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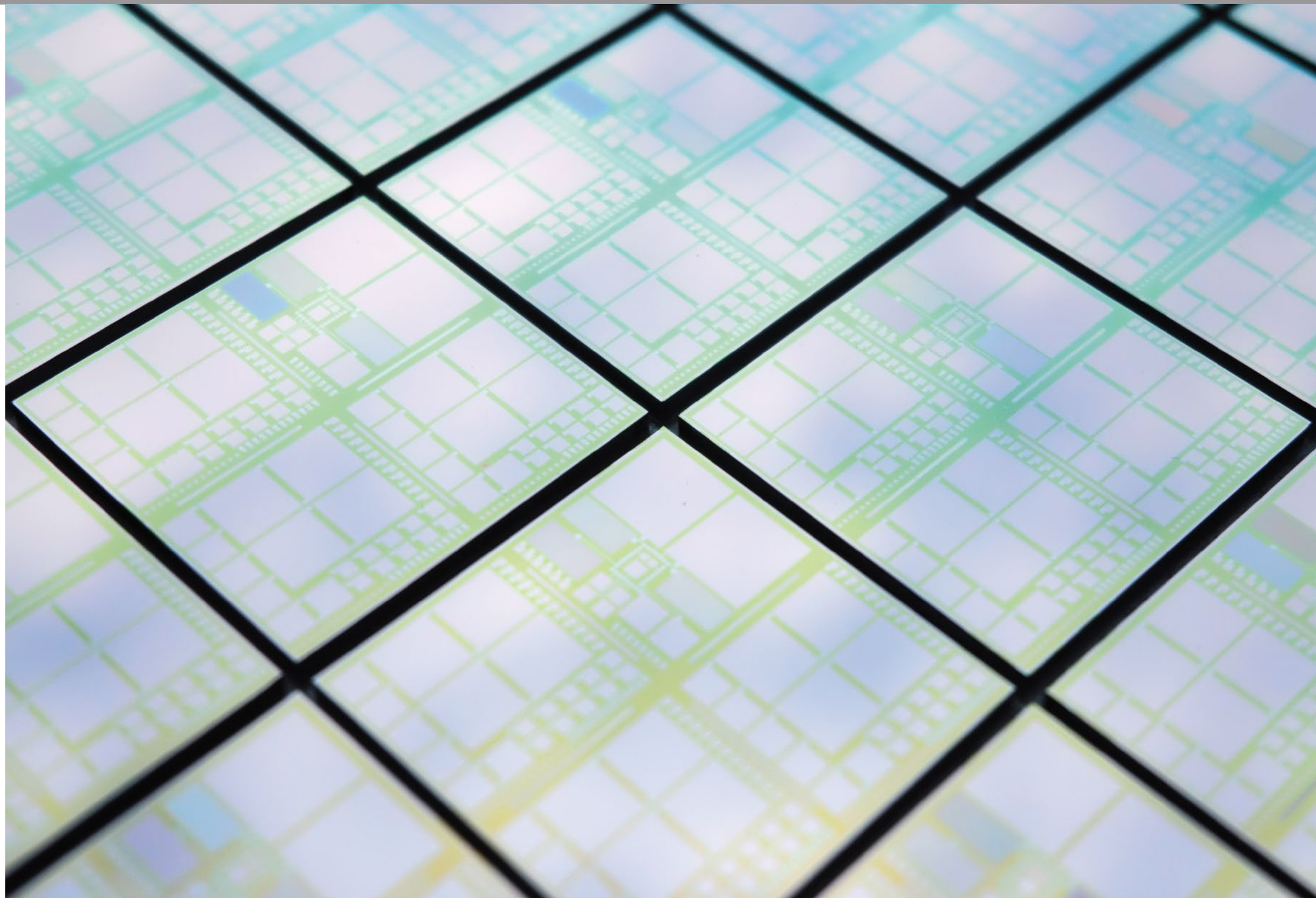
IISB

FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB



Annual Report 2012

Fraunhofer Institute for Integrated Systems and Device Technology IISB

ANNUAL REPORT 2012

Imprint

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Cover Photo:
Semiconductor chips, separated by the novel TLS (Thermal Laser Separation) technique, developed by Fraunhofer IISB together with its industrial partner. Image: Fraunhofer IISB

ACHIEVEMENTS AND RESULTS
ANNUAL REPORT 2012

FRAUNHOFER INSTITUTE FOR
INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

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PREFACE

Energy continues to be one of the global challenges in economics, industry, society – and in research. Sophisticated electronics is a key technology for any kind of groundbreaking progress in this field. The R&D activities of Fraunhofer IISB contribute to energy saving and the reorganization of our energy system for the sake of climate protection and a sustainable security of supply. This is underlined by a number of major events at our institute that took place in 2012.

In spring, we had the pleasure to celebrate two extensions of our infrastructure. First, we opened our new technical center for crystallization and wafering in our branch lab THM in Freiberg, Saxony. There, Fraunhofer IISB is working on the improvement of high-quality semiconductor materials like silicon for photovoltaics or gallium nitride for energy electronics, which are the basis for modern energy supply.

And secondly, we inaugurated our new laboratory building in Erlangen, Bavaria, which is predominantly dedicated to power electronics and its applications in electric mobility and energy technology. The building comprises power electronics labs, workshops for electric cars, and a research and demonstration center for local DC power grids. This significantly enhances our technical capabilities.

The IISB Annual Conference was dedicated to the bulk growth and epitaxy of wide-band-gap semiconductor substrates, which allow the development of energy efficient electron devices and circuits.

This year, two new IISB research groups on energy were established, one in Erlangen, and one at the "Energie Campus Nürnberg" (EnCN). The latter will soon move into the new EnCN building in Nuremberg, which will house several research partners from the Nuremberg Metropolitan region. The regional Fraunhofer Innovation Cluster "Electronics for Sustainable Energy Use" successfully passed its third year and will continue its collaborative work also after the end of the funding period. In view of this development, I am happy that Dr. Martin März, head of our power electronics department, was appointed deputy director of IISB at the beginnig of 2012.

1 *Prof. Dr. rer. nat. Lothar Frey, Director of Fraunhofer IISB. Image: Matthias Heyde / Fraunhofer-Gesellschaft*

Fraunhofer IISB as a partner of industry conducts applied research and development in the areas of power electronics and semiconductor technology, ranging from basic materials to complete systems. In semiconductor technology, comprehensive investments in our cleanroom and laboratory equipment allow us to stay in the forefront of research in this field.

Semiconductor research based on partnership will also be continued together with our partner companies residing in the IISB buildings. Together with NanoWorld Services, we could celebrate the 10th anniversary of their on-site engagement at IISB in Erlangen.

Also in 2012, researches of IISB were awarded with several research prizes, such as the ECPE Young Engineer Award, DGKK Award, the DRIVE-E Student Award, and the Ulrich Gösele Young Scientist Award.

I would like to thank my colleagues at IISB for their successful work, and I would like to express my gratitude to all our partners in industry, research, and public authorities, especially the University of Erlangen-Nuremberg and the funding authorities for supporting us.

Erlangen, April 2013

Prof. Dr. Lothar Frey

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Brief Portrait

The Fraunhofer Institute for Integrated Systems and Device Technology IISB, founded in 1985, conducts applied research and development in the fields of power electronics, micro- and nanoelectronics, and advanced materials. With its process, equipment, and material development for semiconductor technology, its activities in the field of simulation as well as its works on power electronic systems for energy supply and hybrid and electric vehicles, the institute enjoys international attention and recognition.

The headquarters of the IISB is located in Erlangen. Branches of the institute are located in Nuremberg with the Center for Automotive Power Electronics and Mechatronics ZKLM and in Freiberg with the Technology Center Semiconductor Materials THM. The IISB has about 180 employees. It is one of 60 institutes of the Fraunhofer Gesellschaft and does contract research for industry or public institutions. The institute closly cooperates with the University of Erlangen-Nuremberg and is a member of the "Energie Campus Nürnberg" (EnCN).

Scientific Profile

The research and development activities of the Fraunhofer IISB can be summarized in the business areas of:

- Power Electronics

and

- Semiconductors

The following topics are comprehensively dealt:

- Nanoelectronics
- Materials for Electronics
- Power Electronic Systems
- Electric Mobility
- Energy Electronics

1 *Building of the Fraunhofer IISB with test center for electric vehicles, cleanroom, and new laboratory building; behind: cleanroom laboratory and building of the Chair of Electron Devices of the University of Erlangen-Nuremberg. Image: Kurt Fuchs / Fraunhofer IISB*

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PROFILE OF THE INSTITUTE

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Organization and Fields of Activity

The projects and subjects of the Fraunhofer IISB in micro- and nanoelectronics, power electronics, electric mobility, energy supply, and materials research are dealt with interdivisionally in five special departments:

Technology

Here, new materials, devices, and processes from semiconductor technology are developed for CMOS (CLSI, ULSI), nanoelectronics, and power electronics. For that purpose, complete process lines for silicon and silicon carbide are available. In particular, the activities and competences include, inter alia, surface and thin-film technologies for new materials, processes for thin dielectric and metallic layers, ion implantation, circuit modifications and IC repair, nanostructuring, particle electronics, metrology and analysis as well as the development of passive devices.

Semiconductor Manufacturing Equipment and Methods

The focus is put on the development and improvement of new manufacturing equipment and the corresponding methods and processes as well as their implementation in industrial production. Great importance is attached to issues of yield and throughput optimization, process compatibility, contamination, safety, sustainable production, and optimization of resources. Process automation, pre-qualification of equipment, analytics in the IISB analysis laboratory (accredited according to ISO 17025) for micro- and nanotechnology as well as integrated and virtual metrology are possible fields of application.

Technology Simulation

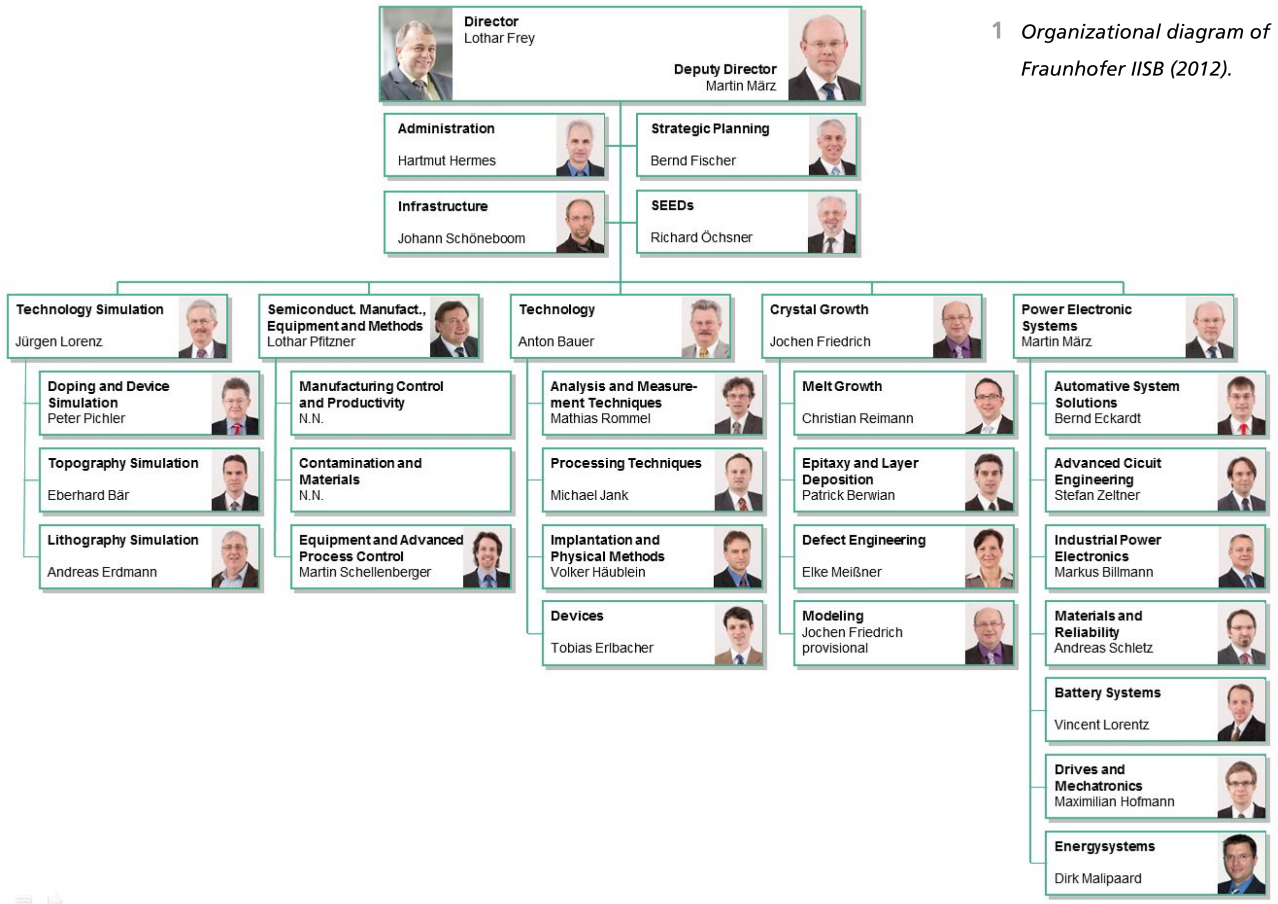
Here, physical models and powerful simulation programs for the optimization of individual processes and process sequences in semiconductor technology are developed and transferred to application. Furthermore, the development of processes, components, and circuits is supported by simulation. Special competence exists in the field of mask design and device development by predictive lithography simulation. Special emphasis is placed on the combination of electric, thermal, and mechanical simulations.

Crystal Growth

The aim is to identify the correlation between the properties of crystalline materials and their growth conditions in order to optimize the industrial process development. For this, experimental and theoretical analyses, metrology, and numerical modelling with software tools specially developed by IISB, represent a strategic alliance. The focus is put on the production of crystal material and crystalline layers for microelectronics, photovoltaics, as well as for optical applications including detector and laser materials.

Power Electronic Systems

The spectrum of the Power Electronic Systems department ranges from the development of new materials reliability testing and error analyses, questions related to circuits and control, packaging and cooling technology, EMC, energy management to the realization of complete system solutions for automotive engineering as well as power supply, and automation engineering. The focus is put on the field of mechatronic system integration, i.e. the integration of power electronics, microelectronics, sensors, and mechanics, electric power converters as well as on technologies for the increase of efficiency and power density in industrial fields of application like electric mobility, power engineering, and network technology.



1 *Organizational diagram of Fraunhofer IISB (2012).*

PROFILE OF THE INSTITUTE

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Fraunhofer IISB in Erlangen

The headquarters of the Fraunhofer IISB is located in Erlangen, right next to the southern campus of the University of Erlangen-Nuremberg. The IISB provides more than 5000 m² of research and development facilities for power electronics, micro- and nanotechnology, and crystal growth. In addition, about 1500 m² of high-class cleanroom area is available, which is partly operated together with the University of Erlangen-Nuremberg. With an area of additional 1600 m², an extension building, which will be used mainly for power electronics, was officially inaugurated in spring 2012. It comprises, inter alia, an application and demonstration center for local DC power grids. Since summer 2010, the IISB has been operating its new Test Center for Electric Vehicles.

Test Center for Electric Vehicles
Electric vehicles make completely new demands on measurement and test engineering. The Test Center offers a unique infrastructure, customized for these requirements. Single components up to complete vehicles can be measured and optimized. The Test Center includes testbenches for electric drives, energy storage devices, electrical and thermal reliability, and electromagnetic compatibility. Core element is a temperature-controllable roller-type test stand. This test stand can be used to test entire vehicles, e.g., with regard to their range under extreme ambient conditions. The Test Center is supplemented by laboratories and workshops for electric cars in the new extension building of IISB.

Cleanroom Laboratories
Fraunhofer IISB provides about 500 m² of own cleanroom area and operates the big cleanroom hall of the University (1000 m²) together with the Chair of Electron Devices. Here, research is done on electron devices, processes, materials, equipment development, and metrology for semiconductor technology on silicon, silicon carbide, and nano particles.

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1 *The new extension building of the Fraunhofer IISB. Image: Kurt Fuchs / Fraunhofer IISB*

Center for Automotive Power Electronics and Mechatronics ZKLM

The Center for Automotive Power Electronics and Mechatronics ZKLM is a branch lab of Fraunhofer IISB located in Nuremberg. The ZKLM is part of the "Power Electronics Systems" department of the IISB.

In the focus of the research and development work at the ZKLM are power electronic system components for next generation vehicles like two-wheelers, cars, buses, trucks, and airplanes. New technical solutions for electric mobility are developed based on innovations in the field of power electronics, particularly for all kind of electric drives, on-board electrical energy management, vehicle-to-grid systems, and electrical energy storages.

About 680 m^2 office and laboratory area are available for the meanwhile more than 20 engineers and technicians.

Since 2007, the ZKLM is also domicile of three further working groups of IISB. The "Materials and Reliability" group is working on new materials as well as on reliability, lifetime, and robustness issues of power electronic systems in the context of individual application requirements and mission profiles. The groups "Industrial Power Electronics" and "Energy Systems" develop components for the power engineering and modern power grids.

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1 *Stuff of the ZKLM (Center for Automotive Electronics and Mechatronics) in Nuremberg with hybrid and electric vehicles. Image: Bernd Müller / Fraunhofer-Gesellschaft*

Technology Center for Semiconductor Materials THM

The branch lab of IISB in Freiberg, the Fraunhofer Technology Center of Semiconductor Materials (THM) is organized as a joint department of the Fraunhofer Institute for Integrated Systems and Device Technology IISB, Erlangen, and the Fraunhofer Institute for Solar Energy Systems ISE, Freiburg.

THM supports industry in their developments of technologies for the production of innovative semiconductor materials to be used in micro- and optoelectronics as well as in photovoltaics.

The focal areas of research, which are investigated by THM in close collaboration with the Technical University Bergakademie Freiberg, are the production of semiconductor substrates at reduced costs, the improvement of the material quality of crystalline silicon, and III-V compound semiconductors as well as the production of new materials.

In spring 2012, the new crystallization and wafering technical center at THM was inaugurated.

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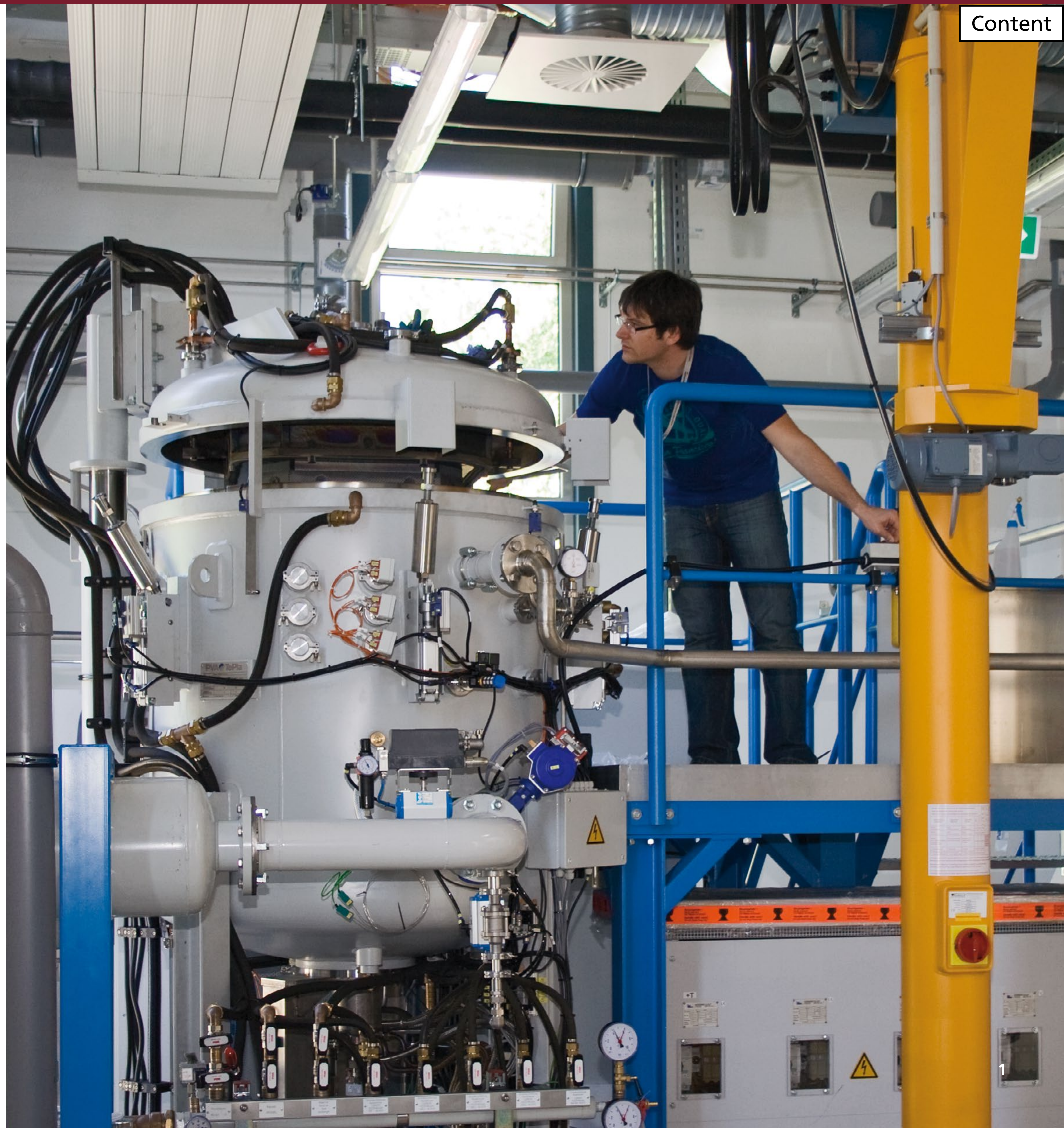

1 *Crystal growth furnace for silicon at the Fraunhofer THM (Technology Center for Semiconductor Materials) in Freiberg, Saxony.*

Cooperation with the Chair of Electron Devices, University of Erlangen-Nuremberg

IISB and the Chair of Electron Devices (German abbreviation: LEB) of the University of Erlangen-Nuremberg are both headed by Prof. Lothar Frey. Within the framework of a cooperation agreement, the two institutions not only jointly operate the University's cleanroom hall and other laboratories, but also work closely together with regard to teaching and research.

The cooperation of the Chair of Electron Devices and the Fraunhofer IISB allows to cover the entire chain of topics from basic research to the transfer to industry, e.g., in the fields of new dielectrics, metal gates, silicon carbide, and printable electronics. 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.

Therefore, the following staff members of Fraunhofer IISB regularly give lectures at the University of Erlangen-Nuremberg:

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

Dr. Tobias Erlbacher
Semiconductor Power Devices

Dr. Michael Jank
Nanoelectronics,
Introduction to Printable Electronics

Dr. Jürgen Lorenz
Process and Device Simulation

Dr. Martin März
Automotive Electronics - Power Electronics,
Architecture and Systems Technology for Electric Mobility

Prof. Dr. Lothar Pfitzner
Semiconductor Equipment Technics

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

Prof. Dr. Heiner Ryssel
Cleanroom technology

1 *Chair of Electron Devices of the University of Erlangen-Nuremberg: main building and cleanroom laboratory. Image: Chair of Electron Devices (LEB)*

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Advisory Board (2012)

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

Dr. Reinhard Ploß (Chairman of the Advisory Board)
Infineon Technologies AG

Dr. Dietrich Ernst
Förderkreis für die Mikroelektronik e.V.

Thomas Harder
European Center for Power Electronics (ECPE)

Dr. Stefan Kampmann
Robert Bosch GmbH

MinR Dr. Ulrich Katenkamp
Federal Ministry of Education and Research (BMBF)

Markus Lötzsch
Nuremberg Chamber of Commerce and Industry

Prof. Dr. Marion Merklein
Dean of the Faculty of Engineering Sciences of the University of Erlangen-Nuremberg

Dr. Andreas Mühe
Siltronic AG

MR Dr. Georg Ried
Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology

Dr. Martin Schrems
austriamicrosystems AG

Dr. Karl-Heinz Stegemann
SolarWorld Innovations GmbH

Dr. Thomas Stockmeier
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Institute-Specific Offers for Contract Research

According to the Fraunhofer model, Fraunhofer IISB finances itself mostly by third-party funds and does applied contract research and development in close cooperation with its partners as contractual partner of industry and public funding authorities. With its activities in power electronics as well as micro- and nanotechnology, the institute offers a wide range of competencies from basic materials and devices, circuits and processes to overall system development. This is complemented by simulation support, the development of manufacturing devices, analysis, and metrology. Last but not least, the cooperation with the University of Erlangen-Nuremberg is one reason why the whole chain from basic research to prototyping and the transfer in industrial realization can be covered. This wide range of services and flexibility are reflected in variety of the possible constellations of contractual cooperation.

The fields of activities of IISB include, inter alia, the following subjects and offers:

Nanoelectronics

Semiconductor Technology

- processing steps and methods for very-large-scale integrated circuits on Si (VLSI, ULSI) (cleanroom class 10, wafer sizes of up to 200 mm, partly 300 mm)
- comprehensive processing technology for SiC
- analysis and repair of prototypes of electronic components (sensors, power electronic devices, passives)
- devices for micro- and nanoelectronics, microsystems technology, power electronics and high-temperature electronics on Si and SiC
- implantation of dopants at low and high energy
- production of thin dielectric and metallic layers, in particular MOCVD
- nanostructuring (nanoimprint, "Focused Ion Beam")
- printable electronics based on inorganic nanoparticles
- qualification of gases and chemicals
- analysis and metrology (for example: MOS, I(U), C(U), film resistor, mobility, doping profile, Hall effect, REM, TEM, x-ray analysis, line width, thickness, wafer flatness, and wafer warping)

Technology Simulation

- development of physical and chemical models, algorithms and powerful simulation software for industrial and academic users
- 2D/3D device simulation, circuit simulation
- process simulation (ion implantation, diffusion, etching, layer deposition)
- powerful lithography simulation by rigorous modeling (Software Dr. Litho)
- investigation of process fluctuations
- coupled electrical, thermal, mechanical, and metallurgical simulations
- coupling of structure and equipment levels

Semiconductor Manufacturing Equimpent and Methods

- development, testing, evaluation, qualification, and optimization of semiconductor manufacturing equipment, production technology
- characterization of equipment, components, and materials
- equipment assessment
- integrated and virtual metrology
- automation, Advanced Process Control, improved process reproducibility
- optimization of yield, throughput, reliability, safety, energy consumption, and resources
- accredited analysis laboratory for micro- and nanotechnology (DIN EN ISO/IEC 17025:2005)
- contamination analysis: trace impurities on semiconductor and photovoltaic substrates, in process chemicals, process gases, and clean room environments (TXRF, AAS, ICP-MS, GCMS, FTIR, VPD-AAS)
- 450 mm manufacturing
- quality management

Power Electronic Systems

The IISB develops power electric systems for industrial plants, households, electric mobility, as well as for power engineering and network technology. Here, our aim is to make power electronics more energy efficient, cost-effective, robust, compact, and system-integrateable. This covers a wide range of competencies and applications:

- power conversion
- system integration, mechatronics, system design
- circuit design and simulation, innovative topologies
- smart power ASIC design
- embedded software

Content

Continuation: Institute-Specific Offers for Contract Research

- circuit and control technology
- thermal management, thermomechanical simulations
- energy efficiency, highest efficiency, highest power density
- energy management
- passive devices
- new materials
- packaging
- construction, simulation
- reliability tests and error analysis
- product-related and lifetime-optimizing engineering
- examples for fields of application: frequency converters, electric drives, automation, automotive engineering, high-performance converters, energy storage devices, energy supply, HVDC, local DC networks, photovoltaics, power supply units, and consumer electronics

Electric Mobility

For more than ten years now, electric mobility has been one of the main focuses of the department of power electronic systems at IISB. With many years of experience, we work together with our partners on the following themes:

- considering the overall system power electronic systems for drives, energy storage devices and board supply networks of electric and hybrid vehicles, especially frequency converters, power converters, storage monitoring, and energy management
- charging stations and systems for grid connection for electric and hybrid vehicles
- space-adapted mechatronic system integration
- development and testing of components and vehicles at the IISB Test Center for Electric Vehicles (test benches for drives, batteries, complete vehicles and EMC)

Energy Electronics

Power electronics is an essential enabler of our future electrical energy supply with a large share of renewable energy sources. Among others, IISB is dealing with the following topics:

- megawatt power electronics
- local dc networks
- electrical energy storages in the power grid
- interfaces between the power grid and mobile systems
- energy systems

Materials for Electronics

High-quality materials with customized properties enable increasing efficiency, reliability, and new functionalities. The IISB is a specialist in:

- ultra-thin layers for nanoelectronics (dielectrics, metal electrodes, methods: MOCVD, ALD, PVD)
- inorganic nanoparticles for printable electronics
- materials for power electronics (SiC, magnetic materials, interconnect materials, sintering techniques, reliability tests)
- simulation and characterization of material properties

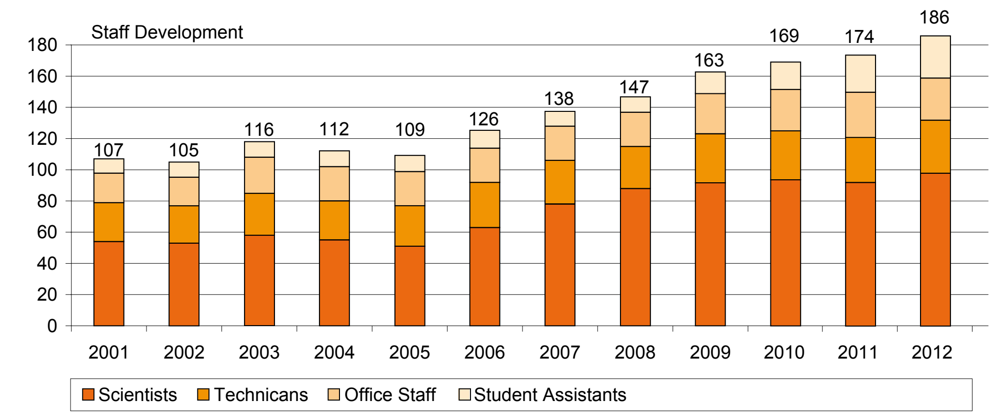
Crystal Growth

- development and optimization of processes and equipment for bulk growth and epitaxy
- optimized mono- and multi-crystalline silicon for microelectronics and photovoltaics
- wide-band-group semiconductors (SiC, GaN) for optoelectronics and power electronics
- compound semi-conductors
- optical crystals (oxides, fluorides)
- detector and laser crystals for medicine, safety and security
- characterization and metrology
- defect engineering
- numerical modeling, software development (CrysMAS)

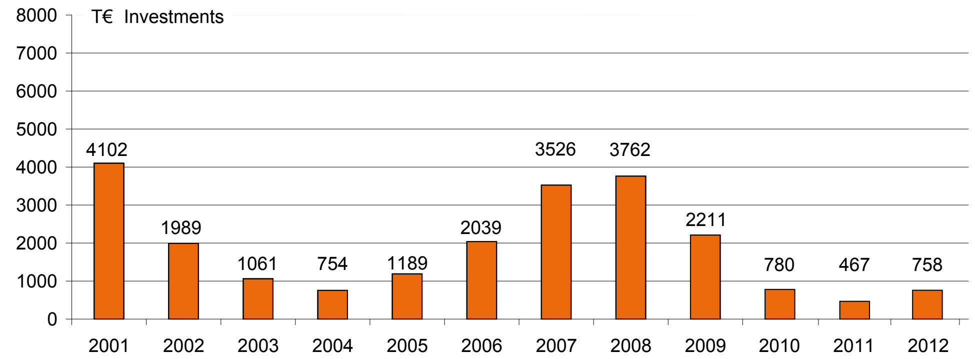
The close cooperation with the University of Erlangen-Nuremberg enables the synergetic use and operation of joint research laboratories, coordination of the research activities and application-oriented education and teaching. The broad scientific basis of the IISB is shown also by its membership in the "Energie Campus Nürnberg" (EnCN), in the networks of the Fraunhofer Group for Microelectronics as well as of the Fraunhofer Energy and Nanotechnology Alliances, the relation to numerous regional, national, and international associations and committees as well as by the cooperation with universities, research institutes, and organizations in Germany, in European countries as wells as, e.g., in the United States, Japan, China, India, and Russia.

Content

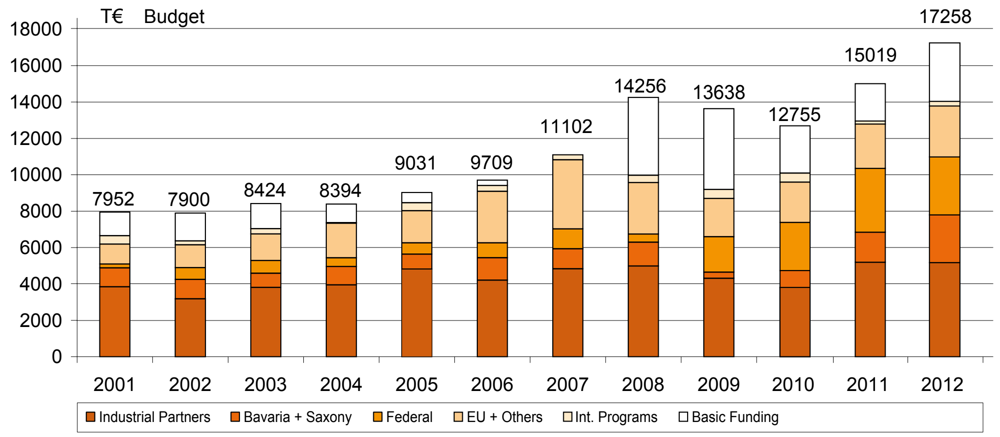
Staff Development, Budget, and Investments



1 *Staff development 2001 - 2012.*



3 *Capital investment (without basic equipment and special funds) 2001 - 2012.*



2 *Operating budget according to financing domains 2001 - 2012.*

FRAUNHOFER-GESELLSCHAFT AND ”FÖRDERKREIS“

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The Fraunhofer-Gesellschaft

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

At present, the Fraunhofer-Gesellschaft maintains 66 institutes and independent research units. The majority of the more than 22,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.9 billion euros. Of this sum, more than 1.6 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

Affiliated international research centers and representative offices provide contact with the regions of greatest importance to present and future scientific progress and economic development.

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

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

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

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

FRAUNHOFER-GESELLSCHAFT AND "FÖRDERKREIS"

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Fraunhofer Groups and Alliances

Fraunhofer IISB is a member of the Fraunhofer Group for Microelectronics as well as of the Fraunhofer Energy and Nanotechnology Alliances.

Fraunhofer Group for Microelectronics

The Fraunhofer Group for Microelectronics VμE has been coordinating the activities of Fraunhofer Institutes working in the fields of microelectronics and microintegration since 1996. Its membership consists of twelve institutes as full members and three as associated members, with a total workforce of around 3,000 and a combined budget of roughly € 325 million. The purpose of the Fraunhofer VμE is to scout for new trends in microelectronics technologies and applications and to integrate them in the strategic planning of the member institutes. It also engages in joint marketing and public relations work.

Further activities of the group concentrate largely on establishing joint focal research groups and projects. In this way, the group is able to provide innovative small and medium-sized enterprises, in particular, with future-oriented research and application-oriented developments that will help them gain a decisive competitive edge.

The core competencies of the member institutes are bundled in the Group's business areas:

- Technology – from CMOS to Smart Systems Integration
- Communication Technologies
- Ambient Assisted Living
- Energy-Efficient Systems and eMobility
- Light
- Safety and Security
- Entertainment

The Business Office of the Fraunhofer Group for Microelectronics based in Berlin serves as central coordination and marketing office. It advises and assists the board of directors of the group on questions regarding strategies, roadmaps, and research coordination.

www.mikroelektronik.fraunhofer.de

Fraunhofer Energy Alliance

The Fraunhofer Energy Alliance is the gateway to the R&D services of the Fraunhofer-Gesellschaft in energy technology and energy economics. In cooperation with partners from industry, the alliance aims at strengthening their technological leadership with regard to energy efficiency and renewable energy sources. The Fraunhofer Energy Alliance offers simplified access to the expertise of the Fraunhofer Institutes particularly to small and medium-sized companies, but also to policy and energy industry.

The Business Areas of the Fraunhofer Energy Alliance are:

- Renewable Energies
- Efficiency Technologies
- Buildings and Components
- Smart Grids
- Energy Storage

www.energie.fraunhofer.de

Fraunhofer Nanotechnology Alliance

The activities of the Fraunhofer Nanotechnology Alliance comprise a wide range of topics such as e.g. multifunctional layers for use in the optical, automotive, and electronics industry. Metallic and oxidic nanoparticles, carbon nanotubes, and nanocomposites are used in actuators, structural materials, and biomedical applications. Moreover, the Fraunhofer Nanotechnology Alliance treats questions regarding toxicology and operational safety when dealing with nanoparticles.

This involves the following Business Areas:

- Nanomaterials and Nanochemistry
- Nanooptics and Nanoelectronics
- Nanobiotechnology
- Nanoprocessing / Handling
- Measuring Methods / Techniques
- Technology Transfer and Consulting

www.nano.fraunhofer.de

1 *SpreePalais in Berlin (Mitte), location of the business office of the Fraunhofer Group for Microelectronics. Image: Fraunhofer-Gesellschaft*

FRAUNHOFER-GESELLSCHAFT AND "FÖRDERKREIS"

Content

Innovation Cluster

At the end of 2012, the Fraunhofer Innovation Cluster "Electronics for Sustainable Energy Use" succesfully completed its funding period. Coordinated by Fraunhofer IISB, research institutions and companies from the Nuremberg Metropolitan Region combine their expertise in this cooperation network and develop innovative products in the fields of power electronics and power engineering. The objective of the Innovation Cluster is to take up existing unique features of the region in an effective way, to enter new markets and therefore to safeguard jobs in the long term. Even after the funding period, this coopration continues by regular exchange and joint projects.

Electronics for Sustainable Energy Use

Efficient and modern electronics, in particular power electronics, can make an essential contribution to energy saving. Whether in household appliances, consumer electronics or in the office, whether in industrial plants, power supply networks or electric vehicles – potential savings can be found along the entire chain from power generation and power distribution to the end-consumer. Due to low-loss components, tailored materials, and intelligent systems, devices, vehicles, and industrial plants are not only less energy-consuming and more efficient, they also become more operationally reliable and compact.

In close cooperation with the existing industrial networks and associations, the Innovation Cluster is intended to realize an even closer coordinated linking between local economy and research. Besides Fraunhofer IISB, research partners of the Innovation Cluster are the University of Erlangen-Nuremberg, the University of Applied Sciences in Nuremberg, the Bavarian Laser Centre, and Fraunhofer IIS. The Innovation Cluster also cooperates closely with the "Bayerischer Cluster Leistungselektronik" (Bavarian Cluster for Power Electronics) and the European Center for Power Electronics, which is located in Nuremberg. Cluster research was funded by the Bavarian State Ministry of Economic Affairs, Infrastructure, Transport, and Technology and by the Fraunhofer-Gesellschaft within the framework of the "Joint Initiative for Research and Innovation" of the Federal Government as well as by means of orders from industrial partners.

The research activities of the Innovation Cluster comprise the following areas:

- energy-efficiency at work and at home
- smart power grids
- electric mobility

The monthly public series of lectures on power electronics initiated in the frame of the Innovation Cluster is still being continued with great success.

Fraunhofer Innovation Clusters

The Innovation Clusters of the Fraunhofer-Gesellschaft are an initiative within the framework of the Federal Government's "Joint Initiative for Research and Innovation". They are regional, application-oriented project clusters between industry and research with a minimum duration of three years. The objective of the Innovation Clusters is to implement interdisciplinary research with scientific excellence in tangible projects. An Innovation Cluster bundles the existing research and development resources and acts as a driver of innovation and as a transfer interface between partners from university to industry. With this initiative, the Fraunhofer-Gesellschaft stimulates the further development of regional centers of excellence and supports the regions' expertise. The project work at the research institutions involved is supported by the Federal Land, industry and the Fraunhofer-Gesellschaft.

www.iisb.fraunhofer.de/innocluster

1 *Established within the Innovation Cluster: IISB application center for DC and highly efficient energy supply technologies. Image: Kurt Fuchs / Fraunhofer IISB*

FRAUNHOFER-GESELLSCHAFT AND ”FÖRDERKREIS“

Content

Förderkreis für die Mikroelektronik e.V.

More than 25 years ago, the founders of the non-profit “Förderkreis für die Mikroelektronik e.V.” (development association for microelectronics) recognized the influence and importance of microelectronics in all technical fields and almost all aspects of daily life, with microelectronics as a key technology and innovation motor being decisive for the economic power, jobs, and wealth of a high-tech producing nation like Germany and thus having an essential meaning for a business location.

Therefore, the “Förderkreis für die Mikroelektronik e.V.” was launched in 1983 with the goal of promoting microelectronics in and for the region of northern Bavaria. This was made possible by generous donations from industry, large subsidies from the Bavarian government, the permanent support by the IHK Nürnberg für Mittelfranken (the local CCI), as well as by enormous investments by the Fraunhofer-Gesellschaft, and resulted in the start-up of chairs of the Friedrich-Alexander University of Erlangen-Nuremberg and institutes of the Fraunhofer-Gesellschaft (among them the IISB) with ultra-modern equipment.

Besides the industrial members, academic partners of the Förderkreis are the two Fraunhofer institutes IIS and IISB in Erlangen, and of the University of Erlangen-Nuremberg the chairs of Technical Electronics, Reliable Circuits and Systems, Information Technology with Focus on Communication Electronics, as well as the Chair of Electron Devices, which is held by the director of the IISB, Prof. Lothar Frey.

The large activities of the “Förderkreis” include:

- promotion of the cooperation between science and industry
- support of technical and scientific events and presentations
- granting of awards

Especially by the last item, the Förderkreis realizes its goal of promoting research, development, teaching, and technology transfer together with its partners. Therefore, in 1996 an innovation award for microelectronics was founded, which is annually granted and endowed with 3000 Euros. Criterion for the jury is mainly an outstanding progress in the field of microelectronics, but also its transfer by a practical utilization by industry. Besides a decoration for special achievements in the field of microelectronics, this award also represents a stimulation for innovative activities and the strengthening of the business location Germany, which depends on ultra-high technology for competing in the world market. The IISB could already provide some of the laureates with Dr. Thomas Falter (1996, together with GeMeTec), Dr. Lothar Frey (1999, together with Nanosensors GmbH), Dr. Andreas Erdmann (2000, together with Sigma-C GmbH), and Marc Hainke, Dr. Thomas Jung, Flaviu Jurma Rotariu, Dr. Matthias Kurz, Dr. Michael Metzger as well as Artur Pusztai (2002), Dr. Martin März and Stefan Zeltner (2005, together with Semikron), Dr. Anton Bauer with Dr. Volker Häublein (2006, together with Infineon), Dr. Mathias Rommel and Holger Schmitt (2008, with Süss MicroTec and S.E.T. SAS) and Dr. Jochen Friedrich (2009, together with SolarWorld Innovations), and Markus Billman and Dirk Malipaard (2011, together with Siemens and Konstruktionsbüro Blösch).

Furthermore, the Förderkreis has recognized the importance of protecting the future of technical education. In this context, in 2000 a youth award endowed with 500 Euro was created in order to support the interests and activities of young people as the future creators of our technical progress. The youth award, which is annually announced in about 300 schools in Bavaria, induces a brisk interest.

Moreover, the Förderkreis supports the stays of guest scientists and graduates at the listed Fraunhofer Institutes and microelectronics chairs.

A support of these activities and promotion goals can be achieved best by a membership in the Förderkreis. Details on this and extended information on the activities of the Förderkreis can be obtained from the contact address below or also from the IISB.

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Chief Executive Officer: Dr. sc. techn. h.c. Dietrich Ernst
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TECHNOLOGY SIMULATION

Content

Focal Areas of Research and Development, Trends, and Potentials

The simulation of semiconductor fabrication processes, devices and circuits strongly contributes to the reduction of development costs in micro- and nanoelectronics. Among the authorities who have confirmed this has been the International Technology Roadmap for Semiconductors (ITRS), which in its 2011 issue estimated this time- and cost-reduction at about one third for cases of best practice. The Technology Simulation Department contributes to this with the development of physical models and programs for the simulation and optimization of semiconductor fabrication processes and equipment. Furthermore, it supports the development of processes, lithography masks, devices, circuits and systems by providing and applying simulation and optimization tools.

Whereas process and device simulation has by now become largely established in industry as an indispensable tool for the development and optimization of highly scaled devices ("More Moore"), the area of "More than Moore" – which consists of fields like power electronics, photovoltaics, and microsystems technology – provides a large variety of additional applications. Here, on the one hand, the offer of commercial tools has, as yet, not even come close to attaining a scale comparable to traditional fields such as the simulation of CMOS transistors. On the other hand, especially these new fields of application often require the combination of heterogeneous competencies, because not only electronic, but also thermal, mechanical, optical, and chemical effects are here encountered. This gives rise to an additional demand for research.

The Technology Simulation Department responded to this demand by extending its activities to the "More than Moore" sector. However, when developing the physical models which are the core of each simulation activity, it cannot but become ever clearer that the successful development of simulations for "More than Moore" is impossible without solid expertise in developing simulations for "More Moore". A comparable situation also occurs in industrial production itself: the application of advanced technologies from the "More Moore" sector also leads to improved and more cost-effective products in the "More than Moore" sector. In consequence, the department has started to utilize "More Moore" results also in the "More than Moore" area.

Three projects either started or finished, respectively, in 2012 constitute good examples of current activities of the department: In the CATRENE project EXEPT (Extreme UV Lithography Entry Point Technology Development), finished at the end of October, there were developed the technologies, tools and infrastructure components required for high volume EUV (Extreme Ultra Violet) lithography with 22 nm pitch structures. The success of this project was owed to a close cooperation between the semiconductor equipment industry, various institutes and a mask shop, and this success was acknowledged by the 2012 CATRENE Innovation Award, presented in November at the European Nanoelectronics Forum. IISB strongly contributed to the success of EXEPT by its work on the development and application of new simulation algorithms for EUV lithography. In the FP7 project THERMINATOR, finished in December, there were developed innovative design concepts for modeling, controlling, compensating and managing temperature on semiconductor circuits and systems to be manufactured with the most advanced technologies. The department contributed with coupled electro-thermal simulations, ranging from process and device simulation to the extraction of thermally aware compact models, which can serve as a workhorse for industry. In the FP7 project SUPERTHEME (Circuit Stability Under Process Variability and Electro-Thermal-Mechanical Coupling), coordinated by IISB and started in October, six companies and three institutes develop a simulation system which will enable the investigation of the impact of process variations, which are largely caused by the equipment used, on the devices and circuits fabricated. Such effects are not only challenging for aggressively scaled logic and memory devices, but also for advanced analog ICs with somewhat relaxed dimensions.

The department will continue to hold to its present approach and to perform focused work on physical models and algorithms – on the one hand in order to develop the necessary skills and tools and, on the other hand, in order to transfer these results to applications in industry. Here, a close and confident cooperation based on sharing the work according to the individual competencies and requirements of the partners has been a key element of the success achieved for many years. The overall mission is to extend the well-established and well-proven contributions which simulation offers for aggressively scaled devices in the "More Moore" area to the more diverse requirements and applications which are opening up in the "More than Moore" one.

1 *Dr. Jürgen Lorenz, head of the department. Image: Kurt Fuchs / Fraunhofer IISB*

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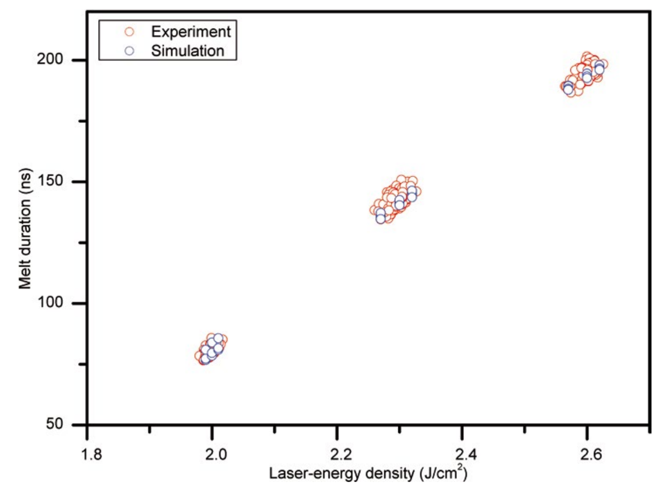

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Modeling and Simulation of Boron Redistribution during Melting Laser Annealing

Melting laser annealing (MLA) is a process which allows dopant activation and damage removal of ion-implanted silicon samples. During this process, the surface of a silicon sample is heated by laser irradiation until it melts. The melt front then proceeds deeper into the material until the maximum melt depth is attained. During the subsequent recrystallization, a high-quality silicon crystal is formed by liquid phase epitaxy. Furthermore, the dopant atoms are incorporated into the silicon lattice and become electrically active. Due to the low thermal budget of a laser pulse with pulse duration in the nanosecond regime, annealing, melting and recrystallization of the implanted region takes place within a few hundred nanoseconds while areas away from the surface are not affected. This can, for example, be used for shallow junction formation and 3D integration.

While models describing the dopant redistribution caused by conventional anneals such as rapid thermal annealing, flash-lamp annealing, or non-melting laser annealing are already available in commercial TCAD simulation tools, no model describing melting-laser annealing has yet been included here. Furthermore, the dopant redistribution mechanism causing the shape of the boron profiles measured after MLA has not yet been fully understood. Therefore, we investigated the redistribution mechanism of boron and the integration of a model for MLA in the European project "ATEMOX" (www.atemox.eu), using a XeCl excimer laser with a pulse duration of 160 ns.

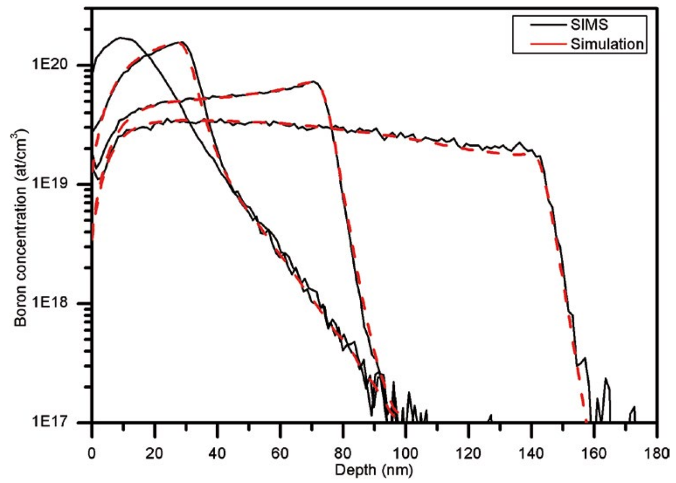
The models developed here can be separated into two parts: first, the thermal simulation considering the shape of the laser pulse, laser light absorption and reflection, a transient simulation of the heat flux, melting of the surface layer, and undercooling during recrystallization; second, a model describing the dopant redistribution that is solved and synchronized with the thermal simulation.

After calibration, the thermal model is in excellent agreement with the melt durations, measured during experiments as shown in Figure 1. The spreading in the measured and simulated melt durations results from a slight variation in the energy, shape, and duration of the laser pulse.

As the boron redistribution mechanisms resulting in the profiles measured by secondary ion mass spectrometry (SIMS) were unknown, we investigated different possible mechanisms by simulation. Outdiffusion of the boron atoms from the liquid phase could be excluded, while thermodiffusion – which is redistribution caused by the huge temperature gradient induced by the laser irradiation – could explain some of the measured profiles, while failing to describe others.

Finally, a model based on the adsorption of the boron atoms at the solid-liquid interface could explain the depletion at the surface as well as the shape of the boron profiles deeper in the silicon for the different laser energy densities. The measured and the simulated profiles for three different laser-energy densities are shown in Figure 2. This comparison also shows that the thermal model calibrated by melt-duration measurements not only reproduces the correct melt-duration, but also the correct melt-depth.

1 *Comparison between the measured and the simulated melt durations.*



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2 *Simulated and measured boron profiles after melting-laser annealing. The three profiles shown were obtained after LTA with laser-energy densities of 2.0 J / cm², 2.3 J / cm², and 2.6 J / cm².*

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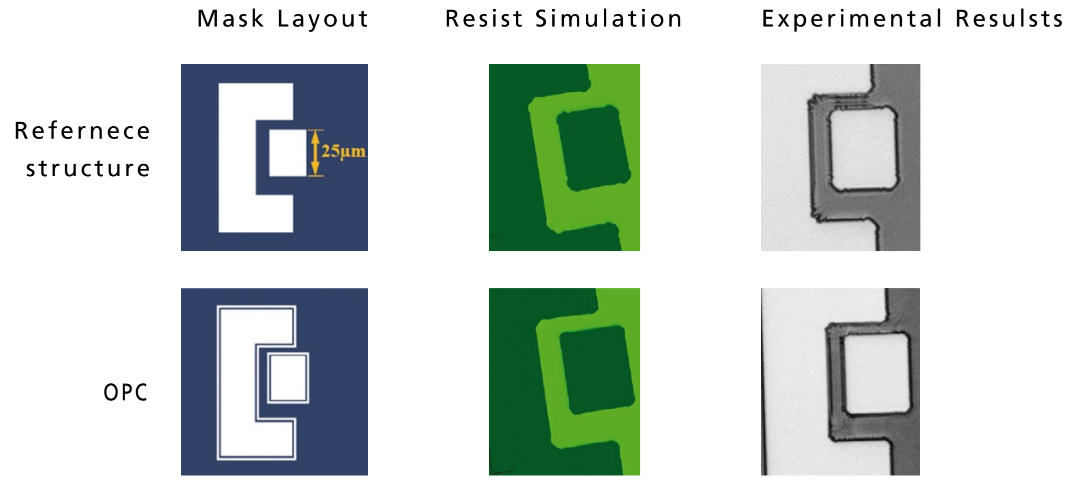
Simulation for Low-Cost Lithography

Continuous miniaturization is one of the main characteristics of today's semiconductor industry. However, not all semiconductor devices can or need to be shrunk to the utmost extreme. While fabrication sites for the manufacturing of the smallest integrated circuits commercially available (CPUs and RAM) are mostly located in the US and in the Far East, the European industry focuses on the fabrication of more specialized devices, often using larger structures to build them. Structure sizes of 1 µm and above are still highly relevant for applications such as the packaging of integrated circuits and the manufacturing of integrated power-electronic systems and of micro-mechanical devices. The desire to improve the throughput yield of the lithographic processes used to manufacture these structures is a strong incentive to use modern optimization techniques, such as the placement of assist structures on the photomask (known as Optical Proximity Correction or OPC), and to choose the materials (especially the photoresist) in such a way that the outcome of the lithography process is as insensitive as possible to variations in the processing conditions. The IISB has investigated the potential of numerical simulations for low-cost lithography applications within the framework of the project "MALS", funded by the Bayerische Forschungsstiftung, and the project "SEAL/FISMA", funded by the European Commission.

In the realm of high-end photolithography (used for structure-sizes of approx. 100nm and below) it is already common practice to use numerical simulation and optimization algorithms during process development. Here, numerical techniques have helped to drastically reduce the costs of process development. The same benefits can be expected from the introduction of numerical simulations into the development of processes for the manufacturing of structures with sizes of 1 µm and above. However, one has to take into account the different cost models and also simplify the numerical techniques used in high-end photolithography. One example of how this can be done is shown in Figure 1, which shows the printing of a test structure on a mask aligner at a proximity gap of 50 µm. When printing this structure using a standard mask layout (top row in Figure 1) one can observe a number of artifacts in the resulting photoresist profile, especially near the corners and in regions where the two parts of the structure are very close to each other. The bottom row shows the results using a mask layout that was the result of a simple numerical optimization. The classical OPC-approach, as used in high-end photolithography, would be



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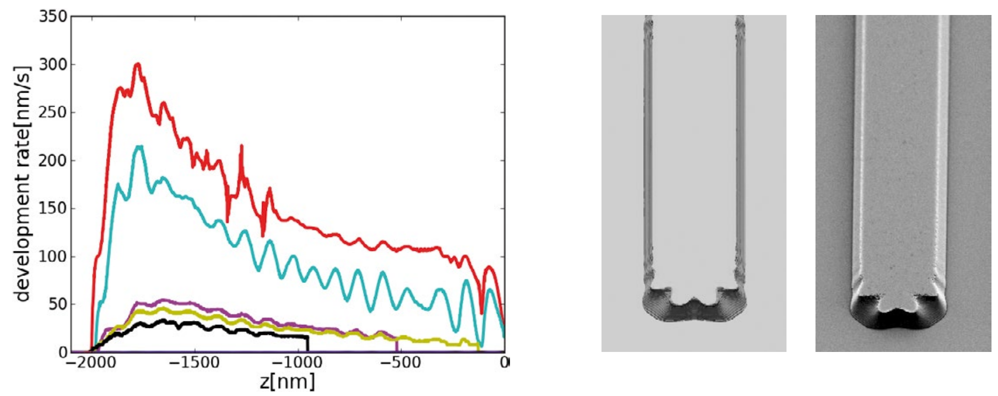
to locally modify the mask layout and to optimize these modifications until a solution is found that suppresses all of the artifacts. This approach typically requires large computational resources (complex layouts can only be optimized on a high-performance computing cluster) and results in mask layouts that contain many tiny assist structures that can significantly increase the costs of the mask.

The OPC-approach shown in Figure 1 is quite different. It is based on a global modification of the layout, consisting of a rim laid around the entire structure. The width of the rim and its distance from the structure are the parameters to be optimized. They were restricted to values above 700 nm, which guarantees that the costs for the mask remain moderate. The experimental pictures in Figure 1 show that, with this simple and straightforward approach, it is possible to suppress the artifacts observed when using a standard mask.

Another important aspect of numerical simulation for low-cost lithography is the correct prediction of the side-wall angles of photoresist profiles, because these have a large impact on the throughput yield of the process. The biggest obstacle in the simulation of photoresist development is the fact that one needs a calibrated model for each photoresist. A very cost-efficient way to calibrate photoresist models is the use of a dissolution-rate monitor (DRM). Figure 2 shows the DRM-data for a DNQ-resist and the result of a simulation based on this data set as compared to a real 10 µm line. An excellent agreement between simulation and experiment can be observed, demonstrating the potential of numerical simulations to replace test exposures in low-cost lithography applications.

1 Comparison between a standard mask layout and a computationally optimized mask layout. The top row shows the standard mask layout, the bottom row the optimized mask layout. Experimental pictures provided by SUSS MicroOptics.



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2 Data obtained from a dissolution-rate monitor (left) and a comparison between a simulation based on this data set and a real 10 µm line (right). The DRM-data was provided by the FH Vorarlberg.

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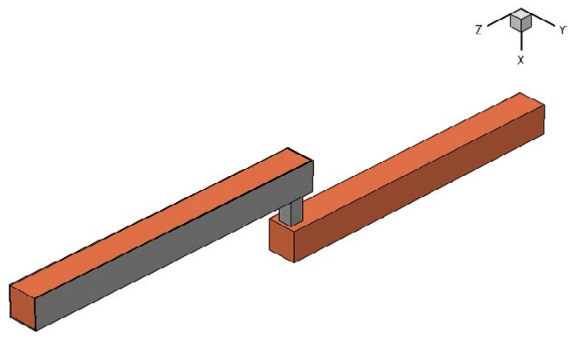

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Interconnect Modeling for Design for Reliability

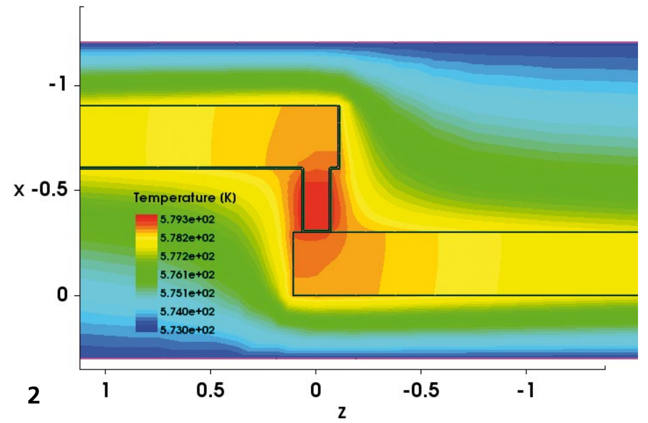
For investigating reliability of interconnects, thermal, electrical and mechanical effects are all highly relevant. The aim of the work of Fraunhofer IISB within Work-Package 2 of the CATRENE project RELY is to establish and demonstrate thermal, electrical, and mechanical simulation models for interconnects as a basis for studying reliability. In the following example, there is demonstrated the application of such models to a structure consisting of two metal lines connected by a via. The goal of the simulations is to allow predictions regarding interconnect reliability, for instance by describing the change in the resistance over time.

Reliability of current and future interconnects needs to be considered when attempting to optimize overall circuit reliability. The phenomena that need to be taken into account are rather complex, as a variety of physical quantities and effects are involved. These are, among others: the temperature distributions, the mechanical stress in the structures, and the mass flow in the interconnecting lines and vias. The last-mentioned in particular is among the most important determining factors with respect to the failure of interconnects and needs to be adequately modeled in order to permit the quantitative assessment of interconnect reliability. The aim of the RELY project is to derive rules for an optimized design in order to improve reliability. Parameters of interest are, for instance, the layout, or other geometrical quantities of the interconnect.

For the example shown, structure-creation is based on the in-house tools of Fraunhofer IISB as well as on geometrical modeling engines available within the Synopsys TCAD framework. Different levels of structure-creation are available, ranging from schematic modeling (such as for the example shown) to simulations which also take into account process effects leading to non-ideal geometries. The electrical, thermal, and mass-transport simulations shown have been carried out with the tools Synopsys Sentaurus Interconnect.

The geometry of the interconnect structure is shown in Figure 1. It consists of two copper lines connected by a via and a tantalum barrier layer partly surrounding the upper copper line. For visualization reasons, the oxide dielectric in which the metal is embedded is not shown. The boundary conditions imposed for the simulations are a fixed temperature of 300 °C at the top and at the bottom of the simulation region, a current density of $7 \cdot 10^6$ A / cm^2 for the interconnect terminals at the simulation domain boundaries, and a stress-free state at 250 °C. The temperature distribution under operation is shown in Figure 2. The effect of Joule heating is visible, though it does not lead to a significant increase of the temperature. The copper mass flow has been simulated based on the driving forces due to current density, as well as due to temperature and stress gradients. For the specific conditions studied, a small void forms in the copper beneath the via, resulting in a deteriorating conductivity. This can be displayed by modeling the resistance and its change over time. For a simulated time of 20000 s, the result is shown in Figure 3. It can be seen that only a slight increase in resistance occurs. For other scenarios, the increase might be more severe and even lead to interconnect failure.

1 *Geometry of the simulated interconnect structure consisting of two metal lines connected by a via.*



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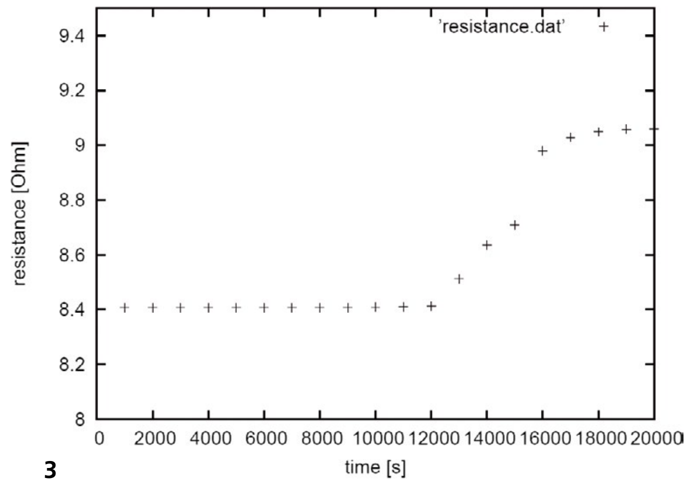
2 *Simulated temperature distribution under operation.*



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3 *Modeled change of the resistance over time.*

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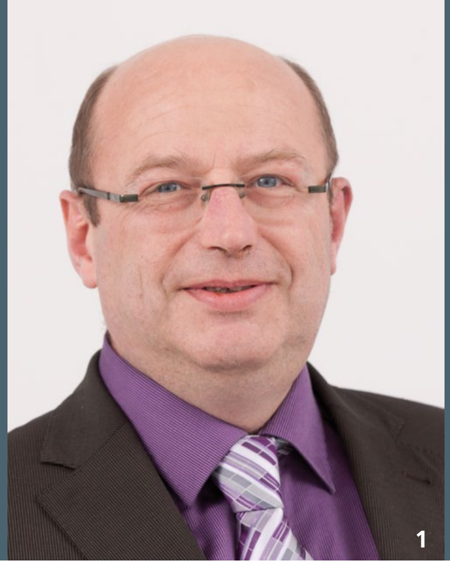
CRYSTAL GROWTH



Content

Focal Areas of Research and Development, Trends, and Potentials

The research focus of the Crystal Growth department is on clarifying – in close collaboration with our industrial partners – how the material properties of bulk crystals, as well as those of thin epitaxial or other functional layers, correlate with their respective conditions of production. This basic understanding of the correlation between material quality and growth conditions is of the utmost importance for any improvement in bulk crystal growth and layer deposition techniques used in industry with a view to achieving larger crystal dimensions, less harmful crystal defects, more uniform electrical and structural properties and new materials. The strategy adopted by the IISB together with its subsidiary in Freiberg, the Fraunhofer Technology Centre for Semiconductor Materials (THM), is the optimization of the crystal growth processes through a combination of thorough experimental process analysis, tailored characterization techniques and numerical modeling. For that purpose, IISB and THM are provided with a well-suited infrastructure, consisting of R&D type furnaces and epitaxial reactors, state of the art metrology tools as well as powerful and user-friendly simulation programs. These programs are especially suitable for heat and mass transport calculations in high-temperature equipment with complex geometry. In 2012, the Crystal Growth department of Fraunhofer IISB has already consolidated its position as a worldwide-acknowledged center of competence in the field of crystal growth.

In the field of crystallization of solar silicon, the IISB, together with its subsidiary in Freiberg, the Fraunhofer Technology Centre for Semiconductor Materials (THM), and its partners from industry and academia began to investigate how the directional solidification process for multicrystalline silicon ingots can be further improved. Experiments were carried out in a lab-scale furnace at IISB and in a special R&D pilot plant scale furnace at THM with the aim of reducing detrimental dislocation clusters and grain boundaries. The reduction of these crystal defects is considered to be a likely way of closing the currently existing efficiency gap between multicrystalline and monocrystalline materials.

Another topic being researched by the IISB is the analysis of the interaction of crucible materials and coating with silicon. A special furnace was in operation which permitted, for example, the in-situ measurement of the contact angle between the silicon and the crucible. Furthermore, we began with the preparative work for an experiment to be carried out in outer space under microgravity conditions in April 2013. The goal of this experiment is to analyze the interaction of foreign particles like SiC with the moving solid-liquid interface during the growth of silicon crystals.

In the field of wide-band-gap semiconductors, we have begun to support our industrial partner in the further development of the HVPE technique for growing GaN boules. The focus of the research activities here is on improving the efficiency of the conversion of the precursors to GaN. Furthermore, valuable knowledge could be gained about the structural properties of free-standing GaN and of bulk crystals by using the high-resolution analytic tools available at IISB. In close collaboration with the University of Erlangen – Nuremberg, we made progress in setting up an experimental high-pressure system to be used for the ammonothermal synthesis of nitrides, e.g. GaN. In parallel, a thermal model was developed for the ammonothermal growth reactor and validated by experimental data. In the field of SiC we started to study how the minority carrier lifetime of the SiC epilayers can be improved as a prerequisite for power devices with high blocking voltages. Furthermore, we began, together with our partners, to develop a luminescence scanner for rapid detection of recombination active defects in SiC substrates and epilayers.

At our subsidiary THM in Freiberg, we began, in close collaboration with the Technical University of Freiberg, to work on developing new materials which have a high application potential for future energy conversion and storage systems. Our goal is to correlate the properties of such functional layers to the conditions of their synthesis, using physical and chemical routes. To this end, small application demonstrators made out of these new materials have also been developed.

Two research awards given to the IISB have strengthened the international reputation of the Crystal Growth Department. Dr. Birgit Kallinger received the Young Scientist Award of the German Association of Crystal Growth (DGKK e.V.) for her detailed investigations into the avoidance of basal plane dislocations during SiC epitaxy. Dr. Christian Reimann received the Ulrich Gösele Award for his investigations into the formation of foreign phases in multicrystalline silicon. Several invited talks during international conferences as well as participation in different national and international expert panels in the field of crystal growth also underline the reputation of the Crystal Growth Department. Further elements of the networking process were the events organized by IISB. Moreover, the Crystal Growth Department works closely together with different research institutions and maintains not only national, but also international, relations of cooperation with industry.

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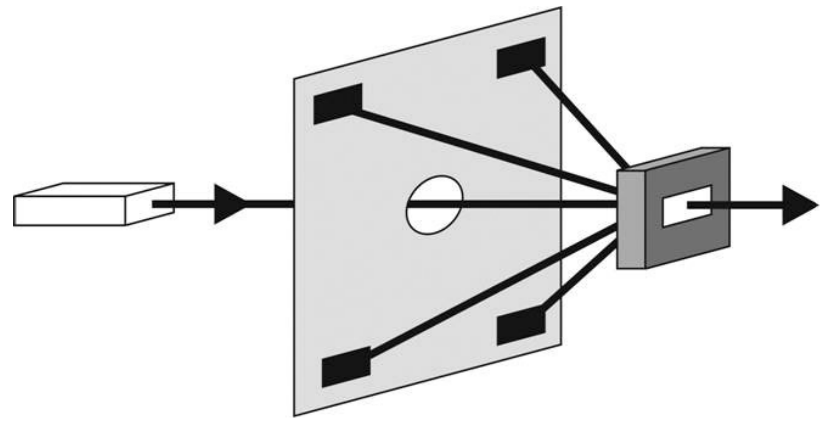
1 *Dr. Jochen Friedrich, head of the department.*

CRYSTAL GROWTH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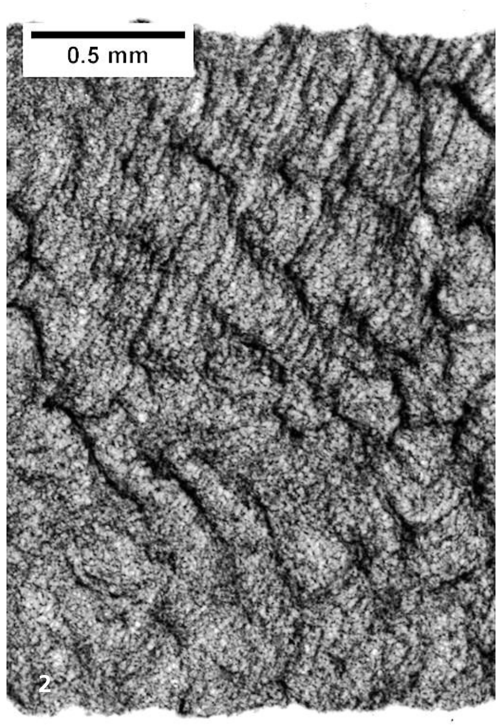
Insight in the Microstructure of Semiconductor Materials and Devices by Synchrotron White Beam Topography (SXRT)

Microstructure and Dislocations in Semiconductor materials: A macroscopic phenomenon often has its origin on the atomic or microscopic scale. If a material is produced in larger dimensions (wafer or crystal size), it is often difficult to identify the individual cause on the nanometer scale and relate this to millimeter or centimeter features. Thus, the microstructure of a semiconductor material, regardless of whether it is a matter of crystals, poly-crystals or epitaxial layers, is an important issue with regard to said material's targeted electronic properties and contains extremely critical information. If we define microstructure as a material's physical structure observed on a microscopic scale, it can be regarded as the sum and arrangement of microscopic areas with perfect crystal structure and areas with structural disturbances. Depending on the material, dislocations may multiply and create extended defects e.g. dislocation arrays or grain boundaries. If a replication on a larger scale occurs, this can also cause severe obstacles e.g. with regard to the growth of volume crystals for substrate purposes. The crystals can develop sub-grain boundaries and may subsequently break at these points upon further growth.

Synchrotron white-beam topography (SXRT) is a unique, powerful and non-destructive method for the observation of the microstructure of a material on a centimeter scale and moreover, opens the way to the investigation of functional layers, and of structured or stacked materials with regard to buried or underlying substrates or technological disturbances, something which is not possible by any other means. A device or wafer can be inspected across its entire area by either back-reflection or transmission geometry. The contrast visible on the SXRT topogram is generated by different interaction processes, but mostly refers to strained lattice regions, which differ from the primary diffraction condition for various reasons (dislocations, poly-crystals, inclusions, local elastic strain and so on).

The diffraction of the synchrotron white beam produces a so-called Laue pattern in which any one of the diffracted spots contains a full topogram of the interaction volume. Fig. 1 shows a schematic drawing of the SXRT principle for back-reflection topography. Our SXRT investigations were performed at the Topo-Tomo beamline of the Angström-source Karlsruhe (ANKA). Within the framework of the optimization of a crystal growth process for GaN volume crystals, we used, for example, the SXRT method to investigate the evolution of the microstructure of a GaN bulk crystal at various crystal heights representing different stages of the crystal growth process. Fig. 2 shows, as an example, the topogram of the crystallographic c-plane of a GaN wafer. Sub-grain boundaries appear as black lines forming a cell-type structure. The irregular outer edge of the topogram indicates that significant strain is present in the material. A thorough study was performed on different crystallographic directions of the crystal. These SXRT investigations led, for the first time, to a deeper understanding of the three-dimensional situation as regards the developing dislocation microstructure in bulk GaN across the entire expanse of the crystal. The crystal growth process can now be further inspected with regard to the influences of particular process parameters, in such a way that further improvements of the crystal quality will be possible.



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1 *Schematic drawing of the principle of SXRT back-reflection topography: The white synchrotron beam interacts with the sample and produces a Laue pattern on the high-resolution film placed in front of the sample in the direction of the incoming beam. The single spots represent the individual topograms.*

2 *SXRT back-reflection topogram [0002] of a c-plane wafer from a bulk GaN crystal. The black lines forming a cell-type structure represent sub-grain boundaries.*

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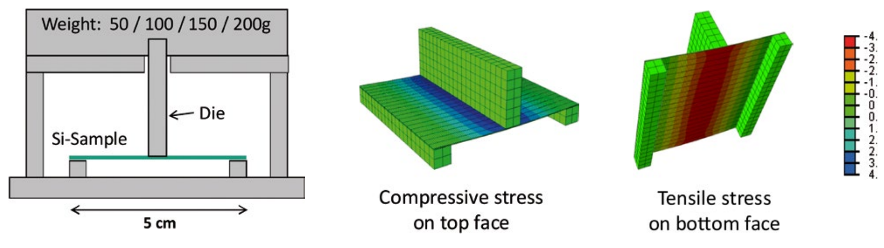
CRYSTAL GROWTH

Influence of Annealing Conditions on the Reduction of Dislocation Densities in Multi-Crystalline Silicon Wafers and Ingots

For silicon solar cell production there are currently used two different crystallization processes: single crystalline growth by the Czochralski method and directional solidification resulting in multi-crystalline ingots. Single crystalline material offers better material quality and produces solar cells with higher energy-conversion factors ($\eta_{max,\ 2012}$ = 25.0 %) than those produced by multi-crystalline material ($\eta_{max,\ 2012}$ = 20.4 %). But it does so at higher production costs. Among the factors affecting energy conversion are: limited recombination; active crystal defects such as impurities coming from the silicon feedstock and the crystallization furnace; and structural defects such as grain boundaries and dislocations. Dislocations are defects introduced by plastic deformation, due to mechanical stresses occurring during and after crystal growth. Researchers and solar cell manufacturers agree that the high density of dislocations in multi-crystalline silicon has to be reduced in order to achieve more efficient solar cells. Two strategies could be promising in future: Reduction of dislocation generation during crystal growth; or thermal annealing of the silicon crystal after solidification.

Advanced crystal growth processes use a mono-crystalline seed as a starting point for crystallization, or dendritic nucleation at the crucible bottom, in order to grow crystals with a lower dislocation density. On the other hand, several research groups have shown results produced by thermal annealing procedures after crystal growth which suggest that these procedures can indeed produce a reduction in dislocation. It is known already from metal physics that thermal annealing of a plastically deformed material can lead to a recovery of its mechanical properties by dislocation reduction and rearrangement.

Within the framework of the SilKriT project, IISB investigated the possibility of reducing, by thermal annealing, the dislocation density of multi-crystalline wafers and bricks as grown. To investigate the response of multi-crystalline silicon to thermal annealing, two types of experiments were conducted: the thermal annealing of wafers and small bricks by the application of mechanical stress to promote dislocation movement (see Fig. 1), and long-term annealing experiments with a boron source to analyze the effects of improving dislocation mobility by diffusion gettering. The samples were annealed at temperatures ranging from 1200 °C to 1365 °C, for up to five hours with applied load, and for up to 96 hours with a boron source.



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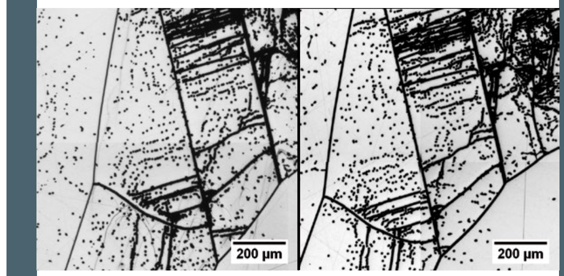

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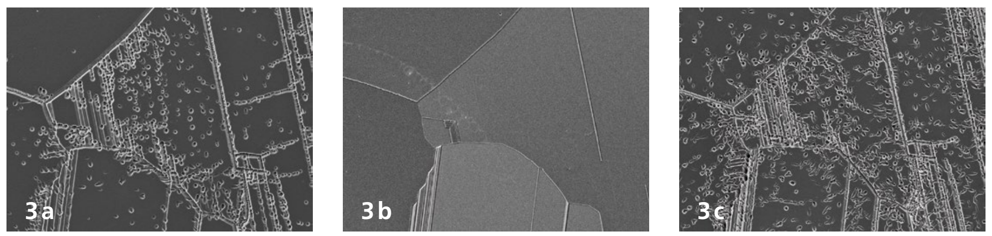
None of the experiments conducted using the application of mechanical stress to wafers or bricks led to any measurable reduction of the dislocation density, regardless of the annealing time and the magnitude of applied stress. Fig. 2 shows a microscope image of one sample before and after annealing. No change in the dislocation microstructure is observable. Crystal defects are made visible by a wet chemical etching solution which preferably attacks crystal defects protruding from the sample surface. Dislocations are made visible as circular etch pits. Grain boundaries result in line-shaped depressions.

The long-term annealing experiments with boron source likewise show no reduction in dislocation density (see Figs. 3a and c). The boron source creates a boron-rich layer in the silicon sample with a thickness depending on the annealing time. Boron is a dopant for silicon, which changes the electrical characteristics of the material in the boron-rich layer. The etching behavior depends on the amount of free charge-carriers in the material, and because of that, after the annealing process, no dislocations can be made visible with wet chemical etching solution, which had successfully revealed dislocations before the annealing (see fig. 3b). By using an etching solution suitable for highly doped material, dislocations can be made visible again (see Fig. 3c).The results show no hints of dislocation reduction by thermal annealing of multi-crystalline silicon. When comparing these results to what is known from metal physics, one has to conclude that recovery in cold-worked metals is observed at plastic strain-rates greater than ten percent while the plastic deformation in the ingot growth of silicon never exceeds one percent. Moreover, metals which show a high tendency for recovery always exhibit high stacking-fault energies. Silicon has a stacking-fault energy comparable to copper, in which hardly any recovery is observed. Therefore, it could be concluded that dislocation-reduction in multi-crystalline silicon by thermal annealing is not possible under the process conditions adopted. The work was honored with the Fraunhofer IISB Research Award 2012.

1 *Experimental setup for thermal annealing of mc-Si wafers with an applied mechanical load. A die applies bending stress to the wafer, the magnitude of bending stress can be varied by different weights.*

2 *Visible light microscopy images before and after annealing treatment with applied load; dislocations and grain boundaries were made visible by wet chemical etching: no dislocation density reduction can be observed.*



3 *Secondary electron microscope images before (a) and after annealing with a boron source (b) and after annealing with a boron source and etching with a solution suitable for highly doped material (c).*

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CRYSTAL GROWTH

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Grain Growth Control during Directional Solidification of Multi-Crystalline Silicon

Crystalline silicon has hitherto been the dominant material for the production of solar cells. There are two different technologies for crystal growth of solar silicon in industrial application. The first one is the relatively expensive Czochralski crystal growth technology, which results in mono-crystalline silicon, whereas the second one is the relatively cheap "directional solidification" method which produces multi-crystalline silicon ingots. Counterbalancing the lower expense of the latter method is the fact that the efficiency of multi-crystalline silicon is 2% less compared to mono-crystalline silicon, due to crystal defects such as grain boundaries, dislocations, and a higher contamination level. However, the process of directional solidification exhibits further potential for improving the resulting quality of the multi-crystalline material. One approach is the reduction of the density of recombination-active crystal defects, such as dislocations, so as to increase the solar cell efficiency at the same cost level.

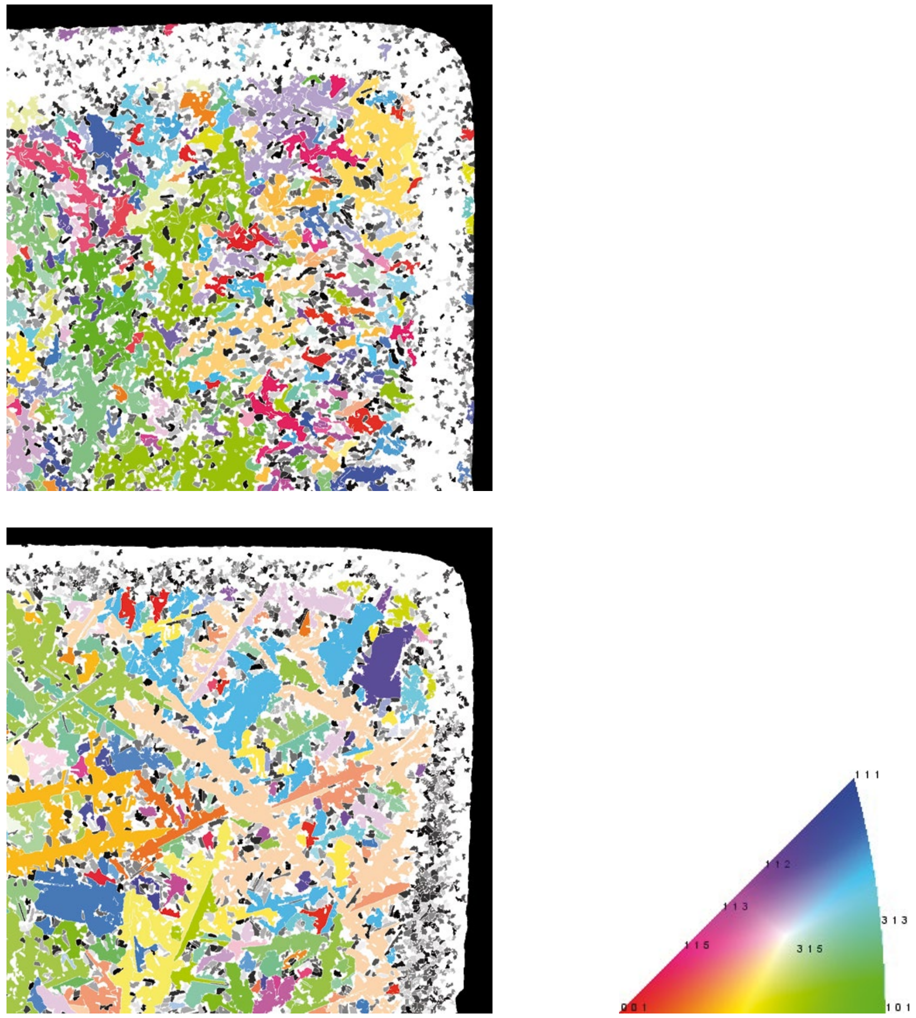
During the directional solidification process silicon is molten in a crucible at 1450 °C. It is then directionally solidified from bottom to top. After an initial heterogeneous nucleation of silicon at the crucible bottom, grains should grow in a columnar structure to the top of the ingot. The grain structure, in combination with the thermal cooling history of the silicon ingot, can affect the generation and multiplication of dislocations and therefore the efficiency of the solar cell. The control of the initial grain growth is therefore an important task to tackle if we are to further improve the quality of multi-crystalline silicon ingots for PV application.

At Fraunhofer THM a special R&D furnace was installed which provides the possibility of controlling the grain growth during directional solidification of multi-crystalline silicon. To influence the initial nucleation process a special heat-exchanger unit was installed under the crucible bottom. This tool provides the possibility of extracting the heat from the silicon melt either over the whole crucible bottom area or only locally. This in turn makes it possible to control the number of crystal seeds and the nucleation area respectively. The heat-exchanger unit operates with argon gas, which can be switched on or off during the whole process. In Fig 2 the initial grain structure of 2 different crystals, grown with different cooling rates, is shown. In one case dendrites grow along the crucible bottom. In the other case small grains appear at the crucible bottom.

The results clearly show that it is possible to trigger the initial grain growth by choosing suitable cooling conditions.

This provides the further possibility of improving the material quality of multi-crystalline silicon ingots and thereby increasing the efficiency of the resulting solar cell.

1 *R&D furnace with a special heat-exchanger unit under the crucible bottom at the Fraunhofer THM in Freiberg.*



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2 *Initial grain structure measured by the Laue Scanner tool of two different crystals grown at different cooling rates.*

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SEMICONDUCTOR MANUFACTURING EQUIPMENT AND METHODS

Content

Focal Areas of Research and Development, Trends, and Potentials

The core competence of the department "Semiconductor Manufacturing Equipment and Methods" is the multidisciplinary research and development for manufacturers of equipment, materials, and semiconductor devices. The decisive factor for this is the expertise in process development, metrology, analytics, software, simulation, and device integration combined to develop tailor-made solutions together with customers.

For this approach, a wide-ranging expertise is essential which manifests itself in the competence area regarding equipment, advanced process control, manufacturing science, productivity, contamination, and materials. Experts from the fields of electrical engineering, materials science, mechanical engineering, physics, computer science, and chemistry work together on the issues that will sustainably influence efficiency in the construction of manufacturing equipment, the production of materials for manufacturing, and IC manufacturing itself.

The scope of developments ranges from lead research for novel processes and measurement methods to the application of new research results in cooperation with corporate partners and to the assessment and optimization of equipment in an industry-compliant environment. Essential for a conclusive and comprehensible assessment is the successful accreditation of IISB's testing laboratory according to DIN EN ISO 17025 in 2009.

Preliminary research in the reporting period includes, for example, the optimization of UV-based measurement of thinnest layers under vacuum conditions, or the development of a novel approach for optical nanotopography measurements on reflecting surfaces. On the side of application-oriented research, IISB leads the EU project "SEAL" which aims at developing and evaluating innovative process and metrology equipment in a European network of 36 equipment suppliers, device manufacturers, and research institutions to make them ready for series production. To support the collaboration of semiconductor stakeholders in Germany, a BMBF-funded study on the development of common themes for semiconductor manufacturers and their suppliers was started.

The ENIAC project "IMPROVE", which aimed at doing research in the field of cutting-edge methods for increasing the efficiency of domestic and European semiconductor manufacturing, was successfully finished and received the ENIAC Innovation Award during the European Nanoelectronics Forum in November 2012. An overview about the IMPROVE project as well as research results are presented in separate reports. The ENIAC project "EEMI 450" with focus on the specification and preliminary development of equipment and materials for the upcoming production on 450 mm silicon wafers was also finished successfully in 2012.

Successfully completed collaborations like "NANOCMOS", "PULLNANO", "SEA-NET" or "IMPROVE", as well as ongoing projects such as "SEAL", "Enable450" or "UTTERMOST" make highest demands – especially in the European context – on knowledge and communication skills of the researchers involved: automated process control, integrated and virtual metrology, environment, energy and resource optimized manufacturing, yield optimization, predictive maintenance, throughput optimization, device integration, 450 mm processes and devices as well as simulation of manufacturing equipment and components are just some of the challenges that can only be met successfully in a multidisciplinary approach. Research projects of this kind as well as bilateral development projects with industrial partners confirm the broad approach of the department which is well-positioned for the future due to its variety of topics.

The described research activities are complemented by the involvement in national and international committees and panels: staff members of the department are active in several committees and sections of the "VDI/VDE-Fachgesellschaft GMM" and take leadership roles in the development of SEMI standards and the ITRS, the International Technology Roadmap for Semiconductors.

1 *Prof. Lothar Pfitzner, head of the department.*

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SEMICONDUCTOR MANUFACTURING EQUIPMENT AND METHODS

Successful finalization of the Project IMPROVE: A Boost for European Semiconductor Manufacturing Efficiency

Motivation

The European semiconductor industry offers excellent technologies, and the race on the world market has not yet been decided, not by a long shot. The key to success lies in intelligent products as well as in efficient production. In the joint research project IMPROVE, a consortium of key European chip manufacturers, research institutions, universities, suppliers and service providers were working together on sustainably enhancing the efficiency of European semi-con-ductor fabs. The project was successfully completed by mid-2012.

R&D Approach of IMPROVE

Since the area of "productivity enhancement" covers a broad variety of methods and applications, the consortium focused on the field of "manufacturing science" and concentrated on joint R&D activities the approach of which was oriented to the question: 'how to make the information that is buried inside typical day-to-day fab data available for enhanced process control'. Thus, the focus of R&D in IMPROVE was on the new manufacturing solutions: virtual metrology (VM), predictive maintenance (PdM) and adaptive control planning (ACP), as explained in the Fraunhofer IISB's 2010 annual report.

Results from IMPROVE

Scientists from Fraunhofer IISB actively paved the way for successful collaboration and developed novel manufacturing science solutions:

- Acting as "honest broker", Fraunhofer IISB carried out a workshop-based survey amongst the nine participating European manufacturing sites to collect information on their current state and their needs, building up the knowledge-base for the project's work packages.
- Based on survey results, there were developed general specifications and UML models for VM, PdM, data frame-works and other IMPROVE R&D topics.
- Together with partners, the "IMPROVE Framework" was modeled as a "digital nervous system" that might be used to integrate VM, PdM and ACP and to transfer data amongst them and with existing fab systems.
- Together with Infineon and ams, solutions for VM, PdM and ACP were researched, implemented and evaluated – examples for this work are provided in the following articles.
- To support the modeling activities, a "virtual equipment" was developed, which comprises an equipment simulator and a means of introducing project disturbances (e.g., parameter drifts, process faults, maintenance events) to test and benchmark VM and PdM algorithms in different situations – something that could not easily and quickly be done using real equipment.
- The "IMPROVE Calculator" was also developed in order to assess benefits, risks, costs and Role of the new manufacturing solutions VM and PdM, including sensitivity analyses to identify critical parameters.
- The "Equipment Forum" was initiated as a communication platform with equipment suppliers and equipment-related projects – this forum was well received and will continue in existence beyond the finalization date of IMPROVE.
- Finally, building on relevant project results, the "Book of IMPROVE" was prepared, a scientific-technical collection of definitions, results, best practices and literature to support the effective implementation of the new manufacturing solutions.

1 *The ENIAC Joint Undertaking took the initiative to recognize the most innovative projects with an award. The project IMPROVE received this distinction at the European Nano electronics Forum 2012.*

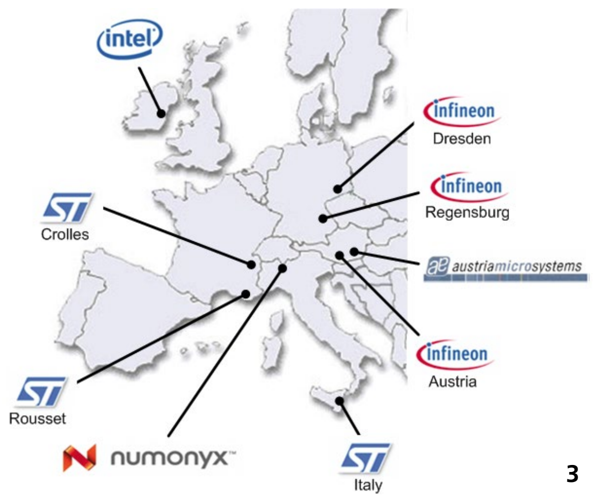
IMPROVE had an overall budget of 37.7 million Euro and was funded by the German Federal Ministry of Education and Research to the extent of 3.5 million Euro.

The acronym IMPROVE stands for "Implementing Manufacturing science solutions to Increase EquiPment pROductiViy and fab pErformance".

2

Next Steps

Being part of a lively and dedicated R&D community in IMPROVE, Fraunhofer IISB has developed and defined a new state-of-the-art with regard to manufacturing-sciences solutions. More than was ever expected, the project work revealed that data from equipment, metrology steps, logistics and other areas of the fab is an excellent knowledge-source about the current manufacturing state and a good basis for improvement measures. If we are to achieve high fab productivity, the move from static to dynamic and interacting control systems, as developed in IMPROVE, is inevitable.



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2 *R&D for the improvement of new manufacturing equipment and the corresponding methods and processes at Fraunhofer IISB. Image: Kurt Fuchs / Fraunhofer IISB*

3 *Joint R&D with more than 30 partners from 6 nations: IC makers: ams, Infineon, Intel, LFoundry, Micron, STMicroelectronics.*

Solution providers: Camline, Critical Manufacturing, InReCon, iSyst, LAM, Lexas Research, PDF solutions, Straatum, Technofitings.

Research institutions and universities: CEA-LETI, CNR-IMM, Dublin City University, Ecole des Mines de Saint Etienne - Centre Microélectronique de Provence, Fraunhofer IISB, Italian National Council of Research, LTM CNRS, University of Applied Sciences Vienna- Neustadt, University of Augsburg, University of Erlangen-Nuremberg, University of Milano, University of Padua, University of Pavian of Virtual Metrology in the semiconductor manufacturing process flow.

SEMICONDUCTOR MANUFACTURING EQUIPMENT AND METHODS

Virtual Metrology – A new Method in Process Control

In semiconductor manufacturing, the implementation of Advanced Process Control (APC) systems has become essential in order to achieve cost-effective manufacturing at high quality. Within the European ENIAC project "IMPROVE", there were successfully developed new control methods, such as Virtual Metrology (VM), and solutions for their generic implementation in existing fabrication environments.

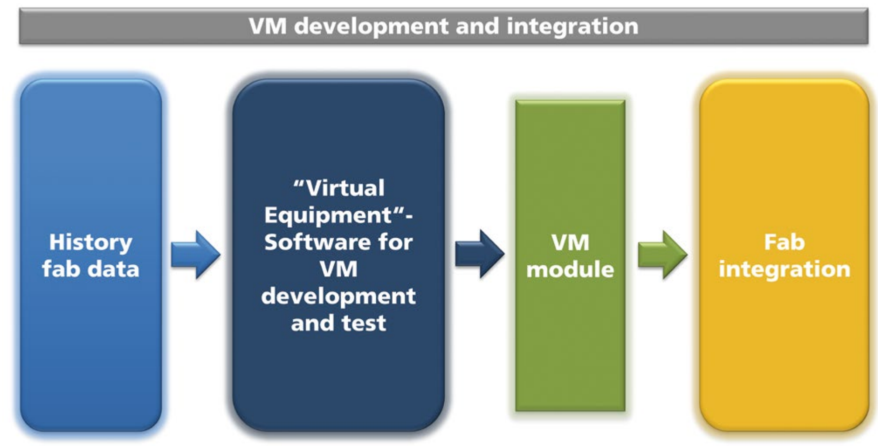
Virtual Metrology Algorithms and Benefits

IC manufacturing is characterized by the continued requirement to increase device functionality and system integration at reduced cost per function. To achieve cost-effective manufacturing and to improve process quality, existing APC technologies, e.g. run-to-run control, are complemented by new techniques such as Virtual Metrology. Stand-alone and integrated metrology of critical parameters have been key measures used to reliably determine quality parameters on monitor or product wafers in individual process-steps and in the overall processing sequence of semi-conductor manufacturing. Virtual Metrology aims at supporting these conventional measurements by prediction of post-process metrology results based on equipment and process parameters, complemented by logistic data and, if required, by data from preceding process- and metrology-steps. Figure 1 depicts the place of VM execution in a process flow.

In addition to the support of APC methods and metrology operations, the main benefits of Virtual Metrology are that process monitoring and control can be achieved on a wafer-to-wafer basis and that those parameters which are not accessible with in-line measurements may, in this way, still be predicted. In Virtual Metrology, typically statistical models are developed and trained from historical fab data to enable precise prediction of quality parameters and to make allowances for time-dependent process variations, e.g. process drifts or changes introduced by maintenance or product variation. Figure 2 depicts a Virtual Metrology development example for a complex trench etch process which is conducted for two levels of etch-depth, for a large variety of products, and on different etching chambers. By VM, the etch-depth is precisely predicted, as can be seen from the comparison to the reference metrology results.

VM Test and Implementation

Within the European project "IMPROVE", the applicability of VM algorithms has been demonstrated for a variety of important unit processes, e.g. dry-etch, chemical vapor deposition and



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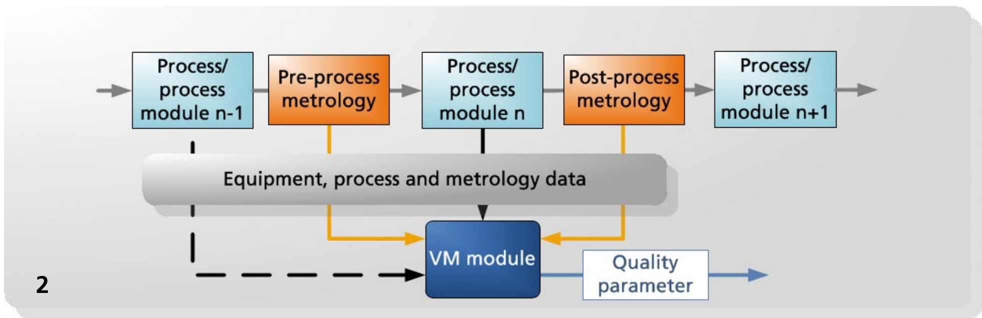
rapid thermal oxidation. In addition to the development of VM algorithms in unit processes, key requirements for successful VM implementation are that these algorithms be susceptible of being systematically tested on new data and that their robustness with regard to process variations be susceptible of being assessed. For this purpose, a Virtual Equipment test bench was developed to support the development, test and implementation of VM models (Figure 1). To enable a generic, reusable application of VM algorithms in fab environments with different data and automation infrastructure, a software framework solution was also developed and realized within the context of "IMPROVE". This framework acts as a layer between the different fab architectures and the various components and services required for VM deployment in production. In summary, major development steps have been successfully accomplished in order to enable the proliferation of Virtual Metrology in semiconductor manufacturing.

1 A Virtual Equipment test bench supports the development, test, and implementation of VM models.



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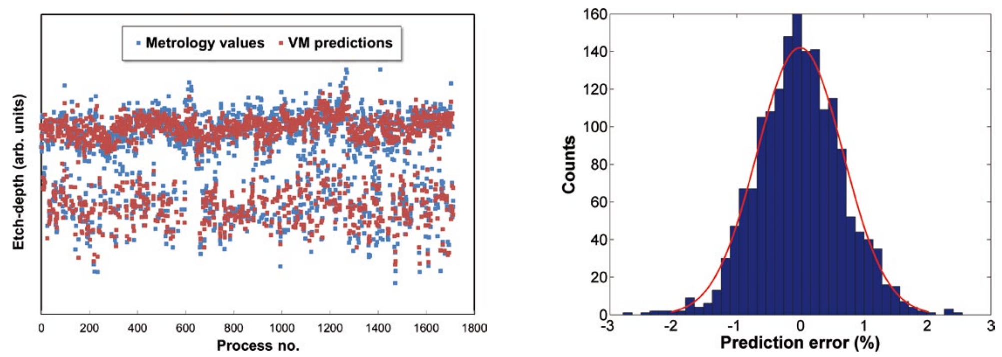
2 Integration of Virtual Metrology in the semiconductor manufacturing process flow.



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3 Precise predictions of etch-depth in a trench etch process by Virtual Metrology verified by comparison to reference metrology measurements.

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Predictive Maintenance for Optimization of Maintenance Planning in Semiconductor Production

Predictive Maintenance (PdM) is a new technique for the prediction of equipment failures and of likely end-of-lifetime dates for components subject to wear-and-tear. Utilizing multivariate statistical learning methods, these PdM predictions aim at achieving improved maintenance planning and at preventing unscheduled equipment downtime, waste of spare parts, and scrap production.

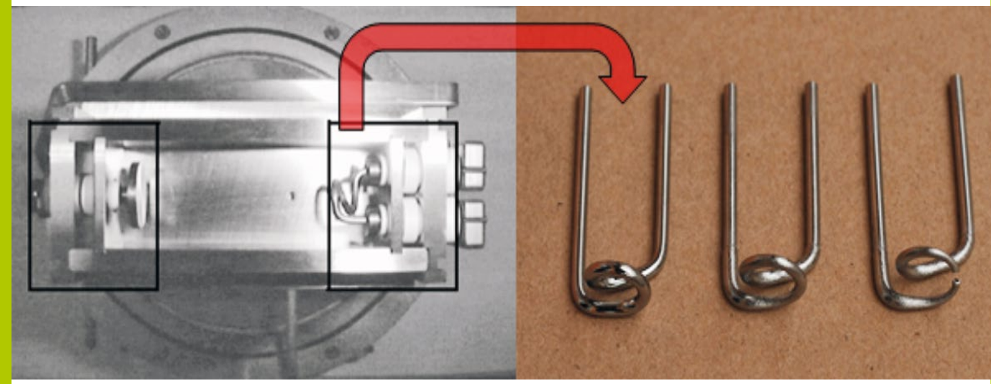
Maintenance Planning in Semiconductor Manufacturing

A significant part of the operational costs in a semiconductor manufacturing plant is related to the frequent need for maintenance of the manufacturing equipment, which causes unscheduled downtime, scrap production and logistic challenges. In addition to random equipment failures, some of these maintenance necessities emerge periodically due to wear and tear of certain parts. The length of such a periodic maintenance interval is not always constant, due to the influence of actual processing conditions, as well as random factors, e.g. the quality of the spare parts used and of the maintenance actions.

To prevent unscheduled downtime and scrap production, today's most common maintenance strategy (Preventive Maintenance, PM) aims for the time-based replacement of spare parts at an early stage, so as to prevent sudden equipment failures. This strategy results in additional, early maintenance actions, and therefore causes unnecessary non-productive downtime and increased spare-part consumption. For better equipment and spare-part utilization, it is necessary to predict the exact point in time when the system will fail. This innovative approach is also called Predictive Maintenance (PdM) and is currently acquiring more and more importance in semiconductor production.

PdM Implementation

PdM can be implemented by direct wear-and-tear measurement, but this is only possible in some special cases. Especially in semiconductor production, where many critical processes are executed under vacuum conditions, direct wear-and-tear measurement is usually very difficult and costly. An alternative approach is the utilization of statistical modeling methods together with equipment-, process-, and logistical data in order to identify equipment conditions that tend to permit negative phenomena with respect to the wear-and-tear condition of the equipment or of certain parts subject to wear-and-tear.



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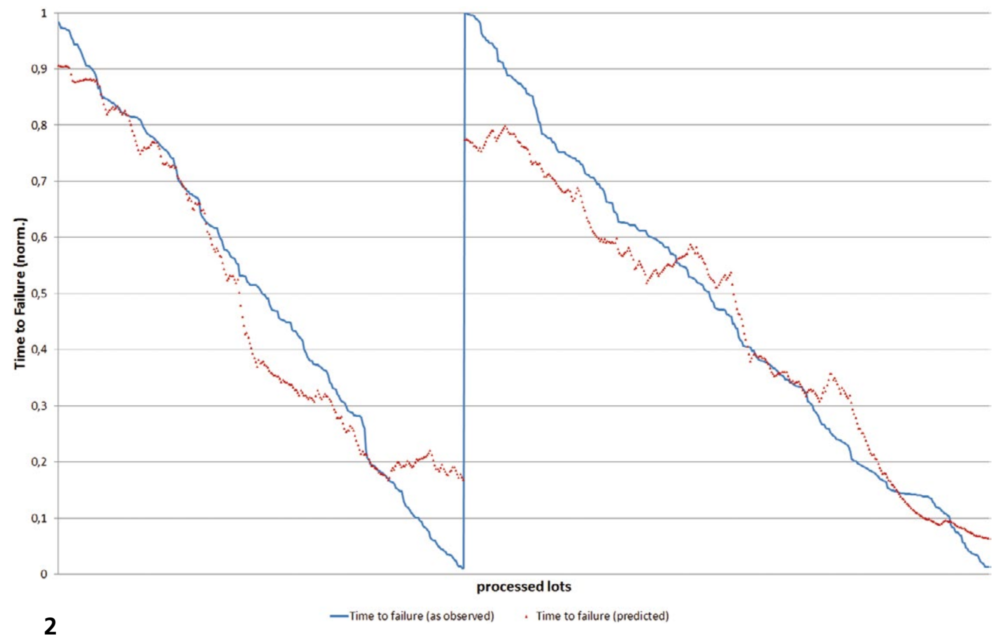
In some cases, component wear-and-tear can be predicted by the monitoring of a single piece of equipment or process parameter and by defining the end-of-life limits for this particular parameter (univariate case). In other cases, this is not possible due to strong interactions between different input parameters. In this multivariate case, all relevant parameters have to be taken into account, and reliable wear-and-tear indicators have to be calculated. Utilizing machine-learning techniques, models can be built from historical production data to predict the next equipment failure and to calculate a health factor that can be used for logistical decision-making.

1 Filament degradation in the ion source due to sputtering effects is the main reason for maintenance in ion implantation. Image: ams AG

Within the frame of the ENIAC project IMPROVE, PdM models were created for prediction of the filament breakdown in ion-implanter sources (Figure 1). Figure 2 shows the "time-to-failure" curve for two maintenance cycles (real and predicted). As a modeling method, Bayesian Networks regression was selected, resulting in a prediction error of below 9 h and thereby permitting "just-in-time" maintenance decisions.



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2 Observed and predicted "time-to-failure" curve, representing the degradation of two ion source filaments.

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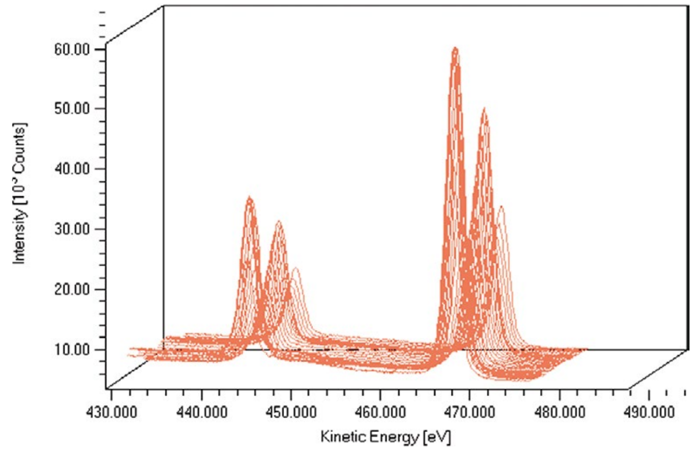

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Successful Joint Metrology Development in the "European Metrology Research Programme"

1 Peter Petrik from the MFA (Budapest) spent one year at Fraunhofer IISB to lead the Institute's activities in a research project on "Metrology for the Manufacturing of Thin Films".

Electronic thin films are the most important components for many European key technologies, such as electronic devices, plastic and printed electronics, opto-electronics, displays, lighting and photovoltaic components. To maintain Europe's leading position in these multi-million-Euro markets it is absolutely necessary to continuously improve quality at reduced cost and time-to-market. The biggest challenge is to effectively control the quality of thin film production by metrology, which has constantly to be adapted to the latest manufacturing demands. It is obvious that sustainable research and development is required to achieve this objective.

The EMRP Programme

In order to drive innovation forward in this area by collaborative, pan-European efforts, combining expertise across different countries, EURAMET (the European Association of National Metrology Institutes) launched the "European Metrology Research Program" (EMRP): its objective is to enable collaboration of European metrology institutes, industrial organisations and academia on joint research projects for metrology.

Based on its long-lasting experience in the area of manufacturing equipment and methods, the Fraunhofer IISB participated in a research project on "Metrology for the Manufacturing of Thin Films", together with eight metrology institutes, such as the Physikalisch-Technische Bundesanstalt (PTB) in Germany or the National Physical Laboratory (NPL) in England. Based on a "Researcher Excellence Grant", Peter Petrik from the Institute of Technical Physics and Material Science (MFA) of the Hungarian Academy of Science took up a one-year research residency at IISB, leading the Institute's activities within the project.

Metrology for the Manufacturing of Thin Films

The objective of the research project was to substantially enhance European competence as regards validated and traceable measurement techniques for the characterization of the main properties of thin films, such as composition, structure or homogeneity.

Peter Petrik's main tasks were the preparation of specific thin-film samples to support the R&D work of the partners, and the development and adaptation of measurement techniques. During his stay he significantly contributed to the development of measurement techniques at IISB (such as ellipsometry, reflectometry, or secondary ion mass spec-trometry).

Petrik was the main organizer of the symposium "Highly precise characterization of materials for nano- and bio-technologies" at the Fall Meeting Conference of the European Society for Materials Research (EMRS) and guest editor of the conference issue of the journal "Applied Surface Science". He made public the results of his research at IISB in three conferences and four articles

The main results at IISB include the development of metrology for ZnO and Al_2O_3 reference layers, as well as the preparation of these layer structures and several patterned wafers. The most important metrologies applied at IISB are spectroscopic ellipsometry, X-ray photoelectron spectroscopy and VUV reflectometry. It has been shown that the high-quality samples prepared at IISB and MFA can be used as reference and calibration materials. The importance of taking into account the surface nano-roughness, possible surface contaminations and interface layers when characterizing ultra-thin layers has been pointed out in the studies. The highly reliable reference dielectric function of ZnO has also been determined, and the sensitivity of the measurement of low-concentration Ga doping demonstrated. The results have been cross-checked by versatile technologies of all the project partners, including X-ray fluorescence and Raman spectrometry. Figure 2 shows depth-profiling XPS measurements on ZnO (10 nm) / Al_2O_3 (3 nm) multilayers created by atomic layer deposition. It was shown that, by using a combination of sensitive techniques, thin films can be resolved even in the nanometer range.

2 Time-resolved depth-profiling XPS measurement on ZnO / Al_2O_3 multilayer system, showing ZnO peaks.

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Content

Focal Areas of Research and Development, Trends, and Potentials

Above all, Technology stands for research and development in the field of electronic devices on all dimensional scales, but also for facility services for customers. From nano-technology through to printable macro-electronics, the Technology Department is your contact for the realization and characterization of single-process steps and devices up to prototypes. Based on comprehensive cleanroom facilities, silicon, as well as silicon-carbide processing, forms the backbone of the technology. Examples for current activities are high-resolution electrical characterization of novel dielectric layers, the development of tailored ion implantation processes, advanced integrated power devices, low-temperature deposition of inorganic materials by printing techniques or the preparation of nanostructures with focused ion-beam technology. The heterogeneous integration of various technologies is currently acquiring more and more importance.

For this purpose, IISB and the Chair of Electron Devices of the University of Erlangen-Nuremberg operate joint clean-room facilities of 600 m² (class 10), provided with CMOS-compatible equipment. This allows the implementation of the most important process steps on silicon wafers with diameters of up to 200 mm. An industrial CMOS process transferred to IISB and adapted for research and development purposes is used as reference and basis for the development of advanced process technologies.

For the development of novel process steps in the field of gate stack engineering, IISB operates advanced sputter and chemical vapor deposition tools, on the basis of ALD and MOCVD, which are used for the deposition of high-k and metallic layers. Adaptation of the process to the particular chemistry of the precursor, deposition of a multiplicity of precursors, and the characterization of the deposited layers are the main tasks of the department. Special activities are focused on ion implantation technologies. At IISB, implantation tools with acceleration voltages ranging from a few eV up to several MeV are available. Special implantations for CMOS as well as for power semiconductors have been established (for example, commercial tools have been modified so to be able to implant several wafer diameters and manifold elements at elevated temperatures).

Further activities focus on the fields of power semiconductors and silicon-carbide electronics. IISB has increased its commitment in these fields by implementing new equipment and processes to meet special requirements necessary for Si and SiC power devices. This is above all a matter of the etching and refilling of deep trenches and high-temperature processing of SiC. A Smart Power IGBT technology with integrated trench isolation has been successfully implemented. This allows the department to strengthen its competence in manufacturing smart-power or high-voltage devices. By now the IISB has developed its resources and expertise to the point where it can perform nearly all manufacturing steps on SiC substrates. The devices currently under development include chemical gas sensors on a MOSFET basis with attached logic gates for high-temperature applications and power devices like vertical or lateral DMOS.

Physical 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 composition, topography, doping profile, and further physical and chemical parameters as well as SEM & TEM investigations, energy-dispersive X-ray analysis, and AFM surface characterization of layers. The specific competence of the department consists in the combination of several methods for failure analysis during the processing of semiconductor devices, or the tracing of causes of failure. The spectrum for electrical characterization has been further increased (e.g. lifetime measurements).

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 prototypes of electronic devices by means of focused ion beam (FIB) techniques and electron beams. In addition to that, nanoprobes for atomic force microscopy are currently being developed, by using FIB to determine physical and chemical parameters such as doping profiles or layer properties with a much higher resolution. Based on these experiences, models have been developed describing the collateral modifications of the substrates outside those areas which were deliberately irradiated.

The focus of the department's activities in the field of printable electronics lies on the investigation and development of manufacturing methods for solution processing of inorganic thin films for electronics. A special emphasis is placed on the interaction of processing and the resulting electrical properties of the application. Based on inks with semiconducting, conducting, and insulating nanoparticles or the respective molecular precursors, there are brought into being thin-film transistors (TFTs) comprising printed features. The properties of functional thin films made by means of liquid processing are also analyzed in detail.

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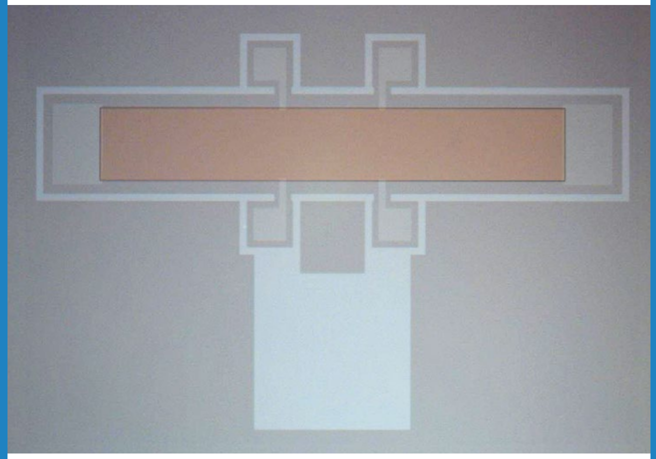
1 *Dr. Anton Bauer, head of the department. Image: Kurt Fuchs / Fraunhofer IISB*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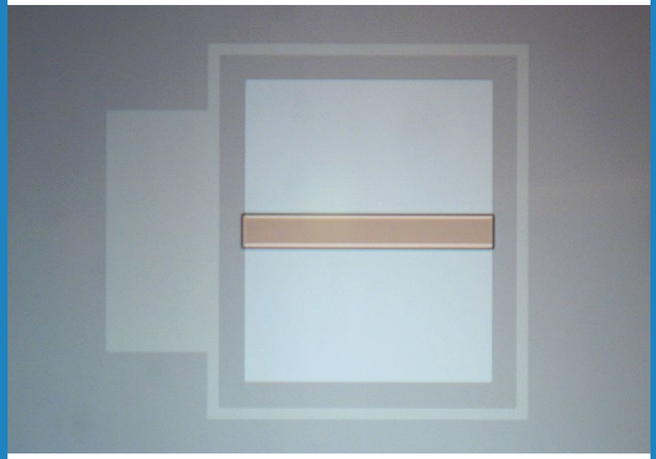
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Content

Investigation and Improvement of the Channel Mobility in 4H SiC MOSFETs

Because of its advantageous physical properties, such as wide band gap, high thermal conductivity or a ten-times-higher critical electrical field strength as compared to silicon, silicon carbide (SiC) is one of the most promising materials for future high-power, high-frequency, and high-temperature electronic circuits. SiC-based devices will allow the building of more energy-efficient power converters (for automotive applications) and HVDC (high voltage direct current) power energy transmissions and will, therefore, contribute to a significant reduction in CO_2 emissions. For more than 15 years, the IISB has been one of the leading institutes in the field of SiC technology in Europe. It operates a complete SiC device manufacturing line including epitaxial growth, ion implantation, high-temperature annealing and oxide growth. This is the basis on which various SiC electron devices with up to 15 mask layers are manufactured at IISB.

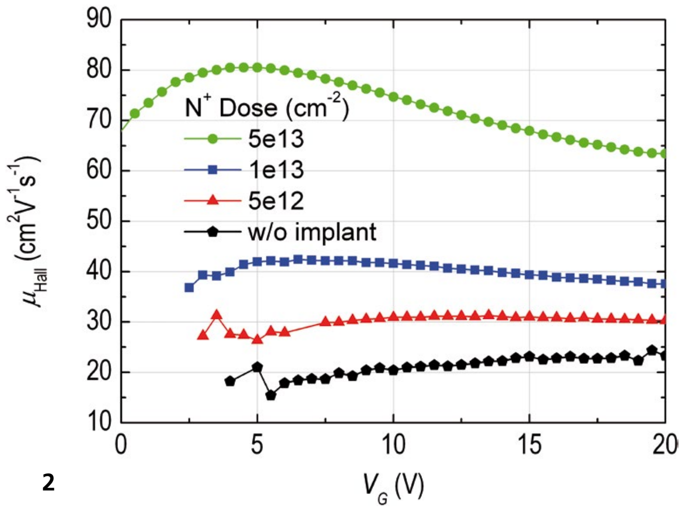
A key device for high power applications is the MOSFET. Such a field effect transistor on SiC, however, displays a significant drawback as compared to silicon MOSFETs: namely, a poor channel field mobility which results in a fairly high channel resistance and therefore limits the maximum transistor currents. In order to investigate the causes of this low channel mobility and, in addition, to improve the channel mobility, an optimized process technology is being developed within the framework of the MobiSiC project which was launched in September 2010. MobiSiC is cofunded within the Programme Inter Carnot Fraunhofer (PICF 2010) by the Federal Ministry of Education and Research (BMBF) on the German side and by the Agence Nationale de la Recherche (ANR) on the French side.

While the IISB develops sophisticated test structures and MOSFETs, beginning with the layout and followed by the processing and electrical characterization of the devices, the French partners from LAAS (Laboratory for Analysis and Architecture of Systems, Toulouse) are responsible for material characterization, such as High-Resolution-TEM, Electron Energy Loss Spectroscopy (EELS) as well as for Hall measurements and provide, therefore, valuable input for improving dedicated process steps.

The IISB and LAAS have developed, for example, MOS-gated Hall structures which were processed together with corresponding MOSFETs. This complex process requires 12 mask layers and involves about 200 single process steps which need to be performed with the utmost accuracy and reproducibility and a reliable process control. Figures 1a and 1b show microscopic pictures of the implanted regions of a MOS-gated Hall bar and a MOSFET, respectively. The analysis of test structures and the MOSFET characteristics confirm that the electron scattering which takes place in the transistor's channel just beneath the oxide / SiC interface plays a major role as regards the channel mobility. Moreover, the scattering can be tuned by providing additional elements at the oxide / SiC interface by means of ion implantation. Figure 2 depicts the Hall mobility of processed MOSFETs as a function of the gate voltage. It is shown that it is possible to increase the Hall mobility significantly, from a value of about 20 $cm^2 v^{-1} s^{-1}$ without channel implant up to a remarkable value of approx. 80 $cm^2 v^{-1} s^{-1}$ with an implanted nitrogen dose of $5 \cdot 10^{13}$ cm^{-2}.

There is an indication that further elements besides nitrogen may improve the channel mobility. In further devices which are currently being processed, therefore, the effects on the channel mobility of impurities such as rubidium or phosphorus near the oxide / SiC interface will also be studied.

1 *Microscopic pictures of the implanted regions of a gated Hall structure (a) and a MOSFET (b).*



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2 *Channel Hall mobility of MOSFETs as a function of the gate voltage for different nitrogen channel implantation doses.*

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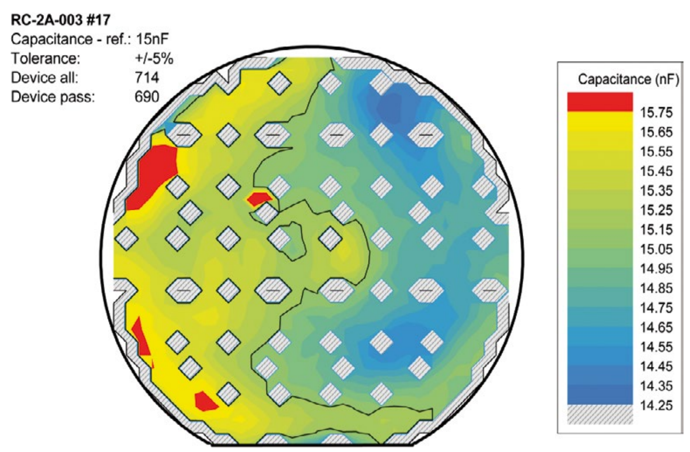

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Content

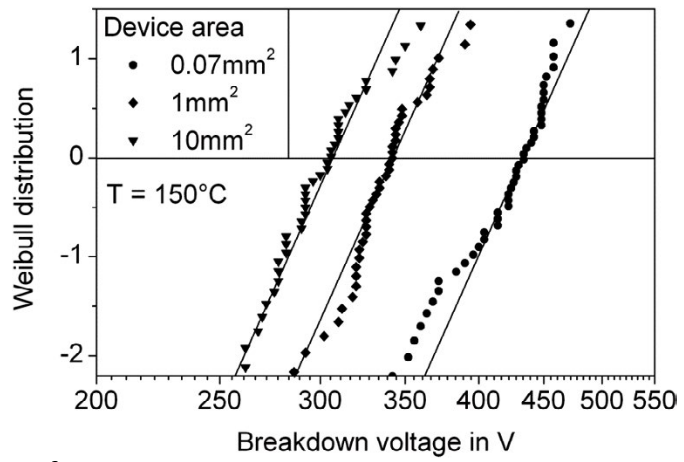
Reliable Systems with Passive Silicon Devices

In modern (state-of-the-art) power modules for switch-mode converters, capacitor-resistor-(RC) networks are implemented in order to damp voltage peaks and oscillations. These dissipative networks are usually designed with several discrete surface-mounted-devices (SMD) and are attached to the power module by means of SMD soldering techniques. By contrast, silicon semi-conductors for power applications (e.g. IGBT) are mounted as bare dies onto the module substrate, using a different soldering technique. Therefore, implementation of damping (snubber) networks in power modules requires an additional soldering process – which tends, however, also to go hand in hand with a reduced reliability due to degradation of the first soldering process of the semiconductor. Furthermore, the temperature coefficients of the discrete devices are different from those of the semiconductors, thus reducing reliability in high-temperature power-cycling applications.

Fraunhofer IISB and Semikron Elektronik GmbH have invented and successfully developed an integrated silicon RC-snubber network for 200 V applications. The focus of an ongoing project funded by the Bavarian Research Foundation (BFS) lies on arriving at a detailed understanding of the failure mechanisms, and the exact lifetime prediction, of the RC-snubber network. Standard end-of-life (EOL) test procedures for thin (gate-) dielectrica, such as the constant-current-stress (CCS) or constant-voltage-stress (CVS) procedures, are not suitable for passive RC-snubbers. EOL-tests, however, such as the ramped-voltage-stress or logarithmically-ramped-current-stress tests, show good results. With a view to testing whether they were "manufacturing-compatible", test structures were designed and characterization was performed at elevated high temperatures in order to accelerate the test procedure. One test result is shown in Figure 2.

Here, the impact of the metallization area of the DUT, which corresponds to the capacitance, on the breakdown voltage is illustrated. This makes it possible to extract appropriate parameters for different device areas. Now it is possible to perform destructive tests on smaller test devices instead of the RC-snubber and to make a prediction of the maximum breakdown voltage under nominal load.

The requirement for the characterization of the RC-snubber network, both on wafer level and when mounted in a power module for fork trucks, is a stable manufacturing process with a high reproducibility. One main challenge is the uniform silicon nitride deposition for the trench capacitor. An example for the optimization of the nitride deposition over the whole wafer surface is shown in Figure 1. A tight distribution of the capacitance value of the RC-snubber was achieved: The yield of the RC-snubber with a nominal capacitance value of 15 nF could be significantly increased. The wafer-to-wafer yield is above 90 % (related to a tolerance of +/-5 % of the nominal capacitance value).



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1 *Wafer map of the capacitance value distribution of the RC-snubber after optimizing the nitride deposition.*

2 *Impact of the mealliztion area of the RC-snubber on the breakdown voltage.*

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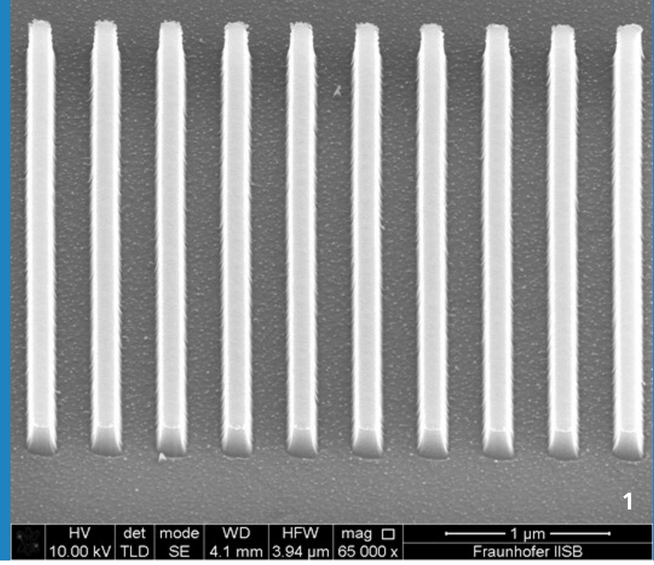

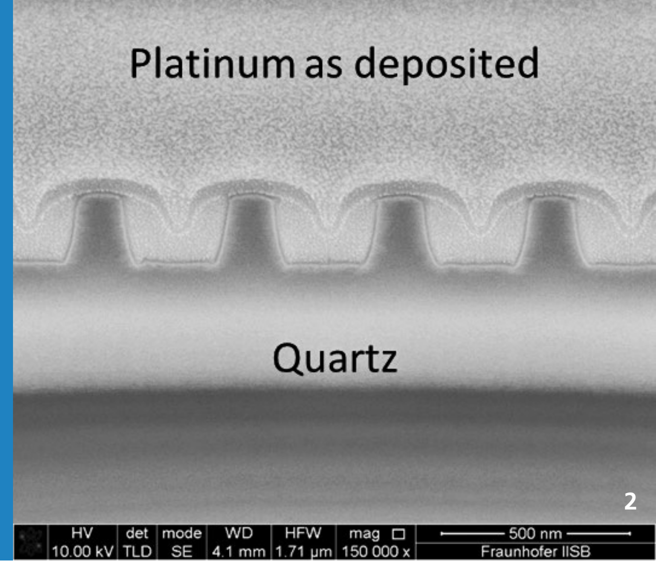

Content

Novel Fabrication Method of Quartz Stamps for UV Nanoimprint Lithography using Gallium-Induced Etch Masks

UV nano-imprint lithography (UV-NIL) is a well-established and cost-effective fabrication technique that allows the transfer of nano-sized features into resist without the use of advanced optical lithography. Unlike optical lithography, UV-NIL is based on the mechanical deformation of a liquid polymer resist by a rigid stamp. While the stamp is in contact with the resist, UV light is used to harden the polymer. After the curing process is finished, the stamp is released from the formed pattern and the next imprint cycle can begin. Results have shown that even features below 10 nanometers can be fully replicated by UV-NIL. At IISB, UV nano-imprint lithography was established in 2005 and, since then, has been successfully utilized in different research projects.

To allow the curing of the polymer resist by UV exposure, UV-NIL stamps have to be manufactured from a transparent material, such as quartz. One possible way to fabricate such nano-structured quartz stamps is a process based on Electron Beam Lithography (EBL) and involving two Reactive Ion Etching (RIE) steps. However, the structuring of a complete quartz stamp with EBL is a time-consuming and expensive process, in particular for users without direct access to an EBL system. Alternatively, a rapid prototyping technique like Focused Ion Beam (FIB) can be applied for the fabrication of UV-NIL stamps.

In the past, the only approaches to stamp fabrication which have been investigated have been those relying on direct milling of material by FIB. The direct structuring of quartz by the ion beam is of course a relatively slow process, since it requires the removal of a large amount of material. Another approach is based on the physical structuring of a chromium layer – just a few nanometers thick – on top of the quartz sample, thus reducing the amount of removed material and the process time. This structured chromium layer can then be used as a mask for subsequent RIE processes. A novel approach established at IISB consists of patterning using the implantation of Ga+ ions via a FIB system and subsequent RIE. As shown in previous publications, gallium-rich areas can serve as etch masks for dry and wet etching of silicon and quartz. The etch-resistance of the implanted areas is assumed to be caused by the formation of gallium oxides which do not react with the etching gases of the dry etching process and can only be removed by physical sputtering.

In contrast to the FIB techniques involving direct milling, the implantation of Ga+ ions works as a "positive" masking process, since only the non-implanted areas are going to be attacked by the dry etching process. Depending on the desired structures (e.g. pillars) this can save a significant amount of time, especially compared to direct milling in quartz.

As mentioned above, one possible application for the resistless Ga+ beam lithography could be the rapid prototyping of quartz stamps for UV-NIL. After optimization of the dry etching process for the use of the implanted gallium mask it was possible to realize quartz nano-structures with steep side-walls (lead angle above 82 degrees). Figures 1 and 2 show an array of lines with around 100 nm line-width, a period of around 250 nm and an etching-depth of about 240 nm. The implantation dose for the mask lies at around $3.6 \cdot 10^{16}$ cm^{-2}. The implantation was carried out using a beam-current of 28 pA which leads to a total writing time of 9.4 seconds. The use of a larger beam-current would reduce the writing time but might lead to a loss in resolution.

The fabricated quartz stamps were coated with an anti-sticking layer and successful test imprints were conducted. All in all, our experiments showed that the gallium-induced etch mask can be a suitable rapid prototyping approach for the fabrication of UV-NIL stamps.

1 *Scanning Electron Microscopy (SEM) image of a line array; line width 100 nm.*

2 *SEM image of FIB cross section through the line array shown in figure 1.*

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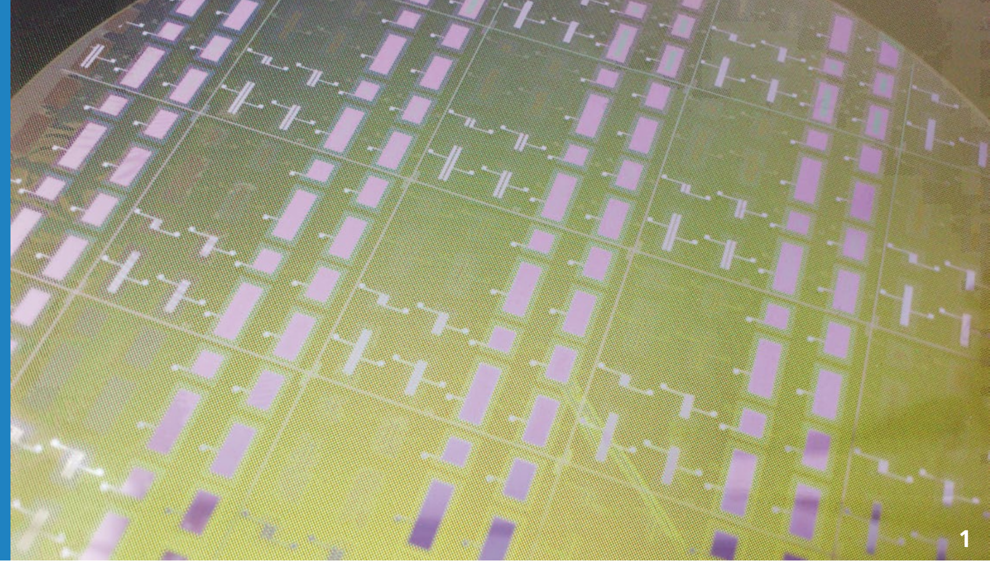
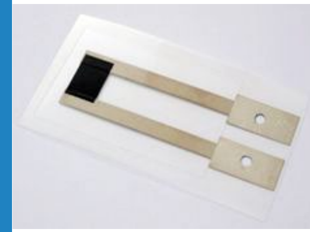




Content

Components for Integrated Thin-Film Systems

Thin-film systems will make possible advanced, ubiquitous and invisible sensor arrays, control and driver units, and signal/data handling for energy, industrial or medical electronics. Imagine sensitive surfaces for widespread temperature- and humidity-monitoring in heating systems, air-conditioning systems, industrial machinery, or ultrathin flexible control systems omitting the use of bulky ICs for medical applications.

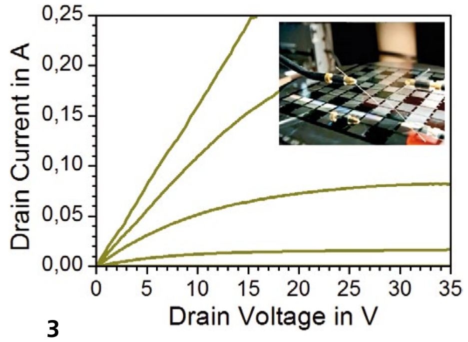
Key features, such as low-cost and low-temperature processing, permit the application of thin-film electronic solutions to almost any substrate one may care to name. Additional specifically addressable features are ultra-thin shape, flexibility, transparency, or large-area feasibility. Passive and active thin-film devices can be integrated together with radically new substrates, such as plastics, paper, or cardboard, but also with mature electronics technologies of the "manifold printed circuit board" variety (such as epoxy , ceramic / DCB, flex, 3D,…), with chip packaging technologies, or even with on-wafer technologies, i.e. with standard silicon or compound semiconductor manufacturing technologies.

While pursuing its course to the perfection of thin-film systems, IISB is developing materials, devices and heterogeneous integration solutions based on both conventional and new material deposition technologies. Technological examples here are nanoparticle dispersions for the deposition of semiconducting and conducting layers by ink jet printing, molecular precursors for atmospheric spray coating of semiconductors and insulators, or sputter- and CVD techniques for low-temperature deposition of semiconductors, conductors, insulators, and encapsulation layers. The currently ongoing European projects POINTS and superLIB enabled the realization, characterization, and integration of certain key devices: a current driver TFT capable of driving several 100s of mA (Figure 1) and a fully-printed temperature sensor (Figure 2) .

The execution of the driver TFT involves its mounting on a silicon carrier, and it utilizes a mask aligner patterning for the metal S / D and the semiconductor. Figure 3 shows typical output characteristics for a device with an active area of ~70 mm².

With respect to the temperature sensor, two materials systems were taken into consideration. Both a compound material comprising a polymer with graphite nanoparticle fillers and the proprietary silicon nanoparticle ink deliver thin films, bringing about the expected PTC and NTC behavior in the application-specific temperature range (Figure 4). They are currently being tested in the battery-module environment at the project partners.

Together with logic circuitry that will be developed in the course of the POINTS project, we can offer a toolset that, on a functional basis, delivers sensing, evaluation, and also acting / driving components and that will be further broadened in its functions in collaboration with our current and future partners. On the technological side, IISB covers the whole value-chain from materials development through to demonstration of thin-film systems in customer-related application cases.



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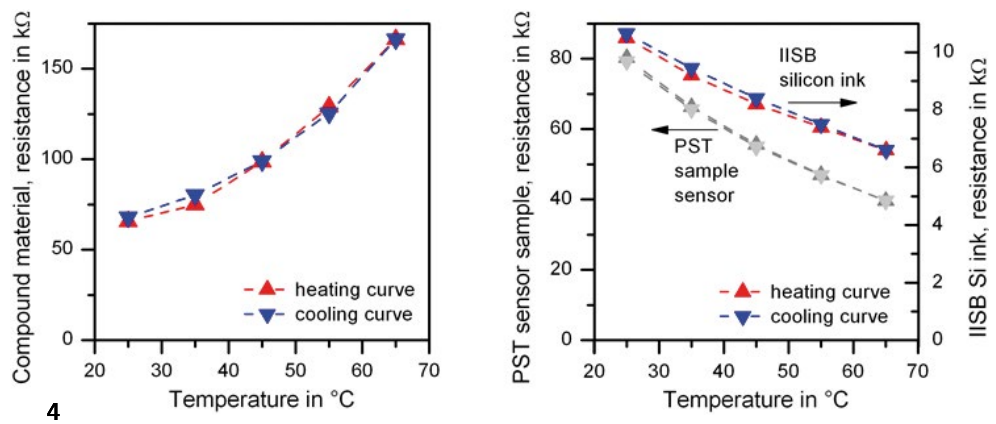

4

1 *Metal oxide (semi)conductors and insulators exhibit wide band gaps and can be employed for transparent applications on glass or plastics.*

2 *Fully screen-printed temperature sensor for integration with battery modules.*

3 *Large-area thin-film transistors deliver driving currents in the 100 mA range. Output characteristics of a TFT with 80 mm² of active area.*

4 *Characterization of sensitive materials for temperature-dependent resistor (thermistor) application. High positive / negative temperature coefficient materials can be integrated into both printed and conventionally processed thin-film systems.*

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POWER ELECTRONIC SYSTEMS

Content

Focal Areas of Research and Development, Trends, and Potentials

The year 2012 was marked by the relocation of the Power Electronics Department to a new extension of the headquarters in Erlangen, which was ready for occupation in spring 2012. In the twelve years since founding, the department has grown to about 90 heads (including students), so that the space situation in Erlangen was becoming intolerable. This could be mitigated only partially by outsourcing activities to the ZKLM in Nuremberg or the THM in Freiberg.

The new labs, designed and equipped to fit requirements exactly, not only make possible more effective working, e.g. work meeting the safety requirements for work under high-voltage and high-energy conditions. With our new vehicle hall, the "e-Car Factory", our four working groups in the field of powertrain electrification now have at their disposal a fully equipped vehicle workshop. An additional workshop could be made available for the students engaged in the university projects EcoCar and Formula Student Electric. An important step, that became possible due to the move, was the spatial merging of the various work teams within the department. Strong staff growth, which is fed primarily by young graduates joining the faculty, inevitably brings the problem of a fall in the proportion of experienced staff to young learners. So much important just now, then, is the close spatial integration, right from day one, of new staff members in project teams comprising older colleagues. Another important step that was made possible by the large power-electronics labs, which now number seven in total, is the even more rigorous separation of the development work for various clients, particularly from the automotive industry, where most projects are subject to very restrictive confidentiality obligations.

Despite the significant additional work load caused by the move and the establishment of the new laboratories, the department once more achieved an excellent economic result, with an industry contribution well above 30 percent. Several EC projects started during the year: E2SG and DCC+D, both focusing on local DC grid issues. Additionally, we were able to enter into the ongoing EC project MotorBrain. APEx, a project funded by the Federal Ministry of Education and Research (BMBF), could also be launched in 2012.

From 12th to 16th March 2012, the third "DRIVE-E Academy" took place at the RWTH Aachen. This academy week is a joint initiative of the Federal Ministry of Education and Research (BMBF) and the Fraunhofer Gesellschaft. Fifty students from all over Germany working in the area of e-mobility experienced a week with professional lectures from well-known speakers, excursions, and the award ceremony for the "DRIVE-E Students' Awards". One of the prize-winners, Florian Hilpert, was himself a student of the University of Erlangen-Nuremberg. We congratulate him and are happy to welcome him henceforth as a colleague of ours in the Power-Electronics Department. We also congratulate the head of our "Drives and Mechatronics" group, Dr. Maximilian Hofmann, who received his PhD in 2012. The Fraunhofer IISB Innovation Award 2012 went once again to the Power Electronics Department for the development and realization of a tri-port high-power DC to DC converter. The system was developed for a German automotive OEM under automotive requirements and sets a new benchmark with respect to compactness, efficiency and functionality.

The new working group "Energy Systems" under the direction of Dipl.-Ing. Dirk Malipaard took up its work on 1st of April. The group is focusing on "Megawatt Power Electronics" for the generation, distribution and application of electrical energy in the high power range. A key topic is the modular multi-level converter (M2C). The group is today located at the ZKLM in Nuremberg and will move to the "Energy Campus Nuremberg" (EnCN) as soon as the facilities "auf AEG" are ready for occupation in spring 2013. The EnCN is a research platform and is committed to putting into practice the vision of a sustainable power society based on renewable energy. The work packages of the IISB focus on new solutions for megawatt power electronics, the integration of electrical energy storage systems in a smart power grid, and convenient wireless energy interfaces to mobile systems such as electric vehicles.

The funding period of the Fraunhofer Innovation Cluster "Electronics for Sustainable Energy Use" ended with the end of 2012. Valuable relations of cooperation with universities could be established, among them a joint working group on drive control with Prof. Bernhard Wagner from the University of Applied Science (GSO) in Nuremberg. The established networks and collaborations will of course be continued and strengthened even beyond the end of the funding period. This point applies even more strongly since the topic energy efficiency will be one of the central challenges of the coming decades in the context of Germany's announced "energy transition", climate change, resource scarcity and sustainability. This confronts society with enormous challenges - but also offers for the Fraunhofer IISB very interesting new topics for engagement and business opportunities. It is up to us to strengthen the leading position in the field of power electronics which we have already attained and to consistently expand it thematically. Sincere thanks go to all the colleagues in the department for their extraordinary engagement, and to all our supporters from industry, politics, Fraunhofer, and the entire institute.

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Universal 22 kW On-Board Rapid Charger for Electric Vehicles

A significant factor in the acceptance of electric vehicles is the availability of a practical charging procedure. Whereas refueling of conventional vehicles is accomplished in just a few minutes, the "fill-up" an electrically-powered vehicle can take hours. As part of the BMBF research project "e performance", the IISB has developed, in cooperation with Audi Electronics Venture GmbH (AEV), a universal on-board rapid (22 kW) charger for high-voltage batteries in electric vehicles. This charger is based on a phase-modular circuit design, as Figure 3 illustrates. With the on-board rapid-charger here developed, the "refuel" waiting time can be reduced to about 30 minutes, assuming a three-quarters empty traction battery with an energy content of 15 kWh.

The approach presented here consists of three identical phase units (7.3 kW), with each of these phase units comprising two identical (3.7 kW) base units. This means that, by using three base units, on-board chargers in the 11 kW class can be easily realized, especially for weaker mains connections (3 x 16 A). Only one base unit is necessary for the conventional single-phase (3.7 kW) mains connection (1 x 16 A).

The phase-modular circuit design provides the possibility of producing identical units in order to bring into existence a broad on-board charger product line for 3.7 kW, 11 kW and 22 kW requirements, with overall low system costs, thanks to the use of high-volume base units.

Achieving a true modular system means not only partitioning the power-electronic unit but also adopting a modular-control approach. Figure 2 shows the main control board as developed, which is, for example, responsible for communication via CAN with the overall energy system control unit, or with the control of the mains connection according to DIN EN 61851-1. Moreover, Figure 2 shows the boards necessary to control the AC / DC converter and the galvanic isolated DC / DC converter for one phase unit.

For achieving smaller ripple currents, especially in the case of the 22 kW version of the on-board charger, the control section provides interleaved gatesignals for the power semiconductors. By using this approach, less passive components can also be used in the high power section, which means saving on weight, volume and costs.

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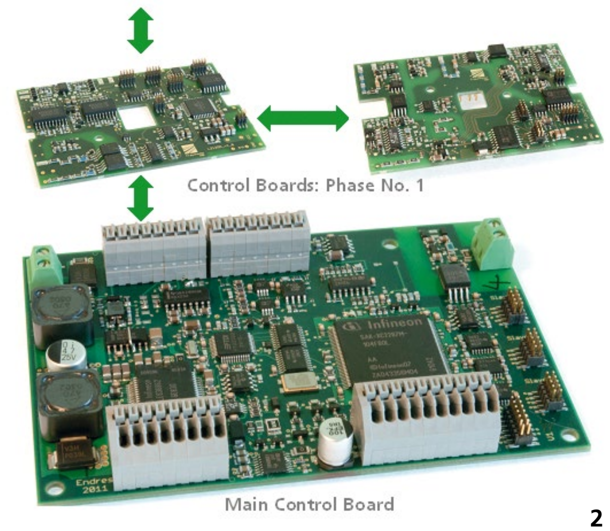

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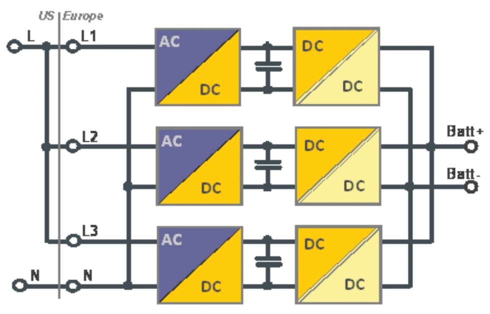
Despite using a very flexible circuit design concept, which is designed for a worldwide use on different main voltages as well for delivering a constant battery charging current in the case of a single AC phase mains connection, the 22 kW variant (see Figure 1) offers a galvanic insulation of the high-voltage battery in a very small overall volume of less than 12 liters and a high efficiency of up to 94 %.

Besides the possibility of bringing into existence a broad productline of chargers with only one high-volume base unit, the phase-modular circuit design concept also offers further advantages. Examples are: the increased redundancy in the case of malfunction or failure of one of the mains phases (e.g. due to a switched-off fuse in the AC distribution), or the increased efficiency in the so-called low-load operation area. Figure 4 shows how the efficiency of the on-board charger can be significantly increased by switch-off of two of three units under light-load conditions. Thus the high-efficiency operation area, with an efficiency of over 93 %, can be expanded from about 63 % to 88 % of the output powerrange.

Moreover, inasmuch as it uses the very latest power semiconductors involving GaN or SiC technology, the concept here presented is also ideal for future scenarios such as V2G (Vehicle to Grid), which makes possible the integration of mobile energy storages into smart grids, by using on-board chargers, thus creating the possibility of a bi-directional energy-transportation.

1 Universal 22 kW on-board rapid charger.

2 Phase-modular control concept.



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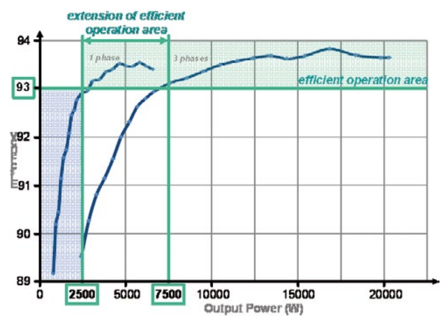

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3 Phase-modular circuit concept.

4 Increased high efficient operation area by switch-of units under light-load conditions.

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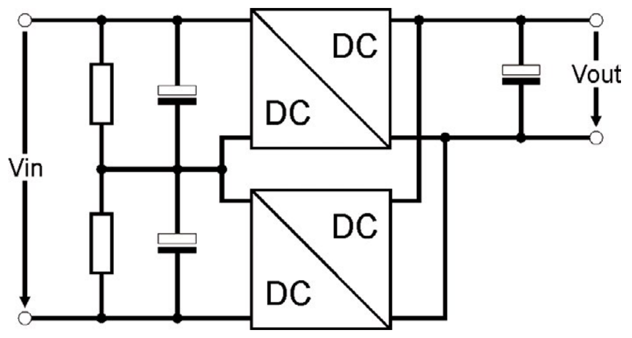

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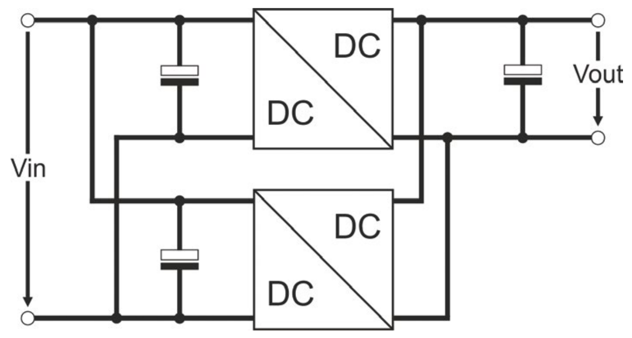


2

Content

An innovative Approach for Wide-Range Isolating HV-DC / DC-Converters

For the ongoing process of electrification in vehicles, light trucks and public transport a very compact, powerful and highly efficient DC / DC converter solution is needed in order to supply the currently-used 12 V, 24 V and (in the near future) 48 V units out of high-voltage powertrains with a voltage range from 250 V to 400 V or 500 V to 800 V.

A solution for this challenge is an innovative DC / DC converter approach. With its two interleaved phases, which can be connected in a parallel input / parallel output or a serial input / parallel output configuration, the converter concept developed here can be adopted to 250 V, to 400 V, to 500 V, or to 800 V very easily. Another advantage of their serial input connection is the use of MOSFET power switches with a blocking voltage of 600 V for a converter with an input voltage range up to 800 V. With the superior electrical properties of 600 V devices in comparison to 1000 V or 1200 V devices, the converter prototypes developed were able to reach a power density of 5 kw / dm³.

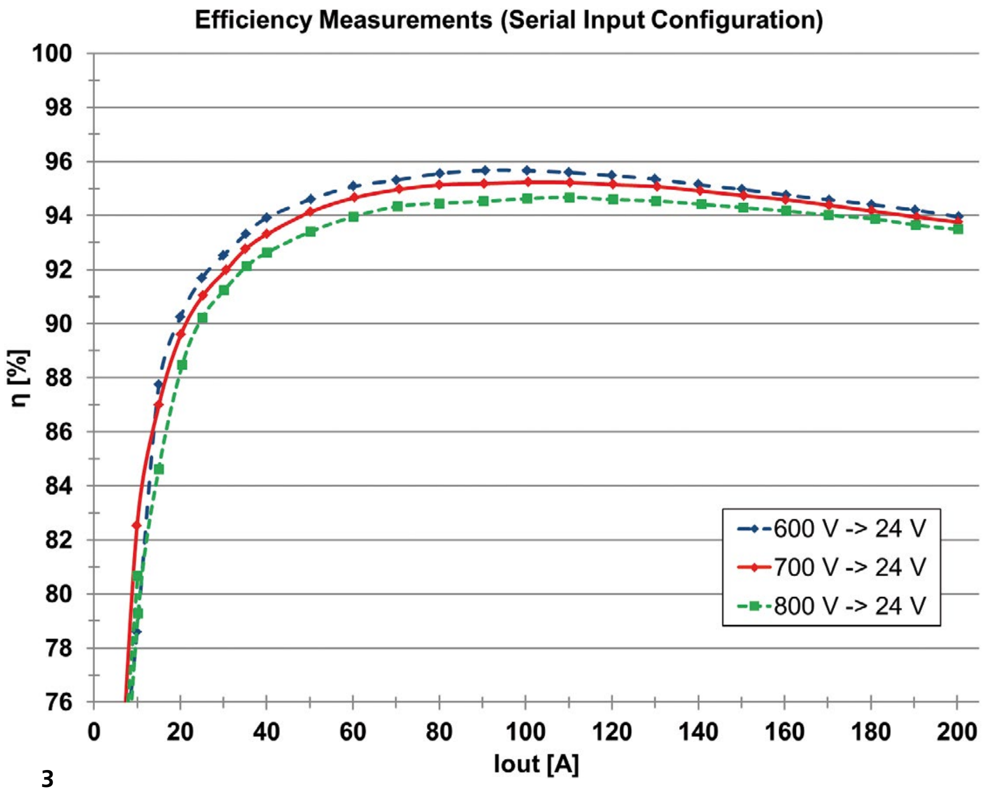
With this two-phase topology, and only minor changes to the transformer, the following input and output voltage ranges were realized:

Input voltage range	Outout voltage range	Outout power
500 V ... 800V	16 V ... 24 V ... 32 V	5,0 kW
250 V ... 400 V	16 V ... 24 V ... 32 V	5,0 kW
250 V ... 400 V	9 V ... 12 V ... 16 V	2,5 kW
250 V ... 400 V	34 V ... 48 V ... 54 V	5,0 kW
500 V ... 800 V	34 V ... 48 V ... 54 V	5,0 kW

This very flexible DC / DC converter design is fully digital controlled by a FPGA for pulse-pattern generation and a 8-bit microcontroller for the implemented CAN-Bus control and thermal derating.

A control strategy to balance serial-input-connected and parallel-output-connected phases was researched, implemented and successfully tested. At the same time, a new improved parallel control structure without wind-up and significantly reduced resource usage was developed.

Besides the power density and the flexible and modular concept, a main achievement of the converters as developed is their outstandingly high efficiency, especially under part-load conditions. That is a great advantage in comparison to a conventional design with 1200 V semiconductors.



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1 *DC / DC converter phases in serial input and parallel output configuration.*

2 *DC / DC converter phases in parallel input and parallel output configuration.*

3 *Outstanding high efficiency measurements, especially under part-load conditions.*

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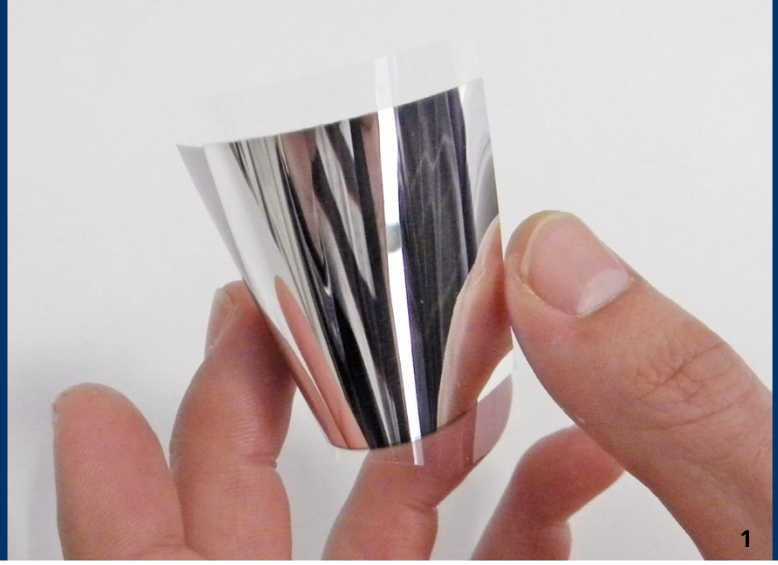

Content

New Materials for Capacitors

Passive components still play a vital role in electronics circuit design. A wide spectrum of operations, such as filtering, damping or energy storage, are still performed by these components. The power that must be handled by these devices ranges from microwatts to kilowatts. Unfortunately, passive devices have not kept pace with the rapid development in the semiconductor industry regarding power density and thermal management. This leads to a relatively low overall performance as compared to their active colleagues. Consequently, passive devices are often bulky in design, giving them a bad reputation. They are often seen as a necessary evil.

Today's capacitors are dominated by three material technologies: aluminum, ceramics and film. All are represented in the power range mentioned above, though each has specific characteristics. Aluminum electrolytic capacitors are available in a wide capacitance spectrum, ranging from one micro-farad to one farad. Typical rated voltage ranges up to 500 V. But the operating-temperature range is poor. Future potential for fundamental improvement is considered to be minimal. State-of-the-art ceramic capacitors are made of three ceramic material classes. In brief, the main difference consists in the relative permittivity. Class I ceramic dielectric constant goes up to 200, Class II up to 10000 and Class III is all situated above this figure. The main drawback of ceramic dielectrics is the more or less strong dependence of capacitance upon voltage. The higher the dielectric constant, the higher the capacitance drops with rising voltage. To make things worse, there also exists a strong dependence on temperature. To overcome these phenomena would be a major progress, marking a vast field for material research. Polypropylene is the material that is mainly used in film capacitors. The production process makes film thicknesses of as low as 2.3 µm possible. But higher energy densities are required. Thus, the operating-field strength of the material has to be increased. Materials of extreme purity are demanded. Another option is to use film materials other than plastics. Two ways for improving capacitor technology thus become clear: ceramic materials with high relative permittivity, voltage and temperature stability; and film materials displaying high operational field-strength.

A promising approach for better ceramics-based capacitors is one involving the use of nano-crystalline glass-ceramics. Barium-titanate-based liquefied material forms a glass-like state by undercooling. In a second, well-defined tempering process, nano-crystalline phases grow. These process steps result in densely-packed nanocrystallites embedded in a continuous glass phase free of pores. As a result, the breakdown voltage is much higher as compared to porous ceramics. Due to the nano-crystallites' dimensions, the dielectric constant is high in the range of the ferroelectric domain and its temperature dependence is correspondently low. Breakdown voltages of over 20kV / mm and dielectric constants of 4000 have been reported. The material complies with X8R characterization.

Systems used in high-power applications for energy transmission and distribution have to deal with high operational field-strength. DC-link capacitors in conventional design are therefore large and heavy. Ultra-thin glass with thicknesses as low as 12 µm could thus increase energy-density to a great extent. Within the envisaged application, capacitors will become smaller, since the internal-series connection or the metallization of many capacitors will become unnecessary. The breakdown voltage of a single ultra-thin glass sheet is 1200 kV / mm. The relatively high dielectric constant of 5.1 supports the effort to create smaller devices. Ultra-thin glass as dielectric also offers one more benefit: thermal management is easier, as the material allows far higher hot-spot temperatures. Thus, higher power-dissipation can be tolerated. With higher temperature differences from hot-spot to surface, and a larger thermal conductivity of 1 W / (mK)[3], more heat can be dissipated.

But having a dielectric does not imply that one has a capacitor. The construction of a capacitor requires a detailed look at the electric constraints. Isolation distances and field control has to be kept in mind as well as parasitic effects such as resistance and inductance. These are mainly determined by the metallization and the interconnection technology. Endurance and fatigue aspects complete capacitor design.

IISB's group Materials and Reliability participates in public funded projects like SUPERGRID and EPa which cope with the tasks of making capacitors for high voltage applications in an extended temperature range. Many thanks to the Federal Ministry of Education and Research (BMBF) and the State of Bavaria for the financial support of this work.

1 *Double sided metallized ultra-thin glass sheet for capacitors.*

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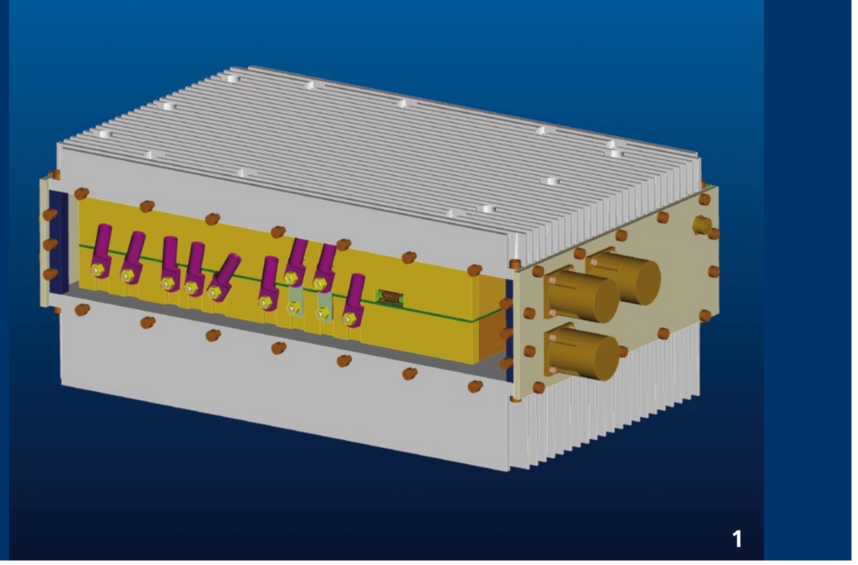

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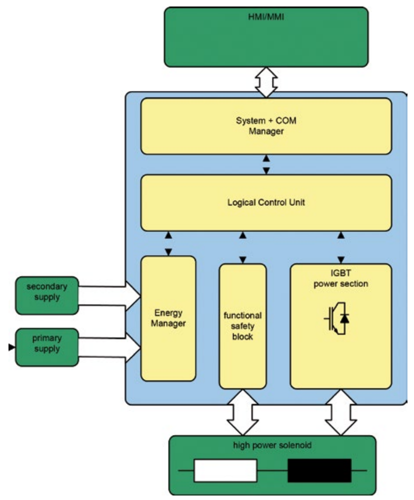

2

Content

IGBT based Control of High-Power Solenoids

Today, high-power solenoids are used in a wide range of applications in various sectors of industry. One can find them as pull or push solenoids in steel works, as electromagnetic brakes for railed vehicles, as excitation field generation in electric motors, as magnet separators in waste sorting plants, as deflecting magnets for particle accelerators, and as deflecting coils and focusing magnets in electron microscopes or electron beam welding machines. In a further field of application, one can find solenoids as lifting solenoids in mobile or stationary magnet cranes for lifting, holding, transporting and handling of heavy magnetic goods

The requirements placed on control units for high-power solenoids vary depending on the particular application. This article describes essential functional requirements for lifting-solenoid control units and a first application-oriented realization of such control units at Fraunhofer IISB:

- To generate a stable and continuous magnetic field a direct current is needed, althought the current orientation is irrelevant.
- To adapt the magnetic force to the load, the magnetic field strength has to be adjustable.
- To compensate for the lower magnetic force at the start of the lifting action – caused by air gap – a current boost function is needed.
- After lowering the load, a degaussing function is desirable, in order to remove the solenoid remanence.
- To reduce handling time, a rapid deexcitation of the solenoid has to be possible.
- To reduce the effort of assembly and the risk of interface-caused failures, the number of cable interfaces should be kept as low as possible.

The functional safety issue is especially closely focused on. In contrast to standard inverter applications, where the safe state for the load is “SWITCH OFF”, in solenoid lifting applications it is the continuing flow of current that ensures the magnetic force and prevents the uncontrolled dropping of the load and thus the risk of serious injury or death. Consequently, “KEEP ON RUNNING” is the safe state for this application.

This also means that safety precautions have to be taken to handle the following risks:

- Failure of the power supply
- Failure of the power semiconductors

The example actually realized is based on a strictly generic and modular concept.

The input power supply interface is designed to be redundant, for functional safety reasons. A supervisory system monitors the input power supply, detects possible failures and ensures the emergency current flow in the solenoid.

The power section is based on IGBT bridge topology. The main advantage compared to traditional DC contactor solutions consists in a strongly increased operational availability, since the missing switching cycle sometimes caused breakdowns. These breakdowns resulted from electric arcs emerging between the switching contacts when the current in inductive loads was turned off. In addition a DC contactor control unit would require more construction volume, would be more expensive, less dynamic, would need more activation power and, finally, would produce acoustic noise and a huge amount of electromagnetic noise during the electric arc generation.

Solenoid current adjusting is achieved, as before, by excitation field control. In this way, the switching losses of chopping IGBTs can be eliminated. As an additional benefit, the electromagnetic emission is minimized. On the other hand, with a direct current control loop by PWM-control of the IGBT´s there also exists a potential for cost-reduction, minimization of construction space plus better dynamic performance.

By using a special design concept, we are able to achieve, in the quasi static ON-condition, a significant reduction in static ON-losses. This means that forced cooling is not needed.

The emergency current flow relevant to functional safety can be ensured even in cases of control unit breakdown, IGBT failures or power supply failures.

For minimized material handling times a fast “release” of the load is essential. To achieve this aim, a reliable state-of-the-art design solution is also implemented on the basis of IGBT.

Especially when working with sheet metal, a degaussing function is very useful. Because the metal sheets are relatively lightweight, the magnetic force caused by remanence alone is enough to pull the sheet along, even without there being any activation from the operator. Therefore, with the aid of IGBT´s the degaussing function is implemented.

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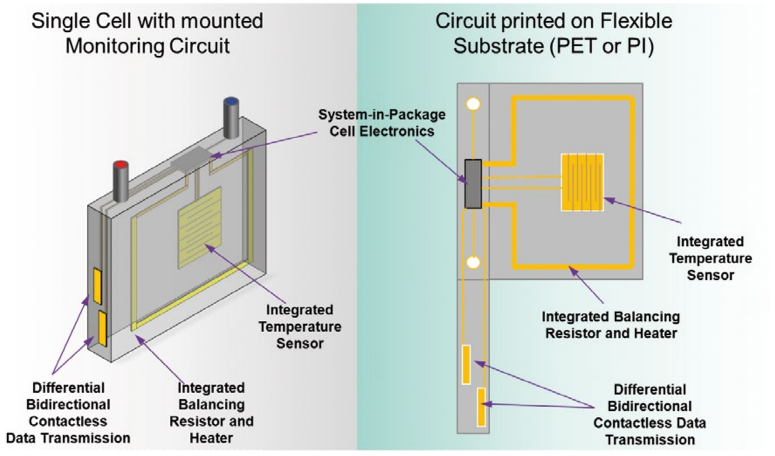
1 *Magnetic control (mobile version). First prototypes of the control unit have been tested successfully and are presently being verified by the project partner.*

2 *Schematic view of the BSB controllerbox.The complete sequence control system, HW condition monitoring, analog signal managing as well as error handling is realized in an LCU and can be adapted in an easy way for special components.*



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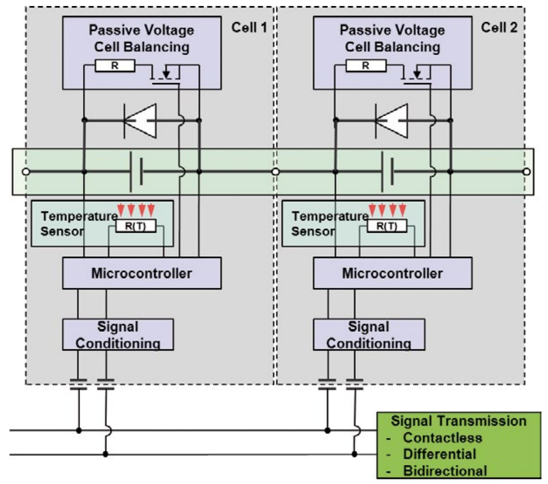

2

Content

Modularity and Flexibility Enhancement in Battery System Design through Distributed Battery Monitoring used in Smart Battery Cells for Hybrid and Electrical Vehicles

The state-of-the-art centralized battery-monitoring architecture has major drawbacks which prevent the cost-efficient development of battery systems for electrified vehicles:

- The assembly and contacting of the battery cells for monitoring their voltage is very expensive, even if manufactured in high volumes.
- The high number of connectors is a source of failures.
- Different applications, such as different types or models of electric vehicles, often have different requirements and specifications. In most cases, this leads to a full redevelopment of the battery modules and the battery monitoring circuit board.
- The redevelopment of battery monitoring boards increases the time-to-market, as well as the development and the production costs, which makes the centralized battery monitoring architectures economically unviable for the mass market.

This new distributed-battery monitoring architecture consists of smart battery cells with integrated electronics, allowing bidirectional contactless communication between each of the smart battery cells and the battery management system:

- The monitoring and balancing functions are integrated on each smart battery cell, thus improving reliability and reducing the effort involved in assembling and contacting.
- The printed resistor used for passive cell-balancing and integrated into the battery cell can be additionally used for heating the cell in winter conditions.
- Smart battery cells make possible much shorter times-to-market when developing novel battery packs, since no more complex application for specific battery-monitoring circuits and boards need to be developed.
- The modularity and flexibility-in-use of the smart battery cells is greatly improved.
- The hardware of the battery-management system can be standardized and re-used in new and different developments by improving the software part alone.
- The smart battery cells provide all the integrated electronics that need to be monitored.
- The electronics integrated into the smart battery cells protect it against counterfeiting.
- The cell voltage, temperature, pressure, and balancing current can be measured by the monitoring electronics and sent to the BMS without any additional contacting effort needed when constructing the battery module.

Different data transmission methods can be used for the bi-directional communication interface between the battery-management system and the battery cell electronics: ohmic contact, radio frequency (RF), optical (e.g., opto-coupler), inductive (e.g., transmission over a transformer), or capacitive. The ohmic contact requires a high contacting effort; therefore it is economically less than optimal. The RF solution is interesting but is susceptible to strong electromagnetic interferences (EMI) and other perturbations occurring in battery packs. The optical solution is promising in theory, but the reliability issues mean that it is not a practical method at the present time. The inductive solution can be very cheap, but for a proper magnetic coupling, a core is required, which makes it bulky.

Capacitive coupled transmission is the method of choice for transmitting data between the battery-management and the battery cells since it does not require a great amount of effort for contacting. Using the parasitic capacitors provided by simple copper strips directly applied to the receivers of the battery cells makes this solution extremely cost efficient. No specific dielectric is required. Large tolerances are acceptable for the capacitors, since they are only transmitting data signals.

With this system providing integrated voltage- and temperature-sensing, integrated passive cell-balancing (which can also be used for cell heating in winter conditions), and with an external bi-directional capacitive communication interface providing a low-cost galvanic isolation, battery pack designers now no longer need to worry about the contacting of the sensing elements. Also, the development and manufacturing costs of the battery pack are optimized and the time-to-market when developing a new battery pack is strongly reduced, since the development of a battery-monitoring circuit for each single battery module becomes unnecessary.

Comparison of the currently commonly-used centralized battery-monitoring and the new distributed battery-monitoring architectures:

Component	centralized	distributed
Wiring and contacting effort	very high	lowest
Modularity and flexibility	low	very high
Robustness	good	better

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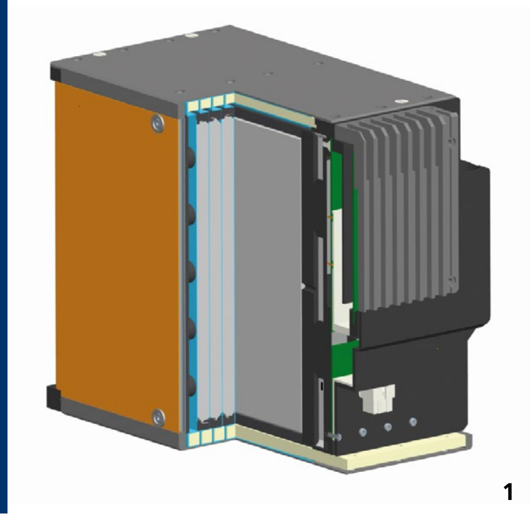
1 *Smart battery cell with integrated cell monitoring electronics.*

2 *Electronic architecture of distributed battery monitoring.*

POWER ELECTRONIC SYSTEMS



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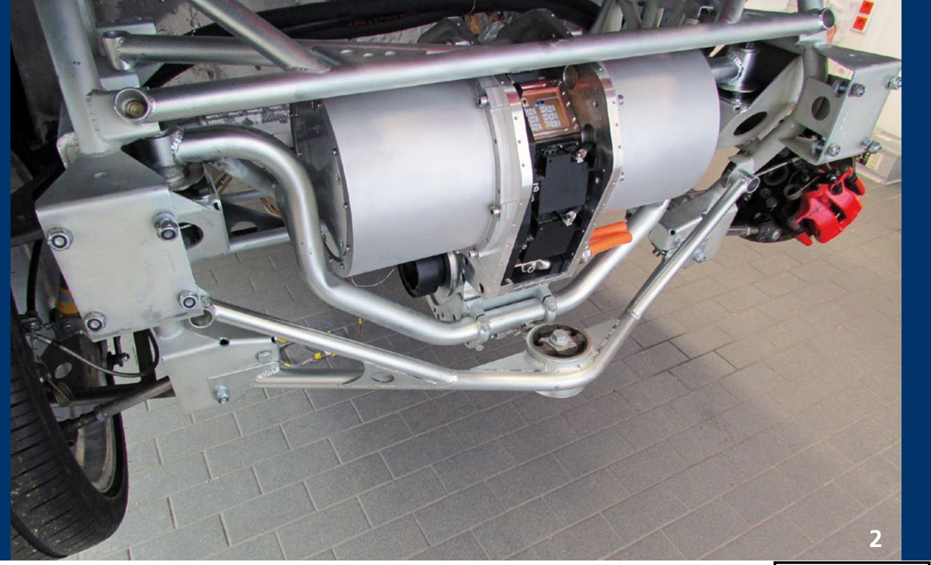


2

Content

Street-Legal Electric Vehicle Demonstrator Platform

A research platform for the evaluation and optimization of electric vehicle powertrain components is currently being developed. The vehicle is based on the chassis of an ARTEGA GT and electrified entirely with Fraunhofer IISB components.

Some of the specific focuses of research within this vehicle project are:
- Efficient and system-integrated HV-powertrain
- Overall vehicle energy management (electrical and thermal)
- Operational strategy for increased part-load efficiency (e.g. variable DC-link voltage)
- Position-tolerant inductive charging at the vehicle-front
- Model-based vehicle control system using Matlab / Simulink and dSpace
- Advanced vehicle safety architecture
- Street legality

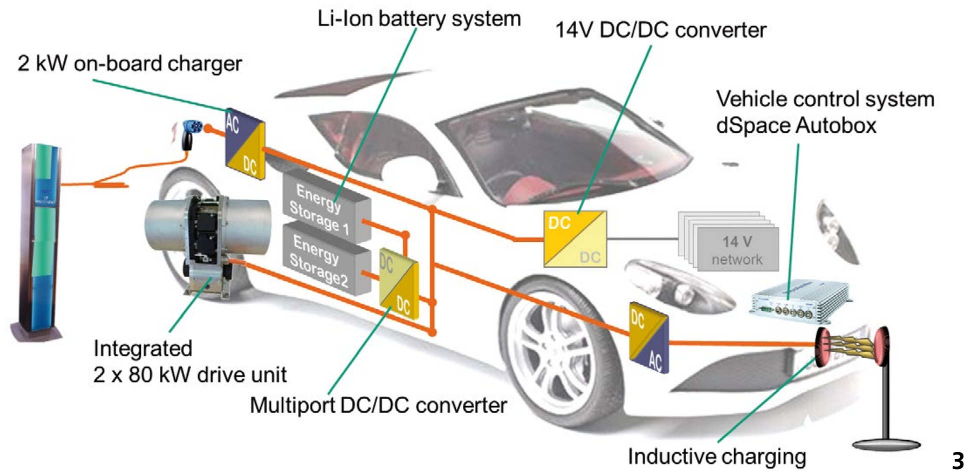
The propulsion power is delivered from an integrated central drive unit with two independent electric machines which have a maximum power output of 2 x 80 kW. The double-IGBT-inverter is completely integrated in the drive-system, which results in an optimized system set-up in terms of packaging, EMC-behavior and costs. Two independent field-oriented control (FOC) algorithms are implemented on the central inverter control board, which is based on Infineon TriCoreTM with additional safety watchdog. An independent torque allocation for each wheel of the axle is realized this way. Permanent magnetic synchronous motors with a nominal voltage of 400 V and buried magnets are used for an improved field-weakening operation and a high part-load efficiency.

All converters necessary for electrical energy-management, power supply and charging are integrated into the energy storage (355 V and 14 kWh) which therefore transforms into a smart battery unit. This kind of system partitioning follows the basic idea of a "site-of-action integration" concept and minimizes voltage cable harness and system costs. The high-power Li Ion cells (40 Ah) are divided into 8 submodules with an end-of-charge voltage below 60 V. Each of the submodules is equipped with voltage / temperature measurement for the individual cells and passive balancing. Double-sided water cooling – using thin heat-spreaders between the cells – results in greatly reduced thermal resistances and therefore minimizes the temperature gradient within the whole battery system.

An innovative multiport DC / DC-converter is used in the electric vehicle platform for managing the high-voltage electrical system. This allows a flexible combination of different energy storages with different voltage levels (e.g. a traction-battery with additional supercap storage for peak acceleration- and break-power). The converter provides a variable output-voltage for the DC-link of the drive-system, depending on the driving situation. Investigations prove the possibility of raising the overall vehicle drive-train efficiency especially for low-speed driving cycles with this strategy. For the supply of the vehicle's 14 V-systems, a combination of two DC / DC-converters is installed. Both are fed directly from the HV-battery system. The use of two DC / DC-converters with different output-power levels (2 kW and 500 W) results in an optimized efficiency for all operating modes (e.g. driving or charging) and power demands.

For the evaluation and demonstration of different charging strategies for the vehicle's traction battery, three different technologies are installed in the vehicle:
- 3 kW position-tolerant inductive charging in the license plate holder at the vehicle-front
- 3 kW on-board AC-charger
- 22 kW DC fast-charging

The component development and the detailing of the system architecture was carried out in 2012. The integration of the systems and of the vehicle control system was also begun in that year. The aim for 2013 is the official approval and homologation for the street-legality of the demonstrator vehicle.



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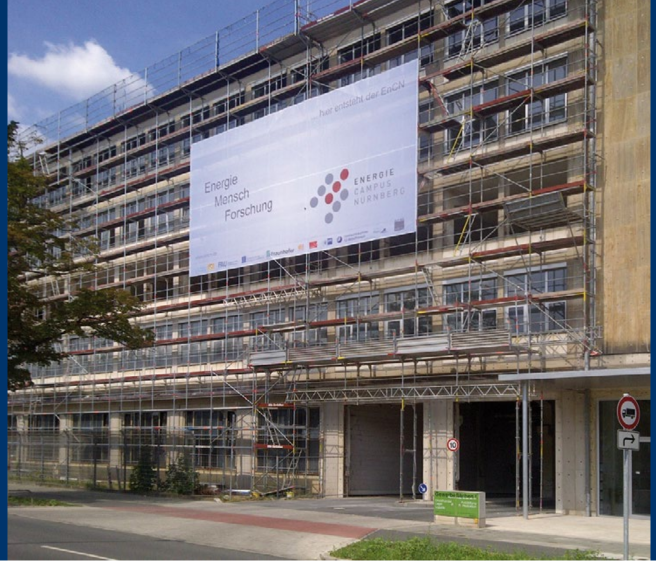
1 *Li-Ion 44 V battery module with double sided cell-cooling.*

2 *2 x 80 kW integrated drive-unit*

3 *Topology of the vehicle HV-system*



Content

Energy Campus Nuremberg - an Interdisciplinary Cooperation Project

Economically, ecologically and socially sustainable energy concepts are closely linked to the use of renewable energy and to enhanced energy efficiency. The "Energy Campus Nuremberg" (EnCN) is a research platform for the development and demonstration of a closed renewable-energy supply chain. This interdisciplinary research project includes the combination of power-generation from renewable sources with efficient and intelligent energy-transportation and storage systems. The EnCN targets basic research but also supports the development of practicable solutions and marketable products. The whole value-creation chain is covered, from energy generation right up to its utilization.

The accomplishment of these goals is guaranteed by the unique collaboration of six national research organizations:

- Fraunhofer Institute for Integrated Systems and Device Technology (IISB)
- Fraunhofer Institute for Integrated Circuits (IIS)
- Fraunhofer Institute for Building Physics (IBP)
- Friedrich-Alexander-University of Erlangen-Nuremberg (FAU)
- Georg Simon Ohm University of Applied Sciences Nuremberg (OHM)
- The Bavarian Center for Applied Energy Research (ZAE Bayern)

All the activities of the different partners take place in the new EnCN laboratory facility on the historical former AEG industrial complex. In 2012, the EnCN laboratory was voted a "Selected Landmark" in the nationwide "365 Land-marks in the Land of Ideas" competition.

The EnCN works in several interdisciplinary research areas:

- Materials research and process-development for solar-power generation and the transportation of energy
- Power electronics and information technology as well as energy-flow control for electric grids ("smart grids")
- Increasing energy efficiency by means of new materials, processes and electronics as well as through building tech-nologies
- Optimal and holistic intelligent energy systems as well as methods for process management

Within the EnCN framework, the Fraunhofer IISB is working on three projects with a special focus on power-electronic systems for future energy networks: Energy-flow control systems in the grid, interfaces between stationary energy supply grids and mobile consumer loads, and energy storage within the grid.

Due to changes in the energy supply system there will, in future, be an increased use of power-electronic systems. In particular, the utilization of modular-multilevel-converters will make it possible to achieve a more flexible and efficient control of the energy-flow within the grid. The goal of the research is to design power-electronic components with increased efficiency and increased lifetime and simultaneously to reduce system costs. This includes a complete power-electronic system design as well as component development. One part of this project focuses on packaging solutions as a technical base for the use of future high voltage wide-band-gap semiconductors in power-electronic applications. By optimization of the module design, advantages in efficiency and system costs can be achieved. A specialized design of the module increases the system availability under fault conditions. The development of a power-electronic system demonstrator provides the opportunity to optimize and validate dimensioning methods, simulation models and control algorithms.

The connection between the grid and mobile consumer loads (e.g. electric cars) poses high demands with respect to consumer acceptance. These include ease of operation, safety, and robustness against weather and vandalism. A common solution is the use of wireless and contactless interfaces. The project focuses on new approaches in the field of inductor dimensioning, circuit design and system technology. The goals for a wireless energy transmission are a high tolerance in positioning between receiver and transmitter, a high efficiency in transmission, low electromagnetic fields, bi-directional energy transmission and an integrated communication channel in the interface. The requirements for an industrial implementation have still to be researched. One major challenge in the transition of the energy system towards sustainable energy supply is the development of suitable energy-storage systems. Applications within the energy network involve very high requirements regarding operational safety, availability, efficiency and system costs. This project focuses on the development of an intelligent energy-storage system with several independent DC-ports to integrate different electrical-storage technologies simultaneously. This storage station can be used to increase the voltage quality in the grid, to buffer fluctuating regenerative energy sources and as an uninterruptable power supply. Furthermore, this system can be used for the rapid charging of electric vehicles.

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1 *The EnCN building in Nuremberg. Image: EnCN*

2 *EnCN - A „Selected Landmark" in the federal „Land of Ideas" competition. Image: Kurt Fuchs / EnCN*

Content

1 *From left to right: Dr. Christine Thomas, Head of the sub-department "Innovation in the Service of Society" (Innovation im Dienste der Gesellschaft) set up within the Federal Ministry for Education and Research (BMBF), Head of the Fraunhofer IISB Prof. Lothar Frey, Bavarian State Secretary for the Economy Katja Hessel, and Fraunhofer Senior Vice President Research Planning Prof. Ulrich Buller during the opening ceremony of the extension to the Fraunhofer IISB in Erlangen. Image: Kurt Fuchs / Fraunhofer IISB*

Selected News

Electronics for Energy Supply and E-Mobility – Fraunhofer IISB Extension is opened

On the 30th of March 2012, the extension to the Fraunhofer IISB in Erlangen was officially opened. Research and development work on highly efficient power-electronic systems is to be carried out at this new facility – research, that is to say, which will be of great significance especially to such issues of burning relevance to the immediate future as energy supply and e-mobility.

Using modern power electronics, electric energy can be converted and distributed without major losses and exactly as required. In this way, significant savings in energy consumption can be achieved – be it at home or at work, in industrial production or in terms of the transport of electricity on all the most various levels of the electrical power grid. In the energy grid of the future, the surely impending expansion of the cables and interfaces linking the producers and consumers of, and the storage facilities for, such energy will require new power-electronic solutions. Without the key technology that is power electronics, the switchover to a regenerative energy supply is impossible. E-mobility also requires efficient power electronics. Power-electronic converters form a significant part of drive units, battery systems and charging devices for electric and hybrid cars. When, in their capacity as representatives of the sponsors, the Bavarian State Secretary for the Economy, Katja Hessel, and Dr. Christine Thomas, Head of the sub-department "Innovation in the Service of Society" (Innovation im Dienste der Gesellschaft) set up within the Federal Ministry for Education and Research, officially opened the IISB extension for use, several types of work were already underway within the offices. These included electronic laboratories and vehicle workshops under the management of Dr. Martin März, Deputy Director of the IISB and Head of the IISB Power-Electronic Systems Department.

Another example is the "Application Centre for Direct-Current Technology and for the Power-Supply Solutions of Tomorrow" which is established in the extension as part of the Fraunhofer "Electronics for Sustainable Energy Use" (Elektronik für nachhaltige Energienutzung) Innovation Cluster, coordinated by the Fraunhofer IISB. The potentialities as regards the replacing of parts of today's AC grid with a DC grid will be developed and tested here – a course of action which would make it possible to dispense with unnecessary conversions and inefficient power supply units.

Content

Continuation: Selected News

"With regard to those topics ever increasing in relevance and importance: energy supply and e-mobility, the institute in Erlangen is a place of genuine greatness," stresses the Bavarian State Secretary for the Economy Katja Hessel. "Its research helps to make our energy supply more efficient. Because this research tends to the development of systems which will ensure that no kilowatt-hour will be produced that is not actually used."

The Head of the IISB, Prof. Lothar Frey, adds: "For this reason, the IISB works closely together with industry - especially with the vigorous power-electronics, automobile-supply and energy-technology industries in the metropolitan region of Nuremberg, as well as the company associations resident in the region. Industry and research in Bavaria both profit from this proximity."

Some 8.3 million Euros were contributed as subsidies to the building of the Fraunhofer IISB extension as part of the package of measures introduced by the Federal German Government and the Free State of Bavaria with a view to stabilizing and enlivening the national and regional economy in the wake of the international economic crisis of 2008 / 2009.

The Fraunhofer IISB thanks the sponsors for the friendly support given by the Bavarian State Ministry for Economy, Infrastructure, Traffic and Technology as well as the Federal Ministry for Education and Research (BMBF).

Research for the "Energy Transition" – Fraunhofer and the TU Bergakademie inaugurate a new Technical Center for Crystallization and Wafer Processing in Freiberg

The new technical center for crystallization and "wafer" production has been formally opened at the Fraunhofer Technology Center THM in Freiberg on Wednesday the 7th of March 2012. The Fraunhofer THM is a jointly-run division of the Fraunhofer Institute's IISB in Erlangen and the ISE in Freiberg. It also cooperates with the TU Bergakademie Freiberg and the local semiconductor industry in order to support and strengthen the economic and commercial region of Freiberg in the field of electronic materials production. The aim of the new technical center is to conduct research into semiconductor materials displaying better qualities and more efficient production methods.

The Fraunhofer Technology Center for Semiconductor Materials THM, founded in 2005, complements with its research the development tasks of the semiconductor industry concentrated in Freiberg. After more than two years of planning and building, the Technical Center for Crystal-

1 *The new extension building of the Fraunhofer IISB in Erlangen. Image: Kurt Fuchs / Fraunhofer IISB*

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lization and Wafer Processing for Semiconductor Materials is now being inaugurated there. The new laboratory area, which cost some 9.9 million Euros, was 60 % financed from EU resources, with the remaining 40 % of funding being taken over, in equal parts (20 % each), by the Federal German Ministry for Education and Research and the State of Saxony.

The main emphasis of research in the new technical center lies on the question of how to produce crystal materials, and wafers made from them, more economically, while also improving on the qualities of the material, e.g. silicon for microelectronics and photovoltaics as well as gallium nitride for energy electronics. Efficient semiconductor materials are the basis for a modern energy supply system, because energy can be produced, transmitted, changed and stored efficiently by them.

"A pleasantly close cooperation links the TU Bergakademie Freiberg with the Fraunhofer Technology Center for Semiconductor Materials THM", says Dirk Meyer, Professor of Physics and Pro-Rector for Education at the TU Bergakademie Freiberg. "For the endeavor of the Bergakademie to achieve and further develop a closed chain of innovation, in the field of materials in research and education, from mineralogy through to condensed-matter physics and chemistry, our cooperation with the THM means a successful synthesis of academic research and education with technological application", adds Prof. Meyer.

The formal opening, in the Alte Mensa on the Petersstraße in Freiberg, has been attended by Dr. Henry Hasenpflug, Saxony's State Secretary for Economy and Art, Bernd-Erwin Schramm, Mayor of the city of Freiberg, Prof. Dirk Meyer, Pro-Rector for Education at the TU Bergakademie Freiberg, Prof. Dr. Ulrich Buller, board member for research planning of the Fraunhofer-Gesellschaft, Prof. Eicke Weber, Head of the Fraunhofer ISE, Prof. Lothar Frey, head of the Fraunhofer IISB, Prof. Hans Joachim Möller, Head and Spokesman of the Fraunhofer THM, as well as Dr. Jochen Friedrich, Deputy Head and Spokesman of the Fraunhofer THM in Freiberg.

"The 'energy transition' in Germany initiated by the Federal Government will require great efforts in all social areas. Besides the actual production of renewable energies, the intelligent and safe distribution as well as the saving of electrical energy are matters of great significance here. All this can only be achieved through tailor-made solutions in micro and power electronics. Cheap electronic materials of high quality which are used in the form of crystal materials and of the wafers made from them occupy a key position", states Jochen Friedrich.

1 *Dr. Jochen Friedrich (left), Deputy Spokesman for the Fraunhofer THM in Freiberg, presents crystal materials. Image: Marko Borrmann / Fraunhofer THM*

2 *Official inauguration ceremony of the new technical center for crystallization and wafer processing at the Fraunhofer THM in Freiberg (Saxony). Image: Marko Borrmann / Fraunhofer THM*

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Custom-Made Substrates for Energy-Efficient Wide-Band-Gap Components – 14th Annual Conference of the Fraunhofer IISB Electrifies the Semiconductor Materials Scene

About 40 % of worldwide energy requirements are to be traced back to the use of electrical energy. The use of modern electronics means that it is now possible to realize considerable potential savings. For example, electronic components and circuits can now be produced on the basis of semiconductors with wide band gaps that are much more efficient as compared to the already-established silicon technology. Examples of such components are electricity-saving lights using gallium nitride LEDs, inverters for solar and wind plants with circuit breakers made of silicon carbide, or the energy-saving generation of UV-light using devices made of aluminum nitride.

Dr. Jochen Friedrich, head of the Crystal Growth Department at the Fraunhofer IISB and host of the 14th IISB annual conference, says: "Our annual conference this year has as its keynote compound semiconductors, which were invented 60 years ago in Erlangen. The commercialization of components made from these materials has been pushed on strongly over the last ten years. An important precondition was the availability of the materials in sufficient amounts, sizes and quality to attain the level of performance required from the components. Present developments mean that new fields of application for energy-efficient component made of semiconductors with a wide band-gap are opening up, so that this commercialization will proceed further."

The 14th annual conference, then, which took place on the 6th of December 2012, took as its central theme the wide-band-gap semiconductors silicon carbide, gallium nitride, and aluminum nitride. Experts from industry and science gave presentations on the current state of crystal and substrate production, as well as on the epitaxy and the processing of new components based on those semiconductors. They also discussed with the several experts in attendance the influence of these materials on the properties of the components.

The 14th annual conference took place in conjunction with the 27th DGKK (Deutsche Gesellschaft für Kristallwachstum und Kristallzüchtung e.V.) workshop "Epitaxy of III / V-Semiconductors", which was organized by the University of Erlangen-Nuremberg and the Fraunhofer IISB under the patronage of the DGKK Working Group on Epitaxy. The event – which was sold out, with 130 participants – was not only a success for the Fraunhofer IISB. The huge resonance it enjoyed shows the current standing of the semiconductor theme and the current importance of semiconductor and component specialists.

University of Erlangen-Nuremberg expands its Range of Large-Scale Machinery in Cleanroom Laboratory

A new system for ion implantation was put into operation at the Fraunhofer IISB in Erlangen. The new piece of large-scale machinery, weighing 15 tons and costing 3 million Euros, was set up in the cleanroom jointly operated by the University of Erlangen-Nuremberg and the Fraunhofer IISB. This new equipment acquisition means that the possibilities of both facilities as regards research and theory in the field of semiconductor technology for micro, nano and power electronics will be significantly extended.

Today, ion implantation is the standard process for the doping of semiconductors. The ions of the desired dopant are accelerated in an electric field and shot onto the surface of semiconductor wafers. Depending on the different velocities, or rather the different energies and dosages, with which these alien elements are shot onto the semiconductor, there emerge different profiles in terms of penetration depth into the solid body of, for example, a silicon wafer. The possibility of selecting both this and the allocation material itself means that the electric qualities of semiconductors can be set more or less precisely as required. This is an important requirement for the realization of modern semiconductor devices.

The Fraunhofer IISB is one of the leading research facilities for ion implantation in Europe and has decades of experience on this field. The IISB's new ion implanter replaces the older system and is one of the larger items involved in the current modernization of the cleanroom equipment in Erlangen – a modernization which is supported by funds from the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology, the Federal German government, and the EU. Using the new system, researches on semiconductor wafers with a diameter of up to 200 mm will be possible, as opposed to only 150 mm hitherto, using the old one. In addition, the energy range for the acceleration of the ions will be expanded significantly. From now on, it will be possible to produce singly charged ions with an energy bandwidth of 2 to 270 kilo-electronvolts (keV). Especially in the lower energy range, very thin implantation layers can now be created - something which is important for steady miniaturization in device technology. Also new is the use of up to triply charged ions, thus allowing implantations with energies up to a maximum of 810 keV.

"The spectrum of materials for implanted elements comprises the standard dopants for silicon wafers, such as boron, phosphor and arsenic, but also elements such as aluminum and nitrogen for the doping of silicon carbide, a semiconductor which offers many possibilities especially in high-temperature and power electronics", explains Dr. Volker Häublein, who is responsible for the ion implantations as a group leader at the IISB.

1 Dr. Jochen Friedrich, head of the Crystal Growth Department at the Fraunhofer IISB and host of the 14th IISB annual conference, explains the research activities of the institute in the field of wide-bandgap semiconductors.

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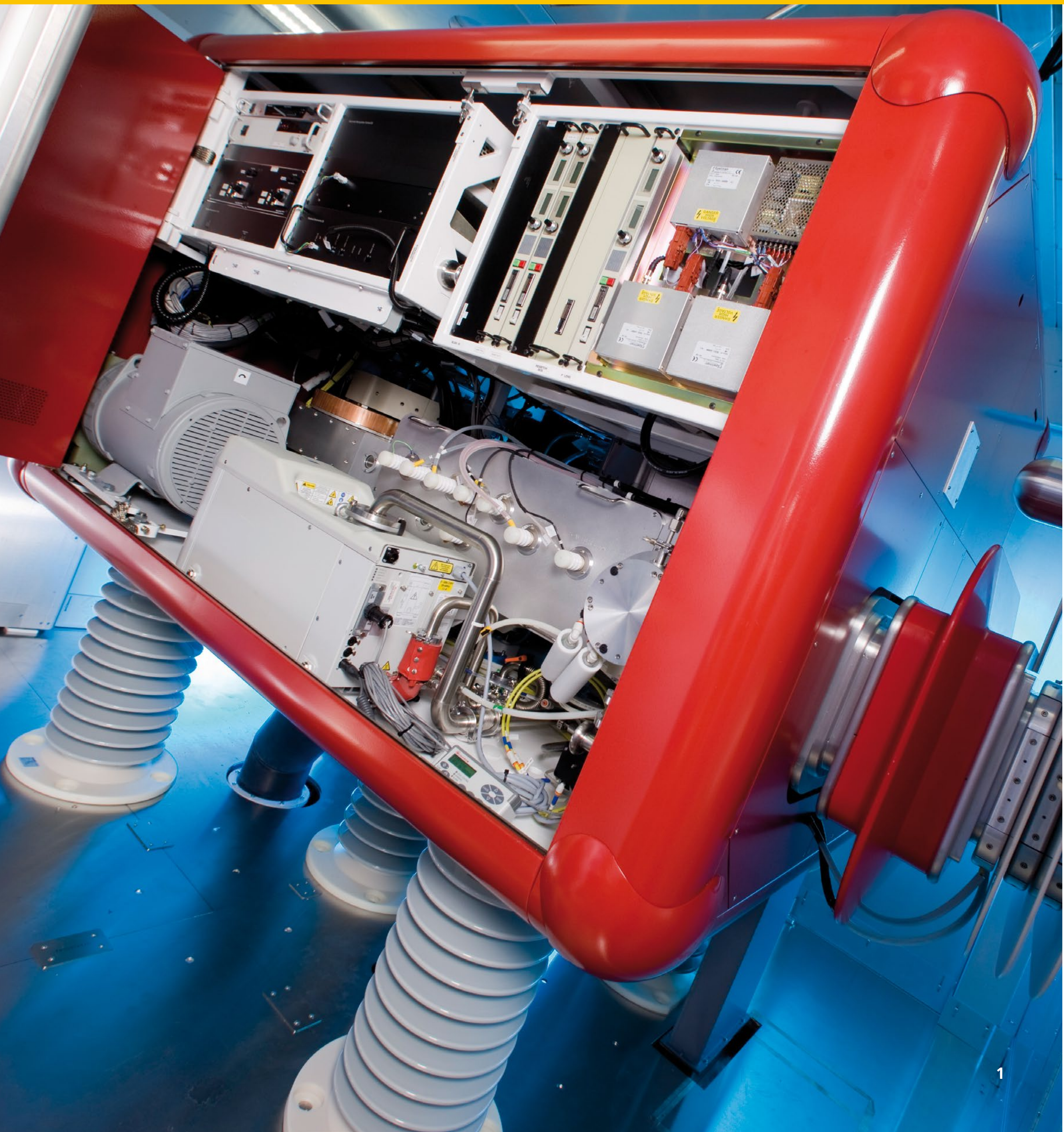

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Furthermore so-called "eccentrics", such as cesium, rubidium or lanthanum, can now be implanted outside of the classical semiconductor technology. The delivery of the system, as well as its installation in the cleanroom, meant a huge logistic effort. More than 24 tons of transport-weight required the use of three standard trucks and one heavy-duty truck. A special construction made of steel girders and aluminum plates was used to stabilize the floor of the cleanroom laboratory so as to allow it to bear the weight of the heavy system. The university, as the host of this cleanroom, which is one of the biggest of its kind for research and theory in Germany and even in Europe, participated by carrying out the necessary renovations on the laboratory level of the cleanroom building.

Lothar Frey, director of the Fraunhofer IISB and holder of the Chair for Electron Devices at the University Erlangen-Nuremberg said: "The modernized equipment in the cleanroom will render still closer the already close, synergetic cooperation between the Fraunhofer IISB and the University of Erlangen-Nuremberg. Besides the expanded possibilities for research, the cleanroom now offers an attractive environment for students of technical disciplines such as electronic engineering or nano-engineering."

Fit for E-Mobility – DRIVE-E Academy and DRIVE-E Studienpreis 2012

Within the Framework of the DRIVE-E Academy, the Federal Ministry of Education and Research (BMBF) and the Fraunhofer Gesellschaft recently awarded the DRIVE-E Studienpreis for 2012. With 62 applications from universities lying as far apart as Aachen and Dresden, Bremen and Konstanz, the interest in the DRIVE-E Studienpreis has been livelier than ever before. On the 14th of March 2012, the Ministry of Education and Research, together with the Fraunhofer Gesellschaft awarded for the third time, in Aachen, awards and distinctions to outstanding pieces of work by students on the topic electric mobility.

"The federal government's aim is that there should be one million electric vehicles on German roads by year 2020. For this aim to be achieved, we need highly motivated and qualified up-and-coming young scientists. We are happy that the young generation is interested in this topic." This are the words of Thomas Rachel, Parliamentary State Secretary in the BMBF, addressed to this year's award winners on the day of the event.

The first prize in the "Diploma / Master's Thesis" category went to Fabian Peters from the University of Bremen. Peters had examined, in his Master's thesis, the factors tending to limit the

1 *Fraunhofer IISB's new ion implanter covers an energy range from 2 keV up to 810 keV. Image: Kurt Fuchs / Fraunhofer IISB*

2 *Delivery of the new ion implanter to the cleanroom laboratory of the University of Erlangen-Nuremberg.*

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energy density and lifespan of lithium ion batteries. The second prize went to Xuyang Men from the RWTH Aachen, whose Master's thesis looks likely, thanks to its development of an online diagnostic system, to make it possible to reliably predict the range of electric vehicles.

The jury awarded the first prize in the category "Term Project / Capstone Project / Bachelor's Thesis" to two students. Florian Hilpert from the University of Erlangen-Nuremberg was distinguished for his project thesis, in which he made calculations about the thermal behavior of drive engines. Johannes Burkard from the RWTH Aachen got his prize for his Bachelor's thesis in which he examined the possible flaws occurring in a battery-charging device and strategies to avoid them. The second prize went to Lisa-Maria Zak from the University of Applied Sciences in Augsburg. She had developed, in her Bachelor's thesis, an optimized concept for cooling lithium ion batteries.

This award ceremony for the DRIVE-E Studienpreise formed the highlight of the DRIVE-E Academy. From the 12th to the 16th March 2012, selected students of various technical subjects took a close look at all the important aspects of this issue soon to be of crucial relevance. On the Academy's agenda were lectures by top-flight experts, practical workshops, and a trip to the Europäisches Zentrum für Alternative Antriebe set up by General Motors in Mainz-Kastel as well as to the company e-WOLF in Frechen near Cologne, which develops electric vehicles from the prototype stage right up to the start of production. This year the DRIVE-E program was organized together with partner universities for the first time. With the RWTH Aachen, there was won as a partner a university with the very highest reputation in the field of e-mobility.

The Academy and the Studienpreis form two key component parts of the DRIVE-E program for the up-and-coming generation of graduates, which was established jointly by the Federal Ministry for Education and Research (BMBF) and the Fraunhofer-Gesellschaft (FhG) in 2009. On the FhG side, it is specifically the IISB that acts as initiator and organizer of the DRIVE-E program.

R&D for SMEs – 10 Years of Cooperation between NanoWorld Services GmbH and Fraunhofer IISB

NanoWorld Services GmbH and the Fraunhofer IISB in Erlangen have now been cooperating closely with one another for 10 years. The Institute's work together with this leading producer of scanning tips for Atomic Force Microscopy is a perfect example of successful R&D practice.
Jörg Diebel, manager of NanoWorld Services GmbH, took this anniversary occasion as an oppor-

1 *Students of the DRIVE-E Academy inspect an electric vehicle. Image: Stephan Rauh / BMBF / Fraunhofer-Gesellschaft*

2 *The participants of the DRIVE-E Academy 2012 in Hamburg. Image: Stephan Rauh / BMBF / Fraunhofer-Gesellschaft*


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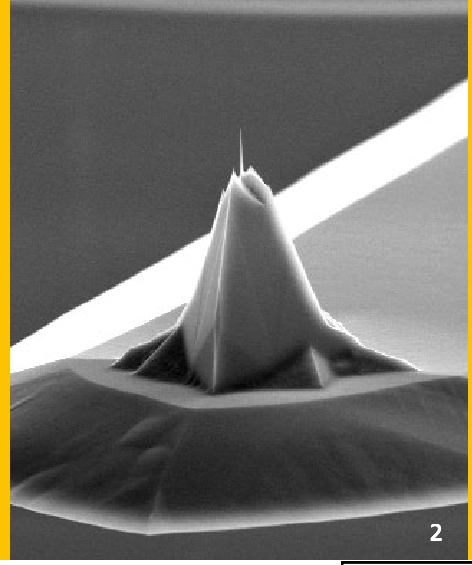
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tunity to honor all that the two organizations have achieved together and, at the joint summer festival held on 19th of July 2012, to thank all the employees of both for their contributions to these achievements. In addition, the guests received – by way of a gift representative of the region – a beer stein especially designed for this occasion. "Our cooperation with the Fraunhofer IISB offers an attractive combination of scientific research and product-specific development. This is of incalculable value for a high-tech company like NanoWorld," said Diebel.

Already as early as 2002, NanoWorld was deeply impressed by the groundbreaking work being done by the Fraunhofer IISB in the field of nanostructuring and decided to establish an MEMS foundry of its own. NanoWorld Services GmbH is part of the NanoWorld Group, whose members are leading actors in the development, production and sales of AFM probes made of silicon and of other materials used in Atomic Force Microscopy (AFM).

AFM is a high-resolution imaging process and allows the characterization of surfaces in the atomic realm. The screening of the surface is carried out by means of ultra-fine needles – the so called "AFM scanning tips". Or, conversely, the AFM process can also be used for the grafting of molecules and atoms onto bearer substrates, e.g., for the purpose of research on quantum computers.

Until now, the close cooperation has proven extremely positive for both partners and has provided NanoWorld with access to the modern laboratory infrastructure and the very well-equipped cleanroom laboratory of the Chair of Electron Devices (Lehrstuhl für Elektronische Bauelemente, or LEB) of the University of Erlangen-Nuremberg, which is co-administered by the IISB. Over the years, several projects in the field of thermal und field emission AFM probes, some of them partly publicly funded, have been executed. The results flow directly into the steady improvement of the products. NanoWorld also uses the expertise of the IISB in the field of the ultra-precise modification of structures by means of focused ion beams (FIB), for example in the case of the refinement of high-resolution nano-probes.

For Prof. Lothar Frey, head of the Fraunhofer IISB and current holder of the Chair of Electron Devices (LEB) at the University, the cooperation with NanoWorld is a real win-win-situation: "We are very content to have proven so attractive to industry and to have brought highly qualified jobs into the region. The IISB not only benefits from the direct exchange in-house but also gains thereby an immediate insight into the requirements and latest developments on the market."

Passion for Electronics – Dr. Martin März becomes Deputy Director of Fraunhofer IISB

Dr. Martin März, Head of the Power-Electronic Systems Department at Fraunhofer IISB, has been appointed to the position of Deputy Director of the IISB. In this function, he has been supporting the Institute's Director, Prof. Lothar Frey, in the management of the research faculty since the beginning of the year. In his field of expertise, Martin März is meeting the challenge of the present age – modern power electronics is essential for the successful introduction of e-mobility.

After finishing his studies and his doctorate at the University of Erlangen-Nuremberg, Martin März, born in 1962, worked for five years in the Semi-Conductor Division of Siemens AG, later called Infineon Technologies AG. In April of 2000, he moved over to the Fraunhofer-Gesellschaft in order to build up the "Power-Electronic Systems" Department at the IISB. Today, this department has become the biggest at the Fraunhofer IISB and has significantly contributed to the Institute's growth. Besides his own department, Martin März leads the Nuremberg branch of the IISB, the Centre for Automotive Power Electronics and Mechatronics (ZKLM). He has applied for around 50 patents, given lectures about automotive electronics and e-mobility at the University of Erlangen-Nuremberg (FAU) and is committed to supporting youth – for example, through the student project TechFak EcoCar of the FAU or as the person responsible for the BMBF-Fraunhofer young-academic support program for e-mobility, DRIVE-E.

Electric energy is distributed by power-electronic components and systems and changed into the form needed, e.g., from DC into AC or from one voltage level to another. The technological challenge is to keep heat losses as low as possible, in other words, to work with a high effectiveness and therefore energy-efficiently. Questions of cost-optimization, robustness, safety and reliability also play a big role, as well as heat removal, volume and weight reduction and the system integration of the electronics directly at the place where they perform their function, e.g., in the drive unit of an electronic vehicle. This offers broad fields of application for Martin März and his employees – ranging from drive, battery or charging systems for e-mobility, highly efficient electricity supplies for consumer electronics, and power converters for photovoltaic plants right up to heavy-duty power switches for high-voltage DC transmission (HVDCT). The work done by the team regularly sets benchmarks for effectiveness and performance density.

Here, Martin März works together with numerous industry partners especially from the metropolitan region of Nuremberg, which stands out due to its density of power-electronic, energy-technological and automobile-supply companies. He is the close contact for regional and international industrial associations, such as the Bavarian Cluster on Power Electronics, or the European Center for Power Electronics (ECPE). He is also a member of the Steering Committee of, and Priority Area Manager in, the Fraunhofer System Research Group on Electromobility (FSEM) and Project Leader of the Fraunhofer Innovation Cluster "Electronics for Sustainable Energy Use",

1 *Prof. Lothar Frey (left), Director of the Fraunhofer IISB, and Jörg Diebel (second from left), Manager of NanoWorld Services GmbH, celebrate the close cooperation between Fraunhofer IISB and NanoWorld at the joint summer festival.*

2 *Ultrasharp high aspect ratio AFM tip after FIB nano-structuring by IISB and post-processing. Image: NanoWorld Services GmbH*

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coordinated by the IISB. In addition to this, he actively participates in the National Platform on E-Mobility and holds membership in several scientific advisory councils and committees of experts.

The IISB runs an extensive test center for electronic vehicles in Erlangen under the management of Martin März. More vehicle workshops and laboratories have been added, due to the building of an extension. This dovetails well with the next model project of this power-electronics expert: a completely electronically-driven sports car.

Jochen Friedrich takes over the Chairmanship of the "Deutsche Gesellschaft für Kristallwachstum und Kristallzüchtung e.V."

Dr. Jochen Friedrich, Head of the Crystal Growth Department at the Fraunhofer IISB in Erlangen and Deputy Spokesman for the Fraunhofer THM in Freiberg, took over the chairmanship of the Deutsche Gesellschaft für Kristallwachstum und Kristallzüchtung e.V. (DGKK) on the 1st of January 2012. The DGKK, which consists of approx. 400 members, is the umbrella organization for crystallographic scientists and technologists in Germany. Its task is to develop research, theory, and technology in the field of crystal growth and crystal breeding.

Many radical transformations and developments of the past 50 years would not have been possible without the availability of synthetically produced crystals with special qualities. Without crystals there would be no computers, no cellphones, and especially no Internet. What DVD players, games consoles, or the screens of modern televisions have in common is that it is artificially created crystals which make all these devices possible. Crystals are key materials for the efficient production and transmission of energy – as, for example, in photovoltaic systems. In optics, crystals are integrated into highly developed systems in the form of windows and lenses. Devices equipped with laser and detector crystals have made possible the development of new medical treatments, of resource-saving methods in material processing, and of modern measurement technologies, including satellite-based environment-observation.

The production of such crystals is called crystal growth. It is estimated that some 10.000 jobs in Germany are connected to crystal growth. That includes the original crystal producers but also suppliers for systems and devices as well as for process materials. For these crystal experts the DGKK, a registered public association in Germany, has been the designated professional federation for about 40 years now. The statutory task of the DGKK is to support research, theory, and technology in the field of crystal growth. The DGKK disseminates information about ongoing work in this field, and about results achieved in it, through the medium of meetings and messages: It promotes scientific contacts between its own members and also their relations to other scientific societies. It also represents the interests of its members on a national and international level.

Dr. Jochen Friedrich has occupied the chair of the DGKK since the 1st of January 2012. This eminent scientist has been conducting applied research in the field of crystal growth for some 20 years now. After completing first his university studies in the field of Materials Science and then his doctorate, taken at the Institute for Materials Science at the University of Erlangen-Nuremberg, he moved on to the Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen. Today, he manages the Crystal Growth Department there and is also responsible for the Fraunhofer Technology Center for Semiconductor Materials THM in Freiberg. Jochen Friedrich has been the recipient of several awards for his research in the field of crystal breeding, including the Wissenschaftspreis des Stifterverbandes (2003), the VDE / VDI-GMM-Preis (2005), the IWCGT Best Lecture Award (2008) and the Hans-Georg-Waeber-Innovationspreis (2009). The main emphasis of the research being conducted by Jochen Friedrich and his 45 employees in Erlangen and Freiberg today lies on silicon crystal growth for microelectronics and photovoltaic systems, on bulk crystal growth and the epitaxy of so called semiconductors with wife band gap, and on the development of new detector and laser crystals, including measurement technology and computer simulation.

1 *Dr. Martin März, Head of the Power-Electronic Systems Department at Fraunhofer IISB, has been appointed to the position of Deputy Director of the IISB in 2012. Image: Kurt Fuchs / Fraunhofer IISB*

2 *Dr. Jochen Friedrich, Head of the Crystal Growth Division at the Fraunhofer IISB and Deputy Spokesman for the Fraunhofer THM in Freiberg, took over the chairmanship of the Deutsche Gesellschaft für Kristallwachstum und Kristallzüchtung e.V. (DGKK) in 2012.*

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Patents

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Billmann, M.; Dorn, J.:
Leistungshalbleitermodul für die Energieverteilung

Freudenberg, B.; Radel, G.; Trempa, M.; Dadzis, K.; Dietrich, M.; Nauert, D.; Proske, S.; Reimann,C.; Friedrich. J.:
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Participation in Committees

Bauer, A.J.
- Koordinator der VDE / VDI – Fachgruppe 1.2.4 „Heißprozesse“

Burenkov, A.
- Member of the Program Committee of the V All-Russia Science and Technology Conference „Problems of advanced Micro- and Nanoelectronic Systems Development“ MES-2012, Moscow, RUS, October 2012

Erdmann, A.
- Member of the Program Committee of the “Micro- and Nanoengineering Conference Europe (MNE) 2012”, Lyon, FRA, September 2012
- Member of the Program Committee of SPIE Advanced Lithography, San José, CA, USA, February 2012
- Co-chair of the SPIE Optical Design Conference Europe, Barcelona, ESP, November 2012

Erlbacher, T.
- Mitglied im Arbeitskreis „Materialien für nichtflüchtige Speicher“ der Deutschen Gesellschaft für Materialkunde

Frey. L.
- Mitglied der Studienkommission Elektrotechnik, Elektronik und Informationstechnik
- Mitglied der Deutschen Physikalischen Gesellschaft
- Mitglied der Böhmischen Physikalischen Gesellschaft
- Member of the Excellence Cluster “Engineering of Advanced Materials” (EAM) der Universität Erlangen-Nürnberg
- Mitglied der Erlangen Graduate School in Advanced Optical Technologies (SAOT)
- Mitglied des wissenschaftlichen Beirats des Leibnitz-Instituts für Innovative Mikroelektronik IHP Frankfurt/Oder
- Member of the Evaluation Panel (NT-L) of the Swedish Research Council
- Representative of the Fraunhofer Gesellschaft / Microelectronics Alliance at the European Semiconductor Industry Association (ESIA)
- Nationale Plattform Elektromobilität, AG1
- Wissenschaftlicher Beirat der NaMLab GmbH in Dresden
- Advisory Board, Res. Inst. for Tech. Phys. and Matl. Sci. (MFA), Budapest, HUN
- Kerngutachter in der Auswahlkommission „Kooperative Projekte“ der Fraunhofer Gesellschaft mit dem Max-Planck-Institut
- Wissenschaftlicher Beirat der Gesellschaft für Mikro- und Nanoelektronik GMe, Vienna, AUT

Friedrich, J.
- Vorsitzender der Deutschen Gesellschaft für Kristallwachstum und Kristallzüchtung e.V. (DGKK)
- Mitvorsitzender des DGKK-Arbeitskreises „Herstellung und Charakterisierung massiver Halbleiter“

Content

Continuation: Participation in Committees

- Councíler in the Executive Committee of the International Organization of Crystal Growth (IOCG)
- Program Co-Chair of the "International Conference on Crystal Growing" (ICCG-17), Warsaw, POL
- Advisory Committee of International Workshop on Crystalline Silicon for Solar Cells
- Advisory Committee of International Workshop on Modeling of Crystal Growth
- Reviewer for Journal of Crystal Growth, Applied Physical Letters

Häublein, V.

- Koordinator der VDE / Vdi – GMM Fachgruppe 1.2.2. „Ionenimplantation"

Jank, M.P.M.

- Working group on nanomaterials **–** European Semiconductor Industry Association (ESIA)

Lorenz, J.

- Chairman of the Modeling and Simulation International Working Group (ITWG) of the ITRS (International Technology Roadmap for Semiconductors)
- Member of the Electrochemical Society
- Member of the Institute of Electrical and Electronics Engineers (IEEE)

März, M.

- Wissenschaftlicher Beirat „Bayerisches Cluster Leistungselektronik"
- Wissenschaftlicher Beirat „Conference on Integrated Power Systems" CIPS
- Fachbeirat im „Forum Elektromobilität e.V."
- Nationale Plattform Elektromobilität, AG1
- Center for Transportation & Logistics Neuer Adler e.V. (CNA), Steuerungskreis Automotive
- DRIVE-E Akademie, Gutachterkreis und Programmkomitee

Meißner, E.

- Member of the International Steering Committee „International Workshop on Bulk Nitride Semiconductors"
- Member of the Publication Committee of the International Workshop on Bulk Nitride Semiconductors
- Reviewer for Journal of Crystal Growth and Materials Chemistry and Physics

Öchsner, R.

- Member of the "Factory Integration Working Group (FITWG)" of the "International Technology Roadmap for Semiconductors (ITRS)"
- Member of Semicon Europe Semiconductor Technology Programs Committee (STC)
- Member of the Steering Committee European 450 mm Equipment & Materials Initiative: EEMI 450
- Mitglied im Kernteam Spitzencluster Automation Valley
- Member of the Advisory Committee "online educa", International Conference on Technology Supported Training and Learning
- Member of SEMI European Equipment Automation Committee
- Member of SEMI Task Force: Equipment Productivity Metrics Task Force
- Member of SEMI Task Force: Process Control Systems (PCS)
- Member of SEMI Task Force: Data Quality

Pichler, P.

- Member of the Board of Delegates of the European Materials Research Society (E-MRS)

Pfitzner, L.

- Honorarprofessor an der Universität Erlangen-Nürnberg, Fachbereich Elektrotechnik
- Chair of IPWGN (International Planning Working Group of Nanoelectronics)
- Chairman of the Executive Committee and of the 4th International Conference on "450 mm - Status and Overview" 2012, Dresden, Germany, October 9-10
- Member of the Program Committee of the 5th International Conference on "450 mm - Status and Overview", Dresden, October 09 – 10, 2013
- Member of the Program Committee ISSM 2012 (IEEE „International Symposium on Semiconductor Manufacturing „), Tokyo, JPN, October 15-17
- Member of the Program Committee ISSM 2013, September 6, 2013, HsinChu, Taiwan
- Member of the Program Committee of the FCMA, International Conference on " Frontiers of Characterization and Metrology for Nanoelectronics", Gaithersburg, MD, USA, March 25-28, 2013
- Chairman of the „Yield Enhancement Working Group" (ITWG) of the ITRS (International Technology Roadmap for Semiconductors) Conference 2012, Tokyo, JPN, December 3-4
- Mitglied der VDE/VDI-Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik, Fachbereich „Halbleitertechnologie und Halbleiterfertigung", Leiter des Fachausschusses „Produktion und Fertigungsgeräte"
- Mitglied der VDE/VDI-Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik, Fachbereich „Halbleitertechnologie und Halbleiterfertigung", Leiter der Fachgruppe 1.1„Geräte und Materialien"
- Co-chair of the SEMI Task Force „Environmental Contamination Control"

Content

Continuation: Participation in Committees

- Co-chair of the Standardization Committee „Equipment Automation Standards Committee“ of SEMI
- Member of the „Global Coordination Committee“ of SEMI
- Member of the “European Planning Group for 450 mm Technology (“EEMI450”)”
- Mitglied des Strategischen Beirats des österreichischen Bundesministeriums für Verkehr, Innovation und Technologie (BMVIT) für die Initiative „Intelligente Produktion“

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

Rommel, M.
- Koordinator der VDE/VDI-GMM-Fachgruppe 1.2.6 „Prozesskontrolle, Inspektion & Analytik“

Ryssel, H.
- International Committee of the Conference “Ion Implantation Technology” (IIT). The conference takes place biannually alternatingly in Europe, the USA, and East Asia.
- Mitglied der Informationstechnischen Gesellschaft (ITG): Leiter des Fachausschusses 8.1 „Festkörpertechnologie“
- Mitglied der VDE/VDI Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik (GMM), Leiter des Fachbereichs 1, „Mikro- und Nanoelektronik-Herstellung“, Leiter der Fachgruppe 1.2.2 „Ionenimplantation“
- Mitglied des Beirats der Bayerischen Kooperationsinitiative Elektronik / Mikrotechnologie (Bayerisches Staatsministerium für Wirtschaft, Verkehr und Technologie)
- Mitglied der Böhmischen Physikalischen Gesellschaft
- Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE)
- Editorial Board of “Radiation Effects and Defects in Solids” Taylor & Francis Ltd., Abingdon, U.K.
- Member of the European SEMI Award Committee
- Ambassador des Excellence Cluster “Engineering of Advanced Materials” (EAM) der Universität Erlangen-Nürnberg
- Ambassador der Erlangen Graduate School in Advanced Optical Technologies (SAOT)

Schellenberger, M.
- Leiter der europäischen SEMI PCS-Taskforce
- Mitglied im Programmkomitee und Steeringkomitee der europäischen AEC/APC-Konferenz

Smazinka, T.
- DKE UK 767.3 EMV - Hochfrequente Störgrößen

Conferences, Workshops, Fairs, and Exhibitions

Kolloquium zur Halbleitertechnologie und Messtechnik
IISB, Erlangen, October 17, 2011 – February 06, 2012

4. Erlanger Symposium über Kristallzüchtung von Halbleitern und optischen Kristallen
Erlangen, January 20, 2012

Schülerbesuch Gymnasium Eckental
IISB, Erlangen, January 26, 2012

8th International Thin-Film Transistor Conference
Lisbon, POR, January 30 – 31, 2012

Schülerbesuch Gymnasium Stein
IISB, Erlangen, February 07, 2012

“realize your visions!”
Nuremberg, February 16, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Thermal Management“
IISB, Erlangen, March 05, 2012

OE-A 26th Working Group Meeting
Cambridge, UK, March 06 – 07, 2012

42. Deutsche Kristallzüchtungstagung DKT 2012,
Freiberg, March 07 – 09, 2012

DRIVE-E-Akademie und DRIVE-E-Studienpreis 2012
Aachen, March 12 – 16, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Elektromagnetische Verträglichkeit (EMV)“
IISB, Erlangen, March 19, 2012

31. Treffen der Nutzergruppe Heißprozesse
IISB, Erlangen, March 21, 2012

47. Treffen der Nutzergruppen Ionenimplantation
IISB, Erlangen, March 22, 2012
Kolloquium zur Halbleitertechnologie und Messtechnik
IISB, Erlangen, Summer Semester 2012

Printed Electronics Europe 2012
Berlin, April 03 - 04, 2012

MRS Spring Meeting 2012
San Francisco, CA, USA, April 09 – 13, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Bipolare SiC-Bauelemente“
IISB, Erlangen, April 16, 2012

12th European Advanced Process Control and Manufacturing Conference
Grenoble, FRA, April 16 – 18, 2012

Besuch des Kollegiums des Fachbereiches Elektrotechnik der Rudolf-Diesel-Fachschule
IISB, Erlangen, April 19, 2012

Girls’ Day 2012
IISB, Erlangen, April 26, 2012

Content

Continuation: Conferences, Workshops, Fairs, and Exhibitions

PCIM 2012 – International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management
Nuremberg, May 08 – 10, 2012

26. Internationale Fachmesse für Qualitätssicherung Control 2012
Stuttgart, May 08 –11, 2012

Fraunhofer Energietage „Lösungen für die Energiewende“
Berlin, May 10 – 11, 2012

Forum ElektroMobilität KONGRESS 2012
Berlin, May 15 – 16, 2012

23rd Annual SEMI Advanced Semiconductor Manufacturing Conference (ASMC 2012)
Saratoga Springs, NY, USA, May 15 – 17, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Aufbautechnologien im Test“
IISB, Erlangen, May 21, 2012

21st IEEE International Symposium on Industrial Electronics – ISIE 2012
Hangzhou, CHN, May 28, 2012

International Conference on Computational Science – ICCS 2012
Omaha, NE, USA, June 04 – 07, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Batterie-Management-Systeme für die Elektromobilität“
IISB, Erlangen, June 18, 2012

International Conference on Extended Defects in Semiconductors
Thessaloniki, GRE, June 24 – 29, 2012

Workshop on Dielectrics in Microelectronics (WoDiM)
Dresden, June 25 – 27, 2012

International Conference on Ion Implantation Technology – IIT 2012
Valladolid, ESP, June 25 – 29, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Isolierende Gleichspannungswandler für E-Fahrzeuge“
IISB, Erlangen, July 16, 2012

6. Wissenschaftstag der Metropolregion Nürnberg
Erlangen, July 20, 2012

Schülerbesuch Emil-von-Behring-Gymnasium Spardorf
IISB, Erlangen, July 25, 2012

19th International Conference on Ion Implantation Technology
Valladolid, ESP, July 25 – 29, 2012

7th International Conference on Advanced Materials – ROCAM 2012
Brasov, ROM, August 28 – 31, 2012

European Conference on Silicon Carbide and Related Materials – ECSCRM 2012
Saint Petersburg, RUS, September 02 – 06, 2012

SISPAD 2012 – International Conference on Simulation of Semiconductor Processes and Devices
Denver, COL, USA, September 05 – 07, 2012

Advanced Process Control Conference (APC)
Ann Arbor, MI, USA, September 10 –12, 2012

38th International Conference on Micro and Nano Engineering MNE 2012
Toulouse, FRA, September 16 – 20, 2012

E-MRS 2012 Fall Meeting
Warsaw, POL, September 17 – 21, 2012

42nd European Solid-State Device Research Conference – ESSDERC 2012
Bordeaux, FRA, September 17 – 21, 2012

4th Sino-German Symposium “The Silicon Age”
Berlin, September, 18 – 23, 2012

10th Fraunhofer IISB Lithography Simulation Workshop
Hersbruck, September 20 – 22, 2012

32. Treffen der Nutzergruppe Heißprozesse
Reutte, AUT, September 26, 2012

48. Treffen der Nutzergruppe Ionenimplantation
Reutte, AUT, September 27, 2012

Kolloquium zur Halbleitertechnologie und Messtechnik
IISB, Erlangen, Winter Semester 2012/2013

DGKK-Workshop „Herstellung und Charakterisierung von massiven Halbleiterkristallen“
Freiberg, October 04 – 05, 2012

6th International workshop on Crystalline Silicon for Solar Cells (CSSC6)
Aix-les-Bains, FRA, October 08 – 11, 2012

4th International Conference on „450mm – Status and Overview“
Dresden, October 09 – 10, 2012

Plastic Electronics Conference
Dresden, October 09 – 11, 2012

SEMICON Europa 2012
Dresden, October 09 – 11, 2012

Deutsche IMAPS-Konferenz
Munich, October 12, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung“, Themenschwerpunkt „Digital Power“
IISB, Erlangen, October 15, 2012

Schülerbesuch Friedrich-Alexander-Gymnasium Neustadt a.d. Aisch
IISB, Erlangen , October 17, 2012

EAM Symposium 2012, Exzellence Cluster Engineering of Advanced Materials
Oberhof, October 24, 2012

e-studentday 2012
Stuttgart, November 05, 2012

NAMES AND DATA
SCIENTIFIC PUBLICATIONS

Content

Continuation: Conferences, Workshops, Fairs, and Exhibitions

Cluster–Seminar „Niederspannungs-Gleichstromnetze / LV DC Grids"
IISB, Erlangen, November 07 – 08, 2012

13. Firmenkontaktmesse der Ingenieurwissenschaften und Informatik contactING 2012
Nuremberg, November 15, 2012

Preisverleihung Energie Campus Nürnberg „Ein Ort im Land der Ideen" 2012
Nuremberg, November 16, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung", Themenschwerpunkt „Intelligente e-Antriebe für die Elektromobilität"
IISB, Erlangen, November 19, 2012

Fachtagung Nanoadditive, Bundesanstalt für Material Prüfung (BAM)
Berlin, November 19 – 20, 2012

19. Nordbayerische Kontaktmesse für Industrie und Studierende technischer Fachrichtungen CONTACT 2012
Erlangen, November 21, 2012

International Conference On Smart Grid Technology, Economics and Policies SG-TEP 2012
Nuremberg, December 03 – 04, 2012

27. DGKK-Workshop „Epitaxie von III/V-Halbleitern"
Erlangen, December 06 – 07, 2012

14. Jahrestagung des Fraunhofer IISB – Maßgeschneiderte Substrate für energieeffiziente Wide-Bandgap-Bauelemente
IISB, Erlangen, December 06, 2012

GMM-VDE/VDI-Fachgruppe 1.2.3, Abscheide- und Ätzverfahren, Fachausschuss 1.2: Verfahren, Nutzergruppentreffen PVD, PECVD und Ätzen
IISB, Erlangen, December 12, 2012

GMM-VDE/VDI-Fachgruppe 1.2.3, Abscheide- und Ätzverfahren, Fachausschuss 1.2: Verfahren, 15. Workshop der GMM – Fachgruppe 1.2.3 Abscheide- und Ätzverfahren
IISB, Erlangen, December 13, 2012

Leistungselektronik - Öffentliche Vortragsreihe des Fraunhofer-Innovationsclusters „Elektronik für nachhaltige Energienutzung", Themenschwerpunkt „SiC- und GaN- Bauelemente im Vergleich"
IISB, Erlangen, December 17, 2012

Publications

Agudelo, V.; Evanschitzky, P.; Erdmann, A.; Fühner, T.:
Evaluation of various compact mask and imaging models for the efficient simulation of mask topography effects in immersion lithography
Proceedings, SPIE, 8326, 832609, 2012
DOI: 10.1117/12.916344

Alt, N.S.A.; Meißner, E.; Schlücker, E.:
Development of a novel in situ monitoring technology for ammonothermal reactors
Journal of Crystal Growth 350, 2, 2012
DOI: 10.1016/j.jcrysgro.2011.12.012

Alt, N.S.A.; Meißner, E.; Schlücker, E.:
Development of a novel in situ monitoring technology for ammonothermal reactors
Phys. Status Solidi C 9, 3, 436, 2012

Alt, N.S.A.; Meißner, E.; Schlücker, E.; Frey, L.:
In situ monitoring technologies for ammonthermal reactors
Journal of Crystal Growth 350, 2, 2012

Alt, N.S.A.; Meißner, E.; Schlücker, E.; Frey, L.:
In situ monitoring technologies for ammonthermal reactors
Physica status solidi, 3, 436, 2012
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Azizi, M.; Meißner, E.; Friedrich, J.:
Considerations on the effect of interstitial and precipitated Fe in intentionally Fe-doped mc-silicon
Trans Tech Publications, 725, 145, 2012
DOI: 10.4028/www.scientific.net/M

Baum, M.; Polster, S.; Jank, M.P.M.; Alexeev, I.; Frey, L.; Schmidt, M.:
Efficient laser induced consolidation of nanoparticulate ZnO thin films with reduced thermal budget
Applied Physics. A 107, 2, 269, 2012
DOI: 10.1007/s00339-012-6871-0

Content

Continuation: Publications

Beltran, A.M.; Schamm-Chardon, S.; Mortet, V.; Lefebvre, M.; Bedel-Pereira, E.; Cristiano, F.; Strenger, C.; Häublein, V.; Bauer, A.J.:
Nano-analytical and electrical characterization of 4H-SiC MOSFETs
Material Science Forum 717, 134, 2012
DOI: 10.4028/www.scientific.net/MSF.7.11.134

Brandl, M.; Gall, H.; Wenger, M.; Lorentz, V.; Giegerich, M.; Baronti, F.; Fantechi, G.; Fanucci, L.; Roncella, R.; Saletti, R.; Saponara, S.; Thaler, A.; Cifrain, M.; Prochazka, W.:
Batteries and battery management systems for electric vehicles
Proceedings, IEEE, EDAA, Design, Automation & Test in Europe Conference & Exhibition (DATE), 971, 2012

Burenkov, A.; Bär, E.; Lorenz, J.; Kampen, C.:
Correlation-aware analysis of the impact of process variations on circuit behavior
Proceedings International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), 260, 2012

Burenkov, A.; Hahn, A.; Spiegel, Y.; Etienne, H.; Torregrosa, F.:
Simulation of BF3 plasma immersion ion implantation into silicon,
Proceedings of the 19th International Conference on Ion Implantation Technology IIT 2012, Valladolid, 233, 2012
DOI: 10.1063/1.4766531

Burenkov, A.; Sekowski, M.; Belko, V.; Ryssel, H.:
Angular distributions of sputtered silicon at grazing gallium ion beam incidence
Beam interactions with materials and atoms 272, 23, 2012

Cristiano, F.; Essa, Z.; Qiu, Y.; Spiegel, Y.; Torregrosa, F.; Duchaine, J.; Boulenc, P.; Tavernier, C.; Cojocaru, O.; Blavette, D.; Mangelinck, D.; Fazzini, P.F.; Quillec, M.; Bazizi, M.; Hackenberg, M.; Boninelli, S.:
Implantation-induced structural defects in highly activated USJs: Boron precipitation and trapping in pre-amorphised silicon
IEEE, 131, 2012
DOI: 10.1109/IWJT.2012.6212827

Daves, W.; Krauss, A.; Häublein, V.; Bauer, A.J.; Frey, L.:
4 H-SiC MOSFETs with a stable protective coating for harsh environment applications
Materials Science Forum, 717, 1089, 2012
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Denisov, A.V.; Molchanov, A.; Punin, Y.O.; Krymov, V.M.; Müller, G.; Friedrich, J.:
Analysis of the growth conditions of long single crystalline basal-plane-faceted sapphire ribbons by the Stepanov/EFG technique
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DOI: 10.1016/j.jcrysgro.2012.02.005

Dobmann, S.; Shyroki, D.; Banzer, P.; Erdmann, A.; Peschel, U.:
Resonant metamaterials for contrast enhancement in optical lithography
Optics Express 20, 18, 19928, 2012
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Erdmann, A.; Evanschitzky, P.; Bret, T.; Jonckheerec, R.:
Analysis of EUV mask multilayer defect printing characteristics
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Erlbacher, T.; Bauer, A.J.; Frey, L.:
Significant on-resistance reduction of LDMOS devices by intermitted trench gates integration
IEEE transactions on electron devices 59, 12, 3470, 2012
DOI: 10.1109/TED.2012.2220777

Erlbacher, T.; Bickermann, M.; Kallinger, B.; Meißner, E.; Bauer, A.J.; Frey, L.:
Ohmic and rectifying contacts on bulk AlN for radiation detector applications
Physica status solidi C 9, 3, 968, 2012
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Erlbacher, T.; Huerner, A.; Bauer, A.J.; Frey, L.:
Feasibility and limitations of anti-fuses based on bistable non-volatile switches for power electronic applications
Solid-State Electronics 75, 33, 2012
DOI: 10.1016/j.sse.2012.05.004

Erlbacher, T.; Schwarzmann, H.; Bauer, A.J.; Berberich, S.E.; Dorp, J. vom; Frey, L.:
Improving module performance and reliability in power electronic applications by monolithic integration of RC-snubbers
Proceedings, IEEE, 24th International Symposium on Power Semiconductor Devices & ICs, 283, 2012
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Continuation: Publications

Essa, Z.; Cristiano, F.; Spiegel, Y.; Boulenc, P.; Qiu, Y.; Quillec, M.; Taleb, N.; Burenkov, A.; Hackenberg, M.; Bedel-Pereira, E.; Mortet, V.; Torregrosa, F.; Tavernier, C.:
BF3 PIII modeling: Implantation, amorphisation and diffusion
Proceedings, American Institute of Physics (AIP), 1496, 237, 2012
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Evanschitzky, P.; Shao, F.; Erdmann, A.:
Efficient simulation of EUV multilayer defects with rigorous data base approach
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Fader, R.; Schmitt, H.; Rommel, M.; Bauer, A.J.; Frey, L.; Ji, R.; Hornung, M.; Brehm, M.; Vogler, M.:
Novel organic polymer for UV-enhanced substrate conformal imprint lithography
Microelectronic engineering 98, 238, 2012
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Fader, R.; Schmitt, H.; Rommel, M.; Bauer, A.J.; Frey, L.; Ji, R.; Hornung, M.; Brehm, M.; Vogler, M.:
Substrate Conformal Imprint Lithography of Functional Materials
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Kristalle – Wunderwerkstoffe für die Industrie
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Friedrich, J.; Müller, G.:
Kristallmaterialien – Schlüsselwerkstoffe für Zukunftstechnologien
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ECS Transactions 2013 50, 79, 13, 2012

Führer, T.; Evanschitzky, P.; Erdmann, A.:
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Proceeding, SPIE, 8326, 83260I, 2012
DOI: 10.1117/12.916529

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Gumprecht, T.; Roeder, G.; Schellenberger, M.; Pfitzner, L.:
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Proceedings, IEEE 23rd Annual SEMI Advanced Semiconductor Manufacturing Conference, ASMC 2012, 82, 2012
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Hackenberg, M.; Huet, K.; Negru, R.; Venturini, J.; Fisicaro, G.; La Magna, A.; Pichler, P.:
Modeling boron profiles in silicon after pulsed excimer laser annealing
Proceedings, American Institute of Physics (AIP), 1496, 241, 2012
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Hackenberg, M.; Pichler, P.; Huet, K.; Negru, R.; Venturini, J.; Pakfar, A.; Tavernier, C.; La Magna, A.:
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Applied surface science 258, 23, 9347, 2012
DOI: 10.1016/j.apsusc.2012.01.130

Häublein, V.; Ryssel, H.; Frey, L.:
Purity of ion beams: Analysis and simulation of mass spectra and mass interferences in ion implantation
Advances in materials science and engineering. Online journal, 610150, 9, 2012
DOI: 10.1155/2012/610150

Hofmann, M.; Schletz, A.; Domes, K.; März, M.; Frey, L.:
Modular Inverter Power Electronic for Intelligent e-Drives.
IEEE-Proceedings of 2nd International Electric Drives Production Conference (EDPC), Nuremberg, 2012

Hutzler, A.; Engelmann, S.:
Gezielt maximieren, minimieren und optimieren
Qualität und Zuverlässigkeit 57, 10, 38, 2012

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Continuation: Publications

Jin, Y.X.; Guan, H.Y.; Kong, F.Y.; Wang, J.P.; Erdmann, A.; Liu, S.J.; Du, Y.; Shao, J.D.; He, H.B.; Yi, K.:
Influence of two typical defects on the near-field optical properties of multilayer dielectric compression gratings
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Kallinger, B.; Berwian, P.; Friedrich, J.; Müller, G.; Weber, A.; Volz, E.; Trachta, G.; Spiecker, E.; Thomas, B.:
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Journal of Crystal Growth 349, 1, 43, 2012
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Koffel, S.; Pichler, P.; Reading, M.A.; Berg, J. van den; Kheyrandish, H.; Hamm, S.; Lerch, W.; Pakfar, A.; Tavernier, C.:
Precipitation of antimony implanted into silicon
ECS transactions 41, 23, 9, 2012
DOI: 10.1149/1.3697457

Koitzsch, M.; Lewke, D.; Kaule, F.; Oswald, M.; Schoenfelder, S.; Turek, M.; Büchel, A.; Zühlke, H.:
Thermal laser separation - damage-free and kerfless cutting of wafers and solar cells
Proceedings, INES 6th International Workshop on Crystalline Silicon for Solar Cells, CSSC, 4, 2012

Koitzsch, M.; Lewke, D.; Schellenberger, M.; Pfitzner, L.; Ryssel, H.; Zühlke, H.U.:
Enhancements in resizing single crystalline silicon wafers up to 450 mm by using thermal laser separation
Proceedings, IEEE 23rd Annual SEMI Advanced Semiconductor Manufacturing Conference, ASMC 2012, 336, 2012
DOI: 10.1109/ASMC.2012.6212923

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