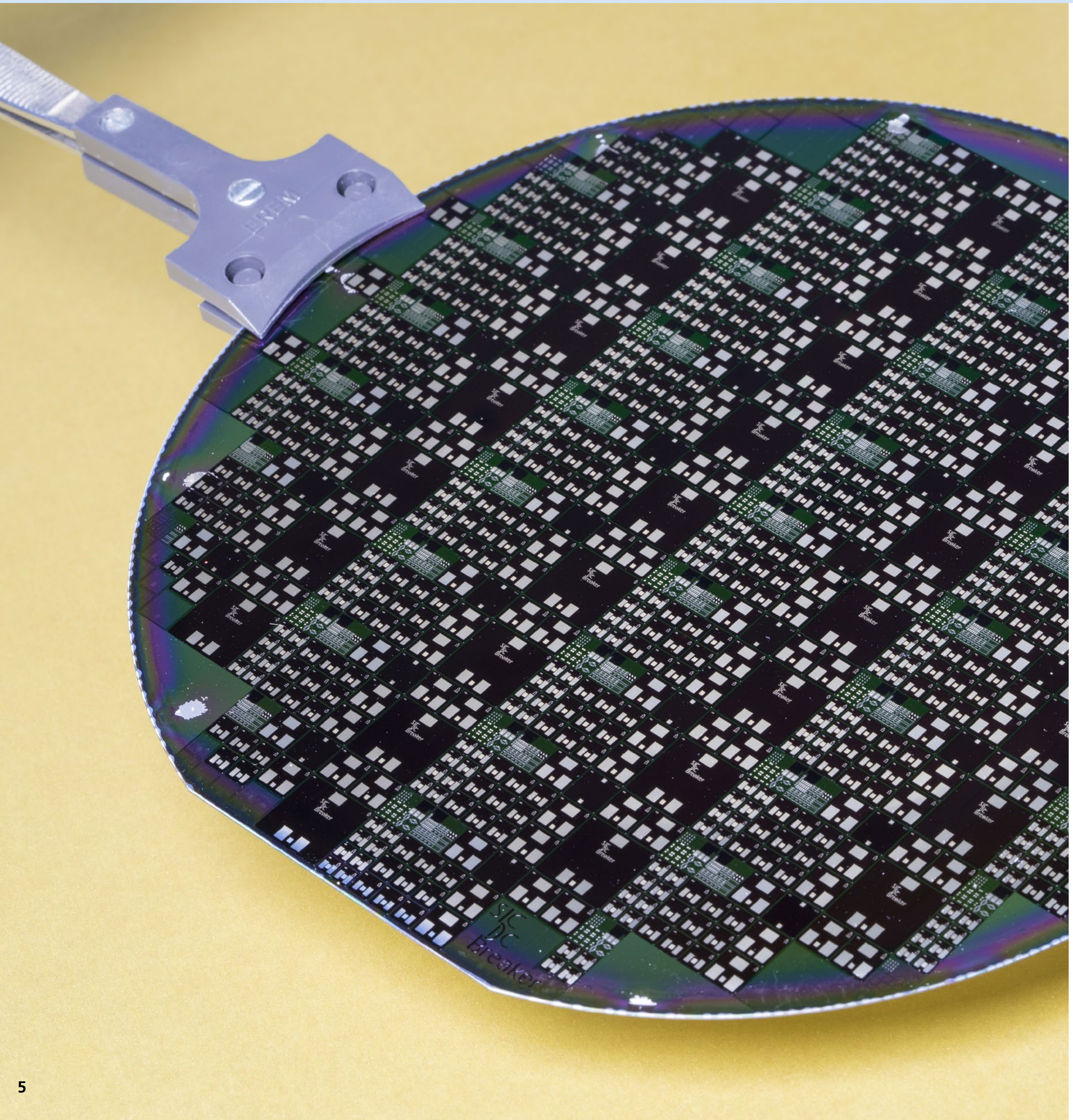
4

3 Single SiC DC breaker chip. © Thomas Richter / Fraunhofer IISB

4 Equivalent circuit diagram of the proposed circuit breaker.

DEVICES AND RELIABILITY

A Monolithically Integrated and Self-Controlled SiC Circuit Breaker



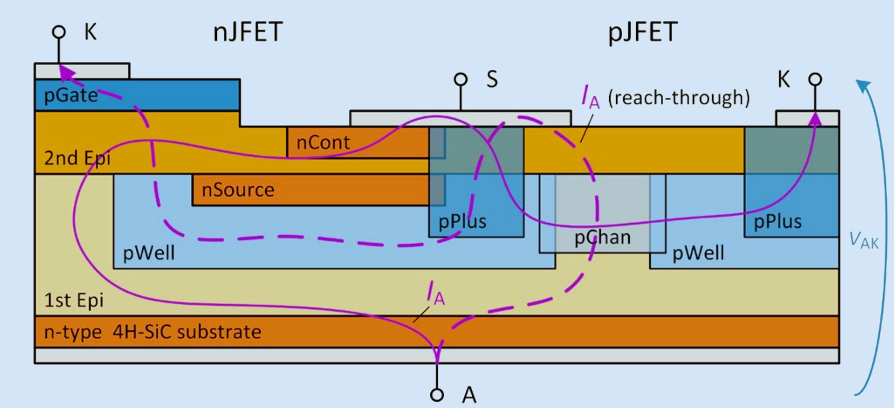
5

The resulting positive feedback of forward voltage drop and control voltage, forced by forward current, constitutes the basis of the self-triggered turn-off mechanism. Former implementations by Fraunhofer IISB and Bremen University successfully assembled laborious circuitries with discrete JFET and MOSFET devices for operation up to 60 V and 400 V DC-link voltage, respectively.

However, as can be obtained from Figure 4, the “thyristor dual” principle demands high voltage robustness towards the gate structures of both JFETs. Therefore, additional passive devices like Zener diodes must be considered, when pursuing a discrete integration approach using conventional transistors. Moreover, such implementations usually make varistors or snubber circuits necessary in order to manage turn-off energy.

In an effort towards monolithic integration, both Bremen University in 2007 and Fraunhofer IISB in 2017 employed TCAD modelling in order to derive first design guidelines. From these guidelines, a refined TCAD model of a novel and scalable topology for a monolithically integrated and self-controlled SiC circuit breaker suitable for 900 V DC applications emerged. In 2020, more than 20 years after its discovery, Fraunhofer IISB could demonstrate the monolithic integration of the “thyristor dual” device by employing a 4H-SiC JFET technology for the first time.

In order to implement the proposed “dual thyristor” concept shown in Figure 4 in a 4H-SiC JFET technology, which is available at Fraunhofer IISB, the topology depicted in Figure 6 is developed.



6

The fabrication of this topology implies growing two nitrogen doped epitaxial layers denoted with 1st Epi and 2nd Epi. The channel lengths of both JFETs are determined by ion implantation of

5 150 mm SiC wafer containing several design variants of the proposed circuit breaker.
© Thomas Richter / Fraunhofer IISB

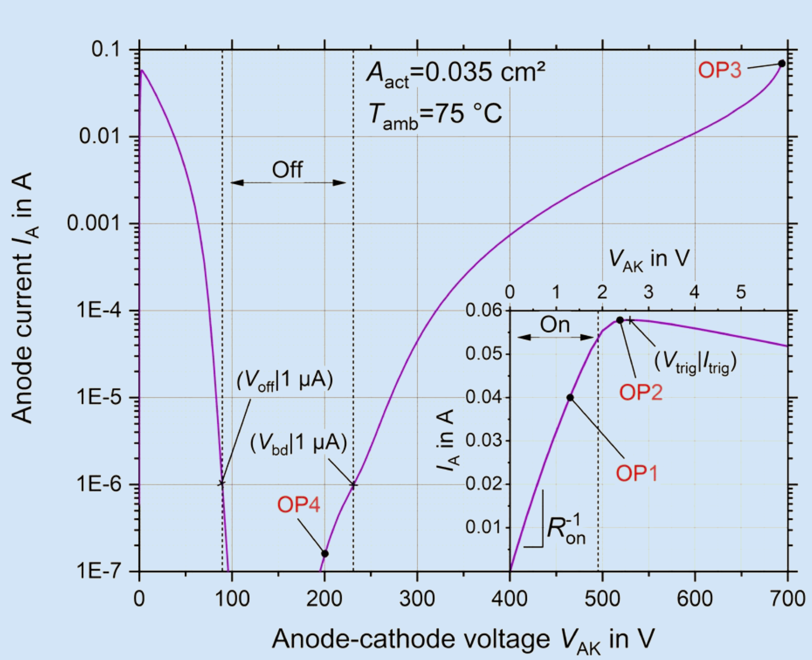
6 Schematic unit cell cross section of the proposed circuit breaker.

DEVICES AND RELIABILITY

A Monolithically Integrated and Self-Controlled SiC Circuit Breaker

p_{Well}, n_{Source} and p_{Chan}. Subsequently, the second epitaxial layer is grown and the p_{Gate} implantation is carried out. In order to create the n_{JFET} MESA gate, the second epitaxial layer is structured using a dry etching process. The deep p_{Plus} and n_{Cont} implantations, firstly, allow a connection from the MESA bottom to the buried p_{Well} regions and, secondly, provide reasonable ohmic contacts. Consequently, p_{Gate} and p_{Well} form gate and bulk of the n_{JFET}, whereas 1st Epi and 2nd Epi form gate and bulk of the p_{JFET}. The floating common source terminal (denoted with S) is realised by a metal layer, which allows carriers to pass the pn-junction at the JFET source terminals. The high potential anode terminal (denoted with A) is located at the device backside, whereas the low potential cathode terminal (denoted with K) is located at the topside. The solid violet line in Figure 6 illustrates the resulting path of the anode current I_A in normal operation.

In Figure 7, the measured quasi-static output characteristics of a monolithically integrated circuit breaker variation for 200 V DC applications are depicted.



7

For forward voltage values V_{AK} lower than approximately 2 V, the circuit breaker is in low-resistive on-state operation, which is indicated by the operation point OP1. In case I_A exceeds the trigger

current level I_{trig}, the circuit breaker switches from OP2 to OP3 in order to temporary conduct the surge current. Subsequently, the supply voltage of 200 V forces the circuit breaker to transit to OP4, where it remains in high-resistive off-state as long as the supply voltage is applied. For V_{AK} higher than the breakdown voltage V_{bd}, I_A flows as reach-through current as illustrated in Figure 6 by the violet dashed line. Hence, this topology exhibits high surge current robustness and allows dissipating turn-off energy without additional passive devices.

7 Measured output characteristics of the proposed circuit breaker.

Fraunhofer IISB gratefully acknowledges the sponsorship of this circuit breaker technology development by the German Federal Ministry of Education and Research (BMBF) under grant 03INT501BA "SiC-DCBreaker". This research project includes collaboration with renowned German partners as well as partners from Japan organized under the NPERC-J consortium. The close cooperation of NPERC-J and Fraunhofer IISB manifests in a research stay of a German Ph.D. candidate at Tokyo Metropolitan University for advanced electrical characterization of circuit breaker devices fabricated at Fraunhofer IISB. With this stay of 6 months, we intent to promote international exchange and further development of SiC power device technology in a pre-competitive research environment.

In the current state of development, monolithically integrated SiC circuit breakers exhibiting V_{bd} up to 850 V and specific on-state resistance of approximately 100 mΩcm² at 200 °C can be fabricated at Fraunhofer IISB. Noteworthily, the proposed topology is scalable with regard to on-state resistance, trigger current level and off-state voltage window. Moreover, since this technology is at the very beginning of development, its potential is still to be exploited. Furthermore, this circuit breaker aims at key technologies for silicon carbide and gallium nitride applications, which have been identified as key technologies in power electronics for the future.

Therefore, the proposed circuit breaker technology may find a prosperous market, while being free of third party IP. Thus, collaboration towards further developing this technology allows our partners to immediately enter the SiC power device domain with a unique circuit breaker device and a process portfolio tailored to their needs.

Contact

Andreas Schletz
Phone: +49 (0) 9131 761-187
andreas.schletz@iisb.fraunhofer.de

VEHICLE ELECTRONICS

2

1

Challenging Times for Advanced Mobility Solutions

Due to the emergence of the corona crisis in March, the shutdown in Germany, Europe and worldwide caused a massive impact on all kinds of mobility solutions. This was also a very challenging situation for the vehicle department, because the shotdown brought several projects to be on hold. However, the vehicle electronics department is covering a wide field of power electronic solutions in various fields of applications. That has reduced the impact of the shut down significantly. The original focus on electric passenger cars is widening to electrified buses, trucks and construction vehicles as well as trains and ships with much higher power and lifetime requirements. An extremely challenging field is electric air mobility. On one side is the urban air mobility with different kinds of multi rotor aircrafts with vertical takeoff and landing (VTOL) capability with a voltage range up to 800 V and requirements of 200 kW up to 1000 kW of electric power, on the other side are hybrid electric regional aircrafts with power demands in the megawatt range. But both applications need very light weight and highly reliable power electronic solutions.

To tackle all these upcoming challenges the vehicle electronics department is working on mechatronic integrated drive inverters, DC/DC converters and chargers with latest Silicon-Carbid (SiC) or Gallium-Nitird (GaN) semiconductors. The mechatronic integration of the drive inverter with the electric motor save space and weight of an additional housing and the failure prone three phase AC cables and connectors. Another positive effect of the integration is the significant reduction of the electromagnetic interference (EMI) caused by the power electronics.

The EMI of ultra-fast switching of SiC and GaN power electronics is an imminent task, making filters more space consuming. To optimize the EMI spectrum and reduce the size of the necessary filter elements, the vehicle electronics department is working on new simulation models and concepts to achieve a low EMI emissions through the design of the power electronic system, optimized passive and active filters and software. This opens up the possibility that the electrical engineer can simulate and adapt the electrical design to the EMI specifications during the early stages of the design process.

Beside the challenges, the SiC and GaN power devices enable the realization of much smaller and more efficient DC/DC converters necessary for future powertrains powered by fuel cells for heavy duty or autonomous vehicles and aircrafts. Placed between the fuel cell and the electric drive and a power in the range up to several hundreds of kilowatt, a high efficiency is mandatory for improved range of the vehicle and low cooling effort on the power electronic converter.

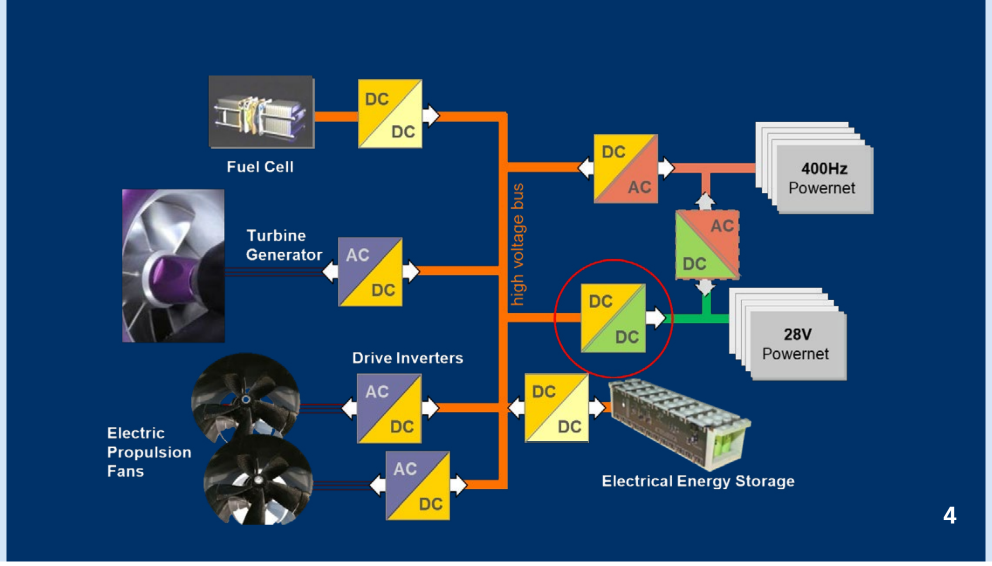
With several new topics, many successful projects and a great team, the vehicle electronics department is looking back on a challenging year. Sincere thanks to all my colleagues for the

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

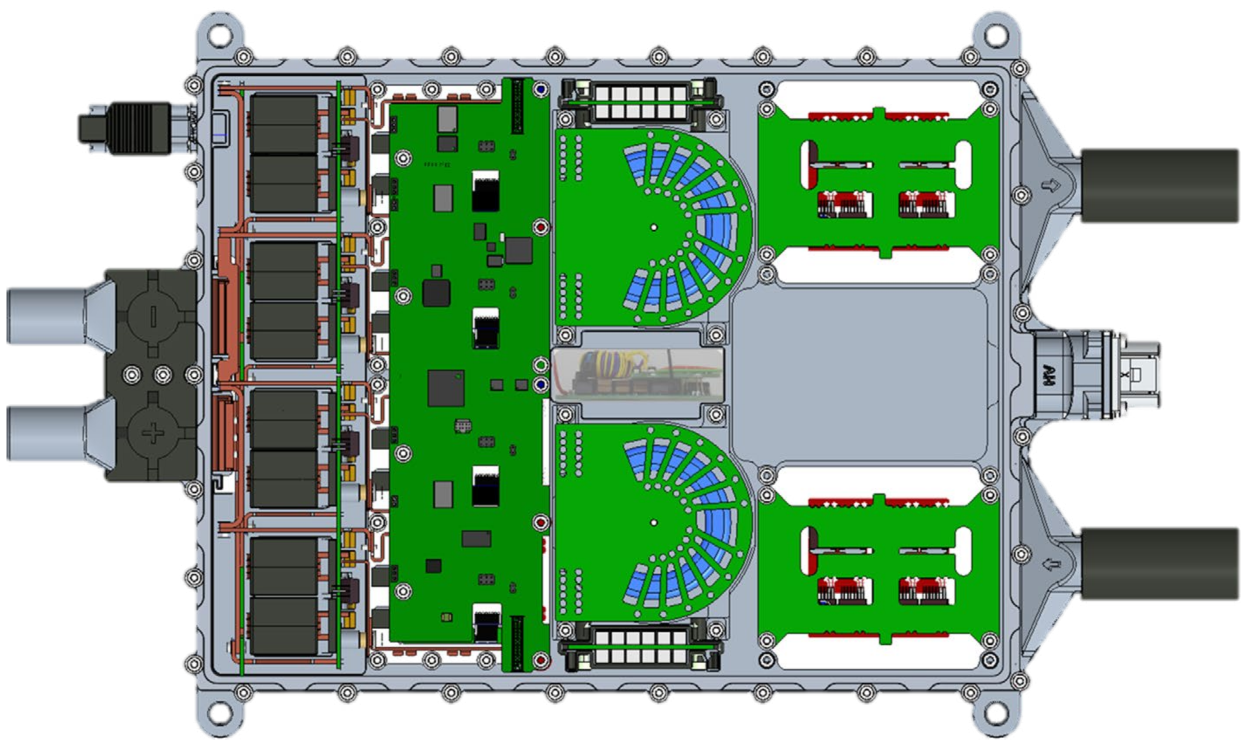
2 *Dr. Bernd Eckardt, head of the Vehicle Electronics department. © Kurt Fuchs / Fraunhofer IISB*

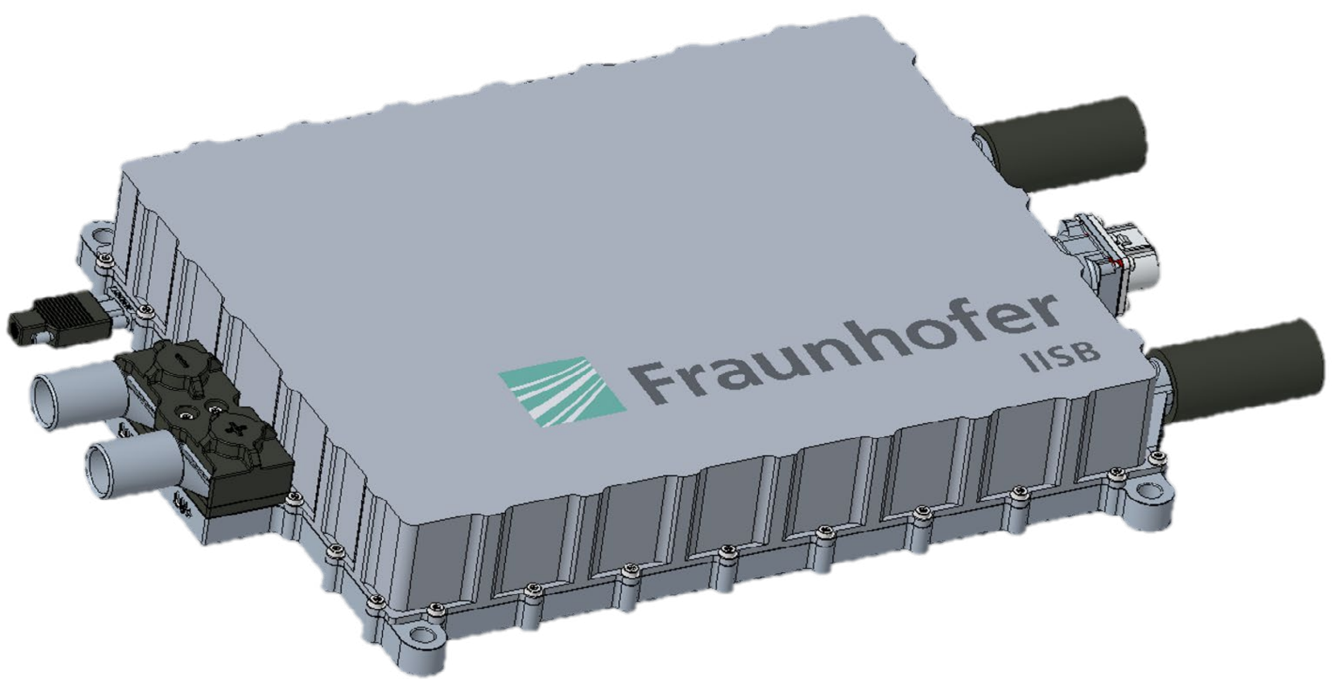
VEHICLE ELECTRONICS

High Power DC/DC Converters for Aviations



4





3

extraordinary work and their flexibility to adapt smoothly to the requirements preventing the spread of the Covid-19 disease.

HIGH POWER DC/DC CONVERTERS FOR AVIATION

Electrification is the key for CO_2 reduction and the main driver for new concepts even in aviation. Electric aircrafts, electric vertical take-off and landing vehicles, delivery drones and autonomous passenger air vehicles are all dependent on the progress in aviation power electronics. Challenges are very high safety and reliability requirements and very high power to weight ratios. The IISB has accepted this challenge in a broad spectrum of power converters. The latest development is a 11 kW high voltage (540 to 840 V) to low voltage DC/DC converter with galvanic isolation to supply auxiliary devices within the traditional 28 V aircraft powernet. The DC/DC is designed to deliver up to 400 A output current. Fulfilling the high safety and reliability requirements mentioned by standards like DO160, DO178, DO254, the DC/DC is, e.g., able to always reach a safe power-off state by additional implemented hardware safety circuits, regardless of the behaviour of the microcontroller or the programmed software. By using high voltage SiC power devices with 100% safety margins, the DC/DC will withstand harsh ambient conditions with higher cosmic radiation. Moreover, aviation power electronics means taken Paschen's law into account. Having the opportunity to operate the DC/DC also in a non-pressurized area of the aircraft it must withstand the much lower breakdown voltages for leakage and creepage distances due to the low air pressure. Hence, an appropriated topology have been chosen to reduce the necessary much higher distances to a minimum. Additionally, a new special sealed housing design will allow to fill the DC/DC with an inert gas.

With 32 cm x 24 cm x 5.5 cm a small volume of ca. 4 liters could be achieved. The estimated power to weight ratio will be around 2 kW/kg. Compared with latest commercial available aviation converters, power to volume as well as power to weight ratio should be raised by approximately 100%. The first measurement results will be expected in 2021.

The presented results have been achieved within the ongoing public founded project GETPOWER2 (LuFo V-3 program) driven by the "Bundesministerium für Wirschaft und Energie".

Contact

Dr. Bernd Eckardt
Phone: +49 (0) 9131 761-139
bernd.eckardt@iisb.fraunhofer.de

3 *CAD of the new 11 kW insulated HV/LV DC/DC converter to support the traditional 28 V powernet from a high voltage DC grid.*

4 *Basic structure of a high power electric distribution network for aircraft applications.*

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

INTELLIGENT ENERGY SYSTEMS

2

1

The department “Intelligent Energy Systems” develops the technologies for the digitalization of the energy conversion and storage in the transportation and energy domains. The department integrates these technologies in interconnected intelligent electric energy systems, building the “Cognitive Power Electronics” ecosystem initiated at the Fraunhofer IISB. Its research and development efforts are focusing on cutting-edge control and power electronic hardware, as well as on advanced software algorithms and data processing technologies making intensive use of artificial intelligence, targeting electrical power conversion and electrical energy storage in mobile and stationary applications, covering the entire power range from a few watts up to gigawatts.

Organization of department

The department is organized in five working groups with a total of about 35 researchers. Highly skilled staff in mechanics, mechatronics, electronics, embedded software, informatics, and computational mathematics with long-term experience in industrial R&D projects and technology transfer allows us to successfully support and accompany our customers in addressing the digitalization challenges in the transport and energy businesses. The close cooperation with the Chair of Power Electronics (LEE) at the University of Erlangen-Nürnberg in Germany provides us with access to the latest fundamental research results and an attractive pool of highly skilled and motivated students.

Activities of the research groups

The group “Data Analytics”, headed by Dr. Martin Schellenberger, helps our partners and customers to get the most out of their data in the context of IoT and Industry 4.0. The group takes an application-oriented approach that includes system analysis, conception, data collection, filtering, clustering, and finally the development and implementation of AI-based algorithms in industrial processes or in embedded systems.

The group “Energy Technologies”, headed by Dr. Richard Öchsner, investigates and optimizes intelligent and decentralized energy systems like fuel-cells and redox-flow batteries for the energy and transportation domains. The focus is on the integration of different physical storage systems (i.e., electrical, thermal, hydrogen) and on the intelligent interconnection as well as control – also based on forecasts – of different energy areas (sector coupling, peak load reduction).

The group “Industrial Power Electronics”, headed by Markus Billmann, supports our customers in solving power electronic challenges in the field of multi-level converters of all voltage ranges. Whether development support or problem analysis for running facilities and equipment, the

1 *Symmetry Device and DC Grid Manager from Fraunhofer IISB in a typical distribution panel (“Intelligent Energy Node” for commercial and municipal applications, R&W Steuerungstechnik GmbH Ahorntal). © Anja Grabinger / Fraunhofer IISB*

2 *Dr. Vincent Lorentz, head of the Intelligent Energy Systems department. © Kurt Fuchs / Fraunhofer IISB*

INTELLIGENT ENERGY SYSTEMS

foxBMS 2 – Second Generation of the Open Source BMS Platform foxBMS Launched

list of strengths in the field of troubleshooting of this group is large: longstanding industrial application experience, fast response time, and familiarity with industrial processes.

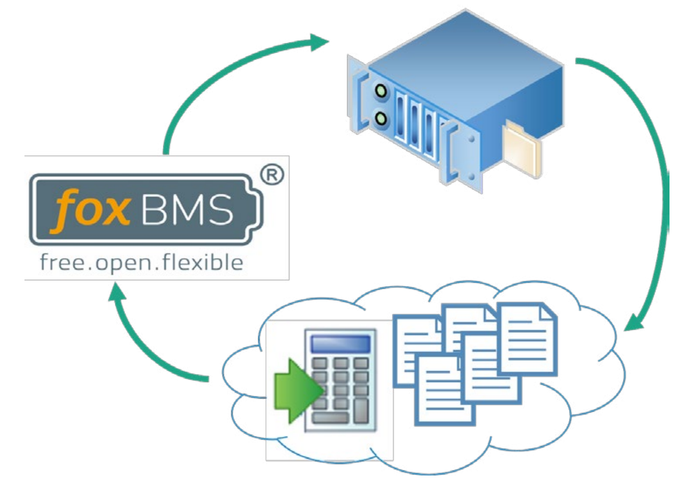
The "Battery Systems" group, co-headed by Martin Wenger and Radu Schwarz, is working on innovative solutions for lithium-ion-based electrical energy storage systems for stationary and mobile applications. The activities range from the development of hardware and software for battery management systems (e.g., foxBMS® platform), algorithms for battery state estimations and predictions, up to the design of full-custom battery systems for large applications like racing cars, submarine exploration robots, ships, airships, and electric gliders.

The group "DC Grids", headed by Bernd Wunder, focuses on innovative solutions for local DC grid systems. Their work ranges from applied research on safety and stability issues of DC networks, through concept studies, up to the development of innovative grid components, such as customized DC/DC converters, DC plugs, and protection devices. Bernd Wunder also represents the DC topic on boards such as VDE/DKE, IEC, eMerge Alliance, and IEEE Smart Grid.

foxBMS® 2 – SECOND GENERATION OF THE OPEN SOURCE BMS PLATFORM foxBMS® LAUNCHED

The markets worldwide are demanding for battery systems with higher energy densities, longer lifetimes, and lower costs, but without compromising safety. In order to guarantee a safe and efficient operation of the battery system, a battery management system (BMS) is required. The main objective of the BMS is the protection of the battery system from unsafe system states by keeping the battery within its safe operating area (SOA). The second objective of the BMS is the optimum use of the battery system in terms of available power, charge and discharge capacity and lifetime.

To support developers, engineers and researchers in the field of energy storage worldwide, Fraunhofer IISB has established the free and open Battery Management System platform "foxBMS®" (www.foxbms.org). In 2020, the foxBMS team developed and established the second generation of foxBMS and successfully derived customer specific adaptions (e.g., for aviation applications or fuel cell stack monitoring) from this completely new BMS platform. This BMS platform consists of a modular hardware and software architecture, a complete toolchain and ecosystem for software and algorithms development. With regard to the newly implemented functional safety features, as well as the accurate and stable battery state estimation, the 2nd generation of foxBMS provides a BMS platform beyond state-of-the-art.



3

3 *Fraunhofer IISB has launched the 2nd generation of its free, open and flexible Battery Management System platform foxBMS®.*

Certification-ready Submodules (Software and Hardware)

The 2nd generation of foxBMS was designed to be in line with functional safety requirements for various domains (e.g., automotive, aviation, railway, industrial, marine). Therefore, key components of the hardware architecture have been selected to not only comply with the ISO 26262, but also the IEC 61508 and other domain specific standards. This enables the designer to reach high safety integrity levels or even directly use certification ready submodules provided by Fraunhofer IISB as a service, for customer specific solutions.

foxBMS 2 will be the first open source BMS platform featuring a multi-domain functional safety strategy:

- Multi-applications: automotive, aviation, industrial, rail, marine, military
- Safety: pre-certified functional safety hardware and software parts
- Components: cutting-edge components from our partners (NXP, Maxim, ADI, Cypress, Intel)
- Edge-Cloud & AI: developed to support data processing on the edge and in the cloud (IIoT, NB-IoT / LTE-M)
- Interfaces: wider connectivity range with additional interfaces (e.g., Industrial Ethernet, Modbus, LIN)
- Robust memories: memory diversification and data integrity (Sampler Flash, FRAM, MRAM)

The architecture of foxBMS 2 is designed similarly to state-of-the-art BMS architectures: BMS Slave Units for measuring cell voltages and temperatures are mounted on each battery module. The BMS Slave Units are then connected to the central BMS Master Unit via a proprietary communication interface depending on the used analog frontend. The software implementing the BMS functionality runs on the microcontroller of the Master Unit.

The following list gives a short overview of the functional safety aspects incorporated into the BMS Master Unit of foxBMS 2:

- Automotive AEC-Q100 Grade 1 qualified components (i.e., -40 °C...+125 °C ambient operating temperature)
- ARM Cortex-R5F MCU for ASIL-D / SIL-3 / DAL-C Systems (TMS570 from Texas Instruments)
- Dual-Core Lockstep MCU with ECC protected Flash, SRAM, internal buses and interfaces
- Built-In Self-Test (BIST) for CPU, Timers, and On-Chip SRAM and Flash
- Voltage and Clock Monitoring, Error Signaling Module (ESM) with dedicated Error Pin
- Supporting ASIL-D battery monitoring integrated circuits
- Smart high-side switches for contactor control with feedback, diagnostic, and override (from NXP)

INTELLIGENT ENERGY SYSTEMS

foxBMS 2 – Second Generation of the Open Source BMS Platform foxBMS Launched

4

- Safety Basis Chip (SBC) for the supervision of all voltages (from NXP)
- Dedicated discrete windowed watchdog for critical software tasks monitoring (from Maxim)
- External memories with ECC using various storage technologies providing highest data integrity (Semper Flash and FRAM with ECC from Cypress, MRAM with ECC from Everspin)
- FreeRTOS and SafeRTOS with MPU from Wittenstein

In addition, various communication interfaces (e.g., CAN, Ethernet, LIN) for improved connectivity were added, meant to be used especially during BMS and algorithm development to support short design cycles.

Modelling workflow for precise battery state estimation using the AI and Cloud technology stack

The 2nd generation of foxBMS introduces several new communication interfaces to the platform that connect it to cloud based data storages and services. This opens new possibilities in the way battery powered applications are monitored and optimally used in terms of state of function and state of health estimation and system maintenance. Furthermore, it eases the development, verification and deployment of battery state estimation algorithms.

A novel approach is to use neural networks (NN) to estimate battery state parameters. For the SOC determination, this approach has the additional benefit that the initial SOC does not need to be known and therefore the need for recalibration is removed. With foxBMS' ability to connect to a datacenter and transfer the current utilization data of the battery into the cloud the NN is further trained based on the new input and the SOC prediction is further improved during operation.

The continually monitored utilization data of a fleet of battery applications allows deeper analysis of the application's impact on the battery lifetime. Based on novel data analysis approaches, it is possible to adapt the control of the battery usage, while still maintaining the application in an optimal performance window. The ability to introduce a priori knowledge about the system, from physics or experience, via hyperparameters enables balanced control and guidance during the learning process. The maintenance of the application can be drastically improved as the history of each battery system is stored inside the data center and even hidden failure causes can be early detected. The battery utilization can be adopted to maximize uptime and lifetime in a specific application.

4 *A battery system for peak load reduction is part of the DC grid at Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

INTELLIGENT ENERGY SYSTEMS

Industrial DC Microgrids for Increased Energy Efficiency

INDUSTRIAL DC MICROGRIDS FOR INCREASED ENERGY EFFICIENCY

DC microgrids have been well established over the last couple of years as a beneficial approach to interconnect distributed renewable energy resources, battery storage systems and loads locally. After maturing in telecommunication and data center applications, DC microgrids are now sparking interest also for industrial applications comprising a large number of speed-regulated drives. The fundamental challenges within these applications are power quality issues due to harmonic distortion caused by a large number of passive rectifiers on the one hand and the difficulty to regenerate braking energy on an economical scale on the other hand.

DC microgrids offer a cost-efficient solution for these challenges by eliminating the rectifier stages through provision of a common DC bus supplying the drive inverters directly. In addition to that, controlling the power flow within a DC microgrid is significantly easier in comparison to the AC mains, because the number of state variables directing the power flow is reduced from the quantity of two in the AC case, namely line voltage level and frequency, to only one in the DC case, which is the bus voltage level. Fraunhofer IISB has participated in different projects involving DC microgrids for industrial applications targeting different power levels.

LARGE-SCALE INDUSTRIAL PRODUCTION FED BY DC POWER

The project “DC-Industrie“, which was funded by the German Federal Ministry of Economic Affairs and Energy (BMWi), aimed at showing the benefits of local DC microgrids for different branches of industry like car manufacturing, machine tool building and plant engineering. After defining a broad consensus among different industrial equipment manufacturers on a comprehensive operating concept for the grid, several demonstration sites were built, commissioned and scientifically analyzed.

Fraunhofer IISB contributed in these fields: investigation of a decentralized load flow management concept that only requires the grid-side voltage value to determine the infeed level of a power source, advanced methods to measure the grid impedance within noisy industrial environments in real-time and development of high-efficiency DC-to-DC converter systems. The converters were deployed to interconnect a battery storage unit and a wood-working tool machine. Besides providing resiliency, the deployment of the active controlled storage system contributed to improve the total energy efficiency of the machine by up to 10% by regenerative braking energy that would otherwise be dissipated into heat.

5 *View into the central distribution cabinet with the main protection devices for the DC grid at Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

6 *Outdoor containers with batteries, fuel cells and electrolysers are integrated into the IISB grid. © Kurt Fuchs / Fraunhofer IISB*

DC MICROGRIDS Standardization

In recent years, the lack of standardization has been a major hurdle for the implementation of real direct current projects. Thanks to the many years of contribution from Fraunhofer IISB, there are now many revised standards. Last year Fraunhofer made a special effort to standardize industrial DC Microgrids. This is how the new standardization project IEC PT 63317 "LVDC Industrial Applications" came about, which has been largely initiated by Fraunhofer IISB employees.

Symmetry Device as a DC Microgrid Front-End

Fraunhofer IISB developed new hardware for a symmetry device for small and medium-sized industrial and commercial companies. This consists of various modules for power conversion, feed-in, storage and delivery of self-generated energy and also offers emergency power functionality. The core of the system is the direct current bus, which enables simultaneous feed-in and supply from different phases of the AC network. This means that normative symmetry requirements according to AR4105 can be implemented. This device is intended as a cost effective solution and can also use self-generated electricity and deliver additional services to the grid (e.g. reactive power compensation or power factor correction). If the symmetry device is used as a DC-Microgrid front-end, particularly high levels of efficiency, simplicity and manageability can be achieved when coupling various regenerative sources and storage systems.

The company Richter R&W Steuerungstechnik GmbH was nominated for the renowned Seifriz Prize in 2020 together with its project partners, the Chair for Measurement and Control Technology at the University of Bayreuth and the DC Microgrids Group at Fraunhofer IISB.

FAST SAFETY DEVICES FOR INDUSTRIAL DC MICROGRIDS

Operating a modern and DC microgrid requires not only converters, storage systems and renewable energy sources, but also an efficient and safe infrastructure to transport the energy. Since DC installations pose several challenges that usually do not occur in normal AC installations – e.g. long standing switching arcs or a change of direction in power flow – those must be addressed as well. This leads in many applications on .. Hence, in the research project „DC-Schutzorgane" („DC safety elements"), funded by the German Federal Ministry of Economic Affairs and Energy, a comprehensive protection system for DC microgrids was developed. Besides responding to the specific technical requirements of DC technology, the system and the individual protection devices – e.g. against arc faults and overvoltages – provide additional information about grid status and their own state of health, allowing predictive maintenance as well.

COGNITIVE POWER ELECTRONICS 4.0 FOR INTELLIGENT DRIVES: DATA-DRIVEN BEARING FAULT DETECTION

Reliable and failure-operable motor and inverter solutions are essential for a variety of automotive or industrial applications. Advanced diagnostic and condition monitoring methods contribute in reducing component-induced system failures, support demand based or predictive maintenance and therefore increase the uptime of the systems. Such additional functionalities require power electronic systems in combination with intelligent algorithms that can be implemented in modern drive systems.

To develop and demonstrate intelligent drives, we have set up the Intelligent Drive Development Platform (IDDP), which comprises a modular electric traction machine, a modular inverter system, and cognitive algorithms that realize the advanced functionalities. In a first demonstrator, we developed the data-driven detection of bearing faults.

1. Modular Electric Traction Machine

We designed, implemented, and characterized a modular 6-phase electric traction machine (see Figure 12) with 150 kW output power and a nominal voltage of 800 V. Ansys/Maxwell was used for the electromagnetic, thermal and mechanical optimization. The machine is realized as an Interior Permanent Magnet Synchronous Motor (IPMSM) due to the broad use of this topology in a variety of applications.

The machine allows the physical implementation and stimulation of different electric machine failures like bearing faults (see Figure 11), rotor eccentricity, short-circuits or demagnetization of single rotor-magnets due to its modular architecture. Therefore, the machine is used as an experimental setup for the development and testing of intelligent drive functionalities.

2. Modular Inverter System

The modular 800 V inverter system utilizes a six-phase topology with a full ceramic DC link capacitor (see Figure 10). We realized the IDDP inverter in a six-phase configuration with a maximum output current of 300 Arms per phase. Due to its planar layout it can be scaled from three up to twelve phases to address especially fail-operational multiphase applications, which are gaining relevance from, e.g., the aviation sector. The inverter has a volume of 6 l and weighs 9.5 kg.

7 *DC-GRID Manager Converter System for set up a full DC-Microgrid. © Kurt Fuchs / Fraunhofer IISB*

8 *DC Power Supply for industrial grids (bidirektional). © Bernd Wunder / Fraunhofer IISB*

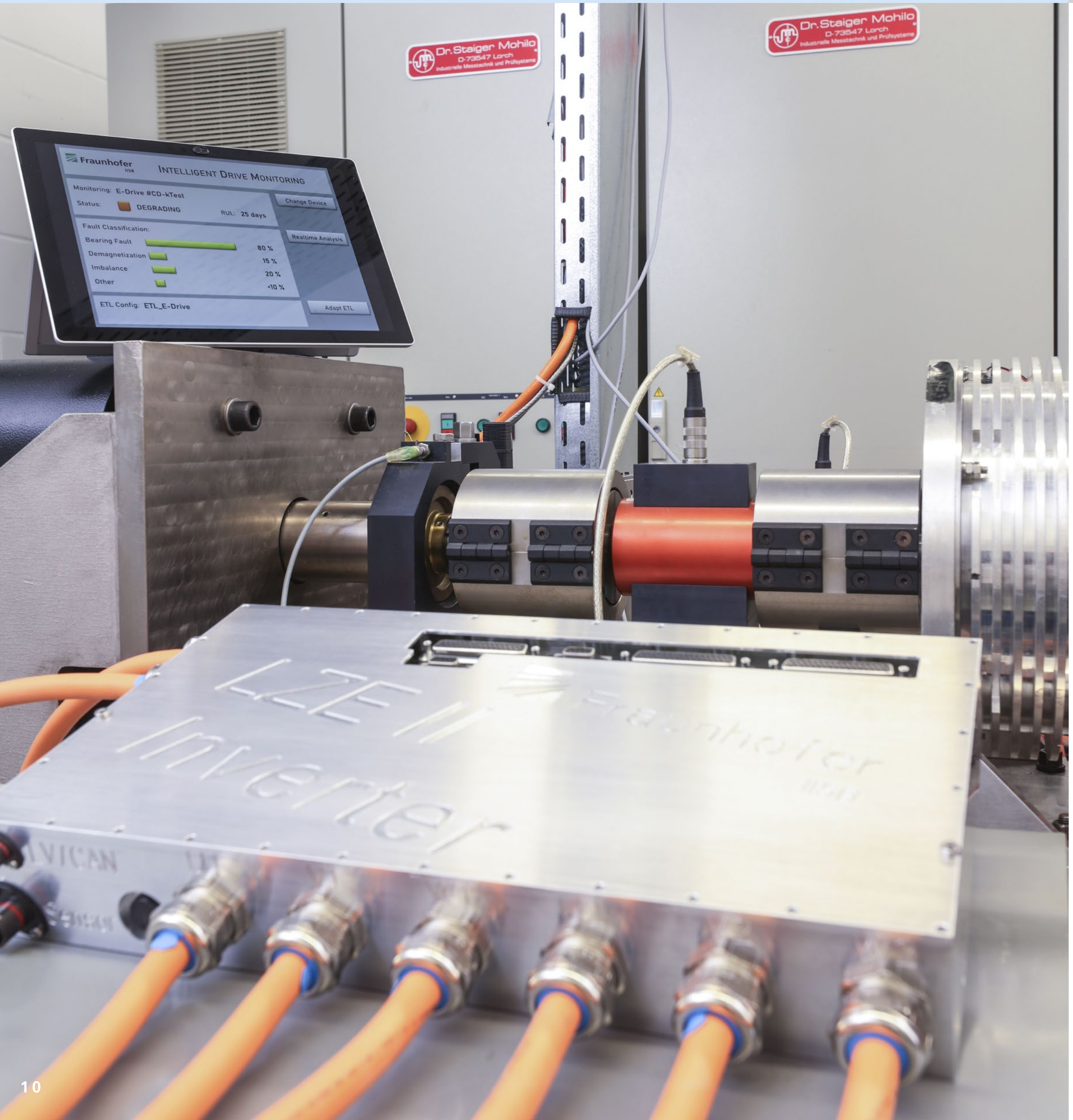
9 *Arcing in the test chamber for DC plug/socket tests and fault analysis. © Anja Grabinger / Fraunhofer IISB*

INTELLIGENT ENERGY SYSTEMS

Cognitive Power Electronics 4.0 for Intelligent Drives: Data Driven Bearing Fault Detection


11


12



10

As the provision of high-quality sensor data is crucial for data analytics, coreless anisotropic magneto resistive (AMR) effect based phase current sensors (CFS1000) are used which promise a high theoretical bandwidth of up to 500 kHz and dynamic current sensing due to low hysteresis effect.

3. Cognitive Algorithms for Intelligent Functionalities

Various failure modes may occur in electrical motors: Mechanical faults include broken rotor bars, cracked rotor end rings, air gap eccentricity or bearing and gearbox faults. Electrical faults may comprise shorting leading to stator or armature faults, turn-to-turn faults or coil to ground faults. Additionally, demagnetization effects due to excessive temperatures or overcurrents may occur. Bearing faults typically are known to be the most common fault types with a share or 30 % to 50 % of the machine failure.

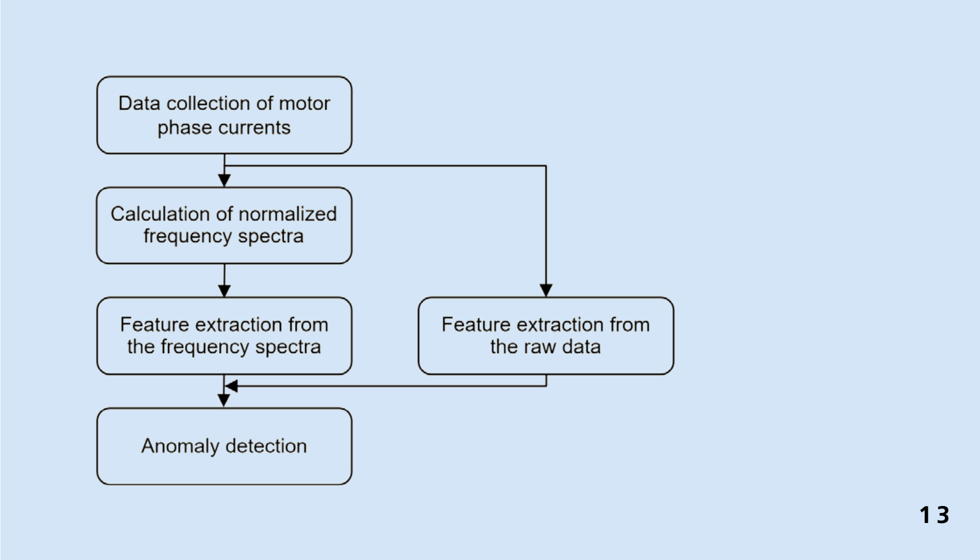
Intelligent algorithms for integrated fault diagnostics are preferably meant to rely on data, which is already precisely measured in the motor control and traction system, without the need for additional sensors. As an example, a bearing damage modulates the stator phase currents at characteristic frequencies, which linearly increase with motor speed. Although motor current signature analysis (MSCA) has been frequently studied, there is a strong demand for reliable algorithms in motors with highly varying operating conditions such as those in electric vehicles. Therefore, we selected the motor phase currents for analysis for the primary phase of the studies, which can be sampled at a higher frequency than other parameters used in motor control.

10 Modular IDDP inverter with integrated AMR based phase current sensors and AC, DC, and Data interfaces. © Kurt Fuchs / Fraunhofer IISB

11 Example of a bearing with one induced outer race fault. © Thomas Richter / Fraunhofer IISB

12 Realized modular 6-phase electric traction IPMSM machine. © Anja Grabinger / Fraunhofer IISB

13 Two approaches for data-driven bearing fault detection.



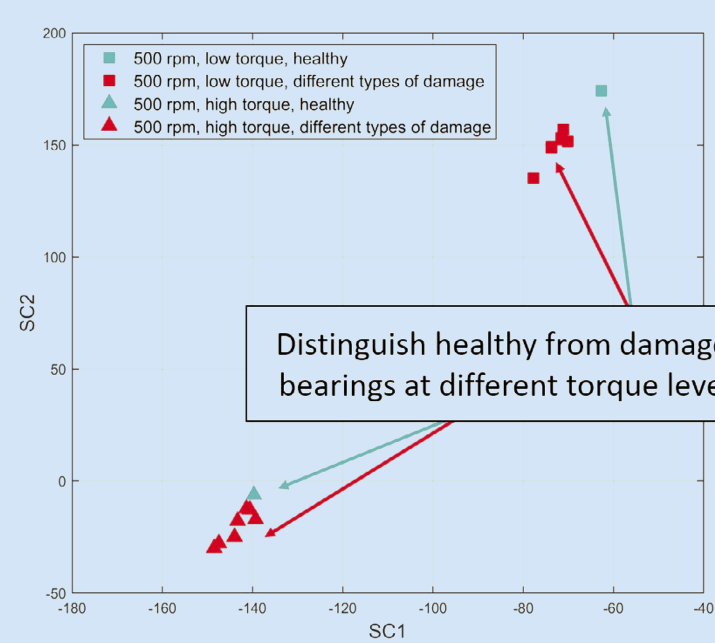
13

INTELLIGENT ENERGY SYSTEMS

Hydrogen Technology at Fraunhofer IISB

In a first approach, we developed algorithms that address a spectral analysis to normalize the motor-speed dependent bearing fault frequencies to the stator current frequency. This enables an accurate, direct comparison of the bearing fault frequencies, which provides valuable diagnostic information. The second approach aims at an end-to-end deep learning approach on the raw data, which should be applicable for various motor operating points (see Figure 13).

For the experimental assessment, a set of bearings was prepared comprising healthy and damaged bearings. We investigated various parameter settings of the motor operation, such as different rotor speeds, torques or inverter switching frequency. For the conducted analysis, the frequency spectra of the three phase currents were calculated so that effects due to the frequency scaling at different motor speeds were eliminated. We applied principal component analysis (PCA) as a basic method to investigate the differences in the spectra. Figure 14 shows the (averaged) coordinates of the current phase spectra derived from PCA at the example of a motor speed of 500 rpm at low and high torque levels. The bearing damage results in a deviation of the coordinates compared to the healthy state for all investigated motor operating points. This deviation can be automatically detected by an algorithm, classifying the bearing as healthy or damaged.



14

15

As a major challenge, the signal changes induced by the motor and inverter are larger than the signals induced by the faults, i.e., the distance of the respective coordinates between the motor operation points in Figure 14 is larger than the distances to the healthy state caused by the damaged bearing. Hence, still referencing to healthy state at a motor operating point is required. Thus, further work will address the development of bearing fault detection algorithms, which include inherent referencing, so they become applicable at all motor operation conditions.

HYDROGEN TECHNOLOGY AT FRAUNHOFER IISB

Fraunhofer IISB is developing outstanding power electronic solutions for stationary and mobile hydrogen fuel cell applications since the year 2000. The main research focus is on power converters with high power density and efficiency in fuel cell systems (for which the Joseph von Fraunhofer Prize 2020 was awarded to the IISB) and on hydrogen system integration.

In order to achieve the CO_2 targets which were defined worldwide, more and more vehicles are being electrified. In addition to hybrid vehicles and pure battery electric solutions, the fuel cell technology offers a possibility for CO_2 emission-free mobility. Whereas for small city vehicles the battery seems to be the most popular energy storage solution, the fuel cell vehicle seems to be the better solution for a long-distance transport vehicle application.

Especially for the required electrification of commercial vehicles, the fuel cell technology represents a promising possibility in addition to overhead power line supply concepts for which the DC/DC converters presented in this report are also used. Therefore, there will be a high demand for very efficient, small and cost-effective voltage converters in the short and medium term.

DC/DC converter technologies

For electrified vehicles with more than one electrical energy storage or an energy source (e.g. overhead line) or with a fuel cell, one or more uni- or bidirectional DC/DC converters are required in the powertrain. Since electrical voltage sources such as batteries or fuel cells can not be simply connected together, the output voltages must be matched to the DC link voltage of the powertrain via DC/DC converters, as shown in Figure 16.

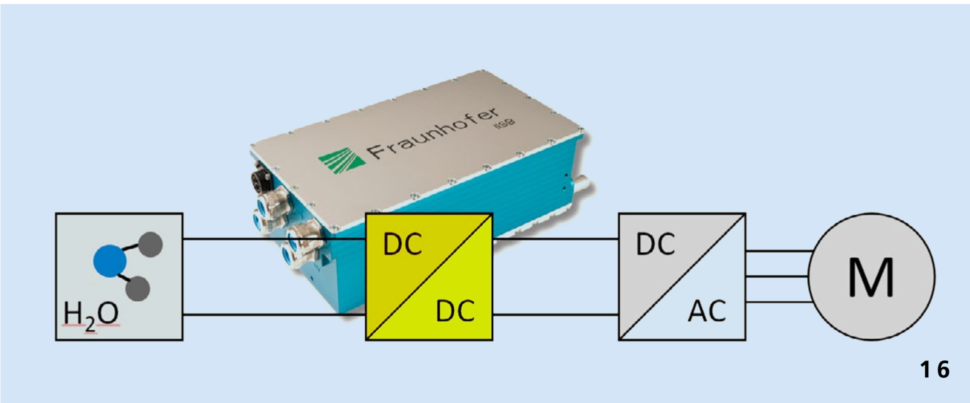
The challenge is that the full drive power from 100 kW up to 1 MW and also the entire drive energy must be transmitted via these DC/DC converters. Therefore, very high efficiency at partial

14 *Principal component analysis of the motor current spectra for a motor rotation speed of 500 rpm at different torque levels. Influence of the damage and the motor operation point is visible from grouping of the points.*

15 *Ultra compact high power DC/DC converter developed by Fraunhofer IISB. © Anja Grabinger / Fraunhofer IISB*

INTELLIGENT ENERGY SYSTEMS

Hydrogen Technology at Fraunhofer IISB



16

16 Schematic view of a drive train with DC/DC converter between fuel cell and drive.

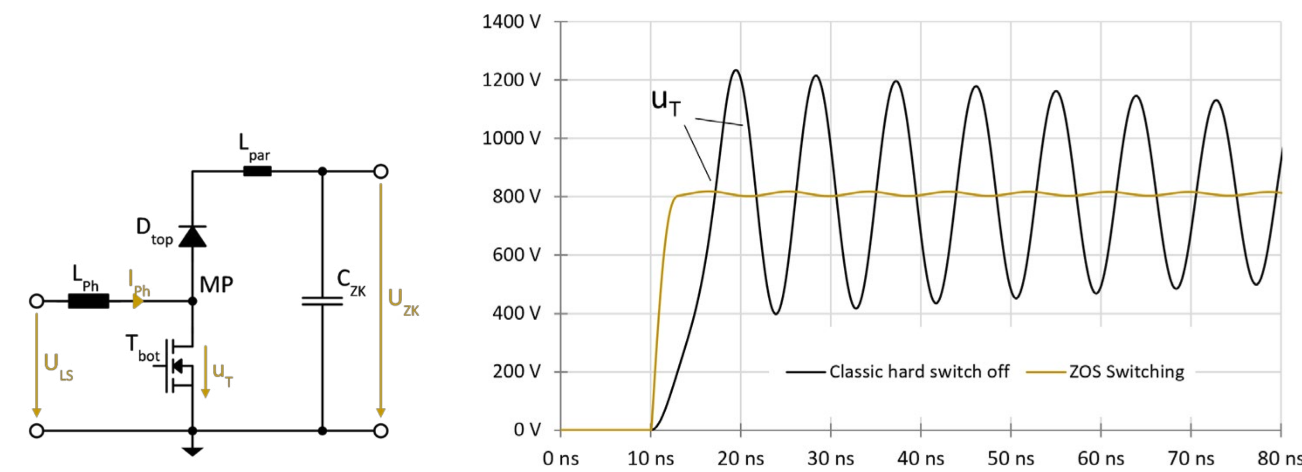
and full load, minimal installation space, and high mechatronic robustness are essential for use in vehicles.

The demand for high efficiency usually results in large components, while a very compact converter generates higher losses. To resolve this conflict, the Fraunhofer IISB is investigating different aspects of DC/DC converters. One example of this is "Zero Overvoltage Switching".

In the field of power electronics, almost no component is "ideal". Rather, every transistor, capacitor, and inductor has parasitic characteristics that cause unwanted losses, oscillations, reactive power, overvoltages, and electromagnetic interference. The state of the art attempts to suppress or minimize these effects. On the other hand, our approach utilizes these effects actively as efficient "devices" for the functionality of the circuit. Known in this context are, e.g., the so-called valley switching or quasi-resonant switching.

The systematic scientific pursuit of the utilization of parasitic effects resulted in the so-called "Zero Overvoltage Switching". Here it was shown in experiments that in certain constellations of the parasitic effects, virtually a fast, loss-free, oscillation-free, and overvoltage-free switching is possible with the newest devices such as GaN and SiC MOSFETs (see Figure 17).

In addition to the scientific presentation of the effect, the technique has also been filed internationally as a patent. The effect is also used in the latest generation of fuel cell DC/DC converters, depending on the operating point. In conjunction with many other technological improvements, this has resulted in a converter that measures only 5 liters in volume despite a high power of 400 A (600 A for a short time) at 850 V.



17

17 Schematic circuit diagram of a boost converter, often used in fuel cell vehicles (left), and simulation of the voltage over the UT switch for classic switching and ZOS (right).

Hydrogen Systems and Integration

The decarbonization of the energy systems is a major challenge of today's society. The Fraunhofer IISB addresses this challenge in various approaches in the field of hydrogen systems. The institute uses hydrogen for its semiconductor processes and can serve as an example and platform to demonstrate the recovery of exhaust hydrogen in industrial facilities, reducing its energy demand.

A system that converts hydrogen-rich exhaust gas from a semiconductor manufacturing unit into electricity has been developed. The heart of the electricity conversion system is a polymer electrolyte membrane (PEM) fuel cell that efficiently converts hydrogen from the exhaust gas with oxygen from the ambient air into electrical energy. Modifications to the fuel cell system allow the fuel cell system to work with hydrogen concentrations between 40 and 100 % by volume. The fuel cell system is thus also able to convert non-pure hydrogen or a hydrogen mixture into electricity. Conventional fuel cell systems, on the other hand, require a hydrogen purity of at least 99.97% by volume. This is the world's first conversion of epitaxial exhaust gas to electricity in a fuel cell.

For characterization of fuel cells and electrolyzers, a hydrogen test bench was developed. It was also used for the development of the demonstration of the electrical recycling of the hydrogen-rich waste gas. In general, this test bench is used to provide services to customers like development and investigation of hydrogen systems, characterization of fuel cells and electrolyzers, development of component models and simulations and model based development of operational strategies.

For mobile applications, that require high drive powers and ranges like ships and trains, innovative hydrogen storage technologies for high capacities are required. Therefore, a focus point of Fraunhofer IISB is the investigation of storage systems that use liquid organic hydrogen carrier (LOHC) as storage medium for hydrogen. LOHCs are organic fluids that are able to bind hydrogen in a chemical reaction at high pressures (hydrogenation) and release it in an endothermal reaction at high temperatures (dehydrogenation). The LOHC used at Fraunhofer IISB is dibenzyl-toluene. The oil is known from heat transfer applications and is stable and well manageable in common environmental conditions. Its maximum energy density, when fully loaded with hydrogen, is 1.9 MW/m³, which is about the fifth of diesel.

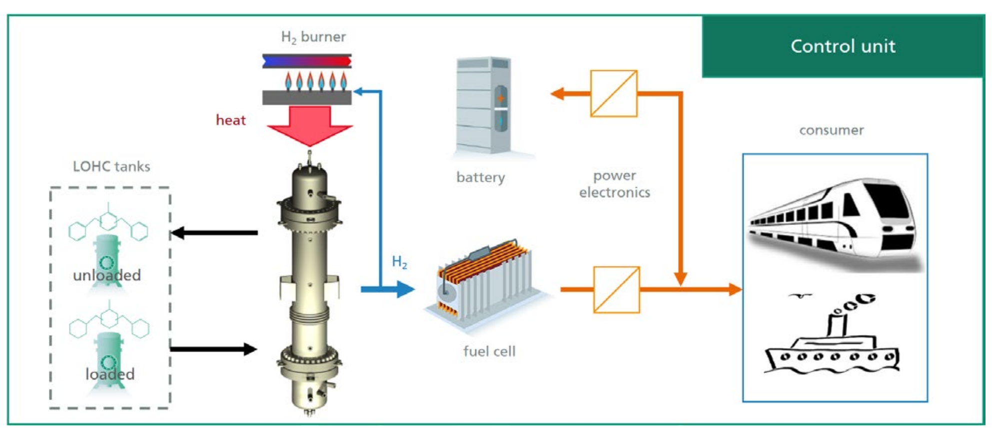
The institute's research platform for the LOHC technology is called LOHC-Container, as it includes the whole LOHC chain in a single 20' container: an electrolyzer for the production of hydrogen, a reactor for the hydrogenation and dehydrogenation process, a fuel cell for the reconversion of the hydrogen into electricity, two storage tanks for the loaded and unloaded LOHC as well as comprehensive measurement and control capabilities.

18

20

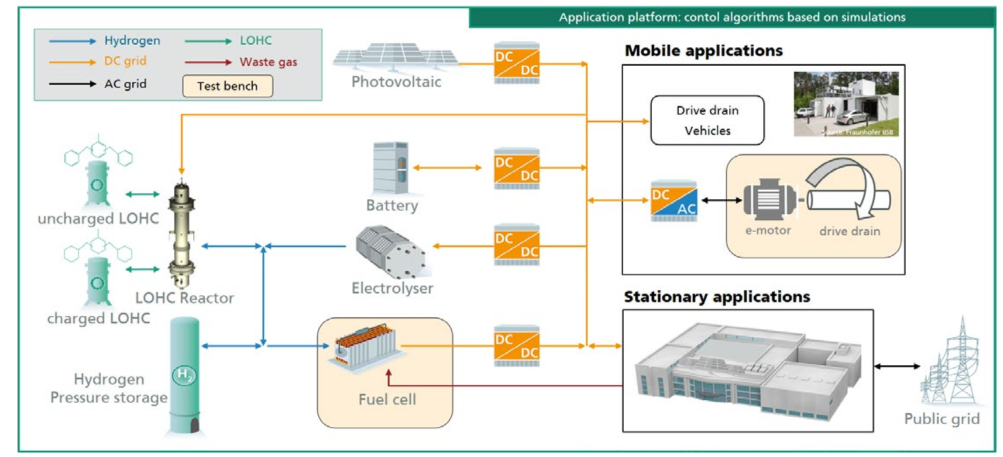
The container is connected to the institute's DC grid, which allows the production of green hydrogen with the local PV plant as well as the analysis of hybrid system solutions in combination with the institute's battery storage. The hybrid system combines various competences of the institute, from power electronics for the converters in the DC-grid, battery management systems for the batteries (open source tool foxBMS®), hydrogen system integration in general and validation platform for system simulation. In cooperation with the Helmholtz Institute Erlangen-Nürnberg (HI ERN), which has knowledge in the areas of reaction kinetics as well as design and developed the reactor for hydrogenation dehydrogenation inside the container, the researchers of Fraunhofer IISB use the container to analyze the hybrid system's behavior and dynamics and create simulation models from the generated data.

An example for analyzed application systems using the LOHC technology is the drive of a train, which was powered by a hybrid system consisting of electric engine, battery, fuel cell and LOHC reactor. The scientific challenge was to operate these components with different dynamics on a mobile platform efficiently in cooperation. Originating from the respective dynamic behaviors, the models of the components were used to develop use cases, concepts, control algorithms and operational strategies for the train. Based on the empirically gained process data, the simulation models can be adapted for other mobile or stationary applications.



19

In summary, Fraunhofer built up a hydrogen infrastructure for it research activities and for providing services to its customers. It covers the whole hydrogen chain from production of green hydrogen by PV, storage of hydrogen using the innovative LOHC technologies and mobile and stationary hydrogen usage and application combined with electrical batteries, power electronics and DC micro grids.



21

18 *Hydrogen test bench at Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

19 *Set up for a case study of the dynamical behavior of a drive train based on LOHC.*

20 *LOHC-Container developed and operated as a research platform. © Kurt Fuchs / Fraunhofer IISB*

21 *Hydrogen infrastructure at Fraunhofer IISB.*

Contact

Dr. Vincent Lorentz
Phone: +49 (0) 9131 761-346
vincent.lorentz@iisb.fraunhofer.de

EVENTS

Joseph von Fraunhofer Prize 2020: Hydrogen to Electricity – A New Generation of DC/DC Converters

1

JOSEPH VON FRAUNHOFER PRIZE 2020: HYDROGEN TO ELECTRICITY – A NEW GENERATION OF DC/DC CONVERTERS

1 *Dr. Bernd Eckardt (left) and Stefan Matlok received the Joseph von Fraunhofer Prize for developing a new generation of DC/DC converters.*
© Piotr Banczerowski / Fraunhofer

FUEL CELLS PLAY A KEY ROLE IN THE TRANSITION TO RENEWABLES IN POWER AND MOBILITY. BUT THE ENERGY EFFICIENCY OF THESE CELLS POSES A MAJOR CHALLENGE, PARTICULARLY IN AUTOMOTIVE ENGINEERING. THE INDIVIDUAL COMPONENTS NEED TO BE AS LIGHT AND SMALL AS POSSIBLE, YET ATTAIN A HIGH EFFICIENCY FACTOR. ONE SUCH COMPONENT IS THE DC/DC CONVERTER THAT MODULATES THE FUEL CELL'S VOLTAGE TO SUIT THE DRIVE AND CONTROLS THE FLOW OF ENERGY. CONVENTIONAL WISDOM HELD THAT IT WOULD BE IMPOSSIBLE TO DEVELOP A SMALLER YET MORE EFFICIENT CONVERTER. RESEARCHERS AT THE FRAUNHOFER IISB DEFIED THAT CONVENTION, MAKING THE IMPOSSIBLE POSSIBLE BY DEVELOPING A NEW GENERATION OF DC/DC CONVERTERS THAT MEET PRECISELY THESE REQUIREMENTS. THIS STRIDE INTO THE FUTURE HAS WON THE RESEARCHERS THE JOSEPH VON FRAUNHOFER PRIZE.

A quick trip to the supermarket or into the city? Battery electric vehicles get the job done well when it comes to short distances. But a fuel-cell drive that converts hydrogen into electricity looks to be the more promising prospect for commercial vehicles, aircraft, and ships. However, this requires many components, and they all have to be smaller and lighter to make the vehicle as energy-efficient as possible. One of these components is the DC/DC power converter. It adapts the fuel cell's voltage to the drive and controls the flow of energy.

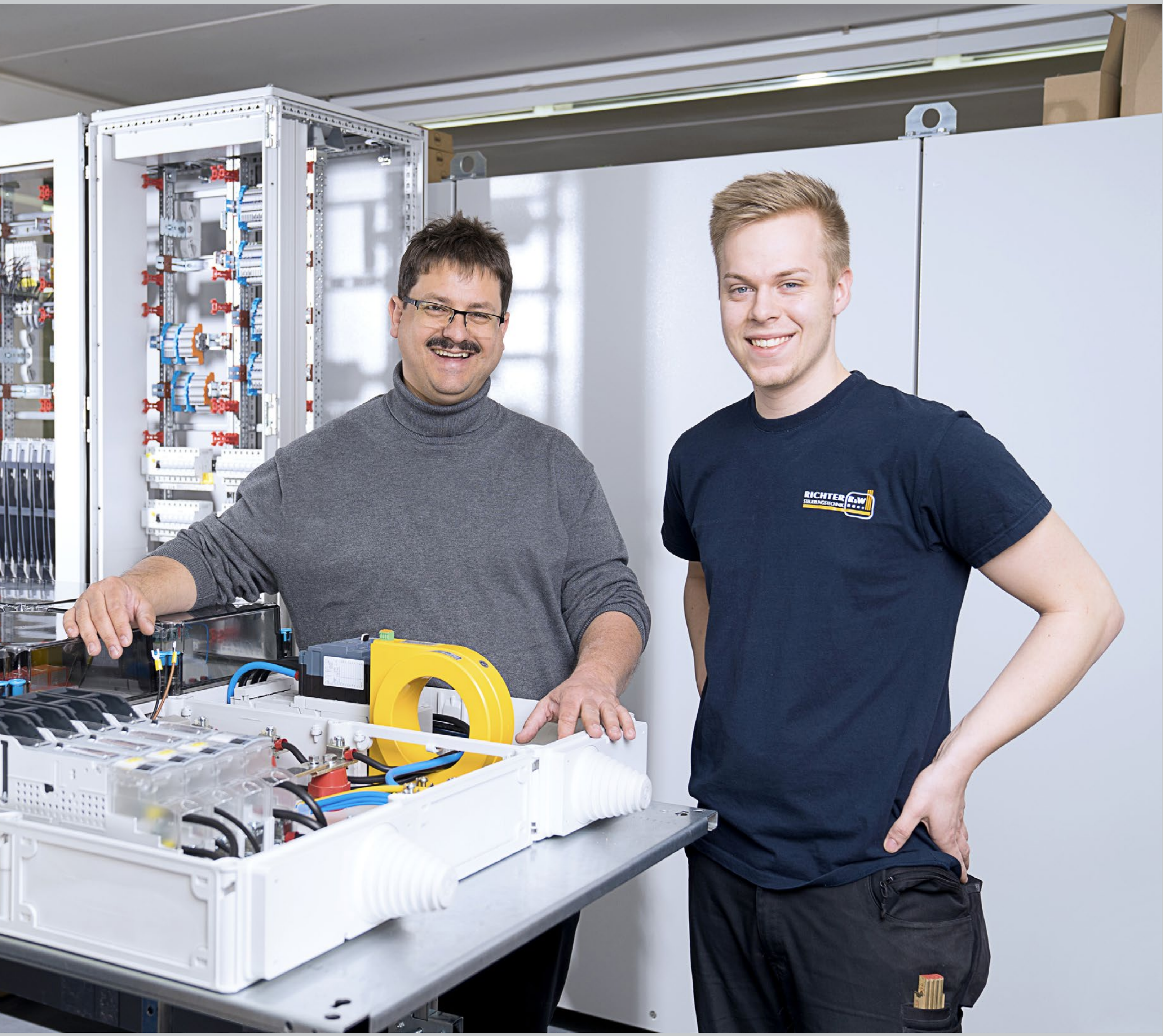
Efficiency increased, losses halved

Dr. Bernd Eckardt and Dr. Stefan Matlok from the Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen have developed a DC/DC converter that achieves very high efficiency despite its extremely compact footprint – and have garnered the Joseph von Fraunhofer Prize for their accomplishment. The jury hailed the outcome of this effort for its future relevance and successful commercial application. "While conventional DC/DC converters have an efficiency of around 97 to 98 percent, ours achieves up to 99 percent," says Eckardt. "This may not sound like much at first, but it means that the losses are more than halved – and every tenth of a percent matters."

After all, 200,000 watts of power flow through the converter. A loss rate of one percent would mean that two kilowatts of power dissipate in the form of heat.

EVENTS

Inspiring Cooperation Between the Handcraft Sector and the Scientific Community



2

In defiance of conventional wisdom

While today's electrical converters for fuel cells occupy around ten liters of installation space, the Fraunhofer IISB converter takes up just half as much room. In conjunction with its high efficiency factor, this is a sensational advance given that high switching frequencies and small components are generally said to cause greater losses. Defying this conventional wisdom, the two engineers developed new technologies that enable converters to be highly efficient yet very small. "What we've achieved was thought to be impossible," says Matlok. "And what made it possible was delving deeper into the physical effects of circuits and components. It is this attention to detail that enabled us to understand and take advantage of new physical effects. This led to new switching methods, among other things. Once again, new technologies are constantly emerging: Our colleagues and specialized companies from the relevant fields are developing ever more powerful individual components, which we as a team can combine to create increasingly powerful converters. After all, Fraunhofer IISB covers all the key technologies in power electronics and has the measuring and manufacturing equipment needed in the various fields." This is how Fraunhofer IISB takes care of the entire value chain from materials development, chip manufacturing and packaging technology to power electronics systems.

Transfer to industry

The researchers installed the voltage converter in a car to test its functional efficiency in an on-site climate chamber, where temperatures varied from minus 25 degrees to 50 degrees Celsius. A winter test carried out in frosty Norway by an automaker also went very well.

INSPIRING COOPERATION BETWEEN THE HANDCRAFT SECTOR AND THE SCIENTIFIC COMMUNITY

IT IS A SUCCESSFUL COOPERATION OF CRAFTS AND SCIENCE: TOGETHER WITH THE UNIVERSITY OF BAYREUTH AND FRAUNHOFER IISB IN ERLANGEN, BERND ZEILMANN, HEAD OF THE ELECTRICAL GUILD BAYREUTH, HAS DEVELOPED AN INTELLIGENT ENERGY SYSTEM THAT ENABLES EFFICIENT AND SUSTAINABLE ENERGY USE IN THE CONTEXT OF THE ENERGY TRANSITION, ESPECIALLY IN THE COMMERCIAL AND MUNICIPAL SECTOR. TOGETHER WITH ITS PROJECT PARTNERS, THE CHAIR OF METROLOGY AND AUTOMATIC CONTROL AT THE UNIVERSITY OF BAYREUTH AND THE FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB IN ERLANGEN, HIS COMPANY, RICHTER R&W STEUERUNGSTECHNIK GMBH, WAS NOMINATED FOR THE PRESTIGIOUS

2 *Bernd Zeilmann (pictured left), managing director of Richter R&W Steuerungstechnik GmbH in Ahorntal, and Sebastian Regus, master trainer and assembly manager, present components for the intelligent energy node (IEK). Various modules are available for the modular system, including an iMSys and feed-in module (iMSys: intelligent measurement module, shown in the foreground of the picture) and a low-voltage distribution module (standing in the background of the picture). © Anja Grabinger / Fraunhofer IISB*

EVENTS

Inspiring Cooperation Between the Handcraft Sector and the Scientific Community

3

SEIFRIZ PRIZE. AS A NATIONWIDE TRANSFER PRIZE OF THE GERMAN SKILLED CRAFTS SECTOR, THE SEIFRIZ PRIZE HONORS AND RECOGNIZES OUTSTANDING COOPERATION BETWEEN CRAFTS AND SCIENCE.

"This nomination is a very great honor and acknowledgement for us, as it makes it clear that technical innovations can be implemented in the crafts sector," says Bernd Zeilmann proudly. He says this has only been possible thanks to the successful cooperation between his craftsman's business and science.

In the cooperation of the three project partners, an intelligent energy node was developed that brings together various modules for the conversion, supply, storage, and distribution of self-generated energy, including emergency power functionality. These modules are perfectly coordinated with each other and therefore work together without any problems, thus primarily saving costs through the use of self-generated electricity and relieving the strain on the networks, explains Zeilmann. This is also achieved by a predictive control concept that takes energy prices into account and calculates the production output of the PV system from parameters such as weather forecasts and sunshine duration. Completely automated, the most favorable conditions for self-consumption, power supply, and storage would be searched for without the customer having to manually intervene. Bernd Zeilmann: "For example, the battery storage is charged when the price is favorable or when excess energy is available. Access to the energy storage is taken when the general conditions such as weather or price are unfavorable for the consumer or the mains supply breaks down."

"A system similar to this one does not yet exist on the market. However, many people are demanding it strongly, as the energy transition is creating new conditions for the energy industry. In addition to reduced grid fees due to peak load reduction, one of the things that is being called for here is flexible energy pricing, whereby electricity prices can change hourly," clarifies Bernd Zeilmann. "Furthermore, up to now, the energy supply in buildings has always been individually planned and developed for the customer's specific needs. That was quite expensive." The modules created now could be produced on a large scale and then installed and combined as standard, depending on requirements. "This also saves money, of course," Bernd Zeilmann is convinced.

With his company, Richter R&W Steuerungstechnik GmbH, Bernd Zeilmann secured the brand name of the novel control and regulation system after patenting it and developing this new type of modular energy system. He was supported in this process by the Business and Innovation Advisory Service of the Chamber of Crafts of Upper Franconia. At the University of Bayreuth, forecasting methods were developed and the system was tested and optimized in the laboratory.

3 *DC voltage module of the modular intelligent energy node (IeK) with grid control unit (DC grid manager of Fraunhofer IISB) and inverter.*

EVENTS

Fraunhofer IISB is Founding Member of the Regional Innovationskunst Initiative

Fraunhofer IISB contributed the power electronics for the integrated DC grid, which are not available on the market.

“In this cooperation, all partners were able to learn a lot from each other – science from crafts and crafts from science,” says Bernd Zeilmann, summarizing his experiences in the project. For him, it is a path that could be taken more often in Upper Franconia thanks to the fitting framework conditions. “There are enough innovative crafts companies, but also excellent research institutions that can benefit from each other.” In order to keep up with the international competition, an accelerated transfer of innovation from research into the field is absolutely essential, he says. This ensures value creation and prosperity in the region.

FRAUNHOFER IISB IS FOUNDING MEMBER OF THE REGIONAL INNOVATIONSKUNST INITIATIVE

THE EUROPEAN METROPOLITAN REGION NUREMBERG DOES NOT ONLY OFFER TOURISTIC HIGHLIGHTS, CULINARY SPECIALTIES, AND A HIGH QUALITY OF LIFE, IT IS ALSO ONE OF THE MOST INNOVATIVE REGIONS IN EUROPE. AS THE LATTER FACT IS NOT COMMONLY KNOWN, RENOWNED COMPANIES, THE LOCAL CHAMBER OF INDUSTRY AND COMMERCE, AND RESEARCH ORGANIZATIONS HAVE FORMED A REGIONAL INITIATIVE TO CHANGE THAT BY A JOINT AND CONCERTED PUBLICITY CAMPAIGN (WWW.INNOVATIONSKUNST.DE).

In the region, numerous global brands as well as a multitude of medium-sized hidden champions can be found. The local patent index is twice as high as the German average. International technology fairs, 20 universities with about 100,000 students, almost 50 R&D institutions, and an age-long history of innovation create the ideal environment for technology enthusiasts who look for a great place to live and work. The Innovationskunst initiative, which was officially launched in spring 2020, wants to increase the public perception of these exceptional circumstances and attract talented and committed people searching for the perfect ground to develop.

Innovationskunst is defined as the skill to create ideas and inventions for their economic realization and to make them work successfully both in the market and in society. Fraunhofer IISB as one of the co-initiators and founding members of Innovationskunst widely contributes to this with its research on electronics for mobility, energy, and industry. In its Innovationskünstler series, the initiative introduces remarkable people from industry and science who live and perfectly represent this spirit. As one of the first in this row, IISB researcher Johannes Geiling and his pioneering activities in hydrogen systems technology were portrayed.

THE ART OF HYDROGEN

Hydrogen Expert and Innovation Artist Johannes Geiling

THAT’S EXACTLY HIS CUP OF TEA - THE WHITE “HYDROGEN CONTAINER” ON THE LAWN IN FRONT OF FRAUNHOFER IISB IN ERLANGEN. SEVERAL TIMES A WEEK, JOHANNES GEILING CHECKS THAT EVERYTHING IS IN ORDER IN THE OUTWARDLY INCONSPICUOUS 20-FOOT CONTAINER WITH ITS COMPLEX INNER WORKINGS.

“Even in home office times, I regularly checked the measurement data recording from home to make sure the system was working properly. If everything runs smoothly in operation and we generate a lot of test data that can then be analyzed with colleagues, that’s great,” explains the graduate energy technologist Johannes Geiling. The 31-year-old from the Bad Kissingen region is passionate about future-oriented energy systems. After studying mechanical engineering with a focus on energy and environmental technology at the Würzburg-Schweinfurt University of Applied Sciences, he went on to earn a master’s degree in energy technology at the University of Erlangen-Nuremberg (FAU). He then became a scientific employee at Fraunhofer IISB, where Johannes Geiling has grown into a hydrogen expert in the energy technology group.

Traditionally, Fraunhofer IISB has focused on semiconductor technology and power electronics for electromobility and energy supply. In the meantime, the entire institute has transformed itself into a large real-world laboratory for the energy transition, because there is no way around topics such as sector coupling, system integration, or mobile and stationary energy and drive systems. Johannes Geiling is not the only one who believes that hydrogen technology will make an important contribution to a truly sustainable energy supply and energy use.

A happy coincidence for the development of the hydrogen container was certainly the founding of the Leistungszentrum Elektroniksysteme (LZE) in 2015. FAU, Fraunhofer IIS, and Fraunhofer IISB wanted to bundle their competencies together with the industry and created a unique research platform through the LZE. The stated goal of the Leistungszentrum is to strengthen research and industry in the field of electronic systems in the Nuremberg metropolitan region. In this environment, the idea of a compact, cross-technology demonstration platform for the generation, storage, and reconversion of hydrogen was born. At the Chair of Chemical Reaction Engineering (CRT), the university already had extensive know-how on the storage of hydrogen using an organic carrier liquid, the LOHC (Liquid Organic Hydrogen Carrier). At IISB, experiments were successfully performed with fuel cells for the conversion of hydrogen from industrial waste gases into electricity. In addition, the activities at the institute in the field of direct current grids were developing into a true success. This meant that the institute already had many of the

4 *#Innovationskunst (The Art of Innovation): Become the Most Inventive Region in Germany.*
© Europäische Metropolregion Nürnberg (EMN)

EVENTS

The Art of Hydrogen

5

necessary approaches for the complete process chain, i.e. for converting electrical energy into chemically bonded hydrogen and generating electricity from it again. The big challenge, however, was to put all the technology together in a single integrated system.

However, in the end the sense of achievement was even greater for the engineer: "It was incredibly exciting to see the system running successfully after the long planning and construction phase. We now have a unique test environment here for real world operations. In the process, the system is directly connected to IISB's real-life laboratory infrastructure via DC coupling and other interfaces."

But development is not standing still. The energy engineer clearly sees a steadily growing demand for the electrification of conventional drive concepts that up to now have been powered by fossil fuels: "Hydrogen would be a real alternative, especially for high-performance and long ranges or for extended operating times. Just think of trains, ships, construction machinery, mining vehicles, or even aviation. Our experiences from the container format have brought us an enormous increase in knowledge regarding interface definition, compactness, and operation of hydrogen systems. Now, we would like to bring industry and SMEs on board to develop and test hybrid energy and propulsion systems with hydrogen and electric batteries."

In the meantime, other regional partners are already using the research platform at Fraunhofer IISB for experiments with hydrogen, such as the Helmholtz Institute for Renewable Energies (HI ERN) in Erlangen. In the last two years, for example, several modifications have been made and test series have been carried out for a follow-up project that will focus on hydrogen drives for railroad trains.

The uniqueness of the system and the wide scientific range from electronics to chemistry and process engineering to control technology fascinated Johannes Geiling from the very beginning. A wide variety of interfaces between the components and technologies had to be defined. And it was not only the combination of many technical aspects that made the work so varied, but also the multi-layered network of partners in the project.

As so often, Johannes Geiling came to Fraunhofer IISB by sheer coincidence. "A few fellow students from FAU were working as student trainees in the energy technology group at IISB. Through them, I found out that graduate theses were also offered there in cooperation with the university. After my master's thesis, my supervisor asked me to work on the project at IISB, which I found very exciting."

Born in Lower Franconia, he feels very comfortable in his new home. "The region offers an outstanding range of cultural activities, and from Erlangen you can quickly get out into the

5 *Hydrogen expert Johannes Geiling is the second innovation artist presented within the series "Place for Innovation Artists" of the Metropolitan Region Nuremberg. In his personal story at #innovationskunst, he explains what he likes about the Metropolitan Region and why he can realize his ideas here. © Thomas Richter / Fraunhofer IISB*

countryside by bike." In addition, the Nuremberg metropolitan region is a perfect fit for his professional passion - the area has a distinctive industrial and research landscape for energy technology. His first contacts with the region came during his studies in Schweinfurt, when he wrote his diploma thesis at N-ERGIE's Sandreuth power plant in Nuremberg.

Looking to the future, Johannes Geiling wants to keep his focus on hydrogen. This is where he would like to drive research, development and, above all, practical applications further forward. "The real scenario is of course difficult to predict, but in principle green hydrogen offers a great opportunity to make electricity from renewable energies usable for the energy, transport, and industry sectors, and to make a serious contribution to sustainable decarbonization. I hope that the implementation can get off the ground before the final fossil resources have been exploited at a destructive expense." A wish that many likely share with him.

HAPPY BIRTHDAY LEISTUNGSZENTRUM ELEKTRONIKSYSTEME (LZE)!

Strong together – the Leistungszentrum Elektroniksysteme (LZE)

THE COOPERATION BETWEEN THE FRAUNHOFER INSTITUTES IIS AND IISB IN ERLANGEN AND THE FRIEDRICH-ALEXANDER-UNIVERSITÄT ERLANGEN-NÜRNBERG (FAU) HAS ALWAYS BEEN GOOD AND CLOSE, WHETHER IN THE FORM OF JOINTLY OPERATED LABORATORIES OR UNITED ACTIVITIES IN RESEARCH, TRAINING, AND TEACHING. WITH THE FOUNDING OF THE LEISTUNGSZENTRUM ELEKTRONIKSYSTEME (LZE) IN 2015, THIS COOPERATION WAS TAKEN TO A WHOLE NEW, STRATEGIC LEVEL - MISSION: MAKING TECHNOLOGIES FROM EXCELLENT RESEARCH SUCCESSFUL BY TARGETED TRANSFER ACTIVITIES.

Complex electronic systems as the base of value creation

Intelligent and powerful electronic systems are the basis of every modern industrial and consumer application and are therefore of highest economic relevance. The economic ecosystem in the Nuremberg Metropolitan Region is also highly dependent on mastery of the subject. Today, an electronic system does not only consist of bare circuit components and devices, it is much more integrated with complex control and regulation software into a specific mechanical, chemical or thermodynamic environment in which it has to operate reliably, safely, and efficiently. Circuit design, communication technology, power electronics, sensor technology, material aspects, and increasingly also artificial intelligence interact here in high complexity. To stay on top of global competition, it is essential to be at the leading edge of this rapid development. This requires one thing above all others - the art of innovation.

6 The Bavarian Minister of Economic Affairs, Ilse Aigner (right), holding a FitnessSHIRT with two integrated electrodes and a breathing band for measuring a 1-channel ECG and the respiratory rate, together with project manager Nadine Lang, at the Ministry in Munich on June 16, 2015. © Marc Müller / LZE / dedimag

Strategic initiative

This was reason enough for FAU, IIS, and IISB to bundle their strengths in this area and align their strategies with each other in the LZE - together, the partners provide all the necessary competencies for the development of complex electronic systems as well as the system know-how for all important sectors of application in a comprehensive manner. The location offers unique conditions throughout Europe for the field of electronic systems with regard to research and industry. The synergies through the strategic initiative of Fraunhofer and FAU combined with a large partner network in the region create visibility, efficiency, and a central point of contact for industrial customers.

Research and transfer at the cutting edge

The LZE works on exciting research topics that are focused on the needs of companies. The digital transformation covers the technical spectrum of the current scientific lead projects of the Leistungszentrum. The activities start with novel semiconductor materials and components to enable low-loss switching in power modules at high voltages and currents for Industry 4.0 applications - also in electronics, sustainability is playing an increased role. These will combine classic power electronics with data analytics and machine learning for intelligent functionalities up to the overall system level, e.g., in drive technology. In addition, a new approach is being investigated to significantly improve wireless communication of nodes in the Internet of Things to realize multi-layered local area networks both in the consumer and industrial sectors. The research also takes into account how the human factor will be integrated by means of innovative digital assistance for manual manufacturing steps using cognitive sensor technology, for example in car production.

In addition to its scientific work, the Leistungszentrum focuses explicitly on the design of structures and cooperation models for transfer and commercialization so that technologies emerging from research can be transferred into products more quickly and in close cooperation with industry. In a highly accelerated market, the speed factor plays the key role. The LZE provides support here, for example, with strategic business field development, new licensing models, career and education programs, or joint roadmapping between science and industry.

EVENTS

IISB Awards 2020

5 years LZE

A press conference on June 16, 2015 officially opened the LZE under the patronage of the former Bavarian Minister of Economic Affairs, Ilse Aigner. For five years now, the partners in the LZE have been continuously developing their close cooperation in research and knowledge transfer. In addition to the institutes and chairs, the LZE now has its own legal structure supported by FAU and Fraunhofer, which extends the opportunities for collaboration with a non-profit society and a technology transfer company. A joint education platform was set up, which offers interesting formats for participants from industry, such as the digitally-based "Knowledge Snacks". The company has launched its own series of events, such as the LZE Tech Day conference and the #inNUEvation innovation conference, in which the pride in the region is already reflected in the name, and several spin-offs have already been established. The open innovation lab JOSEPHS in Nuremberg has also become part of the LZE's startup circle.

The Leistungszentrum Elektroniksysteme in the Nuremberg Metropolitan Region is a central platform in the right spot to provide the regional and Bavarian industry with even better access to the scientifically and economically important area of electronics. According to the motto "Together we achieve more." the collaboration of all three LZE research partners in the regional initiative #Innovationskunst is just consistent.

IISB AWARDS 2020

The research and development prizes awarded annually by the Fraunhofer IISB Executive Board recognize outstanding contributions by colleagues.

The team prize was awarded to Michael Lang, Dr. Christian Reimann and Kevin Schuck from the Materials department. They developed a high-temperature-resistant water-based tantalum carbide (TaC) spray coating. Functional coatings made of high-melting refractory metal compounds such as TaC are very well suitable for thermal protection structures. The coating technology can be used, for example, to make engines more efficient and components for spacecraft more durable.

The individual prize went to Zechun Yu, who works at IISB in the field of packaging technology. In international cooperation with the renowned sintering expert Prof. Katsuaki Suganuma from Osaka University, Zechun Yu developed a new silver based direct bonding technology for power semiconductor devices. The direct bonding process does not require an additional intermediate layer and opens up promising options for the construction of power modules.

7 *Fraunhofer IISB R&D Individual Prize: Zechun Yu for the development of a new silver based direct bonding technology for power semiconductor devices. © Anja Grabinger / Fraunhofer IISB*

8 *Fraunhofer IISB R&D Team Prize (from left to right): Kevin Schuck, Christian Reimann, and Michael Lang for the development of water-based TaC spray coating. © Anja Grabinger / Fraunhofer IISB*

EVENTS

Block Heat and Power Unit (CHP) of the Year

10

9

BLOCK HEAT AND POWER UNIT (CHP) OF THE YEAR

THE MAGAZINE „ENERGIE UND MANAGEMENT (E&M)“ HAS NOMINATED THE NATURAL GAS CHP PLANT AT FRAUNHOFER IISB AS „CHP UNIT OF THE YEAR“, HAVING PREVIOUSLY AWARDED IT THE TITLE OF „CHP UNIT OF THE MONTH“ IN JUNE 2020.

Out of the “CHP of the Month” that E&M presents during a year, the German “Bundesverband Kraft-Wärme-Kopplung e.V.” (B.KWK, “Federal Association for Combined Heat and Power”) selects one plant as the annual champion. In 2020, CHP concepts of combined heat and power plants running on natural gas and biogas with an electrical rating of between 4.7 kW and 2 MW were up for election. The jury was convinced by the concept developed using scientific methods for integrating the CHP plant with a heat and battery storage system into the infrastructure of the Fraunhofer IISB.

In combination with a newly developed intelligent operating strategy for electric power and heat supply and for peak load reduction, a system concept was implemented that serves as a role model for the energy transition. At Fraunhofer IISB, a key research area is the optimization of the energy infrastructure in industrial-scale facilities. As the institute operates not only offices but also air-conditioned clean rooms and laboratories with large energy consumers, it is ideally suited as a demonstration platform for energy system solutions for medium-sized companies and industrial sites. The optimization methods are not only related to the single present energy sectors - heating, electricity and cooling - but also focus on the overall energy system by linking the different sectors.

The plant at a glance

The Fraunhofer IISB operates a natural gas CHP from Tuxhorn (150 kW_{el} and 210 kW_{th}), combined with a 60 kWh battery system and a 24 m³ heat storage tank. As a special feature, the plant is optimized for peak load reduction (peak shaving) of up to 20 %. It is used for supply and research while saving costs. The average overall efficiency in operation amounts to 86.2 % and the running time per cycle is 17 h.

In the E&M issue 23/24 of December 15, 2020, the “Zeitung für den Energiemarkt” (“Newspaper for the Energy Market”) reports about the intelligent load management with CHP, battery and heat storage at IISB.

9 *The magazine “Energie und Management (E&M)” has nominated the natural gas CHP plant at Fraunhofer IISB as “CHP unit of the Year”, having previously awarded it the title of “CHP unit of the Month” in June 2020.*
© Kurt Fuchs / Fraunhofer IISB

10 *Combined heat and power plant and hot water storage tanks in the basement of Fraunhofer IISB: The combined heat and power plant was integrated into the institute's infrastructure as part of the extension building B. It is used there both for heat and power supply and as a research facility.*
© Kurt Fuchs / Fraunhofer IISB

EVENTS

FAU Students win International Contest New Flying Competition 2020

FAU STUDENTS WIN INTERNATIONAL CONTEST „NEW FLYING COMPETITION 2020“

AN AIRCRAFT THAT CAN TAKE OFF AND TOUCH DOWN VERTICALLY, WHICH IS EFFICIENT IN ITS ENERGY CONSUMPTION AND ALSO FLIES AUTONOMOUSLY: THE „TECHFAK ECOCAR“ TEAM FROM THE FRIEDRICH-ALEXANDER-UNIVERSITÄT ERLANGEN-NUREMBERG (FAU) WON THE NEW FLYING COMPETITION 2020 (NFC) IN HAMBURG WITH ITS „NIGHT FURY“ FLYING MODEL. THE INTERNATIONAL STUDENT COMPETITION IS DEDICATED TO THE CONSTRUCTION OF MODEL AIRCRAFTS THAT ADDRESS IMPORTANT ASPECTS OF TOMORROW’S FLYING.

This year, the task of the competition was to develop a flight model that can take off and touch down vertically according to the VTOL principle (Vertical Take-off and Landing) - an aspect that is becoming more and more important, especially with the increasing air traffic in densely populated urban areas. One important guideline was that the design should achieve the same efficiency in horizontal flight as a conventional aircraft, which requires an extensive runway for take-off and landing. The students of the EcoCar team managed this successfully with their VTOL aircraft „Night Fury“.

Versatile and Economical

“With an energy consumption of only 128 watt hours over a distance of 22 kilometers, including vertical take-off and touch-down and various flight operations, ‘Night Fury’ features very low energy consumption,” explains mechatronics student Adrian Sauer, head of the EcoCar team. This is made possible by a particularly efficient design approach whereby the FAU team designed the aircraft around a classic quadrocopter configuration with four lift rotors and an additional thrust rotor. In combination with self-developed lightweight carbon-fiber structures and a highly efficient electric propulsion system, the design allowes a take-off weight of just ten kilograms, including the specified payload of two kilograms. “Although not explicitly required for the competition, ‘Night Fury’ is also capable of flying autonomously,” adds Adrian Sauer.

In competition, ‘Night Fury’ has proven to be very reliable. The FAU students took first place with their model aircraft, followed by Team HORYZN from the Technical University of Munich and Team BEOAVIA from the University of Belgrade. The international field of participants included six groups from Germany, China, Mexico and Serbia. The New Flying Competition takes place every two years since 2016 and is an initiative of Neues Fliegen e.V., an association that originated from the Hamburg University of Applied Sciences.

11 *Team TechFak EcoCar with the trophy for 1st place at the NFC 2020 and the electric VTOL Copter “Night Fury” in front of the Fraunhofer IISB in Erlangen. © Kurt Fuchs / Fraunhofer IISB*

12 *Final briefing of the pilots from Team EcoCar shortly before the flight at the NFC 2020 in Hamburg. © Adrian Odenwald / TechFak EcoCar*

EVENTS

Palomar Technologies and Fraunhofer IISB form Research Initiative on Power Modules for Electric Vehicles

14

13

Team TechFak EcoCar

The TechFak EcoCar team was founded at the FAU Faculty of Engineering in 2008. In this team, students work on challenging projects for the mobility of the future in their spare time or as part of their final theses. An electric car and an electric motorcycle were already developed and built, but the group's current focus is on electric flying. In their work, the students are supported by the infrastructure and power electronics expertise of the Fraunhofer Institute for Integrated Systems and Device Technology IISB, a close cooperation partner of FAU.

PALOMAR TECHNOLOGIES AND FRAUNHOFER IISB FORM RESEARCH INITIATIVE ON POWER MODULES FOR ELECTRIC VEHICLES

PALOMAR TECHNOLOGIES, A GLOBAL LEADER IN TOTAL PROCESS SOLUTIONS FOR ADVANCED PHOTONICS AND MICROELECTRONIC DEVICE PACKAGING, AND THE FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB IN ERLANGEN, GERMANY, ANNOUNCED THEIR JOINT RESEARCH INITIATIVE IN THE AREA OF HIGH-QUALITY, VOID-FREE POWER MODULE PACKAGING FOR ELECTRIC VEHICLES.

"We are delighted to be working with Fraunhofer IISB within this new initiative," said Bruce Hueners, CEO and President for Palomar Technologies and SST Vacuum Reflow Systems. "Palomar Technologies works with research institutes around the world to contribute to the development and advancement of techniques and technologies key to microelectronics packaging for the semiconductor industry. The work with these institutes results in new processes, new products, or new applications for industry."

Fraunhofer IISB conducts applied research and development in the field of electronic systems for application in, e.g., electric mobility, aerospace, Industry 4.0, power grids, or energy technology. In this connection, the institute uniquely covers the entire value chain – from basic materials to whole power electronic systems.

"The packaging technologies are essential for cost effective and reliable power electronics. They offer the potential for improvements in every single domain. This cooperation will allow us to create significant progress in the field of solder materials and processing," explained Andreas Schletz, head of the department for devices, packaging, and reliability at Fraunhofer IISB.

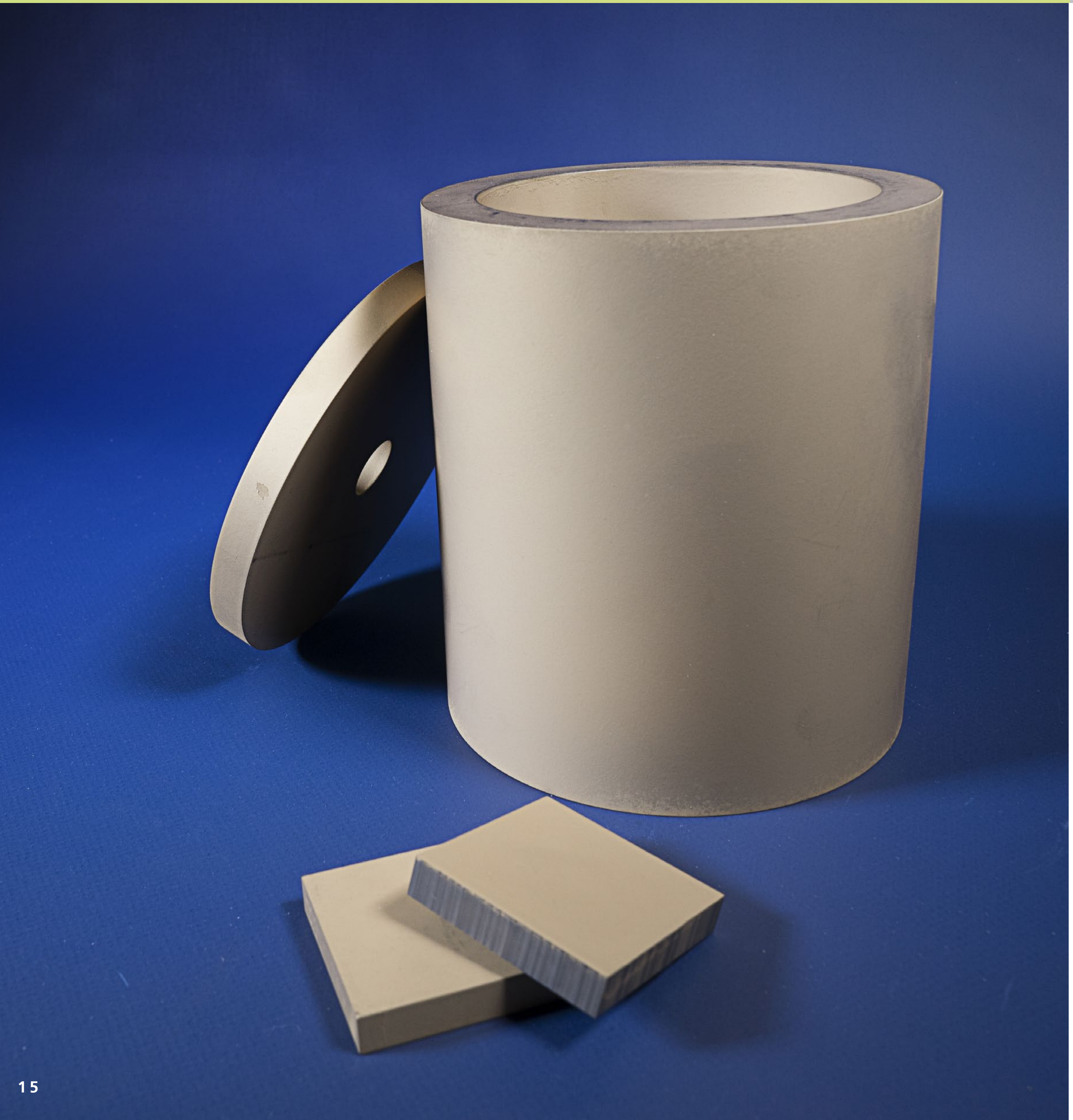
13 *The SST 8301 Automated Vacuum Soldering System placed at Fraunhofer IISB. © Palomar Technologies*

14 *Packaging Technologies in the Fraunhofer IISB Cleanroom. © Anja Grabinger / Fraunhofer IISB*

EVENTS

Ultra-high-temperature-resistant Protective Coatings for Space Applications

16


15

As part of the cooperation, Palomar will place a SST 8301 Automated Vacuum Soldering System within the Fraunhofer Institute. It will be available for demonstrations, prototypes, and research projects focusing on key components inside power electronics, dies to DBC, connectors/pins to DBC and DBC to base plate soldering. The SST 8300 Series Automated Vacuum Pressure System offers superior bond technology for soldering and/or sintering processes. The entire process takes place in a single chamber with a single process profile, however, additional chambers can be added or upgraded in the field as production capacity needs increase.

Today, the SST 8301 is the only solution to use both vacuum pressure and pressure above atmospheric pressure, serving to drive voids close to zero. This technology solves the key problem of voiding and thermal mismatches with the larger surface area attachments in the critical DBC to Baseplate joint. The 8301 is capable of a reliable flux-less soldering with less than 1% voiding, significantly improving yielded throughput.

ULTRA-HIGH-TEMPERATURE-RESISTANT PROTECTIVE COATINGS FOR SPACE APPLICATIONS

DR.-ING. CHRISTIAN REIMANN AND M.SC. KEVIN SCHUCK FROM FRAUNHOFER IISB IN ERLANGEN WON 3RD PLACE IN THIS YEAR'S DLR CHALLENGE OF THE INNOSPACE MASTERS COMPETITION. THE PRIZE WAS AWARDED FOR THEIR IDEA OF PRODUCING SIMPLE AND COST-EFFECTIVE HIGH-TEMPERATURE PROTECTIVE COATINGS ON CARBON COMPOSITE MATERIALS FOR AEROSPACE APPLICATIONS.

Dr.-Ing. Christian Reimann and Kevin Schuck from the Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen were honored for their idea to produce innovative high-temperature protective coatings. The core of this idea is the spray coating technology developed at IISB. This technology makes it possible to apply ultra-high temperature resistant protective coatings to components for aerospace applications.

The INNOspace Masters annually honors innovative ideas and concepts for the transfer of technologies, services, and applications from space to other industries - and vice versa. By winning the award at the DLR Challenge, the Erlangen researchers now gain access to global scientific networks. Likewise, 3rd place comes with funding to carry out their two-year HOSSA research project. The goal is to bring the innovative idea into practical application together with partners from the space industry.

15 *Spray-coated graphite samples with tantalum carbide (TaC) surface layer.* *© Anja Grabinger / Fraunhofer IISB*

16 *Dr.-Ing. Christian Reimann (left) and M.Sc. Kevin Schuck (right), winners of the 3rd place in the DLR Challenge of this year's 'INNOspace Masters' competition.* *© Anja Grabinger / Fraunhofer IISB*

EVENTS

Sensor Technology for Rapid Electronic Detection of Nitrate Concentrations in Soil Samples

18

17

In general, in aerospace, carbon fiber composite components are used in engines, propulsion systems, and thermal protection structures. However, at operating temperatures above 1700 °C, active oxidation and degradation of the materials by particle ablation and delamination occurs. The use of these materials up to now has therefore been limited to applications at lower temperatures, which necessarily also means lower combustion temperatures. But this is coupled with lower efficiencies for engines and propulsion systems. With the technology developed at Fraunhofer IISB, it is now possible to cover the involved carbon components with high-temperature resistant oxidation protection coatings in a simple and cost-effective way. This allows the engines and drives to be operated at higher temperatures and therefore at higher efficiencies

The coating technology also brings other benefits: Spacecraft are exposed to high thermo-stresses and vibrations during the reentry into the earth's atmosphere. With this special coating technology, the exposure times of spacecraft may be extended. This means that the risk of destruction of the spacecraft during re-entry can be minimized while increasing the probability that the spacecraft will return safely to earth.

SENSOR TECHNOLOGY FOR RAPID ELECTRONIC DETECTION OF NITRATE CONCENTRATIONS IN SOIL SAMPLES

IISB PROVIDES A COST-EFFECTIVE METHOD FOR ANALYZING SOIL SAMPLES ON-SITE AND WITHOUT EXTENSIVE LABORATORY EQUIPMENT. THE ION SENSORS USED FOR THIS PURPOSE ARE MANUFACTURED USING A SCREEN PRINTING PROCESS AND CAN BE ELECTRONICALLY READ OUT VIA A VOLTAGE MEASUREMENT. THE MEASURED DATA FROM THE POTENTIOMETRIC DETECTORS ARE THEN DIRECTLY PROCESSED BY MICROCONTROLLER UNITS. THIS MAKES IT EASIER FOR FARMERS TO FULFILL THEIR DOCUMENTATION OBLIGATIONS WITH RESPECT TO THE MANDATORY ANALYSES AND TO CONTROL THE USE OF FERTILIZERS.

As the IISB scientists were able to demonstrate, the inexpensive printed nitrate sensors can match the established methods in terms of measurement accuracy. In addition, the preparation of the soil samples and the recording of the measured values are simpler. In the project "FutureIOT, subproject Agriculture.Digital. Soil Sensors" of the Bavarian Research Foundation, the sensors are being further developed up to the point of connection to cloud applications. The printed ion sensors can also be used in the fitness sector in functional clothing, for example to monitor physiological parameters based on perspiration.

17 *Collecting soil samples at a vegetable farm. In the "Future IOT" project, funded by the Bavarian Research Foundation (BFS), Fraunhofer IISB develops printed, nitrate-selective sensors for optimizing the use of fertilizers. The performance of the low-cost components is comparable to conventional laboratory methods.*
© Anja Grabinger / Fraunhofer IISB

18 *As part of the "Future IOT" project, the screen printed low-cost ion sensors will be interconnected with cloud applications.*
© Anja Grabinger / Fraunhofer IISB

NAMES AND DATA

GUEST SCIENTISTS

H. Du
September 10, 2019 - March 11, 2020
Aalborg University Denmark
Mitigation Strategy for SIC MOSFETs under Short-Circuit Condition

X. Guan
October 01, 2019 - May 30, 2020
Tianjin University, China
In-depth electrical characterization of 4H-SiC VDMOS transistors with different designs

PATENTS (GRANTED IN 2020)

C. Bayer, A. Schletz, T. Erlbacher:
Elektrisches Kabel oder elektrische Litze sowie drahtförmiges elektrisches Verbindungselement mit halbleitendem Funktionsabschnitt
DE 10 2018 217 087 B4

C. Bayer, A. Schletz, U. Waltrich:
Elektrisch leitende Verbindung zwischen mindestens zwei elektrischen Komponenten an einem mit elektronischen und / oder elektrischen Bauelementen bestücktem Träger, die mit einem Bonddraht ausgebildet ist
DE 10 2016 224 631 B4

M. Billmann, C. Lausser, E. Reifert, U. Sutter, D. Tchobanov:
Hochvolt-Bordnetz
EP 3 300 204 B1

N. Böttcher, T. Erlbacher:
Integrierter Kondensator und Verfahren zur Herstellung eines integrierten Kondensators
DE 10 2019 204 503 B3

S. Ditze, A. Endruschat, L. Frey, T. Heckel, C. Joffe, A. Kölpin, A. Roßkopf, B. Sanftl, T. Schriefer, M. Trautmann:
System zur drahtlosen Übertragung von Energie und Daten
EP 3 440 782 B1

T. Erlbacher:
UV-radiation sensor based on diamond
US 10,804,421 B2

T. Erlbacher:
Verfahren zur Herstellung von Halbleiterkondensatoren unterschiedlicher Kapazitätswerte in einem Halbleitersubstrat
DE 10 2018 217 001 B4

T. Erlbacher, A. Hürner:
Monolithisch integrierter Halbleiterschalter, insbesondere Leistungstrennschalter
ZL 201701307781.2

T. Erlbacher, V. Lorentz, G. Rattmann, R. Waller:
Vorrichtung und Verfahren zur Überbrückung eines elektrischen Energiespeichers
EP 2 947 696 B1

NAMES AND DATA

CONTINUATION: PATENTS (GRANTED IN 2020)

T. Erlbacher, S. Matlok:
Electrical circuit arrangement with an active discharge circuit
US 10,530,361 B2

T. Erlbacher, S. Matlok:
Elektrische Schaltungsanordnung mit einer aktiven Entladeschaltung
DE 10 2017 211 030 B4

T. Erlbacher, A. Schletz:
Power Module with a unipolar semiconductor component for a long service life
US 10,659,035 B2

T. Erlbacher, A. Schletz, G. Rattmann:
Hochspannungsfester Si-RC-Snubber durch Serienschaltung von vertikalem RC-Snubber mit lateralen Kondensatoren und Herstellungsverfahren
DE 10 2018 219 994 B4

D. Malipaard, M. März, B. Ruccius:
Current Converter Circuit
US 10,581,341

D. Malipaard, M. März, B. Ruccius:
Stromrichterschaltung
DE 10 2017 221 085 B4

S. Matlok:
Apparatus having a DC-DC converter
US 10,530,265 B2

T. Schriefer, M. Hofmann, N. Moosmann, A. Deibert, T. Gerberich:
Elektrische Kontaktanordnung für einen ersten Pol und einen zweiten Pol einer elektrischen Spannungsquelle
DE 10 2019 207 737 B4

R. Waller, V. Lorentz, M. März:
Electrical bridging device for bridging electrical components in particular an energy source or an energy consumer
US 10,763,595 B1

R. Waller, V. Lorentz, M. März:
Electrical bypass device for bypassing an electrical energysource or an energy consumer
US 10,784,496 B2

R. Waller, V. Lorentz, M. März:
Elektrische Energiespeicherzelle mit integrierter Überbrückungseinrichtung
EP 3 459 133 B1

R. Waller, V. Lorentz, M. März:
Elektrische Überbrückungseinrichtung zum Überbrücken elektrischer Bauelemente, insbesondere einer Energiequelle oder eines Energieverbrauchers
EP 3 378 112 B1

NAMES AND DATA

PUBLICATIONS

I. Abid, R. Kabouche, F. Medjdoub, S. Besendörfer, E. Meissner, J. Derluyn, S. Degroote, M. Germain, H. Miyake:
Remarkable Breakdown Voltage on AlN/AlGaN/AlN double heterostructure
Proceedings of the International Symposium on Power Semiconductor Devices and Ics, Vol 2020, Art. No. 9170170, Vienna, Austria, September 13, 2020 - September 18, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 310-312
ISBN: 978-172814836-6
ISSN: 10636854
DOI: 10.1109/ISPSD46842.2020.9170170

M. Albrecht, F. Klüpfel, T. Erlbacher:
An Iterative Surface Potential Algorithm including Interface Traps for Compact Modeling of SiC-MOSFETs
IEEE Transactions on Electron Devices, Vol 67 (3), Art. No. 8982172 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 855-862
ISSN: 189383
DOI: 10.1109/TED.2020.2967507

M. Albrecht, D. Pérez, R. Martens, A. Bauer, T. Erlbacher:
Impact of channel implantation on a 4h-sic cmos operational amplifier for high temperature applications
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2019 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 1123-1128
ISBN: 978-303571579-8
ISSN: 2555476
DOI: 10.4028/www.scientific.net/MSF.1004.1123

M. Angerer, R. Schwanninger, M. März:
Active common-mode filter for capacitive-coupled isolated signaling
Electronics Letters, Vol 56 (2) (Institution of Engineering and Technology (IET), London, 2020) pp. 73-76
DOI: 10.1049/el.2019.2994

B. Bayer, M. Groccia, H. Bach, C. Bayer, A. Schletz, C. Lenz, S. Ziesche:
LTCC Embedding of SiC Power Devices for High Temperature Applications over 400 °C
Proceedings - 2020 IEEE 8th Electronics System-Integration Technology Conference, ESTC 2020, Art. No. 9229859, Tønsberg, Norway, September 15, 2020 - September 18, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) p. 5
ISBN: 978-172816292-8
DOI: 10.1109/ESTC48849.2020.9229859

C. Bayer:
Robuster Umrichter für Erneuerbare Energien
Mikroelektronik Nachrichten (80), 2020 (Fraunhofer-Verbund Mikroelektronik, Berlin, 2020) p. 12
DOI: urn:nbn:de:0011-n-6023746

C. Bayer, S. Wagner:
Robust converters for renewable energy plants
Mikroelektronik Nachrichten (80), 2020 (Fraunhofer-Verbund Mikroelektronik, Berlin, 2020) p. 10
DOI: urn:nbn:de:0011-n-6143946

C. Bayer, Z. Yu, H. Bach, J. Müller, A. Schletz, :
Future Packaging Technologies in Power Electronic Modules
Power Packaging Virtual Forum, Virtual, November 24, 2020 - November 24, 2020 (2020)
DOI: urn:nbn:de:0011-n-6157213

I. Bejenari, A. Burenkov, P. Pichler, I. Deretzis, A. La Magna:
Molecular dynamics modeling of the radial heat transfer from silicon nanowires
International Conference on Simulation of Semiconductor Processes and Devices, SISPAD, Art. No. 9241646, Kobe, Japan, September 03, 2020 - October 06, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 67-70
ISBN: 978-486348763-5
DOI: 10.23919/SISPAD49475.2020.9241646

L. Di Benedetto, G. Licciardo, T. Erlbacher, A. Bauer, A. Rubino:
A 4H-SiC UV Phototransistor with Excellent Optical Gain Based on Controlled Potential Barrier
IEEE Transactions on Electron Devices, Vol 67 (1), Art. No. 8913626 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 154-159
ISSN: 189383
DOI: 10.1109/TED.2019.2950986

S. Besendörfer, E. Meissner, F. Medjdoub, J. Derluyn, J. Friedrich, T. Erlbacher:
The impact of dislocations on AlGaN/GaN Schottky diodes and on gate failure of high electron mobility transistors
Scientific Reports, Vol 10 (1), Art. No. 17252 (Springer Nature, Berlin, 2020)
ISSN: 20452322
DOI: 10.1038/s41598-020-73977-2

NAMES AND DATA

CONTINUATION: PUBLICATIONS

S. Besendörfer, E. Meissner, A. Tajalli, M. Meneghini, J. Freitas, J. Derluyn, F. Medjdoub, G. Meneghesso, J. Friedrich, T. Erlbacher:
Vertical breakdown of GaN on Si due to V-pits
Journal of Applied Physics, Vol 127 (1), Art. No. 15701 (American Institute of Physics Inc. (AIP Publishing), Melville, 2020)
ISSN: 218979
DOI: 10.1063/1.5129248

S. Besendörfer, E. Meissner, T. Zweipfennig, H. Yacoub, D. Fahle, H. Behmenburg, H. Kalisch, A. Vescan, J. Friedrich, T. Erlbacher:
Interplay between C-doping, threading dislocations, breakdown, and leakage in GaN on Si HEMT structures
AIP Advances, Vol 10 (4), Art. No. 45028 (American Institute of Physics Inc. (AIP Publishing), Melville, 2020)
ISSN: 21583226
DOI: 10.1063/1.5141905

K. Dadzis, R. Menzel, U. Juda, K. Irmscher, C. Kranert, M. Müller, M. Ehrl, R. Weingärtner, C. Reimann, N. Abrosimov, H. Riemann:
Characterization of Silicon Crystals Grown from Melt in a Granulate Crucible
Journal of Electronic Materials, Vol 49 (9) (Springer Nature, Berlin, 2020) pp. 5120-5132
ISSN: 3615235
DOI: 10.1007/s11664-020-08309-1

H. Du, S. Letz, N. Baker, T. Götz, F. Iannuzzo, A. Schletz:
Effect of short-circuit degradation on the remaining useful lifetime of SiC MOSFETs and its failure analysis
Microelectronics Reliability, Vol 114, Art. No. 113784 (Elsevier, Amsterdam, 2020)
ISSN: 262714
DOI: 10.1016/j.microrel.2020.113784

A. Erdmann, H. Mesilhy, P. Evanschitzky, V. Philipsen, F. Timmermans, M. Bauer:
Perspectives and tradeoffs of absorber materials for high NA EUV lithography
Journal of Micro/ Nanolithography, MEMS, and MOEMS, Vol 19 (4), Art. No. 41001 (Society of Photo-Optical Instrumentation Engineers (SPIE), Bellingham, 2020)
ISSN: 19325150
DOI: 10.1117/1.JMM.19.4.041001

S. Faraji, E. Meissner, R. Weingärtner, S. Besendörfer, J. Friedrich:
In-situ preparation of gan sacrificial layers on sapphire substrate in movpe reactor for self-separation of the overgrown gan crystal
Crystals, Vol10 (12), Art. No. 1100 (Multidisciplinary Digital Publishing Institute (MDPI), Basel, 2020) pp. 1-11
ISSN: 20734352
DOI: 10.3390/cryst10121100

J. Friedrich, G. Müller:
Erlangen – An Important Center of Crystal Growth and Epitaxy: Major Scientific Results and Technological Solutions of the Last Four Decades
Crystal Research and Technology, Vol 55 (2), Art. No. 1900053 (Wiley-VCH Verlag, Hoboken, 2020)
ISSN: 2321300
DOI: 10.1002/crat.201900053

M. Gepp, V. Lorentz, M. März, F. Geffray, E. Guyon, F. Chopard:
Spatial and Temporal Temperature Homogenization in an Automotive Lithium-Ion Pouch Cell Battery Module
ELECTRIMACS 2019, Lecture Notes in electrical Engineering, Vol 604 LNEE (Proceedings of 1st European Advances in Digital Transformation Conference, EADTC 2018 and the 2nd European Advances in Digital Transformation Conference, EADTC 2019), Salerno, Italy, April 04, 2019 (Springer Nature, Berlin, 2020) pp. 625-639
ISBN: 978-303037160-9
ISSN: 18761100
DOI: 10.1007/978-3-030-37161-6_47

M. Gerwig, A. Ali, D. Neubert, S. Polster, U. Böhme, G. Franze, M. Rosenkranz, A. Popov, I. Ponomarev, M. Jank, C. Viehweger, E. Brendler, L. Frey, P. Kroll, E. Kroke:
From Cyclopentasilane to Thin-Film Transistors
Advanced Electronic Materials (Wiley-VCH Verlag, Hoboken, 2020)
ISSN: 2199160X
DOI: 10.1002/aelm.202000422

A. Hauke, S. Oertel, L. Knoke, V. Fein, C. Maier, F. Brinkmann, M. Jank:
Screen-Printed Sensor for Low-Cost Chloride Analysis in Sweat for Rapid Diagnosis and Monitoring of Cystic Fibrosis
Biosensors, Vol 10 (9), Art. No. 123 (Multidisciplinary Digital Publishing Institute (MDPI), Basel, 2020) p. 8
ISSN: 20796374
DOI: 10.3390/bios10090123

NAMES AND DATA

CONTINUATION: PUBLICATIONS

K. Heinig, M. Rommel, L. Baier:
Sub-20 nm multilayer nanopillar patterning for hybrid SET/CMOS integration
Micro and Nano Engineering, Vol 9, Art. No. 100074 (Elsevier, Amsterdam, 2020)
ISSN: 25900072
DOI: 10.1016/j.mne.2020.100074

C. Hellinger, O. Rusch, M. Rommel, A. Bauer, T. Erlbacher:
Low-resistance ohmic contact formation by laser annealing of n-implanted 4h-sic
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2019 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 850-855
ISBN: 978-303571579-9
ISSN: 2555476
DOI: 10.4028/www.scientific.net/MSF.1004.718

S. Hessler, S. Knopf, M. Rommel, M. Girschofsky, B. Schmauss, R. Hellmann:
Advancing the sensitivity of integrated epoxy-based Bragg grating refractometry by high-index nanolayers
Optical Letters, Vol 45 (19) (OSA - The Optical Society, Washington D.C., 2020) pp. 5510-5513
ISSN: 1469592
DOI: 10.1364/OL.402768

A. Hirsch, M. Trempa, I. Kupka, L. Schmidtner, C. Kranert, C. Reimann, J. Friedrich:
Investigation of gas bubble growth in fused silica crucibles for silicon Czochralski crystal growth
Journal of Crystal Growth, Vol 533, Art. No. 125470 (Elsevier, Amsterdam, 2020)
ISSN: 220248
DOI: 10.1016/j.jcrysgro.2019.125470

T. Hutsch, R. Doncker, A. Neumann, T. Zetterer, G. Mitic, K. Kriegel, A. Burghardt, A. Sewergin, M. Rittner, F. Simon:
Highly Integrated Switching Cell Design based on Copper Diamond Heat Spreader, 3D Printed Heat Sink and HTCC Logic Board
CIPS 2020 - 11th International Conference on Integrated Power Electronics Systems. Proceedings, Berlin, Germany, March 24, 2020 - March 26, 2020 (VDE Verlag, Berlin, 2020) pp. 397-402
ISBN: 978-3-8007-5225-6; 978-3-8007-5226-3; 3-8007-5225-5

A. Hutzler, B. Fritsch, C. Matthus, M. Jank, M. Rommel:
Highly accurate determination of heterogeneously stacked Van-der-Waals materials by optical microspectroscopy
Scientific Reports, Vol 10 (1), Art. No. 13676 (Springer Nature, Berlin, 2020)
ISSN: 20452322
DOI: 10.1038/s41598-020-70580-3

M. Kocher, H. Schlichting, B. Kallinger, M. Rommel, A. Bauer, T. Erlbacher:
Influence of shallow pits and device design of 4H-SiC VDMOS transistors on in-line defect analysis by photoluminescence and differential interference contrast mapping
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2019 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 299-305
ISBN: 978-303571579-8
ISSN: 2555476
DOI: 10.4028/www.scientific.net/MSF.1004.299

C. Lange, A. Rueß, A. Nuß, R. Öchsner, M. März:
Dimensioning battery energy storage systems for peak shaving based on a real-time control algorithm
Applied Energy, Vol 280, Art. No. 115993, December 15, 2020 (Elsevier, Amsterdam, 2020)
ISSN: 3062619
DOI: 10.1016/j.apenergy.2020.115993

C. Lenz, S. Ziesche, A. Schletz, H. Bach, T. Erlbacher:
Real embedding process of SiC devices in a monolithic ceramic package using LTCC technology
Proceedings - 2020 IEEE 8th Electronics System-Integration Technology Conference, ESTC 2020, Art. No. 9229653, Tønsberg, Norway, September 15, 2020 - September 18, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) p. 5
ISBN: 978-172816292-8
DOI: 10.1109/ESTC48849.2020.9229653

M. Lim, T. Śledziewski, M. Rommel, T. Erlbacher, H. Kim, S. Kim, H. Shin, A. Bauer:
Pre-Deposition Interfacial Oxidation and Post-Deposition Interface Nitridation of LPCVD TEOS Used as Gate Dielectric on 4H-SiC
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2019 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 535-540
DOI: 10.4028/www.scientific.net/MSF.1004.535

NAMES AND DATA

CONTINUATION: PUBLICATIONS

S. Liu, X. Cheng, L. Zheng, T. Śledziewski, T. Erlbacher, L. Sheng, Y. Yu:
Impact of the transition region between active area and edge termination on electrical performance of SiC MOSFET
Solid-State Electronics, Vol 171, Art. No. 107873 (Elsevier, Amsterdam, 2020)
ISSN: 381101
DOI: 10.1016/j.sse.2020.107873

G. Lukin, E. Meissner, J. Friedrich, F. Habel, G. Leibiger:
Stress evolution in thick GaN layers grown by HVPE
Journal of Crystal Growth, Vol 550, Art. No. 125887 (Elsevier, Amsterdam, 2020)
ISSN: 220248
DOI: 10.1016/j.jcrysgro.2020.125887

P. Martínez, S. Letz, E. Maset, D. Zhao:
Failure analysis of normally-off GaN HEMTs under avalanche conditions
Semiconductor Science and Technology, Vol 35 (3), Art. No. 35007 (Institute of Physics Publishing (IOP), Bristol, 2020)
ISSN: 2681242
DOI: 10.1088/1361-6641/ab6bad

T. Menrath, A. Rosskopf, F. Simon, M. Groccia, S. Schuster:
Shape Optimization of a Pin Fin Heat Sink
36th Annual Semiconductor Thermal Measurement, Modeling and Management Symposium, SEMI-THERM 2020 - Proceedings, Art. No. 9142830, San Jose, United States, March 16, 2020 - March 20, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 10-16
ISBN: 978-057843862-7
DOI: 10.23919/SEMI-THERM50369.2020.9142830

H. Mesilhy, P. Evanschitzky, G. Bottiglieri, E. van Setten, T. Fliervoet, A. Erdmann:
Pathfinding the perfect EUV mask: The role of the multilayer
Proceedings of SPIE - The International Society for Optical Engineering, Vol 11323 (Extreme Ultraviolet (EUV) Lithography XI 2020), Art. No. 1132316, San Jose, United States, February 24, 2020 - February 27, 2020 (Society of Photo-Optical Instrumentation Engineers (SPIE), Bellingham, 2020)
ISBN: 978-151063413-8
ISSN: 0277786X
DOI: 10.1117/12.2551870

M. Novak, W. Grübl, J. Müller, A. Schletz:
Selektives Ag-Sintern auf Organischer Leiterplatte
10. DVS/GMM-Fachtagung EBL (Elektronische Baugruppen und Leiterplatten) 2020, Fellbach, Germany, February 18, 2020 - February 19, 2020 (DVS Media GmbH, Düsseldorf, 2020) pp. 210-215
ISBN: 978-3-96144-075-7
ISBN: 3-96144-075-1
ISBN: 978-3-96144-089-4

M. Pourteau, A. Gharbi, P. Brianceau, J. Dallery, F. Laulagnet, G. Rademaker, R. Tiron, H. Engelmann, J. von Borany, C. Rettner, M. Schiedermeyer, A. Apelsmeier, T. Heckel, A. Diepgen, A. Klische, D. Dirksen, M. März:
SiC Power Module with integrated RC-Snubber Design for Voltage Overshoot and Power Loss Reduction
CIPS 2020 - 11th International Conference on Integrated Power Electronics Systems. Proceedings, Berlin, Germany, March 24, 2020 - March 26, 2020 (VDE Verlag, Berlin, 2020) pp. 142-147
ISBN: 978-3-8007-5225-6; 978-3-8007-5226-3; 3-8007-5225-5

O. Rusch, C. Hellinger, J. Moult, Y. Corcoran, T. Erlbacher:
Reducing on-resistance for SiC diodes by thin wafer and laser anneal technology
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2019 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 155-160
ISBN: 978-303571579-8
ISSN: 2555476
DOI: 10.4028/www.scientific.net/MSF.1004.155

S. Saponara, G. Ciarpi, T. Erlbacher, G. Rattmann:
Integrated Passive Devices and Switching Circuit Design for a 3D DC/DC Converter up to 60 V
Journal of Circuits, Systems and Computers, Art. No. 2050039 (World Scientific Publishing Co. Pte Ltd, Singapur, 2020)
ISSN: 2181266
DOI: 10.1142/S0218126620500395

M. Schellenberger, S. Anger, M. Pfeffer, V. Häublein, G. Roeder, A. Bauer:
Smart Platform for Rapid Prototyping: A First Solution Approach to Improve Time-to-Market and Process Control in Low-Volume Device Fabrication
ELECTRIMACS 2019, Lecture Notes in electrical Engineering, Vol 604 LNEE (Proceedings of 1st European Advances in Digital Transformation Conference, EADTC 2018 and the 2nd European Advances in Digital Transformation Conference, EADTC 2019), Salerno, Italy, April 04, 2019 (Springer Nature, Berlin, 2020) pp. 129-135
ISBN: 978-303048601-3; 978-3-030-48602-0
ISSN: 18761100
DOI: 10.1007/978-3-030-48602-0_12

NAMES AND DATA

CONTINUATION: PUBLICATIONS

A. Schletz:
Testing Wide Band-Gap Devices II (Focus on Packaging)
ECPE Tutorial Wide-Bandgap User Training, Berlin, Germany, September 22, 2020 - September 22, 2020 (2020)
DOI: urn:nbn:de:0011-n-6056905

A. Schletz, C. Bayer, A. Hutzler:
Temperature Challenges for Integrated Systems due to High Power Density
ECPE Tutorial Wide-Bandgap User Training, Berlin, Germany, September 22, 2020 - September 22, 2020 (2020)
DOI: urn:nbn:de:0011-n-6056768

A. Schletz, A. Endruschat, T. Heckel:
State of the Art Packaging
ECPE Tutorial Wide-Bandgap User Training, Berlin, Germany, September 22, 2020 - September 22, 2020 (2020)
DOI: urn:nbn:de:0011-n-6056846

H. Schlichtig, M. Kocher, J. Weiße, T. Erlbacher, A. Bauer:
Influence of Aluminum Compensation Effects in 4H-SiC on the Performance of VDMOS Transistors
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2029 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 843-849
DOI: 10.4028/www.scientific.net/MSF.1004.843

T. Schneider, M. Förste, G. Lukin, P. Fischer, M. Barchuk, C. Schimpf, E. Niederschlag, O. Pätzold, D. Rafaja, M. Stelter:
Recent progress of high temperature vapor phase epitaxy for the growth of GaN layers – Controlled coalescence of nucleation layers
Journal of Crystal Growth, Vol 533, Art. No. 125465 (Elsevier, Amsterdam, 2020)
ISSN: 220248
DOI: 10.1016/j.jcrysgro.2019.125465

M. Schulz, N. Schleippmann, K. Gosses, R. Chacon, B. Wunder:
Four switch buck/boost converter to handle bidirectional power flow in dc subgrids
PCIM Europe Conference Proceedings, Vol 1 (Proceedings of International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, PCIM Europe 2020), Virtual, Online, June 07, 2020 - June 08, 2020 (Mesago PCIM, Frankfurt, 2020) pp. 1764-1771
ISBN: 978-380075245-4
ISSN: 21913358

M. Schulz, N. Schleippmann, K. Gosses, B. Wunder, M. März:
Four Switch Buck/Boost Converter for DC Microgrid Applications
2020 22nd European Conference on Power Electronics and Applications, EPE 2020 ECCE Europe, Art. No. 9215754, Lyon, France, September 07, 2020 - September 11, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020)
ISBN: 978-907581536-8
DOI: 10.23919/EPE20ECCEEurope43536.2020.9215754

A. Sciuto, I. Deretzis, G. Fisciardo, S. Lombardo, A. La Magna, M. Grimaldi, K. Huet, B. Lespinasse, A. Verstraete, B. Curvers, I. Bejenari, A. Burenkov, P. Pichler:
Advanced simulations on laser annealing: Explosive crystallization and phonon transport corrections
International Conference on Simulation of Semiconductor Processes and Devices, SISPAD, Art. No. 9241660, Kobe, Japan, September 03, 2020 - October 06, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 71-74
ISBN: 978-486348763-5
DOI: 10.23919/SISPAD49475.2020.9241660

T. Śledziewski, T. Erlbacher:
Sic mosfet with a self-aligned channel defined by shallow source-jfet implantation: A simulation study
Materials Science Forum, Vol 1004 (Proceedings of 18th International Conference on Silicon Carbide and Related Materials, ICSCRM 2019), Kyoto, Japan, September 29, 2019 - October 04, 2019 (Trans Tech Publications Ltd., Bäch SZ, 2020) pp. 850-855
ISBN: 978-303571579-8
ISSN: 2555476
DOI: 10.4028/www.scientific.net/MSF.1004.850

Y. Song, Z. Xu, T. Liu, M. Rommel, H. Wang, Y. Wang, F. Fang:
Depth Profiling of Ion-Implanted 4H-SiC Using Confocal Raman Spectroscopy
Crystals Vol 10 (2), Art. No. 131 (Multidisciplinary Digital Publishing Institute (MDPI), Basel, 2020)
ISSN: 2073-4352
DOI: 10.3390/cryst10020131

Y. Song, Z. Xu, R. Li, H. Wang, Y. Fan, M. Rommel, J. Liu, G. Astakhov, G. Hlawacek, B. Li, J. Xu, F. Fang:
Photoluminescence and Raman Spectroscopy Study on Color Centers of Helium Ion-Implanted 4H–SiC
Nanomanufacturing and Metrology, Vol 3 (3) (Springer Science and Business Media, Berlin, 2020) pp. 205-217
ISSN: 2520811X
DOI: 10.1007/s41871-020-00061-8

NAMES AND DATA

CONTINUATION: PUBLICATIONS

M. Stern, M. Schellenberger:
Fully convolutional networks for chip-wise defect detection employing photoluminescence images: Efficient quality control in LED manufacturing
Journal of Intelligent Manufacturing, Vol 32 (Springer Nature, Berlin, 2020) pp. 113-126
ISSN: 9565515
DOI: 10.1007/s10845-020-01563-4

T. Stolzke, S. Ehrlich, C. Joffe, M. März:
Comprehensive accuracy examination of electrical power loss measurements of inductive components for frequencies up to 1 MHz
Journal of Magnetism and Magnetic Materials, Vol 497, Art. No. 166022 (Elsevier, Amsterdam, 2020)
ISSN: 03048853
DOI: 10.1016/j.jmmm.2019.166022

F. Sturm, M. Trempa, S. Schwanke, K. Schuck, C. Kranert, C. Reimann, J. Friedrich:
Solid state diffusion of metallic impurities from crucible and coating materials into crystalline silicon ingots for PV application
Journal of Crystal Growth, Vol 540, Art. No. 125636 (Elsevier, Amsterdam, 2020)
ISSN: 220248
DOI: 10.1016/j.jcrysgro.2020.125636

A. Tajalli, M. Borga, M. Meneghini, C. De Santi, D. Benazzi, S. Besendörfer, R. Püsche, J. Derluyn, S. Degroote, M. Germain, R. Kabouche, I. Abid, E. Meissner, E. Zanoni, F. Medjdoub, G. Meneghesso:
Vertical leakage in GaN-on-Si stacks investigated by a buffer decomposition experiment
Micromachines, Vol 11 (1), Art. No. 101 (Multidisciplinary Digital Publishing Institute (MDPI), Basel, 2020)
ISSN: 2072666X
DOI: 10.3390/mi11010101

A. Tajalli, M. Meneghini, S. Besendörfer, R. Kabouche, I. Abid, R. Püsche, J. Derluyn, S. Degroote, M. Germain, E. Meissner, E. Zanoni, F. Medjdoub, G. Meneghesso:
High breakdown voltage and low buffer trapping in superlattice gan-on-silicon heterostructures for high voltage applications
Materials, Vol 13 (19), Art. No. 2674 (Multidisciplinary Digital Publishing Institute (MDPI), Basel, 2020)
ISSN: 19961944
DOI: 10.3390/MA13194271

M. Trempa, F. Sturm, C. Kranert, S. Schwanke, C. Reimann, J. Friedrich, C. Schenk:
Impact of different SiO2 diffusion barrier layers on lifetime distribution in multi-crystalline silicon ingots
Journal of Crystal Growth, Vol 532, Art. No. 125378 (Elsevier, Amsterdam, 2020)
ISSN: 220248
DOI: 10.1016/j.jcrysgro.2019.125378

A. Verani, G. Fieramosca, A. Colicelli, R. Di Rienzo, R. Saletti, R. Roncella, R. Schwarz, V. Lorentz, F. Baronti:
FPGA Accelerator for Battery Management Systems in Safety-Critical Applications
Proceedings - 2020 2nd IEEE International Conference on Industrial Electronics for Sustainable Energy Systems, IESES 2020, Cagliari, Italy, September 01, 2020 - September 03, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020)
ISBN: 978-172814017-9
DOI: 10.1109/IESES45645.2020.9210671

S. Waldhör, S. Bockrath, M. Wenger, R. Schwarz, V. Lorentz:
FoxBMS-free and open bms platform focused on functional safety and AI
PCIM Europe Conference Proceedings, Vol 1 (Proceedings of International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, PCIM Europe 2020), Virtual, Online, June 07, 2020 - June 08, 2020 (Mesago PCIM, Frankfurt, 2020) pp. 605-610
ISBN: 978-380075245-4
ISSN: 21913358
DOI: urn:nbn:de:0011-n-5967898

J. Weiße, C. Matthus, H. Schlichting, H. Mitlehner, T. Erlbacher:
RESURF n-LDMOS Transistor for Advanced Integrated Circuits in 4H-SiC
IEEE Transactions on Electron Devices, Vol 67 (8), Art. No. 9132665 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) pp. 3278-3284
ISSN: 189383
DOI: 10.1109/TED.2020.3002730

T. Wicht, S. Müller, R. Weingärtner, B. Epelbaum, S. Besendörfer, U. Bläß, M. Weisser, T. Unruh, E. Meissner:
X-ray characterization of physical-vapor-transport-grown bulk AlN single crystals
Journal of Applied Crystallography, Vol 53 (International Union of Crystallography (IUCr), Chester, 2020) pp. 1080-1086
ISSN: 218898
DOI: 10.1107/S1600576720008961

CONTINUATION: PUBLICATIONS

M. Wu, D. Thakare, J. de Marneffe, P. Jaenen, L. Souriau, K. Opsomer, J. Soulié, A. Erdmann, H. Mesilhy, P. Naujok, M. Foltin, V. Soltwisch, Q. Saadeh, V. Philipsen:
Mask absorber for next generation EUV lithography
Proceedings of SPIE - The International Society for Optical Engineering, Vol 11517 (Extreme Ultraviolet (EUV) Lithography XI 2020), Art. No. 1151706 (Society of Photo-Optical Instrumentation Engineers (SPIE), Bellingham, 2020)
ISBN: 978-151063842-6
ISSN: 0277786X
DOI: 10.1117/12.2572114

Z. Xu, L. Lu, Z. He, D. Tian, A. Hartmeier, J. Zhang, X. Luo, M. Rommel, K. Nordlund, G. Zhang, F. Fang:
Nanocutting mechanism of 6H-SiC investigated by scanning electron microscope online observation and stress-assisted and ion implant-assisted approaches
International Journal of Advanced Manufacturing Technology, Vol 106 (9-10) (Springer Nature, Berlin, 2020) pp. 3896-3880
ISSN: 2683768
DOI: 10.1007/s00170-019-04886-6

Z. Yu, W. Zeng, C. Bayer, A. Schletz, M. März:
Application of response surface methodology for optimization of Ag-Ag Direct Bonding for Wafer-Level Power Electronics Packaging
CIPS 2020 - 11th International Conference on Integrated Power Electronics Systems. Proceedings, Berlin, Germany, March 24, 2020 - March 26, 2020 (VDE Verlag, Berlin, 2020)
ISBN: 978-3-8007-5225-6; 978-3-8007-5226-3; 3-8007-5225-5

Z. Yu, W. Zeng, D. Zhao, Z. Zhang, C. Bayer, A. Schletz, M. März:
Reliability of silver direct bonding in thermal cycling tests
Proceedings - 2020 IEEE 8th Electronics System-Integration Technology Conference, ESTC 2020, Art. No. 9229753, Tønsberg, Norway, September 15, 2020 - September 18, 2020 (Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway Township, 2020) p. 6
ISBN: 978-172816292-8
DOI: 10.1109/ESTC48849.2020.9229753

D. Zhao, S. Letz, A. Schletz, M. März:
A Method for the Characterization of Adhesion Strength Degradation of Thin Films on Si-Substrate under Thermal Cycling Test
CIPS 2020 - 11th International Conference on Integrated Power Electronics Systems. Proceedings, Berlin, Germany, March 24, 2020 - March 26, 2020 (VDE Verlag, Berlin, 2020) pp. 490-495
ISBN: 978-3-8007-5225-6; 978-3-8007-5226-3; 3-8007-5225-5

D. Zhao, S. Letz, Z. Yu, A. Schletz, M. März:
Combined experimental and numerical approach for investigating the mechanical degradation of the interface between thin film metallization and Si-substrate after temperature cycling test
ESREF 2020, the 31st European Symposium on Reliability of Electron Devices, Failure Physics and Analysis, Art. No. 113785, Virtual, Online, October 05, 2020 - October 08, 2020 (Elsevier, Amsterdam, 2020)
ISSN: 0026-2714
DOI: 10.1016/j.microrel.2020.113785

S. Zeltner, B. Seliger, D. Haager, B. Eckardt, H. Bach, Z. Yu, S. Vater, C. Bayer, A. Schletz, H. Umeda, T. Morita:
Advantages and challenges of using sic mosfets in a high power density insulated hv/lv dc/dc converter
PCIM Europe Conference Proceedings, Vol 1 (Proceedings of International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, PCIM Europe 2020), Virtual, Online, June 07, 2020 - June 08, 2020 (Mesago PCIM, Frankfurt, 2020) pp. 1587-1592
ISBN: 978-380075245-4
ISSN: 21913358

V. Zimmermann, A. Zoerner, W. Chen, Z. Yu, M. Jank, C. Bayer, A. Schletz, M. März:
Integration of Printed Electronics in Potted Power Electronic Modules
CIPS 2020 - 11th International Conference on Integrated Power Electronics Systems. Proceedings, Berlin, Germany, March 24, 2020 - March 26, 2020 (VDE Verlag, Berlin, 2020) pp. 137-141
ISBN: 978-3-8007-5225-6; 978-3-8007-5226-3; 3-8007-5225-5

NAMES AND DATA

PHD THESES

J. Förthner:
Laterale und vertikale Ladungskompensationsstrukturen in 4H-Siliziumkarbid
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, October 21, 2020

P. Hofstetter:
Hochausnutzung von Siliziumkarbid-Feldeffekttransistoren in Traktionsumrichtern
Faculty of Engineering Science, University of Bayreuth, Bayreuth, Germany, May 20, 2020

X. Liu:
Anwendung von Nanopartikel-ZnO Dünnschichttransistoren in einfachen Schaltungen
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, June 5, 2020

S. Matlok:
Digitale Regelung bidirektionaler Gleichspannungswandler
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, September 10, 2020

A. P. Pai:
Impact of Silicon Carbide based Power Modules on Mission Profile Efficiency of Automotive Traction Inverters
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, July, 2020

M. Scharin-Mehlmann:
Nano- and Micro-Patterned PDMS Thin-Film for Biocompatible Devices / Nano- und mikrosturkturierte Polydimethylsiloxan Substrate für biomedizinische Anwendungen
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, August 7, 2020

J. Schmenger:
Ein Beitrag zu modularen und hochkompakten isolierenden Schnellladegeräten für Elektrofahrzeuge
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, July 27, 2020

A. Schmidt:
Untersuchungen zu Vanadium-basierten ohmschen Kontakten in AlGaN/GaN-MISHFETs
Technische Universität Bergakademie Freiberg, Freiberg, Germany

T. Urban:
Untersuchungen zur Degradation der Metallisierung von PERC-Solarzellen
Technische Universität Bergakademie Freiberg, Freiberg, Germany

A. Zörner:
Development and Investigation of a Printed Multi-Ion-Selective Sensor System Towards Healthcare Applications
Technical Faculty, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany, 2020

NAMES AND DATA

MASTER THESES

M. Abbasi:
Entwicklung und Bewertung von Betriebsstrategien zur Synchronisierung von automobilen Traktionsumrichtern
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Bayrakdar:
Drehmomentregelung eines elektrischen Achssystems zur Schwingungsdämpfung im mechanischen Antriebsstrang
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

A. Bengl:
Direktgekühlte elektrische Traktionsmaschine
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

V. Dreher:
Herstellung und Untersuchung von Transduktionsschichten auf Kohlenstoffbasis zur Verbesserung von gedruckten ionenselektiven Elektroden
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Fella:
Entwicklung einer zur Vielfach-Parallelschaltung von GaN-Transistoren geeigneten Halbbrücken-Schaltzelle
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

J. Gehring:
Entwicklung und Charakterisierung einer Dual-Active-Bridge mit GaN-Transistoren
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

B. Gutwald:
Entwicklung eines Energie-Messkonzeptes zur Validierung der virtuellen Inbetriebnahme einer Industrieanlage, die mit Gleichstrom betrieben wird
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

F. Halmos:
Multiphysikalische Simulation von Leistungsmodulen unter Feuchtigkeitseintrag
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Hir Safavi:
Entwicklung eines Halbleiterschalters für das Schalten hoher Gleichspannungen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

L. Horter:
Simulation der effecktiven Permeabilität weichmagnetischer Polymerkomposite
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

L. Keller:
Erarbeitung und Bewertung von Konzepten für das galvanisch gekoppelte Laden von Nutzfahrzeugen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

F. Leser:
Entwicklung, Parametrierung und Validierung eines Simulationsmodells zur Zwischenkreisauslegung und Bestimmung der systemwirkungsgradoptimalen Umrichterschaltfrequenz
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

J. Martin:
Konzeptstudie für ein CO_2-neutrales Energiesystem im ländlichen Raum
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Mohadeseh Jahani:
Untersuchung von Treiberschaltungen für SiC-Leistungshalbleiter
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

F. Mu:
End-of-Line Geräuschprüfstand
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

Y. Ouyang:
Entwicklung eines Regelungsmodells für seriell-/parallelverschaltete Dual-Active-Bridge Converter
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

T. Reck:
Einfluss von Oberflächeneigenschaften auf die Korrosion von leistungselektronischen Schaltungsträgern – Vergleich von PCB und DCB Substraten
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

NAMES AND DATA

CONTINUATION: MASTER THESES

M. Retschkowski:
Entwicklung des Sicherheitskonzeptes einer Automatisierungszelle für eine Industrieanlage im Betrieb mit Gleichstrom
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Schlachter:
Simulation, Untersuchung und Kompensation der Drehmomentenvarianz zwischen den Rädern einer heckangetriebenen Twin-Achse
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

T. Schötz:
Simulationsbasierte Untersuchungen zur Auslegung und dynamischen Betriebsführung von LOHC-Systemen mit Brennstoffzelle und Batterie
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Schraml:
Atomlagenabscheidung und Charakterisierung von kristallinem Bornitrid zur Anwendung als 2D-Isolatormaterial
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

J. Schröder:
Wirtschaftliche Analyse der Einsatzpotentiale eines Energieknotens im DC-Netz am Beispiel des DC-Grid Managers
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

J. Schwarz:
Technology Computer Aided Design (TCAD) Modelling and Simulation of SiC Devices and Circuits
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

R. Seyfried:
Experimentelle Untersuchungen zum Einfluss dynamischer Faktoren auf das Betriebsverhalten eines LOHC-basierten Energiespeichers
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

C. Shen:
Bildbasierte Generierung thermoelektrischer Simulationen zur Analyse von Leiterbahnen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

S. Steinmüller:
Untersuchungen zur Parallelschaltung von Netzstromrichtern am Beispiel eines 3L-GaN Umrichters
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

J. Strobel:
Echtzeitüberwachung von leistungselektronischen Systemen mit Hilfe von neuromorphen integrierten Schaltungen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

Z. Tao:
Investigation of Ceramic Embedding Technologies for High Temperature Power Electronics
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Tratnikov:
Untersuchungen zur Kinetik des Bor-Sauerstoff-korrelierten Defekts an hocheffizienten PERC Solarzellen
Technische Universität Bergakademie Freiberg (Freiberg, 2020)

A. Uzun:
EMV-optimierte Raumzeigermodulation für eine 6-phasige Maschine
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

A. Weber:
Defektspektroskopische Untersuchungen an Lichtsensitiven Defekten in Solarsilizium
Technische Universität Bergakademie Freiberg (Freiberg, 2020)

J. Zeltner:
Untersuchung eines Konzeptes zur Herstellung von flexiblen Substraten mittels Inselstrukturierung in starre Substratoberflächen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

J. Zhang:
Ohmsche Kontakte zu AlN/GaN-Heterostrukturen
Technische Universität Bergakademie Freiberg (Freiberg, 2020)

Y. Zhou:
Entwicklung einer weich schaltenden Umrichterzelle und deren Integration in Multilevel-Topologien unter Berücksichtigung von Si / SiC Mischbestückung
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

NAMES AND DATA

BACHELOR THESES

J. Avci:
Optimierung eines gedruckten ionenselektiven Sensors zur Bestimmung von Nitrationen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Bamberg:
Einfluss von Deep Eutectic Solvent basierenden Elektrolyten und der Kathodenpräparation auf die Leistungsfähigkeit der Aluminium Graphit Batterie
Technische Universität Bergakademie Freiberg (Freiberg, 2020)

A. Berwald:
Zustandserfassung an Vergussmassen für Leistungsmodule
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

L. Best:
Untersuchungen zum Einsatz von Nickel-Zink-Ferriten in Spannungswandlern mit hohen Schaltfrequenzen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Endter:
Vanadiumpentoxid als Kathodenmaterial für Aluminium-Ionen-Batterie
Technische Universität Bergakademie Freiberg (Freiberg, 2020)

L. Farnbacher:
Entwicklung einer Schaltung zum zyklischen Umladen von Kondensatoren für Lebensdauertests
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Konrad:
Analyse stromloser Abscheidung von Gold-Nanopartikeln auf freistehenden 2D-Membranen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

A. R. Kumar:
Design and Implementation of Circuitry to Read Spectrometric Information of SiC Photodiodes
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

T. Polster:
Optimierung der Leiterführung eines breitbandigen AMR Stromsensors
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

F. Schofer:
Untersuchung des Potentials von Elektrofahrzeugen zur Lastspitzenreduzierung in einem Industriebetrieb anhand von Simulationen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

S. Schramm:
Entwicklung des Energiemanagements für ein flexibles Energiespeichernetzwerk
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

W. Sodaigui:
Entwicklung eines Spice-Modells für Photovoltaikzellen zur Simulation der Verschattungsproblematik
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

A. Sporer:
Simulation und Charakterisierung magnetischer Streufelder für ein induktives Ladesystem mit geringem Spulenabstand
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

S. Utzelmann:
Analyse eines für hohe Schaltfrequenzen konzipierten isolierenden Gleichspannungswandlers
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

F. Yüksekkaya:
Optimierung eines gedruckten ionenselektiven Sensors zur Bestimmung von Nitrationen
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

B. Zollet:
Untersuchung des Einflusses der p-Wannenregion auf die Sperreigenschaften von 4H-SiC VDMOS Transistoren
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)

M. Zöllner:
Entwicklung eines modularen, elektrischen Energiespeichersystems für unbemannte Luftfahrzeuge
Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen, 2020)