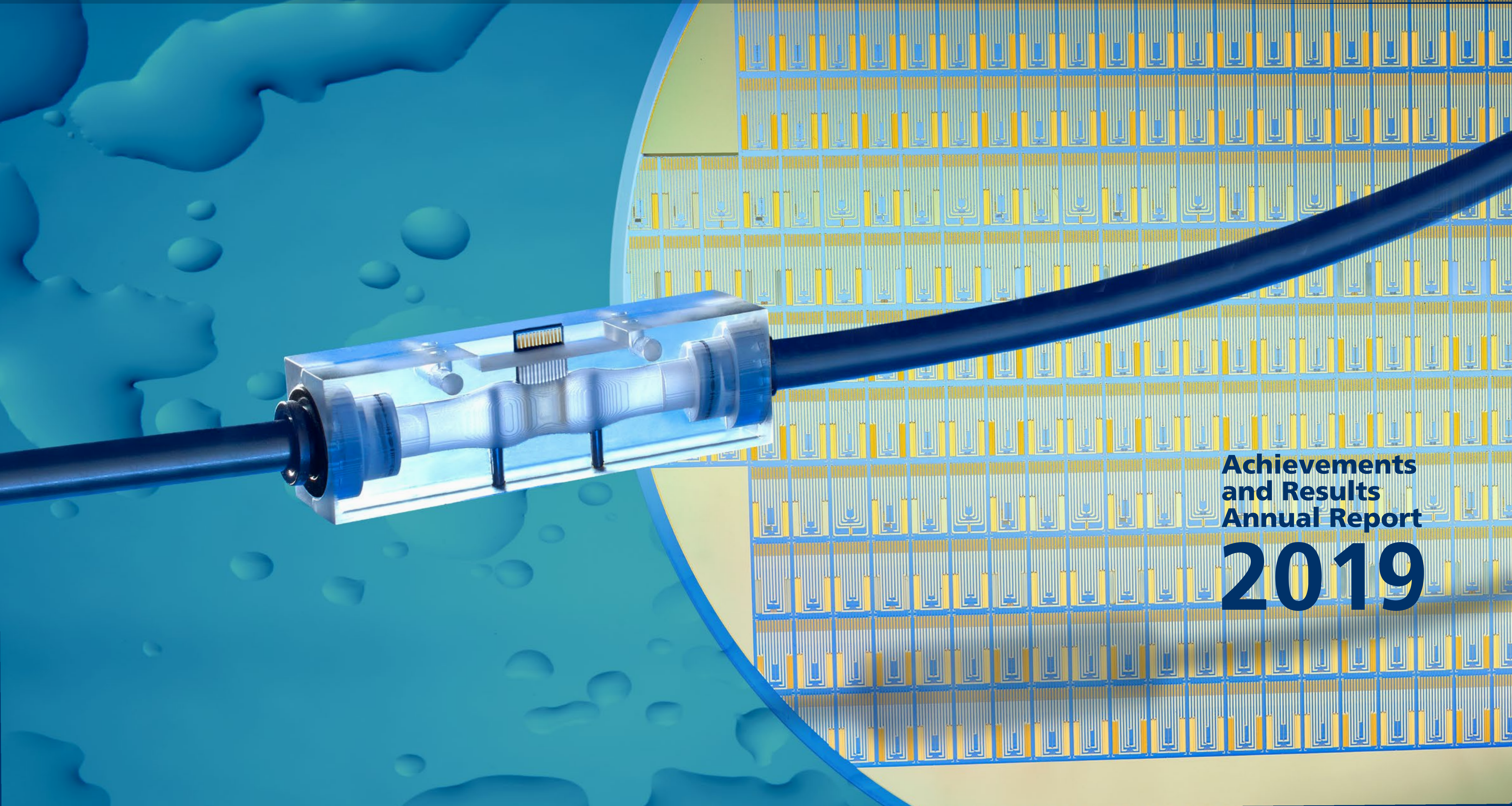
Fraunhofer

ISIT

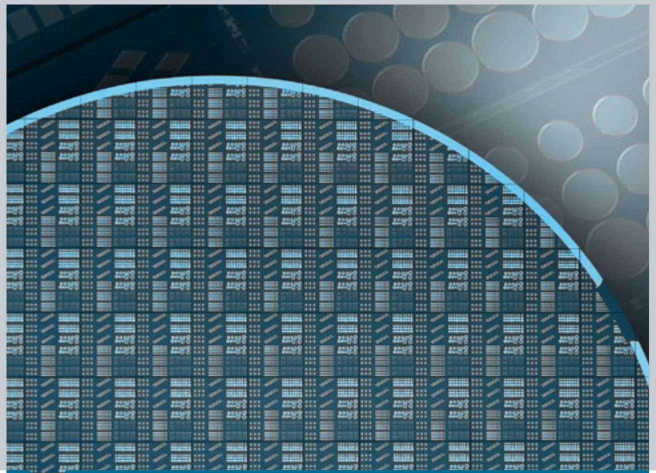
FRAUNHOFER INSTITUTE FOR SILICON TECHNOLOGY ISIT

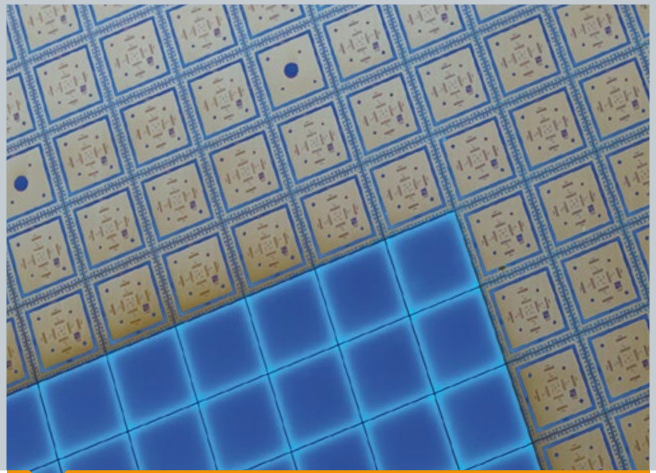
ANNUAL REPORT 2019

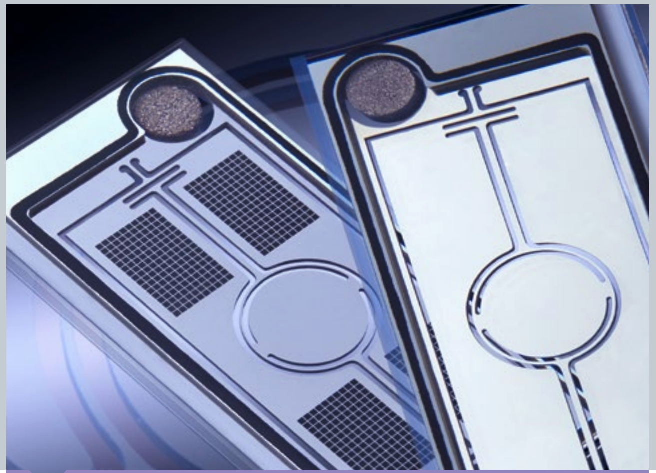
Water is the most valuable resource on earth. We can only live in the presence of water and we use it for drinking as well as for sanitary purposes. – Turning potable water into a disinfecting agent is the idea behind the project MIKROOZON: A small electrolysis device generates a weak, but sufficient concentration of ozone that allows using water as a sanitizing agent directly at the point of use, e.g. in showers toilets or beverage vending machines. – The picture shows a sensor that ISIT developed in MIKROOZON to measure the conductivity, flow rate and temperature of water supplied to the micro ozone generator. The data is used to calculate the electrolysis current that is necessary to obtain the desired ozone concentration.



Achievements and Results Annual Report 2019







ANNUAL REPORT 2019

Dr. Axel
Müller-Groeling
Director of the Fraunhofer Institute for Silicon Technology ISIT since 2016
Cooperations with Academia, Entrepreneurs, Friends.
Consultant of Customers, Partners, Colleagues.
Passion for Innovation, Structure, Rigour (and Table Tennis).
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Dear business partners, dear friends of ISIT, dear colleagues,

ISIT put a lot of effort into Schleswig-Holstein's bid for the Research Factory for Battery Cells during the past year. My colleagues and I coordinated this application for Schleswig-Holstein and presented it to the public in May. From my perspective, the bid turned out to be remarkably rich in content and highly promising. Companies like Danfoss, ThyssenKrupp Marine Systems, and Dräger supported us along with the states of Mecklenburg-Vorpommern and Hamburg. I would like to thank all participants for their hard work on the application, and the town of Itzehoe and district of Steinburg for their regional support of the project. An entire region committed to supporting this project with great enthusiasm and dedication.

The bid lists a number of aspects as advantages of the Itzehoe site, including the existing expertise and research infrastructure in Itzehoe, the availability of outstanding educational institutions, especially in the relevant fields of microelectronics, electronics, and mechatronics, vacant space, and the rapid availability of buildings.

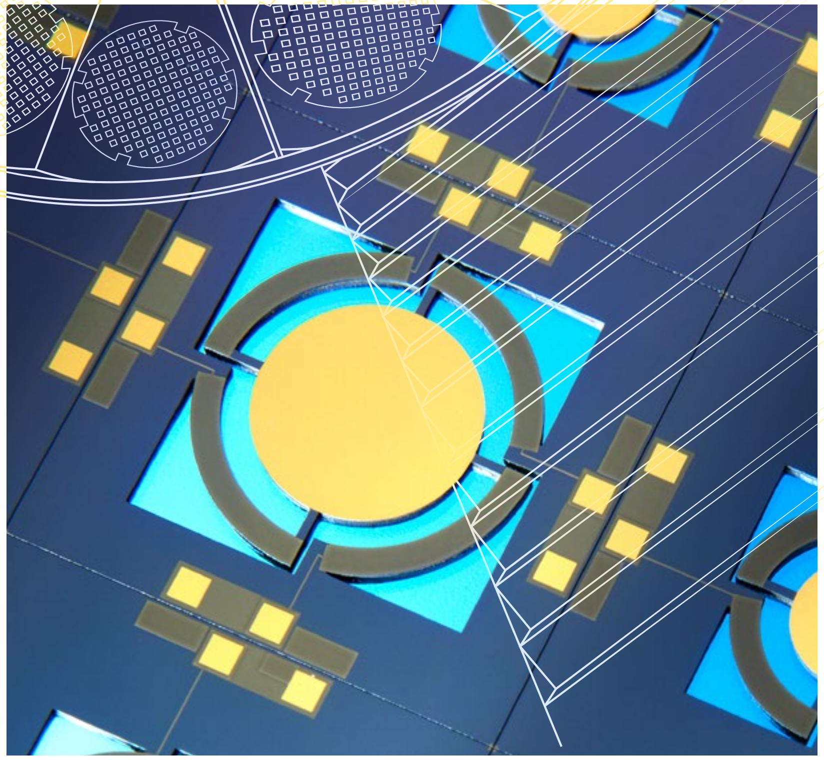
Aside from Fraunhofer ISIT, the Federal Ministry of Education and Research asked seven other research institutes across the country to apply. We faced tough competition for the project by states such as Niedersachsen, Baden-Württemberg, and Nordrhein-Westfalen, and ultimately Münster was chosen last fall. Nevertheless the bid represents a major gain. We identified and efficiently bundled our expertise in the field of storage technologies in 2019, thereby establishing excellent prerequisites for future projects. What's more, we have clearly put Itzehoe and Schleswig-Holstein on the map in battery research.

Strategic Further Development of ISIT

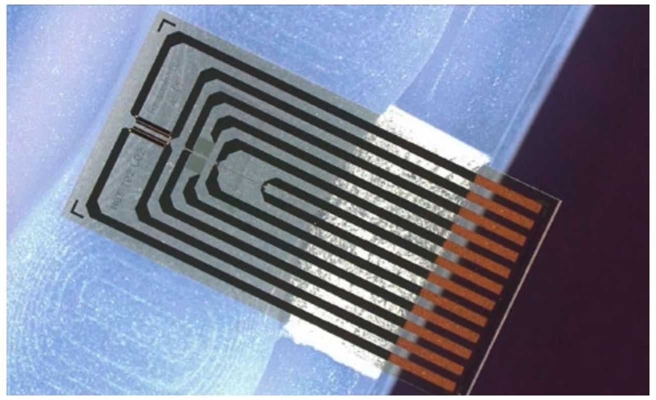
For ISIT, 2019 was dedicated to the organization's ongoing professionalization, with the objective of ensuring that the institute will remain an important driving force behind tomorrow's technology as an economically successful research institution. This also includes a significant strengthening of our personnel expertise. We have therefore pursued an extensive strategy process for ISIT since 2017 and installed uniform controlling and budget processes as well as a performance figure system at ISIT.

In 2019 we established business development as a new function, intensified sales for the institute through concerted market and trend analyses, and considerably accelerated acquisition temporarily with additional external consultants. Within the staff, we promoted personnel development and cultural change by establishing a new career model and also an internal assessment system for individual employees. Such far-reaching changes have an impact on the people in an organization, and I am aware that much is being demanded from our colleagues. I am all the more pleased that our

Lithography at ISIT cleanroom



Piezoelectric MEMS micromirrors



Glass chip with sensor elements to measure water flow, conductivity and temperature

change process, all necessary discussions notwithstanding, is on the right track according to the large majority of opinions in the institute and also within the ISIT advisory board.

We will continue focusing on six strategic application focal points. These include "optical microsystems" such as scanners or projectors and "acoustic microsystems" such as speakers, microphones, or ultrasonic transducers, among other things for medical engineering. The "wafer-level packaging and pilot production" application focal point is dedicated to the systematic transfer of demonstrated methods to industrial production. "Module integration" with its structural and joining technologies as well as its quality and reliability analyses combines microsystems technology components into functional modules. The "next-generation transistors" application focal point is about optimizing existing PowerMOS transistors, vertical power transistors on the basis of gallium nitride (GaN), and aluminum scandium nitride (AlScN) as a new, highly promising material (more on that below). Topics of the "high-performance battery systems" focal point include battery cells for very short charge/discharge times with corresponding converters and battery management systems.

Research Fab Microelectronics Germany

Fraunhofer ISIT is part of Research Fab Microelectronics Germany, which was initiated in 2017 by the Federal Ministry of Education and Research (BMBF) as the largest multi-site consortium of research and development institutions for microelectronics and nanoelectronics in Europe. More than 2000 scientists in 11 Fraunhofer and 2 Leibniz institutes offer the complete value chain for microelectronics and nanoelectronics from one source. FMD has assumed major strategic importance for ISIT in the last three years. We have expanded and modernized the clean room facilities with subsidies of 19.3 million euros. With the additional equipment pool, we were able to significantly improve the technological maturity of our development work and, in particular, further secure ISIT's future technological viability as well.

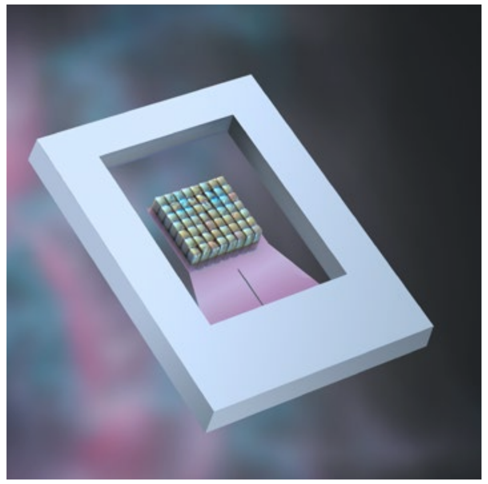
Research Highlights

Fraunhofer ISIT achieved a number of important scientific/technical developments over the last few years. I would like to describe two particularly outstanding developments in more detail:

First there is the discovery of an entirely new property in a material that is significant for semiconductor technology, which promises major development leaps in microsystems engineering and microelectronics. During routine measurements on layers of aluminum scandium nitride (AlScN), a material for microdrives, researchers at Christian-Albrechts University of Kiel and Fraunhofer ISIT observed a change in the crystal structure and discovered that the material has what are known as ferroelectric properties. That means the AlScN crystals can have a permanent spatial electrical orientation, which can be "switched" by applying an electrical voltage. This property can for example be used to store information or to provide particularly strong forces for highly efficient actuators. Thus this discovery may be of major importance in the world of technology. We are only now beginning to survey the diverse new applications in transistors, actuators, and many other technology fields. ISIT in cooperation with CAU and the Fraunhofer Institute for Applied Solid State Physics IAF is currently investigating the extent of possible technical applications offered by this promising discovery in a project subsidized by the Federal Ministry of Education and Research (BMBF) with 2.3 million euros.

As a second research highlight, I would like to point out a new process for the production of microstructures developed at ISIT – powder technology. I believe it has disruptive potential for microsystems engineering. A team of ISIT scientists headed by our Chief Engineer Dr. Thomas Lisec has developed a process for the production of porous three-dimensional microstructures using bonded powder materials. Shrink-free and permanently mechanically stable structures of various geometries can be fabricated using this powder technology, with sizes ranging from a few micrometers up to one millimeter. Powders consisting of particles with dimensions of a few micrometers serve as the base material. The particle material can for all intents and purposes be freely chosen.

ISIT with the support of the state has begun setting up a dedicated laboratory for the powder technology. Fraunhofer ISIT's focus with the new laboratory is on the high-precision production of microstructures from various functional materials with specific magnetic, optical, or chemical properties for sensors and actuators. ISIT scientists have already fabricated miniaturized permanent magnets with the help of this technology, for example for energy harvesters that convert vibrational energy from the surroundings into electrical energy and thereby provide sensors in industry 4.0 applications with their own energy source, but also for sensors to monitor power networks or adaptive lighting systems for vehicle headlights and head up displays.



Magneto-sensitive piezoelectric energy harvester

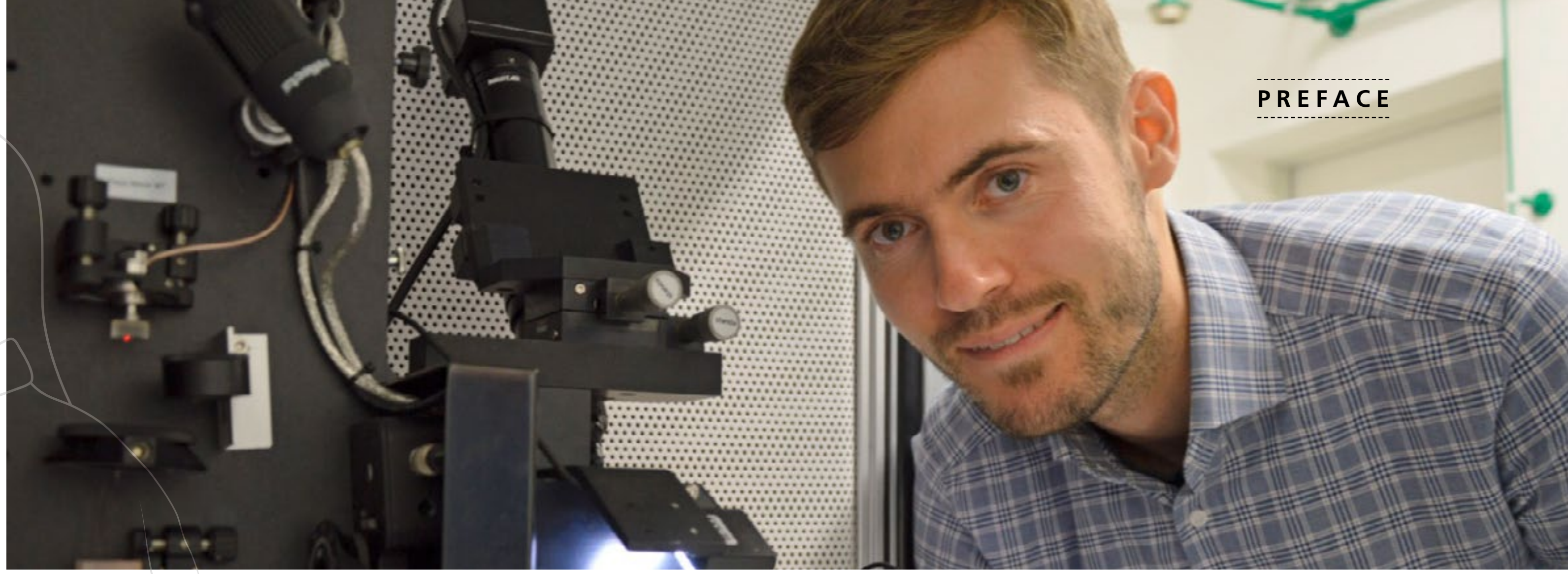
We believe the market potential of this development is huge and can generate an enormous boost to growth. If automating the process succeeds as well, ISIT would initially also be the world's only institution with corresponding production capabilities. Then jobs for pilot production could be created at ISIT and, in case of series production, the process for specific products could be transferred to a regional company or a spin-off to be founded.

Cooperation with Research Institutions in the Region – Student Life in Itzehoe

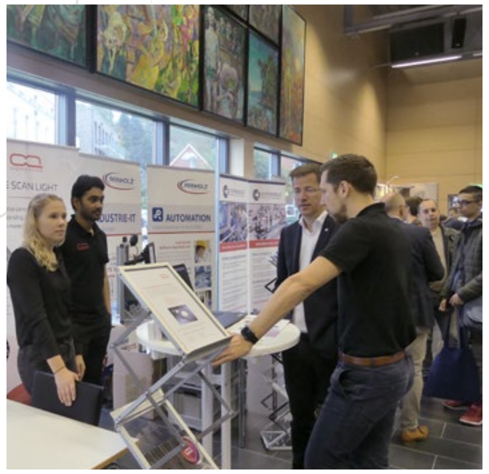
Fraunhofer ISIT actively networks with other research institutions in the region. I have already reported on our intensive cooperation with the technical faculty of CAU, but there have been numerous joint activities with other universities as well. Thus ISIT supported the Future Energies Science Match event in Kiel initiated by the state government as a network partner again this year and, together with many other scientists from Schleswig-Holstein, participated in the program with various contributions on the topics of "power electronics systems", "battery development", and "energy harvesting for autonomous systems".

Microtec Nord was held for the tenth time at ISIT in Itzehoe in 2019. This convention is organized by the West Coast University of Applied Sciences in close cooperation with Fraunhofer ISIT, HAW Hamburg, the IZET Innovation Center, the RBZ, the Itzehoe regional education center, NXP, and the Hamburg metropolitan region. Around 100 experts from northern Germany's microelectronics community discussed the topic of intelligent sensor systems – wireless, self-sufficient, networked.

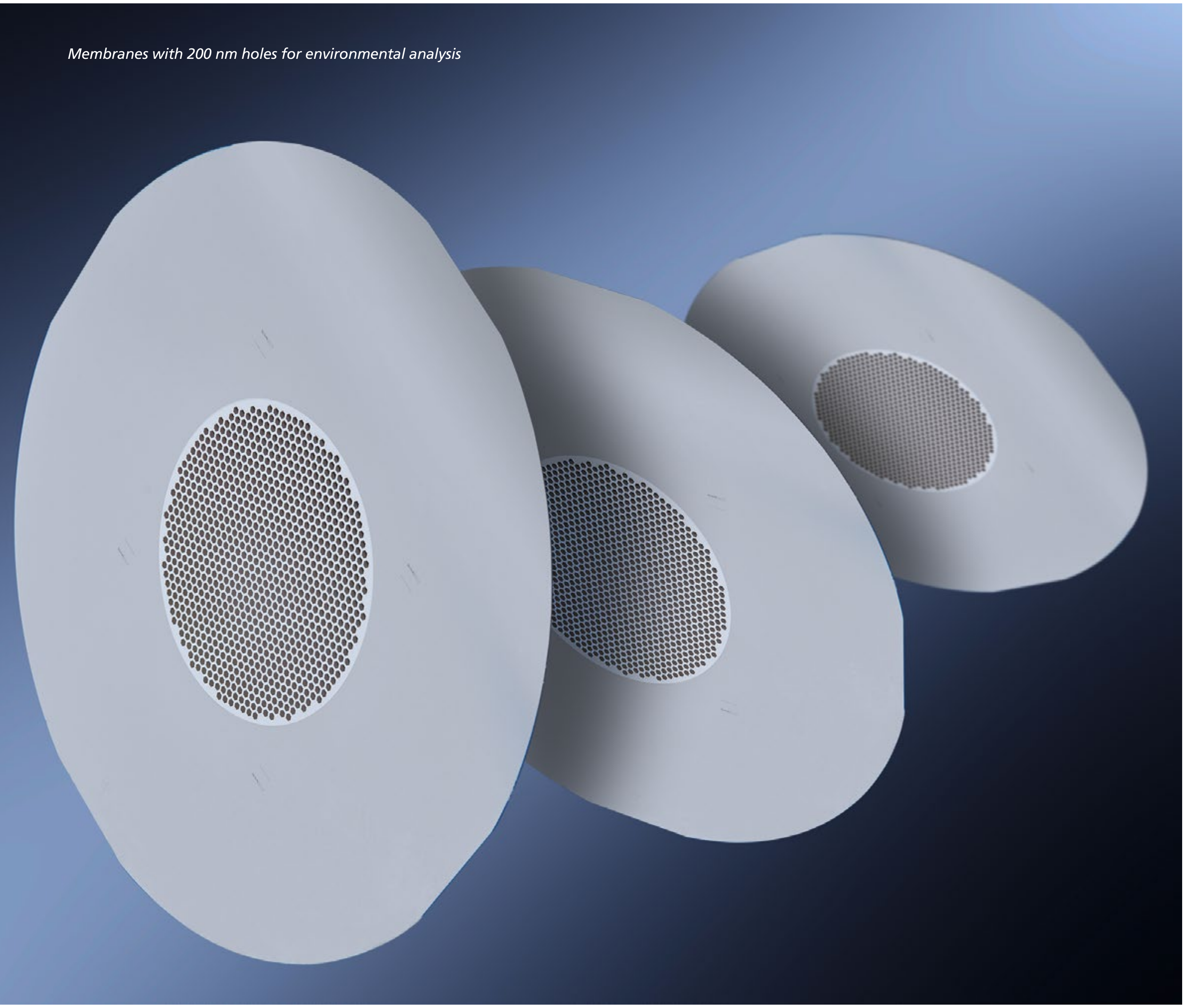
In September ISIT presented itself alongside eight other companies from the Itzehoe innovation region and the IZET



ISIT scientist Dr. Simon Fichtner



Above left: Dr. Axel Müller Groeling in conversation with company representatives from the innovation campus Itzehoe at the company contact day, FH Kiel
Above right: Mark Helfrich, Dr. Andreas Koeppen, Dr. Thilo Rohlfs and Dr. Axel Müller-Groeling presented the application for the Research Factory for Battery Cells.
Bottom: Science Match Future Energies, Sparkassen-Arena-Kiel



Membranes with 200 nm holes for environmental analysis

Innovation Center as the organizer of a company contact day with more than 100 participating companies and several thousand students on the campus of Kiel University of Applied Sciences. The students expressed great interest in the activities of Itzehoe companies and there were numerous productive discussions. Nevertheless, it is very difficult for Itzehoe companies and institutions to attract students.
The clinical center, the IZET Innovation Center, and the regional education center all face the same challenge. Many students are put off by long travel times to the west coast, the associated time and costs, and the difficulties finding suitable housing. Meanwhile the town of Itzehoe has tackled the latter problem and is currently reviewing options for constructing a boardinghouse to provide low-cost student housing. This would also allow a student community to establish itself in Itzehoe. We very much welcome the town's commitment and support this initiative, since we too want to considerably increase the number of students at ISIT going forward.

Conclusion for 2019
Overall 2019 was Positive for ISIT
We can be proud of what we have achieved in regards to the strategy, organization, finances, controlling, and personnel development. While we must not lose sight of the fact that the equipment and buildings are visibly aging and exhibit a need for modernization, we did achieve a balanced budget. Our considerably improved position allows us to look to the future with confidence. It has however also become clear that ISIT is facing a paradigm shift: Maintaining the status quo is not an option for numerous reasons, even after all the measures that have been implemented. Instead ISIT has to set a course for growth, since sustainable financing and maintaining our complex research infrastructure cannot succeed without that. Thankfully ISIT enjoys the full support of the Fraunhofer-Gesellschaft's Executive Board in this undertaking, so that we are able to consistently pursue our transformation process.

I would like to express my sincere appreciation to all employees for their commitment, dedication, and willingness to explore new horizons with us. Although I appreciate that this is not always easy, I believe we are increasingly becoming aware of just how much it pays off.

Dr. Axel Müller-Groeling

ISIT scientists Felix Röben and Christoph Kaufmann speakers at Science Match Future Energies

PS: This preface was written at a time when the coronavirus pandemic is also forcing ISIT to take steps that would have been unthinkable just a short time ago. Details of the effects this will have are not even foreseeable at this time, and will surely be addressed in the 2020 annual report. One thing however is already certain:
Our organization, our newly established functions, and our employees are truly rising to the challenge during this unprecedented crisis. Such times reveal the character of a community. We will pass this test.

ORGANIZATIONAL CHART

Head of Institute
Dr. Axel Müller-Groeling

Deputy Head of Institute
Prof. Dr. Bernhard Wagner

Coordination of Forschungsfabrik Mikroelektronik Deutschland (FMD)
Prof. Dr. Bernhard Wagner

Management-Center
Dr. Axel Müller-Groeling *(acting)*

- Business Development
- Administration
- IT & Processes

Power Electronics (PE)
Prof. Dr. Holger Kapels

- Advanced Power Transistors
- PE for Renewable Power Systems*
- Battery Systems for Special Applications

Micro Manufacturing Processes
Christian Beckhaus

- Process Integration and Pilot Production
- Module Services

MEMS-Applications**
Dr. Fabian Lofink

- Optical Systems
- Acoustic Systems and Micro Actuators

Technology Development
Dr. Oliver Schwarzelbach

FAB
Dr. Mohammad Hejjo Al-Rifai

* External office in Hamburg
** with an external office at CAU Kiel

FRAUNHOFER INSTITUTE FOR SILICON TECHNOLOGY ISIT

Research and Production in One Location

The Fraunhofer Institute for Silicon Technology ISIT develops and produces power electronics and microsystems according to customers specifications. Important areas of application include energy technology, automotive and transport engineering, the consumer goods industry, medical technology, communications technology, and automation. Ultra-modern technological equipment based on 200 mm silicon wafer technology and expertise built up over decades put Fraunhofer ISIT and its customers at the forefront of the field worldwide.

Fraunhofer ISIT supports customers right the way from design and system simulation to the production of prototypes, samples, and preparation for series production. The institute currently employs a staff of 160 persons with engineering and natural sciences backgrounds. Fraunhofer ISIT deals with all the important aspects of system integration, assembly and interconnection technology (packaging), and the reliability and quality of components, modules, and systems. The institute also provides manufacturing support for application-specific integrated circuits (ASICs) to operate sensors and actuators. Activities are rounded off by the development of electrical energy storage devices, with a focus on Li-polymer batteries.

One thing that really sets Fraunhofer ISIT apart is the speed with which it can transfer innovative developments into industrial application and production. To this end, Fraunhofer ISIT operates a wafer production line in its cleanrooms in collaboration with the companies Vishay and X-FAB MEMS Foundry Itzehoe. There are longstanding collaborations with a variety of manufacturing companies local to Fraunhofer ISIT. The quality management system at Fraunhofer ISIT is qualified according to ISO 9001:2015. Fraunhofer ISIT runs an application center at Hamburg University of Applied Sciences, a project group at the FH Westküste University of Applied Sciences in Heide, and a working group at the Kiel University.

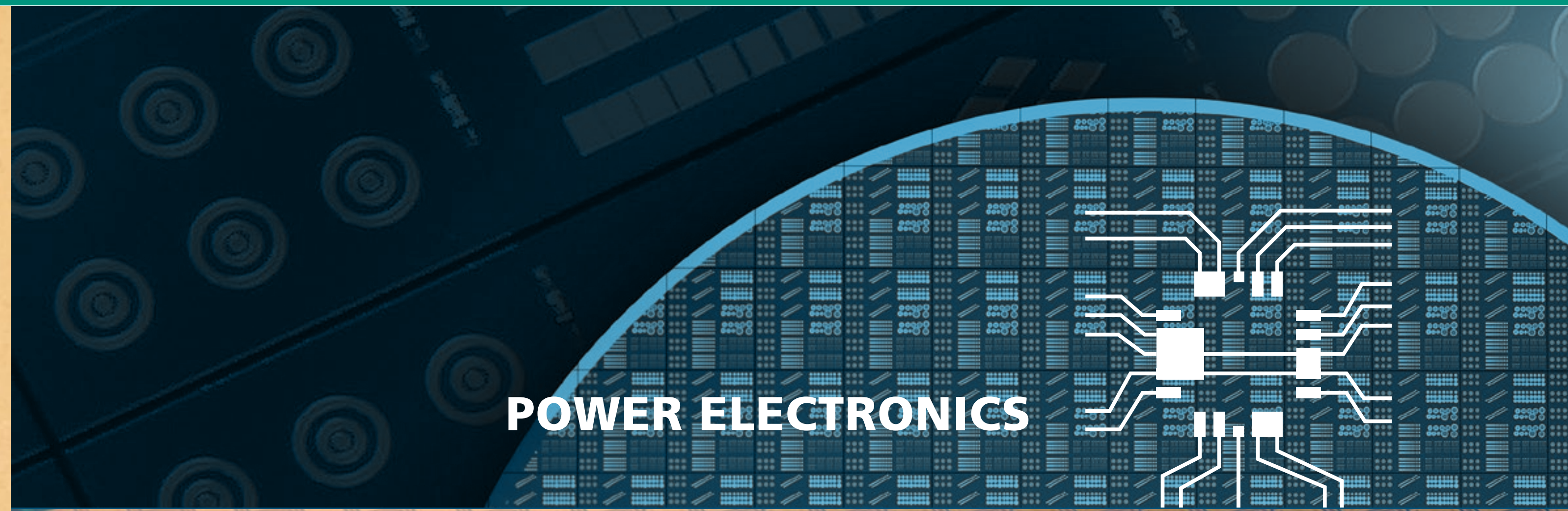
Cooperation with Fraunhofer ISIT

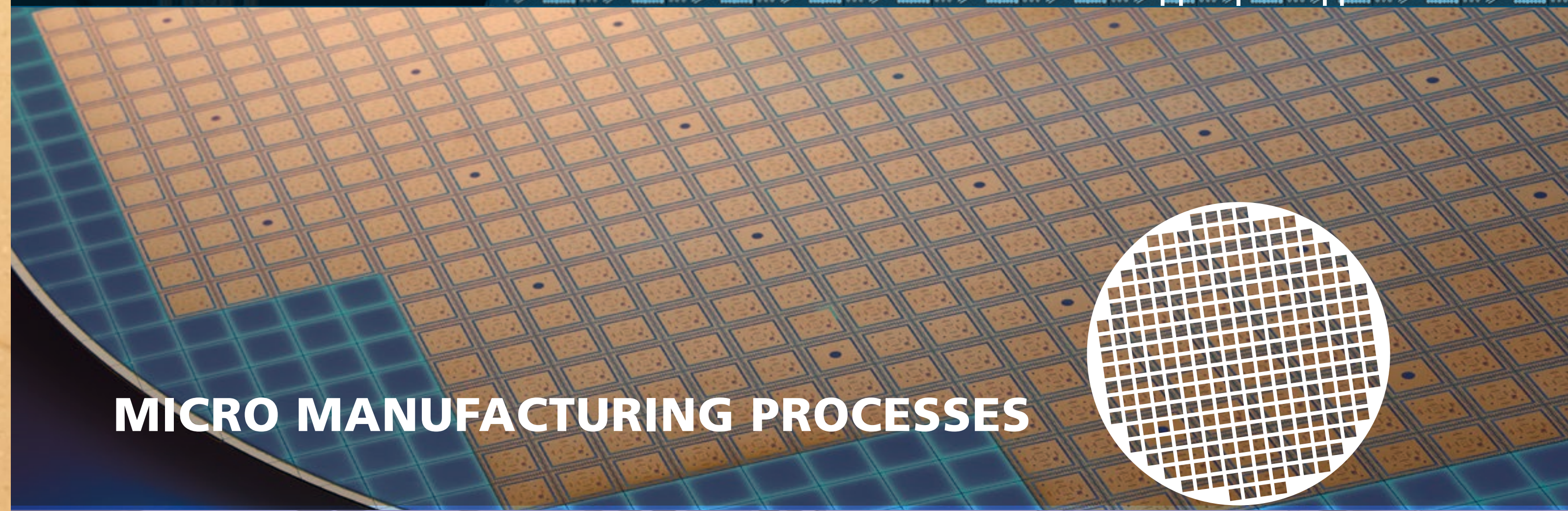
The institute's services assist companies and users in a wide range of sectors. Components, systems, and production processes are developed, simulated, and implemented in close collaboration with customers. This process is aided by Fraunhofer ISIT's use of technology platforms – production process flows defined for whole groups of components – meaning they can be used in production unchanged or with simple modifications to the design parameters.
Fraunhofer ISIT's expertise presents particularly exciting possibilities for small and medium-sized enterprises looking to realize their technological innovations.

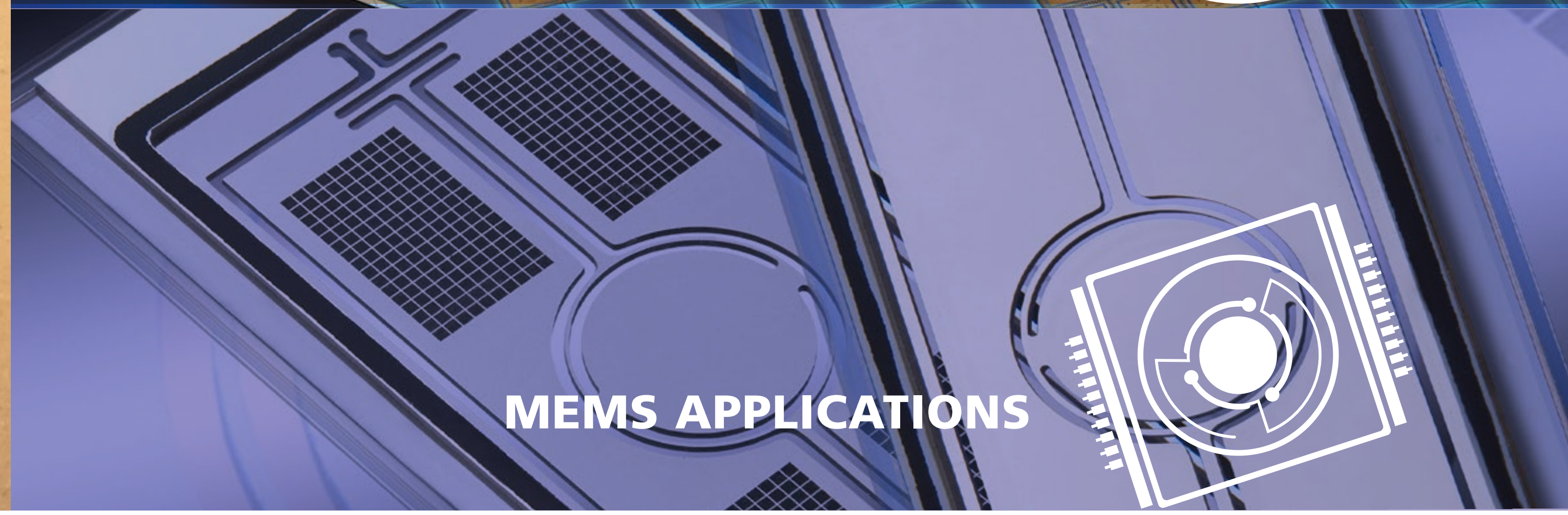
Fraunhofer ISIT is Participant of Research Fab Microelectronics Germany (FMD)

With 13 member institutes and over 2000 active researchers, this research network represents Europe's largest R&D collaboration for micro- and nanoelectronics.
In power electronics, ISIT will provide facilities for the development of gallium nitride as a new material base for innovative power devices that did not previously exist at the institute.
New systems are also being purchased for the development of sensors and actuators, for example equipment for applying piezoelectric and magnetic materials to silicon, vapor deposition systems for special optical and infra-red coatings and furnace systems in which glass wafers can be viscously shaped specifically.
With this new equipment park, ISIT can offer forward-looking manufacturing processes to the industry and is able to develop novel components and convert them into production.

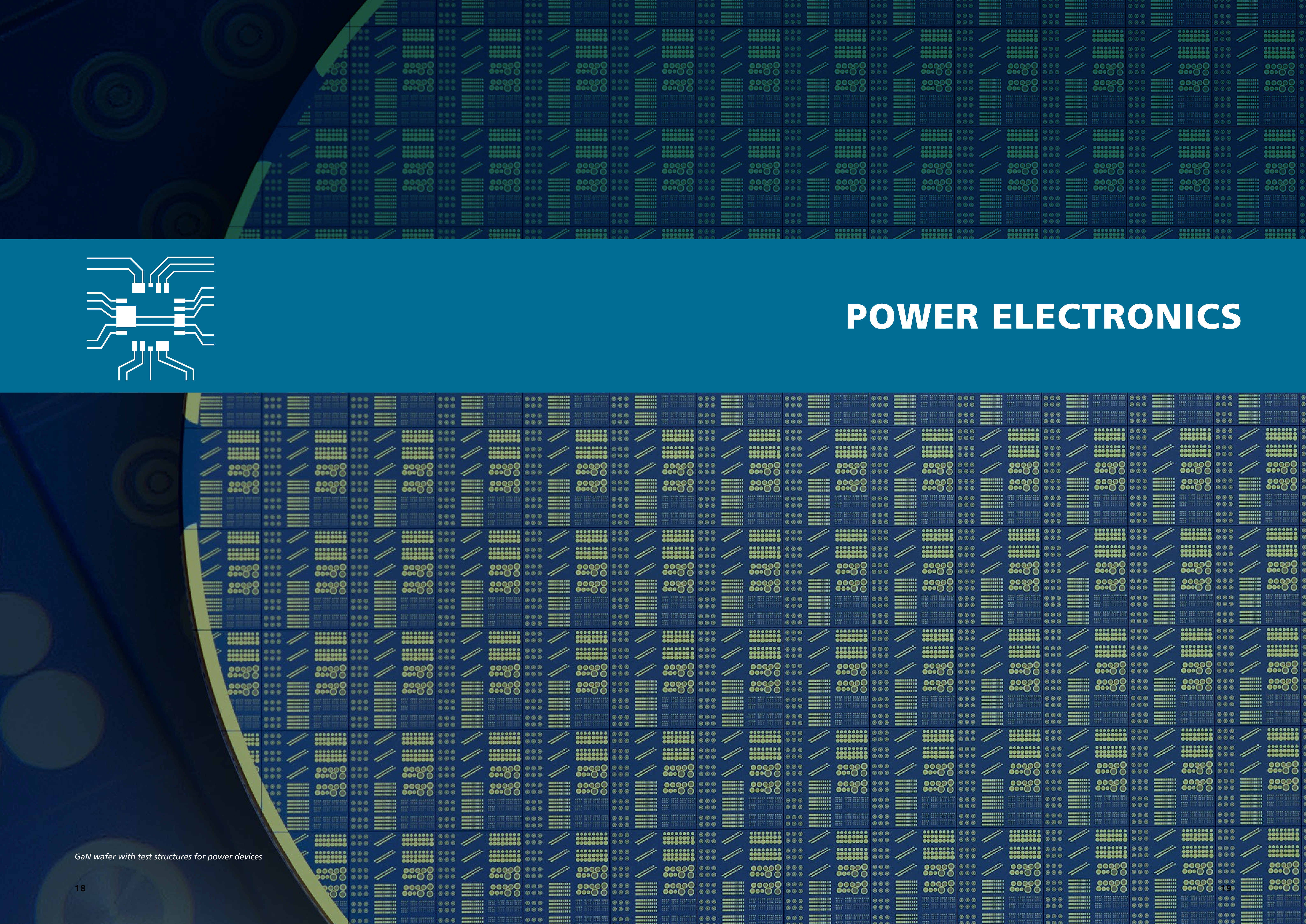
BUSINESS UNITS



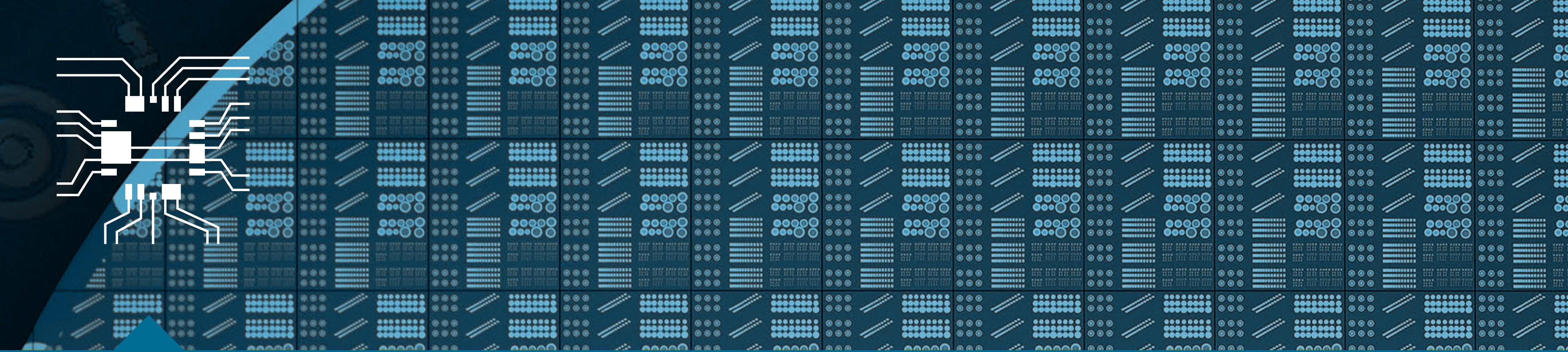




POWER ELECTRONICS



GaN wafer with test structures for power devices



POWER ELECTRONICS

Prof. Dr. Holger Kapels
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Development of Technologies, Components and System Concepts for High-Performance Energy Systems

The business unit Power Electronics at Fraunhofer ISIT develops and manufactures innovative active and passive power semiconductor components based on silicon and gallium nitride, develops power electronic systems and integrates them with high-performance accumulators for special applications towards high-power storage systems.

The advanced power transistors and diodes from Fraunhofer ISIT supporting applications in a wide voltage range from a few 10 V to 1200 V. The development portfolio ranges from silicon-based IGBTs, diodes and MOSFETs to diodes and transistors for highest switching frequencies in the MHz range based on gallium nitride, using modern 8″ manufacturing environment. A particular R&D focus are the application-specific design of the components and the development of new device architectures. Another important research topic is the development of new processes for advanced power device designs on wafer-level. For gallium nitride devices, ISIT is developing also front and back side contacting methods for bulk-GaN wafer and GaN-on-Si wafers.

The Fraunhofer ISIT develops customer-oriented device structures with special pad configurations and for improved integration concepts. For the wafer handling and wafer processing of thin Si substrates, the ISIT developed and applied new carrier wafer concepts together with laser annealing processing. The laser annealing enables the dedicated doping activation allowing customer-specific optimizations of static and dynamic losses while improving the robustness of the components. These activities are supported by numerous simulations, design and test tools. Additionally, the Fraunhofer ISIT has many years of R&D experience in the design and manufacturing of CMOS circuits.

The development of passive electronic components focuses primarily on chip capacitors, precision resistors and inductors as well as corresponding chip-level circuit networks. This involves the evaluation of new materials as well as their implementation in existing process flows.

For the increase usage of renewable energies, the ISIT develops solutions for increased flexibility for the overall grid stability by using the specific possibilities of battery systems. Furthermore, the ISIT is investigating how new control methods can be used to provide important system-stabilizing services and supports the overall system simulation. The main areas of application for these services of ISIT are in the field of regenerative energies, e-mobility and electric flying.

The topic of energy storage has been for a long time one of the key research areas at Fraunhofer ISIT. The ISIT develops batteries and battery systems for a wide variety of applications with its specific requirements, e.g. a particularly high energy density for a long range in electric vehicles or a high power density to charge and discharge batteries quickly. The latter is of particular interest in the storage of wind energy for grid stabilization. By this, it is possible for the ISIT to realize battery systems for special applications, where for instance stability at high temperatures or a particularly high power density is necessary. In the activities, the Fraunhofer ISIT pays special attention to a production-related development.

NEW EQUIPMENT FOR THE DEVELOPMENT OF VERTICAL GALLIUM NITRIDE POWER DEVICES

The Group for Advanced Power Transistors at Fraunhofer ISIT develops new types of power devices. For decades, these power devices have used silicon (Si) as semiconductor material. A few years ago, our group started investigations on using gallium nitride (GaN) for manufacturing semiconductor devices. The reasons for using this wide band gap material are the superior properties of GaN, such a higher switching speed and an improved RDS(on)/VBR(DSS) – ratio, compared to silicon. In the Fraunhofer project "Vertigo" GaN based diodes and transistors are developed. During the project, our knowledge, technology and equipment for processing silicon based power devices will become the working platform for processing the new material.

In this article, we give a short status report about the procurement of further specific equipment for GaN processing that is founded by the "Research Fab Microelectronics Germany".

One step further

State of the art GaN devices are lateral HEMTs (high electron mobility transistor) using the 2D electron gas effect (see figure 1a). The primary goal is to release the full potential of GaN based diodes and transistors by vertical device structures (see figure 1b). In order to satisfy the demand for mass market suitability, the 200 Volt devices are developed and manufactured on a 200 mm platform available at ISIT.
The wafer material consists of 3 layers: a buffer layer for atomic lattice matching deposited on a Si carrier wafer (with a (111) surface), followed by a functional GaN based layer system. The 200 mm substrates with epitaxial layers are purchased from external suppliers and processed in the ISIT clean room.

Additional equipment at ISIT for new GaN device platform

A technology platform for power devices based on the III-V semiconductor material gallium nitride (GaN) is being established at the Fraunhofer ISIT. The development and processing of new power devices based on GaN epitaxy on 200 mm (111) silicon wafers takes place in the clean room at Fraunhofer ISIT, which is originally equipped and used for Si-based micro-electro-mechanical systems (MEMS) such as sensors, scanning micro mirrors and piezoelectric systems. For the development of vertical GaN devices, the existing technology park will be expanded with new equipment and processes. The additional equipment was procured as part of the project „Research Fab Microelectronics Germany", funded by the German Federal Ministry of Education and Research. It will enhance ISIT's capabilities in dry and wet etching, cleaning, tempering and rapid thermal processing as well as the electrical characterization of manufactured components. Most of the systems are already installed and in use.

The new equipment primarily serves to prevent contamination of GaN by Si and adds key processes for GaN based devices that will lead towards innovative research and development projects. With this perspective, Fraunhofer ISIT is as well enhancing device measurement capabilities for static and dynamic wafer and device testing for the new III-V semiconductors.

Author: Frank Dietz

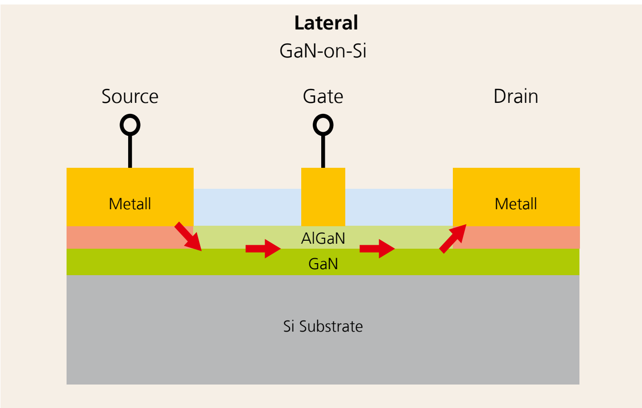

Figure 1a: Schematic of a lateral GaN HEMT device; red arrows show the current path

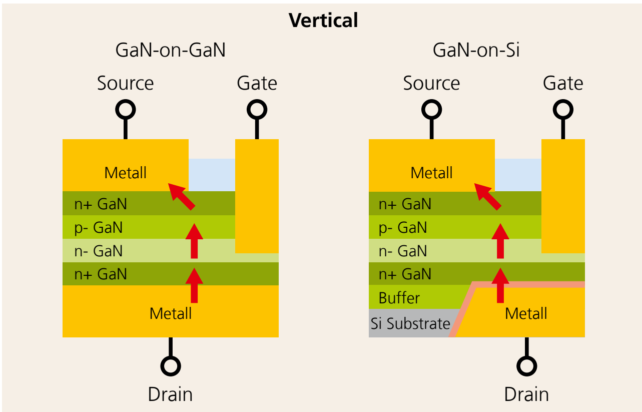

Figure 1b: Schematic of vertical GaN devices; red arrows show the current path

Etch chamber for an existing Centura frame of Applied Materials for patterning GaN layers to prevent doping of GaN by other materials, especially Si, Ge, Al and Mg

Kojo furnace system to perform tempering using different gases, in different pressure ranges from 250 torr to atmospheric

STEAG (Mattson) RTP (Rapid Thermal Processing) system for activating ohmic contacts on GaN layers using different gases

Semitool batch cleaning tool for wet chemical cleaning of GaN surfaces equipped with RCA chamber and rinse chamber

Picosun R-200 Adv Atomic Layer Deposition (ALD) system with Hine loader to deposit dielectric layers with highest uniformity (Copyright: Picosun)

Forschungsfabrik Mikroelektronik Deutschland

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Eine Kooperation von
Fraunhofer MIKROELEKTRONIK
FBH Leibniz Ferdinand Braun Institut
ihp

MICRO-INDUCTANCES FOR POWER CONVERTER APPLICATIONS

Introduction

The miniaturization of passive components becomes increasingly important to reach higher power densities in power supplies. At the same time applications like IoT, smartphones, smart homes, etc. require power converters with reduced size. This future trend is supported by wide band gap devices like SiC or GaN FETs, enabling a new level regarding power losses and switching frequencies.

Following, a brief overview of the development, processing and investigation of micro-inductances on silicon featuring an inductance of about 150 nH and a resistance of 0.66 Ω is presented. A novel fully back-end-of-line (BEOL) compatible fabrication technique is demonstrated to manufacture the inductance cores on silicon substrates, using microscale magnetic powder agglomeration by atomic layer deposition (ALD). This allows a wide range of magnetic materials to be integrated on silicon substrates with a high degree of freedom for innovative core and inductor designs for integrated power supplies. A typical boost converter with a GaN FET was designed to prove the functionality of a micro-inductor in a real application.

Fabrication process of magnetic cores

The fabrication process is illustrated schematically in figure 1. First, a pattern of 3400 µm long, 1000 µm wide and 600 µm deep cavities is transferred by deep reactive ion etching (DRIE) into a 200 mm Silicon substrate. After resist removal and cleaning, the substrate is diced into pieces of 40 mm x 40 mm. In the next step, on each piece the cavities are manually filled with micron-sized magnetic particles of a particular type using doctor blade method. As magnetic materials carbonyl iron powder, alloy powder (QFeSi6.5) and MnZnP ferrite with the particle sizes between 1 to 100 µm were tested. Now, ALD is applied to agglomerate the initially loose particles within the cavities by a thin Al_2O_3 layer to rigid porous structures over the whole cavity depth. By another dicing step, silicon chips are cut from each piece.
To confirm that the particles were agglomerated down to the mold bottom, on a few samples the surrounding silicon has been removed in XeF_2 gas phase. The image of the scanning electron microscope in figure 2 presents one of these cores after release. On the right side, the core is enveloped by a passivation stack including the Al_2O_3 ALD layer. On the left side, the passivation was removed, so that the agglomerated particles are exposed. To obtain inductors from those chips, 8 turns of 100 µm copper wire are manually wound around the central part with the embedded soft-magnetic core (figure 3). Finally, the wire is fixed with instant adhesive.

Simulations

For the design of inductors, Comsol Multiphysics is used as finite-element-method software for the analysis of magnetic fields in the frequency domain. In the first step, the material parameters of the magnetic core were adjusted to match the measurement results. Based on this data set, further design optimizations to an integrated component could be done, before the next prototype generation will be fabricated.

Once the geometry is set, every component gets classified by its material parameters. Comsol provides a library for typical materials like air, silicon, copper, etc. For the magnetic powder-based core, a few values had to be estimated by using the settings of alloy powder core ferrite and adjusting the permeability and electrical conductivity. For the simulation, a sinusoidal current of 1 A is supplied to one end of the wire while the other end is grounded. The frequency of this current source is swept from 100 kHz to 100 MHz. After a simulation run, the complex impedance between both wire ends is known and the inductance can be calculated by dividing the imaginary part with its corresponding frequency, while the resistance is the real part of the impedance.

FEM simulations depict good agreement with the measurements of a high precision impedance analyzer and provide a basis for new designs and optimization steps. Especially, the inductor design with through-silicon-vias and copper tracks is analyzed, which could lead to innovative integration solutions, such as the combination of passive components and new wide band gap power devices on

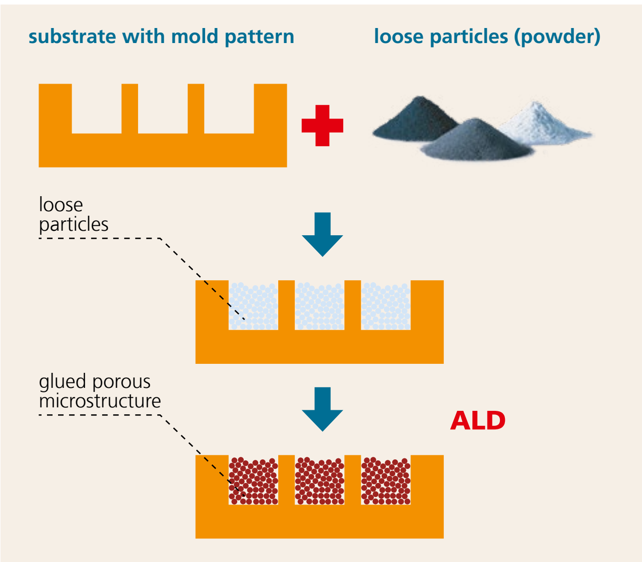


Figure 1: Magnetic core fabrication process

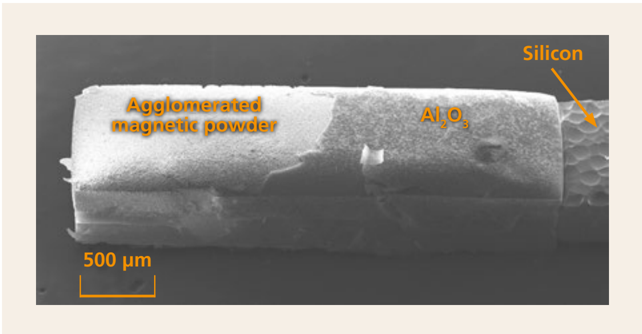


Figure 2: SEM image of the core P04 , after partly removal of the surrounding silicon by etching in XeF_2 gas phase

Figure 3: Geometry of test samples

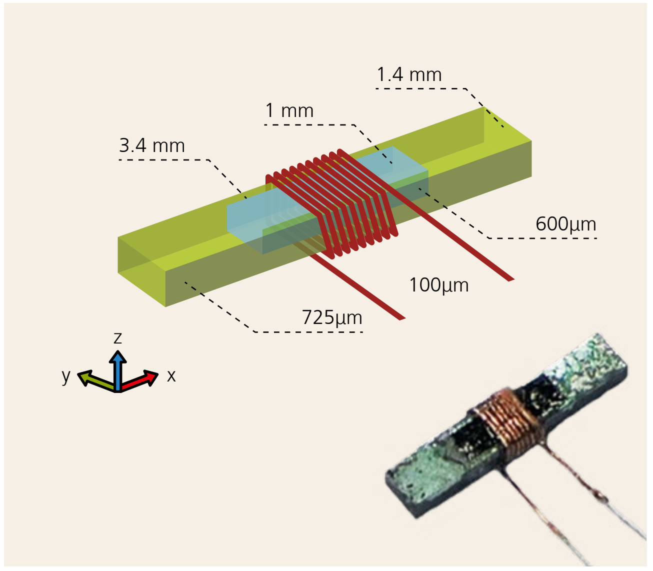
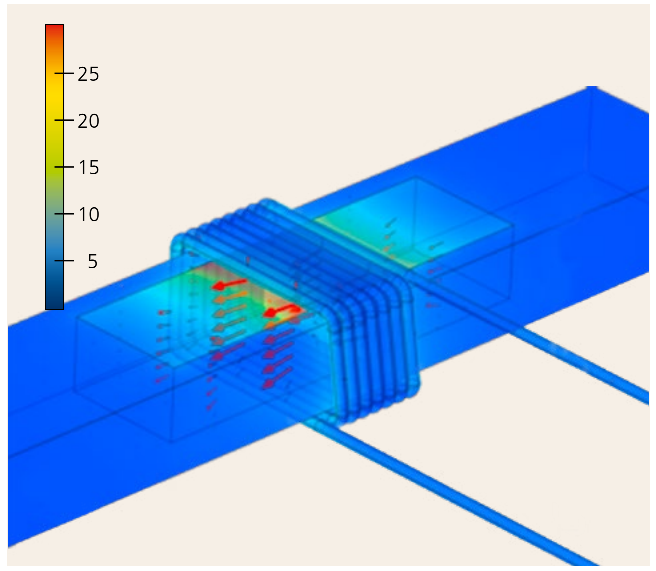
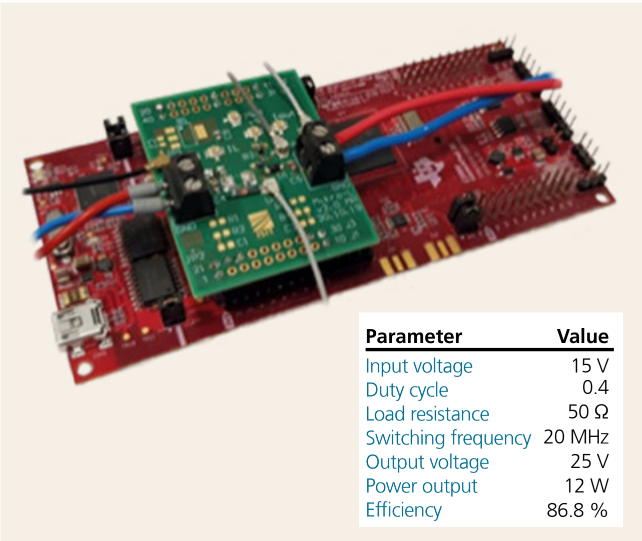


Figure 4: FEM model, magnetic flux density (in mT) at 20 MHz





Parameter	Value
Input voltage	15 V
Duty cycle	0.4
Load resistance	50 Ω
Switching frequency	20 MHz
Output voltage	25 V
Power output	12 W
Efficiency	86.8 %

Figure 5: Boost converter prototype with inductor test sample P 04

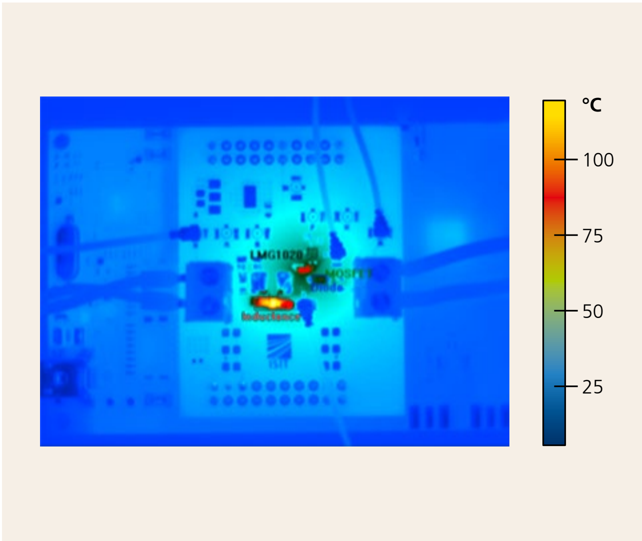


Figure 6: Thermal image of the boost converter

the same ceramic. Beside electrical simulations, thermal simulations of these integrated solutions show benefits because of a better thermal conductivity of silicon compared to commercially available inductors with wires.

Experimental results

About 20 test samples, consisting of different magnetic powder cores, were characterized on a high precision impedance analyzer for switching frequencies from 100 kHz up to 100 MHz. As magnetic core, different materials, particle sizes and even powder mixtures were compared.

For testing one of these inductor samples in a real application, a dc-dc converter for voltages below 50 V and a power level of about 10-20 W set as a target for the first prototype (figure 5). As topology, a standard boost converter, operating with a fixed duty cycle of 0.4 and a switching frequency of 20 MHz, was designed. For first tests, inductor P04, having an inductance of 150 nH and 0.66 Ω at 20 MHz, is used, while a resistance of 50 Ω is connected to the output terminals.

An input voltage of 15 V is boosted to 25 V on the output. In this case the converter reaches an efficiency of 87 %, which is quite a good performance for such an application. In figure 6, the image of the infrared camera shows, where the power losses of 1.84 W are dissipated as thermal energy.

Conclusion

Our investigations show a novel fabrication process for micro-inductances on silicon, based on an ALD process with magnetic powders. The characterization of these test samples depict good results and were proven on a dc/dc converter with high switching frequencies.
The patent of Fraunhofer ISIT about the agglomeration of magnetic powders on silicon is combined with the knowledge of power electronics, motivated by the trend of miniaturization of passive components. Besides, the research and fabrication of GaN devices in our clean room open up an interesting area regarding the integration to „power supply on a chip" solution.

Authors Malte Päsler

Support from Schleswig-Holstein for a new powder technology laboratory.
Minister of Economics Dr. Bernd Buchholz, ISIT Director Dr. Axel Müller-Groeling and ISIT Project Manager Dr. Thomas Lisec

DIRECT COATING OF SEPARATOR ON ELECTRODES FOR LITHIUM BATTERIES

Lithium batteries have undergone a significant expansion of application fields in recent years. Besides their use in electric and hybrid vehicles, this also includes stationary energy storage systems. At the same time, the cell capacity has grown significantly and is now typically between 40 Ah and 100 Ah. This is accompanied by significantly increased demands on manufacturing quality and a strong price pressure.

As part of a project funded by the German Federal Ministry of Economy and Energy, S-ProTrak was focusing especially on the electrode coating and parts of the cell production (separator). Fraunhofer ISIT designed procedures for direct coating of separators on electrode foils using existing patents. The developed technologies were then integrated in prototypes.

Separator technologies

Producing lithium cells and batteries is a complex series of chemical and physical manufacturing and assembly steps. The value chain for lithium cells and batteries is divided into three production areas:

- electrode coating line (mixing, coating and compaction)
- cell production line
- battery production line

The separator of a rechargeable lithium battery is a core element, defining parameters like internal resistance, cycle stability and safety. Conventional separators mainly consist of thin films made of polyolefin, like PE or PP or combinations thereof. The resistivity of a cell increases with the thickness of the separator. However, decreasing the film thickness makes its handling more and more difficult.
The separator concept developed in this project takes this into account by focusing on the improvement of the material quality, which directly leads to a better production yield with less waste and reduced cost. In addition, a significant improvement in the cell performance was expected, leading to cells with a fast charging characteristic. This can establish other fields of applications, for instance starter batteries.

Direct coating of separator films

Core of this innovation is a direct coating of the separator on the electrode foil. This can be done either in a wet on wet process (WoW) directly on the undried electrode foil, or wet on dry (WoD, figure 1) after the electrodes have dried.
For the development of this process, enhancements of existing coating technology, especially for the coating head as well as for the separator slurry formulation were necessary.
The basic separator concept was developed and patented by Fraunhofer ISIT already in 1999. It consists of a lithium conductive ceramic that is bound by a PVDF polymer. Acetone is used as a solvent. In order to be used for a direct coating process on electrodes, the slurry formulation had to be adapted, especially by increasing the viscosity without losing performance. Therefore, the mixing procedure was changed. Using the coating facility of Fraunhofer ISIT and a slot die coating system from FMP, both processes (WoW and WoD) were developed and several dozens of meters of coated electrode foil were produced (figure 2).
With these foils, test cells (full and half cells) were assembled for the electrochemical characterization of the electrodes (figure 3).

The electrochemical characterization and tests show a stable cycling behavior for the WoW as well as for the WoD process. Both technologies have a high potential to enhance production efficiency. Especially the WoW process effectively reduces production cost and energy by making separate production and assembly steps for the separator obsolete.

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Federal Ministry
for Economic Affairs
and Energy

S-ProTrak

Funded by the German Federal Ministry of Economy and Energy

Figure 1: 2-side Wet-on-Dry separator coating

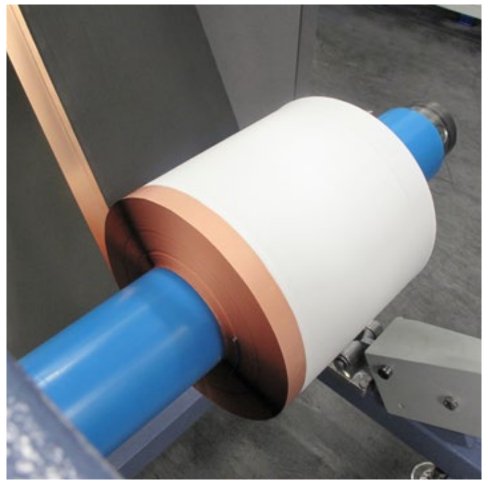
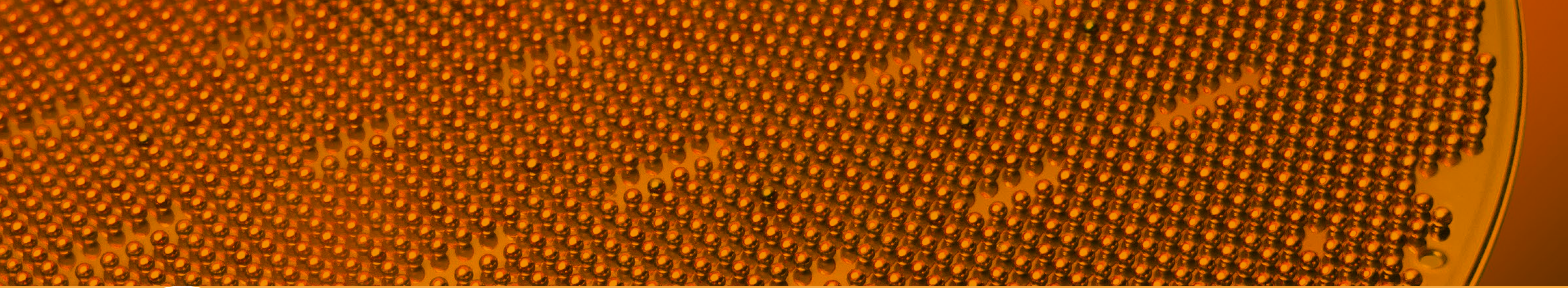
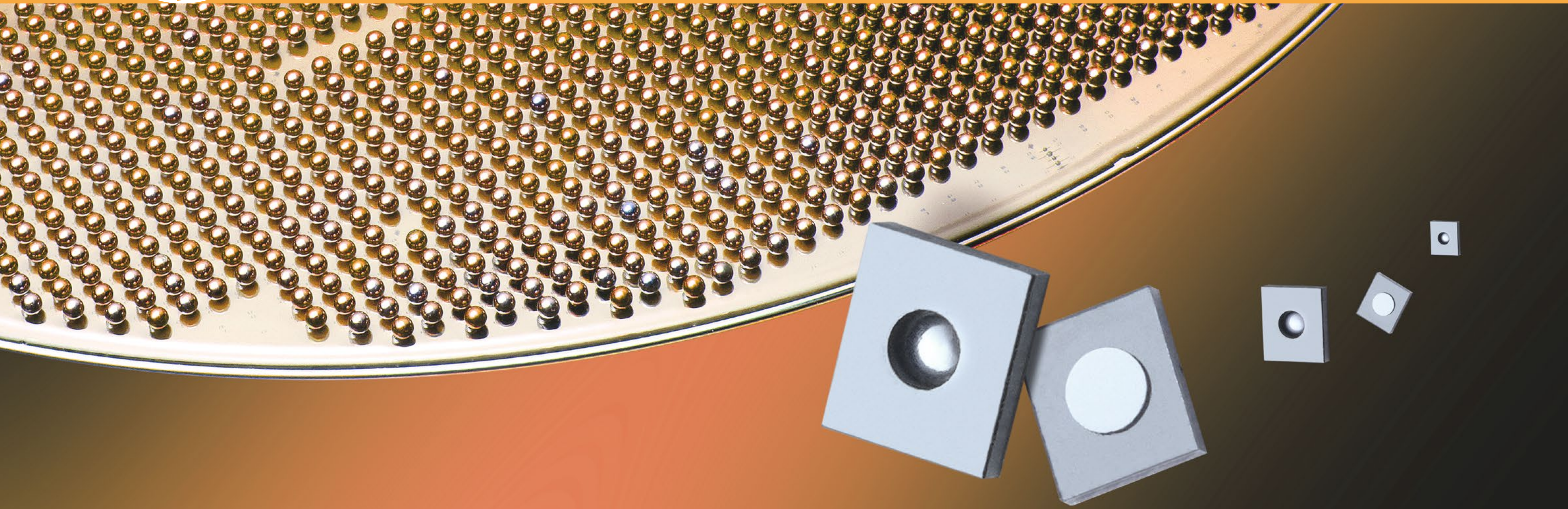


Figure 2: Electrode (anode) coated with separator at Fraunhofer ISIT

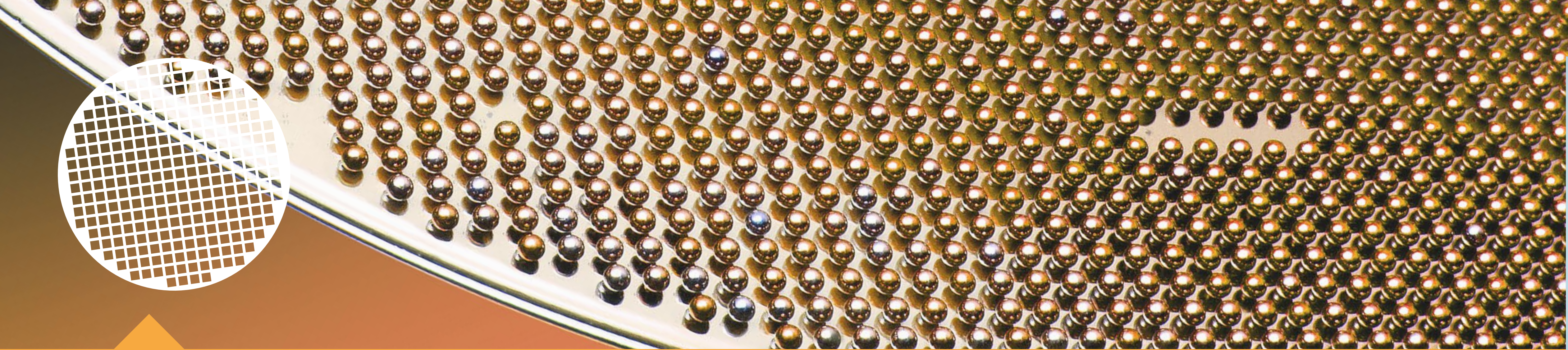
Figure 3: 20 Ah prototype cell with directly coated separator



MICRO-MANUFACTURING PROCESSES



Silicon spheres can be used as pre-forms for plano-convex infrared lenses. In the project MIRS, we developed wafer-level optics for tiny non-contact spot thermometers that could be easily integrated in smartphones



MICRO-MANUFACTURING PROCESSES

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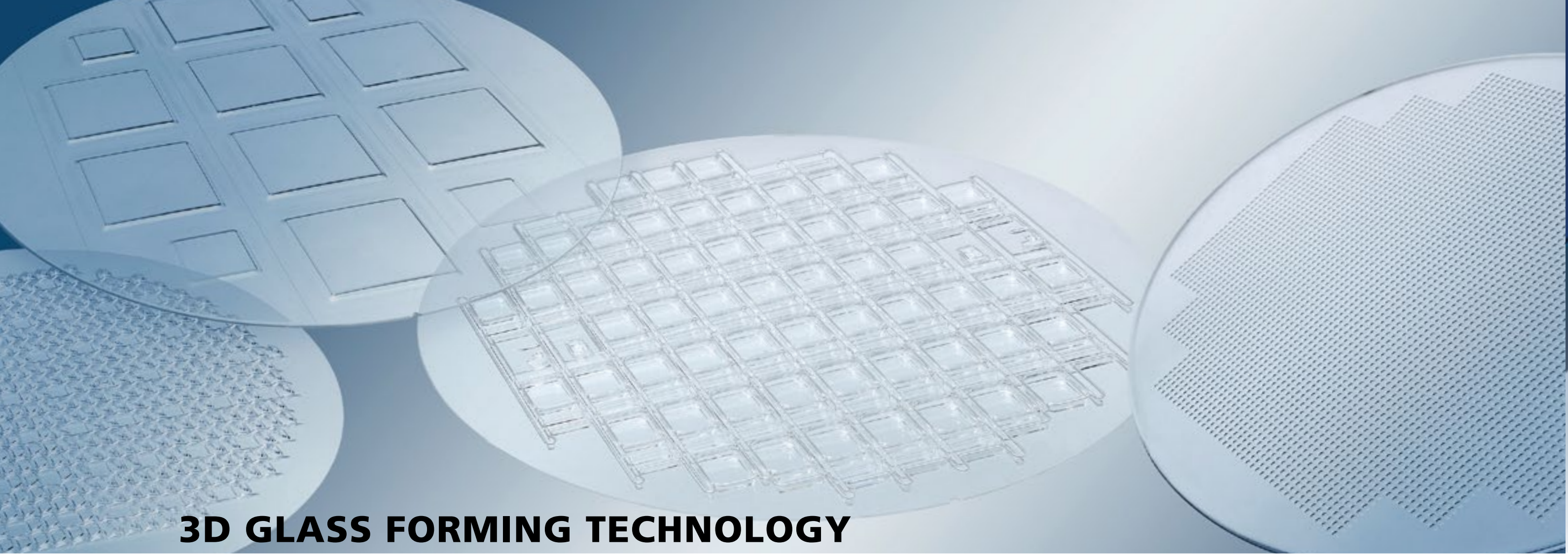
This business unit focuses on the processes, procedures and services that constitute essential prerequisites for research and development in the Business Unit MEMS Applications on the one hand and, on the other hand, also services offered by ISIT directly in the market.

Important offerings at ISIT are wafer-level packaging (WLP) and various individual processes at the wafer level. Here the focus is on the packaging of microsystems on the wafer, but also the further processing of pre-structured wafers and the development of problem-specific technology solutions at the individual process level. The wafer technologies that are developed make it a functional part of a microsystem. Outstanding successes were achieved in the vacuum capping of MEMS sensors by means of eutectic wafer bonding. The technology basis at ISIT is excellent: Front-end processes of the business unit power electronics and the own back-end clean room line with equipment for MEMS-specific manufacturing processes can be used. The lithographic capabilities include a wide-field stepper, backside mask aligner, spray coating and spin coating, and thick resist processing. CVD, PVD, ALD and special tools for thin films are available. The wet processing area comprises anisotropic etching of Si, automated tools for metal etching, and electroplating. In case of dry etching, equipment for DRIE of Si and RIE of oxidic compounds is available. MEMS release etching can be performed using HF and XeF_2 gas phase etching or wet etching.
A specific focus is given to hermetic wafer level packaging of MEMS using metallic, anodic, or glass frit wafer bonding technology. Wafer grinding and temporary wafer bonding are key process steps for thin wafer and 3D integrated products. In addition to the individual processes, Fraunhofer ISIT has established a number of qualified technology platforms. ISIT can also offer the developed components and systems to customers as prototypes or in small series from pilot production. Not only does this require proving that certain manufacturing steps and functional principles are feasible in principle, for example using demonstrators, but also taking all development steps to series readiness – an effort that must not be underestimated. High volume series production can be supported in particular through cooperation with the local company X-FAB MEMS Foundry Itzehoe GmbH, so that the industrial production of larger quantities is also possible in many cases.

After all, Fraunhofer ISIT offers a number of services at the module level to internal and external customers as module services. In assembly and interconnection technology, ISIT specializes in the implementation of innovative processes and technologies in direct cooperation with manufacturers of assemblies, equipment, and materials. The automatic assembly of ultra-thin chips on flexible PCBs has already been tested successfully several years ago. ISIT has all basic technologies for the automated or manual handling of microchips and MEMS as well as their electrical contacting using wire bonding and flip-chip technologies. For power electronics assemblies with improved power cycle performance, ISIT has highly developed thick wire/ribbon bonding technology, both for aluminum and for copper bonding material. ISIT has 20 years of experience with the assessment of quality, reliability, and robustness. Focal points are on the assessment of manufacturing quality, reliability testing, lifetime prediction and failure analysis, and the development of electronics as well as assembly and interconnect concepts, from the chip to the system. Beyond that, ISIT evaluates the aging behavior of assembly and interconnect techniques like chip-on-chip, chip-on-system, chip-on-board, and chip-on-polymer as well as bonding and soldering connections. The scientists create prognostics by means of model calculations, analyses under different environmental conditions, and accelerated aging tests. They also conduct extensive assessments of failure analyses in the prognostics.



3D GLASS FORMING TECHNOLOGY

Different structered glass wafer with caps and lenses

left: Detail view of a glass wafer with silicon vias
middle: Inclined windows on an 200 mm glass wafer
right: Spherical micro mirrors coated with a thin Gold layer

Motivation

Fraunhofer ISIT has a wide portfolio of qualified single process technologies available, which were combined to different specific technology process platforms. They form a kind of tool box to realize various applications. One of these process platforms is glass micromachining. Fraunhofer ISIT developed a process based on hot temperature viscous glass micro-machining. It is mainly used for the production of micro-lenses and glass packages with inclined window surfaces. Using this process, it is possible to structure glass wafers with high aspect ratios on wafer level. A structured silicon wafer is chosen as so-called primitive form, so glasses must be used whose softening temperature is well below that of silicon.

This has the advantage that the standardized methods to structured silicon wafers of a clean room can be used. The etched structures or cavities correspond later the molded areas in the glass. The structured silicon wafer is then anodically bonded to a glass wafer. In this case, a defined pressure within the cavities is enclosed.
When a relative vacuum is enclosed the cavities and the heat treatment takes place under atmospheric pressure, the glass is pressed into the cavities. If an atmospheric pressure is enclosed and the heat treatment takes place under vacuum then the glass is forced out of the cavities. Depending on the application, the glass may now be further processed by grinding and polishing.

OUR SERVICE

- **Development and production of optical components (mirrors, lenses) on 200 mm glass substrates**
- **Realization of glass caps for housings of optical microsystems according to customer requirements**
- **Easy transfer to pilot production**
- **Access to cost-effective production of micro-optical components**

Technology

- Proprietary glass forming process
- Anodic wafer bonding
- Material: borosilicate glasses
- CTE match to silicon
- Fabrication on 200 mm wafer

Technical data for optical packages

- Packages with planar windows
- Packages with inclined windows with angles up to 15°
- Cavity sizes 1mm up to 10 mm
- Cavity depth 0.1mm up to 4 mm
- Roughness < 1 nm (Ra)
- Window deformation < 100 nm (3.5 mm window size)
- Hermetic sealing

Technical data for lenses

- Plano convex, plano concave lenses
- Lens arrays
- Lens diameter: 100 µm – 8 mm
- Sag. height: max: 800 µm
- ROC: 100 µm – 20 mm

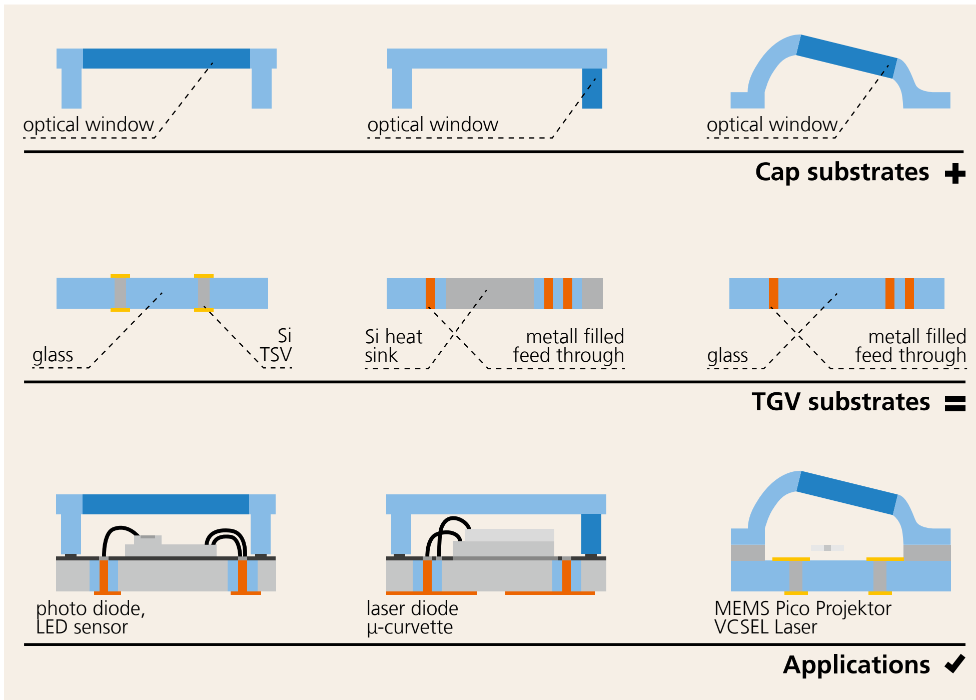
Technical data for Through Glass Vias (TGV)

- Wafer thickness: < 400 µm
- Contact via diameter: < 100 µm
- Contact via pitch: (depending on the aspect ratio): < 90 µm (1:4)
- Via material: Silicon

Applications

- Wafer Level Opto Packaging
- Hermetic Glass Packages
- Optical Windows
- Lens Arrays
- Micro Optics

Author: Vanessa Stenchly



Schematic of different optical housing constructions supported by the modular packaging system

INVESTIGATION OF THE GROWTH OF INTERMETALLIC PHASES IN TIN-SILVER-COPPER SOLDER UNDER ELECTROMIGRATION STRESS

Introduction

Electromigration (EM) is a damage mechanism which can lead to failure over time, in particular in electronic systems getting smaller and smaller. The damage is initiated by electrical current and temperature. A diffusion-based, directed transport of material progressively leads to interruptions in conduction paths and solder connections. Electromigration takes effect by creation of intermetallic phases between pad surface or metallization of the chip surface, and solder.

In a comprehensive study, ISIT examined electromigration in relation to the growth of intermetallic phases in tin-silver-copper solder balls and the failure mechanisms of small electronic devices. To determine the kinetics of this process (time to failure), several components were loaded with current and temperature. The samples were then examined for anomalies by X-ray and metallographic methods.

Electromigration effect

Electromigration is a material migration process: Metal ions are exposed to two forces generated by current flowing through a solder joint. On one hand, an electrostatic force is caused by the electric field strength in the solder joint. A second force can be generated by the momentum that is transmitted from moving electrons to the metal ions in the crystal lattice. The force in direction of the current flow is called „electron wind“ and is a principal cause for electro-migration (figure 1). The creation of intermetallic phases between metallization (conductor/chip) and solder is strongly enhanced by electromigration.

Figure 2a: Overview cross section of CSP with current flow

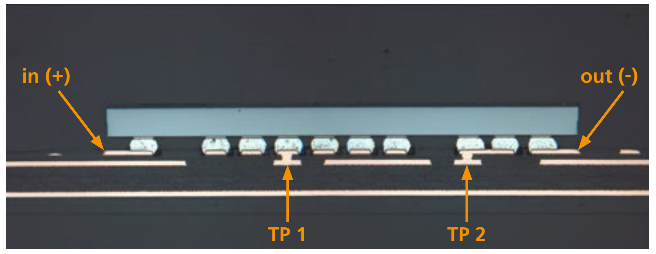
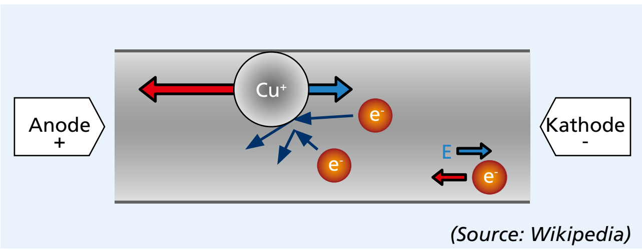


Figure 1: Material transport by electromigration



(Source: Wikipedia)

Figure 2b: Overview solder balls

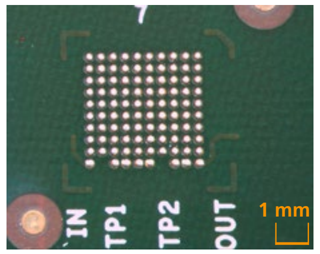


Figure 2c: Thermographic image at 4.5 A, maximum 200°C.

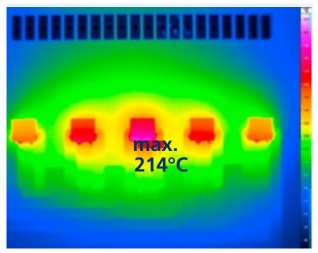


Figure 3: Molten conductor

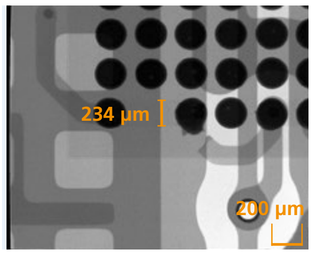
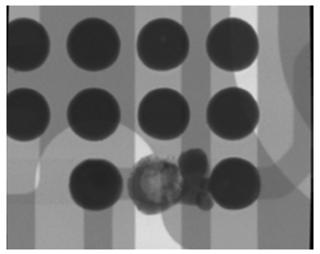


Figure 4: Molten solder ball



Experimental approach

To determine the current carrying capacity of a CSP (Chip Size Package), the component was loaded with increasing current at room temperature (CCC test). Figure 2a shows a cross section of a CSP with 10 solder balls, figure 2b an overview of the solder balls. The current flow is from the left, solder ball 1 (+), to the right, solder ball 10 (-). Measurements were performed on solder balls 4 and 8. Solder balls 3 and 6 were not energized. The tested components were submitted at room temperature to an incrementally increasing current within a range of 1 to 5 A. The current was kept constant for 5 minutes in each step. The temperature of the assembly was measured with a thermographic camera. At 4.5 A, a maximum temperature of 200°C was measured (figure 2c).

In a second test to investigate electromigration, several CSPs were energized with 2 A and stored in a convection oven at 125°C. The test ended when the component failed.

Metallographic and X-ray analysis

First, the failed CSPs were examined by X-ray. Interrupted conductors and molten solder balls could clearly be detected (figures 3 and 4). The effects of electromigration on the solder structure was then investigated by metallographic analysis methods.

CCC Test (Current Carrying Capacity Test)

Figures 5a and 5b show an overview before loading. The solder balls are well formed and the solder shows good wetting, with a thin layer of intermetallic phases. A phase growth can be seen clearly in the cross section on the PCB side. The phase thickness corresponds in part to half of the sphere diameter, figures 6a and 6b.

Electromigration test

Figures 7a and 7b show an overview after the component failed. Looking at the solder structure after loading, the following changes can be found: The copper on the chip

Figure 5a: Overview before power loading

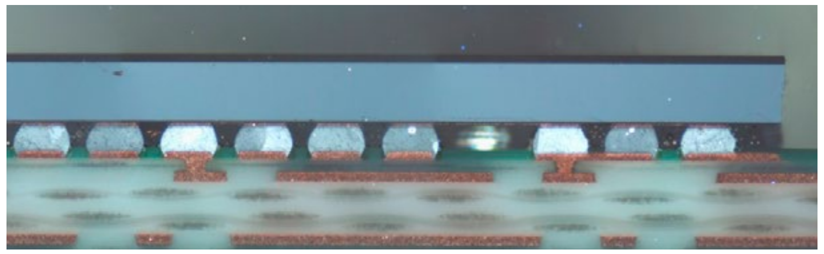


Figure 5b: Solder with thin phases

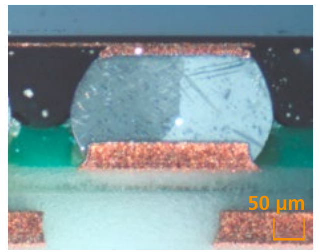


Figure 6a : Overview after powering

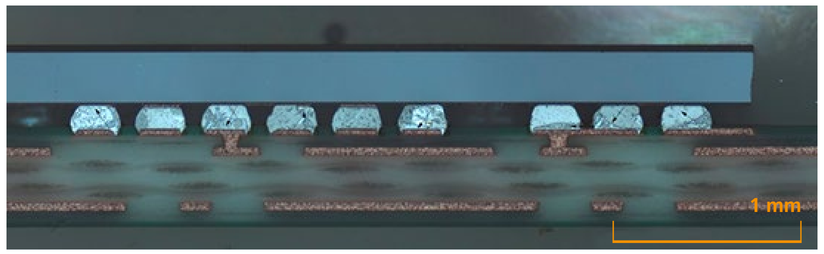
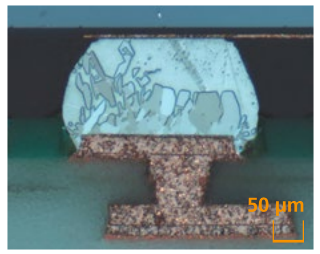


Figure 6b: Thick phase solder



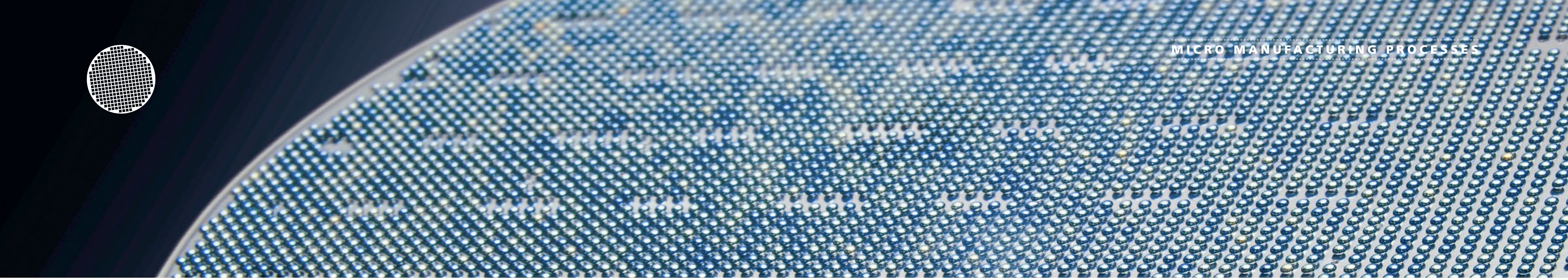


Figure 7a: Failure after 3190 h

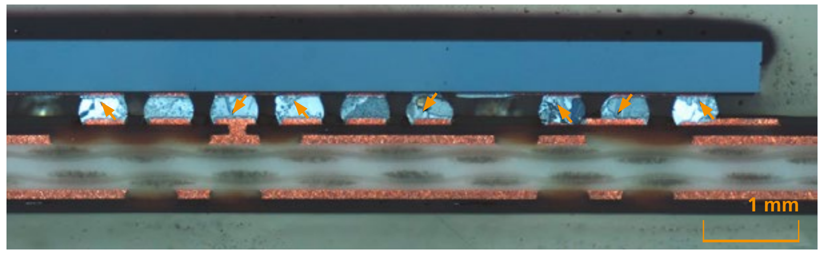


Figure 7b: Dissolution of the chip metallization

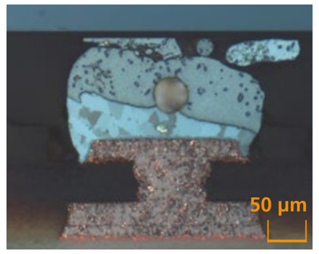


Figure 8: Complete dissolution of the chip metallization

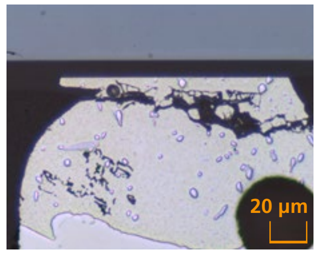


Figure 9: Strong phase growth without dissolving the chip metallization

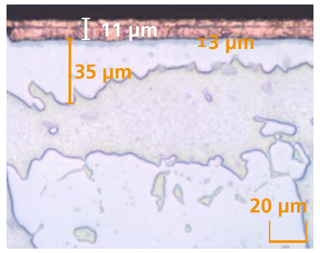


Figure 10: Complete dissolution of the PCB metallization

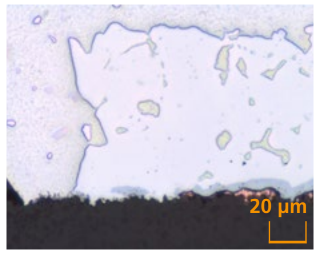


Figure 11: Partial dissolution of the PCB metallization

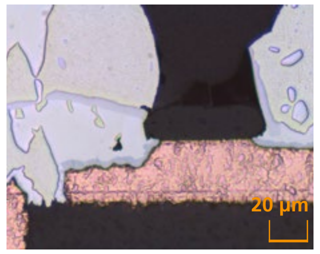


Figure 12: Phase growth without current and temperature load

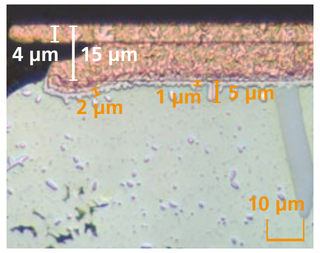


Figure 13: Phase growth with temperature load without current

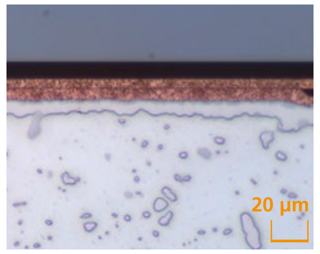


Figure 14a: Electron wind

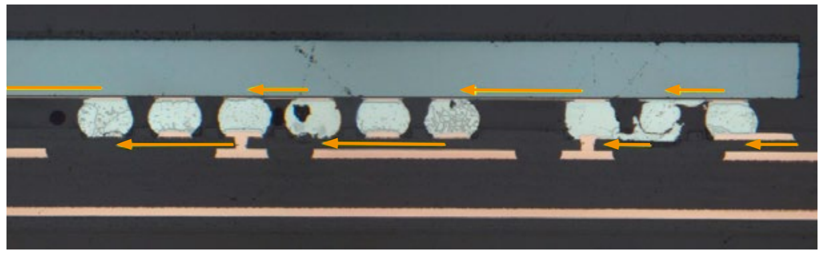
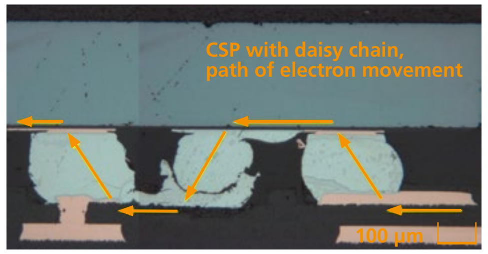


Figure 14b: Diffusion path

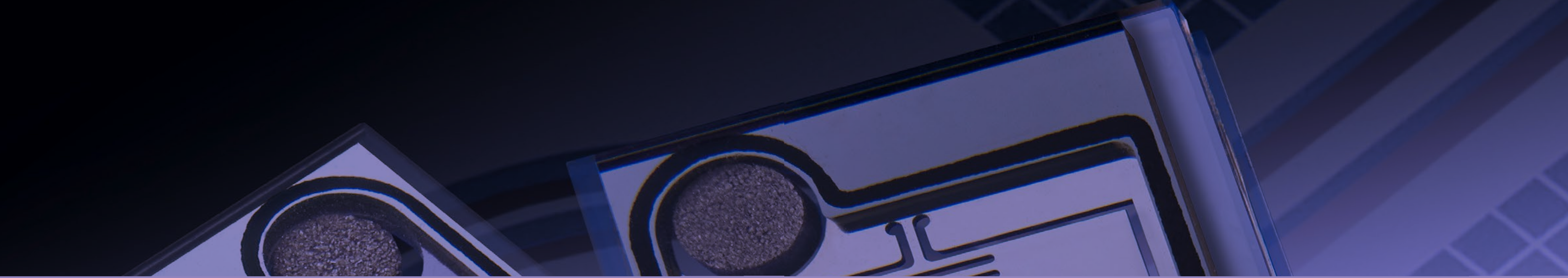


side (UBM, Under Bump Metallization) and on the PCB side goes into solution, which has two effects: The more copper is consumed, the stronger the phase growth. But as the copper becomes thinner, the temperature in the solder gets higher until it is partially melted. The phase growth is strongest on the PCB side. Figures 8 to 13 show detailed images of the solder joints.
Comparing phase growth in tin silver copper balls under current and temperature load with growth only under temperature load reveals a significant influence of the current load. Without additional current load, only a small increase in phase thickness can be recognized. Considering the phase growth with regard to current direction and diffusion path of the metal ions, the following picture results: The current flows from left to right and the electrons move from right to left (figures 14a and 14b).

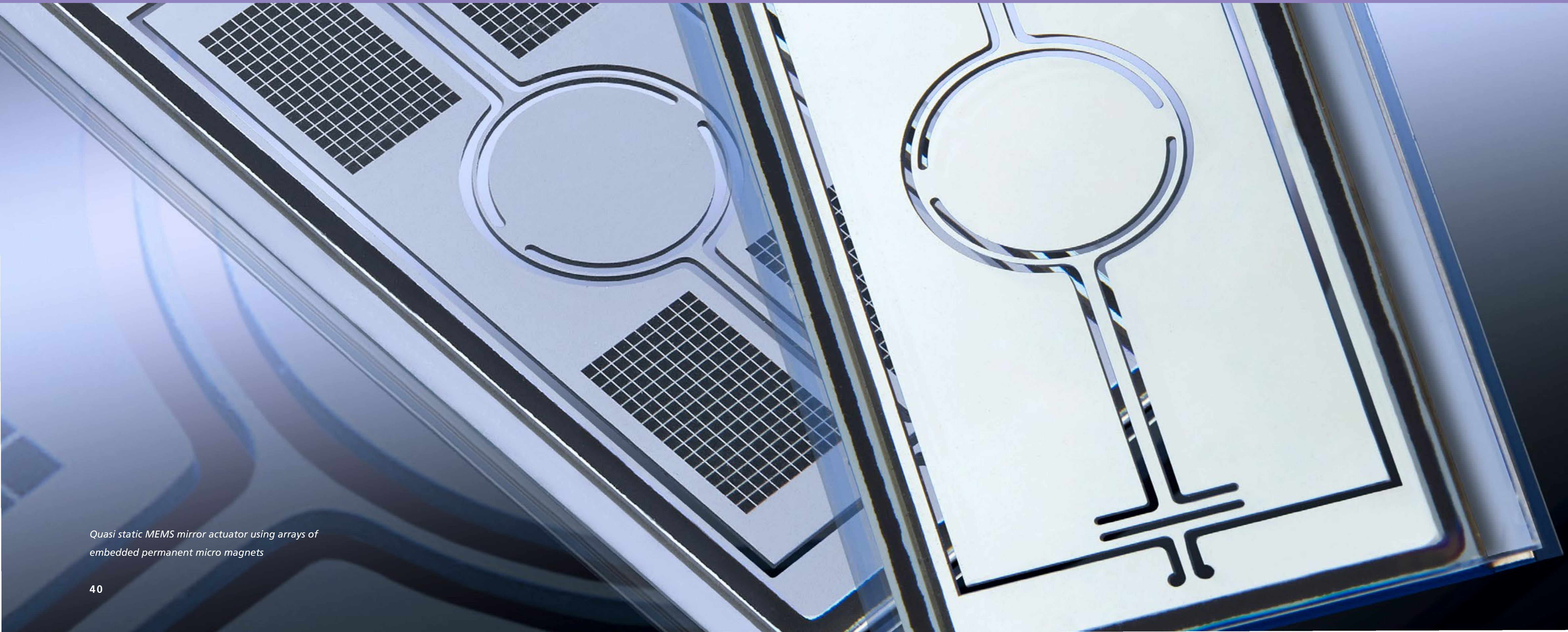
The dissolution of the silicon-side copper starts on the negative side of the solder ball and at the corner with high current density (Current Crowding Effect), the intermetallic phases grow on the opposite side. At high currents and high temperature, the copper also dissolves on the positive side due to the temperature gradient.
The dissolution of the PCB copper starts on the negative side in the high current density area. The copper pad dissolves and interrupts the current flow through the conductor.
The observation of the microstructure shows that a liquid phase reaction takes place. The visible microstructure with the strong phase formation is created by the melting of the solder.

Summary
There is a significant influence of current direction and current density on the solder structure, the terminal metallization and copper conductors. The copper dissolves in the solder and forms distinct intermetallic phases with the tin. This leads to open electrical connections both in the conductor and in the solder joints. The copper pad dissolves on the negative side of the solder joint and phase growth takes place preferentially on the positive side. Both the copper metallization on the chip and on the PCB have a part in the failure process of the component.

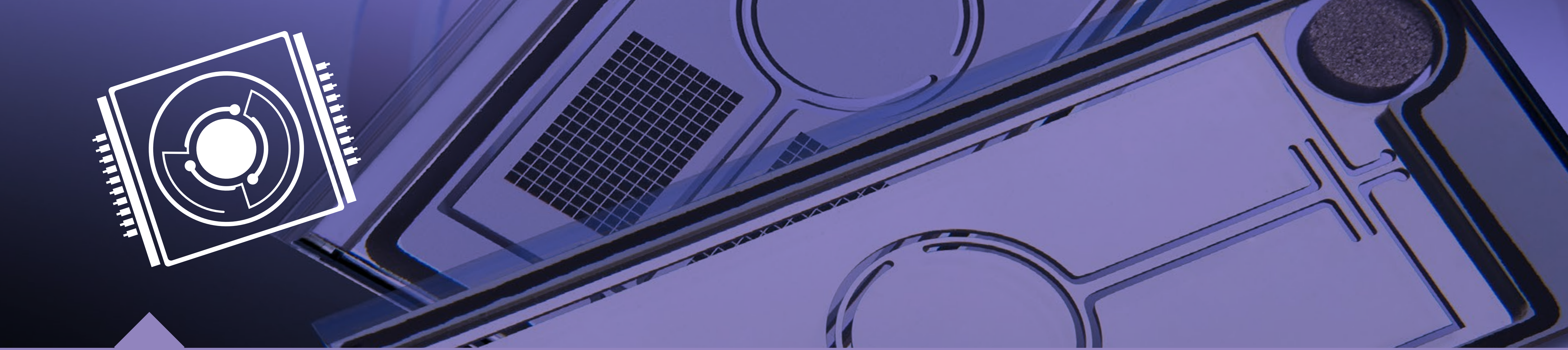
Authors:
Katja Reiter, Dr. Max Hermann Poech



MEMS APPLICATIONS



Quasi static MEMS mirror actuator using arrays of embedded permanent micro magnets



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MEMS APPLICATIONS

ISIT scientists have been working on the development of micro electro mechanical systems (MEMS) for more than 30 years. In the Business Unit MEMS Applications, ISIT focuses on the design, development, and production of MEMS devices for advanced applications

Optical microsystems are one major focus in this business unit. ISIT develops vector scanners and resonant scanners including control and readout electronics for a large number of applications addressing a growing market demand. Among others in laser projection displays, in optical measurement and detection systems (e.g. LIDAR), in applications requiring high laser power in the field of material processing and generative manufacturing as well as for the use in optical telecommunications. Based on a patented manufacturing process, ISIT is the world's only manufacturer of two-axis, wafer-level vacuum-encapsulated resonant MEMS scanners. Operating these scanning micromirrors in a vacuum environment offers significant advantages. Damping by gas molecules is reduced to a minimum, enabling high-frequency scanning with unrivaled scan angles already at low driving voltages.

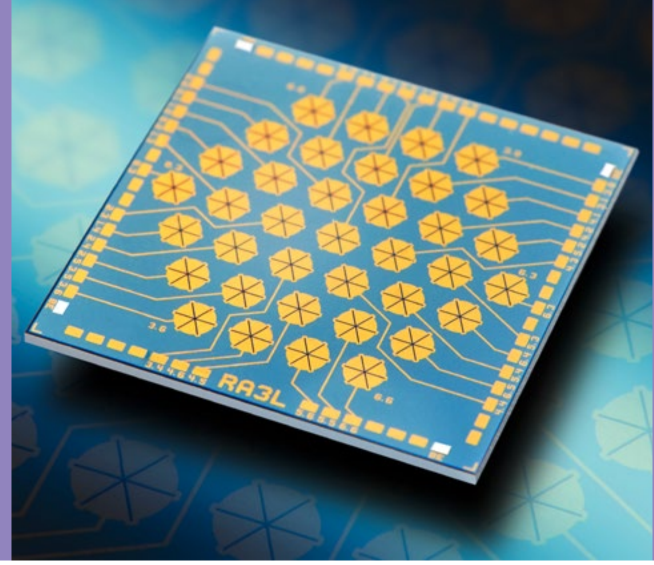
Hermetic encapsulation at wafer level also results in reduction of chip cost, a permanent protection of the micromirrors against all kinds of contamination and even the possibility of steam sterilization in an autoclave making new types of applications for endoscopy possible. ISIT has also realized a 3D camera with a depth resolution of just a few millimeters and a detectable object distance of 5 meters on the basis of 2D MEMS scanners. Novel scanning micromirrors with apertures of up to 2 centimeters and highly reflective coatings even permit highly dynamic dual-axis laser beam deflection for CW laser outputs of up to 500 watts.

Depending on application, either capacitive, piezoelectric or magnetic MEMS actuators are used to drive the ISIT micromirrors. In the case of quasistatically driven scanners, a special wafer-level 3D design enables extremely large tilt angles of more than ±10° with an unbeatable area fill factor of > 90 % for ISIT vector scanners.

A second strategic focus area of the business unit is acoustic microsystems. In this fast-growing field, ISIT is an international leader in research into innovative, highly miniaturized loudspeakers for applications in wearables, hearing aids, AR/VR, wireless headphones and smartphones. The MEMS loudspeakers can easily compete with the sound quality of their conventional electrodynamic counterparts, can be produced much more cost-effectively, reaching very low manufacturing tolerances, which is particularly relevant for array applications. MEMS developped by ISIT also features a high degree of flexibility in lateral layout, which opens up completely new possibilities for application and product design. Further advantages are the high energy efficiency and the high acoustic bandwidth (20 Hz - 100 kHz) of these components. All this together makes ISIT's chip-level loudspeakers particularly attractive for mobile communication devices such as tablets, smartphones, headphones and hearing aids in which high acoustic quality is required while at the same time further shrinking in size and low energy consumption.

Ultrasonic microsystems, e.g. for 3D distance measurements and haptic man-machine interfaces, are another research topic. Depending on the frequency range, the transducers at ISIT are usually designed as thickness-mode or membrane transducers with AlN, AlScN, or PZT as drive material. Efficient ultrasound transducers with center frequencies of a few kHz to several hundred MHz can easily be realized incorporating those materials.

AlScN FOR THE NEXT GENERATION OF PIEZOELECTRIC MEMS ACTUATORS



MEMS chip with piezoelectric ultrasound transducers

Piezoelectric thin films offer greatly enhanced power densities as well as excellent scaling properties for the next generation of MEMS actuators – compared to state of the art electrostatically driven devices. During the previous 15 years, the ISIT has taken a leading role in the integration of aluminium nitride (AlN) and lead zirconate titanate (PZT) films into MEMS devices such as loudspeakers, micro-mirrors and ultrasound transducers. Both AlN and PZT are considered as top-of-their class materials, with AlN benefiting from excellent stability as well as linearity, compatibility and reduced power consumption. On the other hand, PZT is able to provide superior forces – while being otherwise surpassed by AlN. Therefore, we identified the urgent demand to offer a generic solution to the demands of the next generation of MEMS actuators that could combine the advantages of both AlN and PZT.

Following the development of aluminium scandium nitride (AlScN), the ISIT was among the pioneering institutions to evaluate its potential for MEMS actuation. For the first time, we were able to demonstrate that with AlScN a material exists that can indeed combine the advantages of both AlN and PZT: Excellent stability, compatibility, linearity, repeatability and low losses while at the same time providing large forces and displacements [Fig. 1]. Therefore, AlScN is now at the heart of our technology platform for piezoelectric MEMS, offering the universal availability of a superior material to MEMS applications.

Besides offering substantial technological progress, ISIT in coperation with Kiel University achieved a scientific breakthrough with the discovery of ferroelectricity in AlScN (Figure 2). This discovery in turn will provide the foundation for even more powerful actuator solutions by enabling innovative AlScN multilayers in the near future.

The superior properties of AlScN enable to take MEMS actuators to the next level and develop new generations of cutting-edge MEMS for numerous applications. Examples are acoustic and optical MEMS – fields where ISIT is a pioneer since many years. Whilst PZT-based acoustic systems already offer outstanding performance, AlScN now provides a completely linear, bi-directional and yet powerful drive.
This enables even better sound reproduction quality, energy efficiency and miniaturization, making it an ideal solution for ultra-small loudspeakers for wireless headphones, hearables, hearing aids and wearables as well as ultrasound transducers for e.g. gesture recognition and haptic interfaces.
Regarding optical MEMS, ISIT is providing high-performing micro mirrors e.g. for laser projection and 3D distance sensing. However, up to now there were still numerous applications which could not be served properly, mainly due to limitations of the electromechanical driving system.
AlScN for the first time allows to overcome these limitations, enabling quasi-static mirror systems with high tilting angles, outstanding repeatability and great long term stability.
This expands the portfolio by many other applications such as optical cross-connects, LIDAR, autofocus systems and 3D cameras.

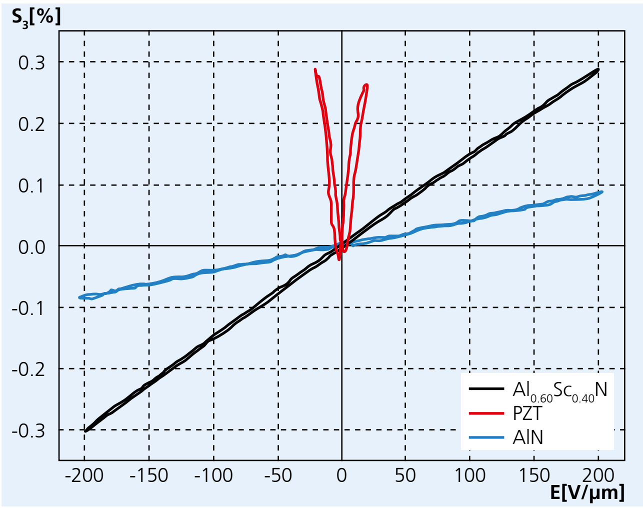


Figure 1: Comparison of the piezoelectric displacement in PZT, AlN and AlScN. Due to large coefficients and superiour stability, AlScN offers excellent strain and linearity at the same time

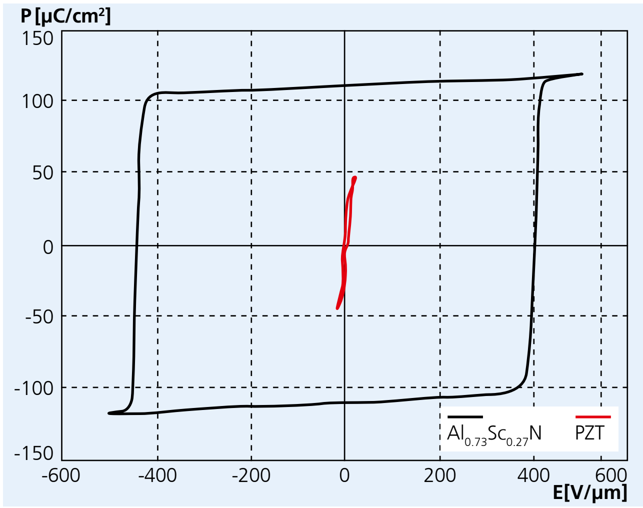


Figure 2: Ferroelectric hysteresis loop of AlScN compared to PZT – considering the key ferroelectric properties such as the remnant polarization, AlScN offers unmatched performance

The huge potential of AlScN described above as well as the continuous utilization of ISIT's past development efforts for integrating piezoelectric AlN and PZT enable us to offer a wide range of in-house MEMS device developments and also R&D services for our partners and customers – with 15+ years of experience.
Besides state of the art deposition capabilities ISIT's dedicated piezoMEMS module offers AlN, PZT and now AlScN and their specific electrodes in one integrated MEMS technology package including the deposition, wet and dry patterning and characterization - all combined with common MEMS process technologies and embedded in a 200 mm MEMS fab environment meeting industrial requirements.

Combined with further technology modules, e.g. our EpiPoly technology module and the (vacuum) wafer level packaging (vWLP) capabilities, a variety of innovative high performance piezoMEMS devices can be realized.

Authors:
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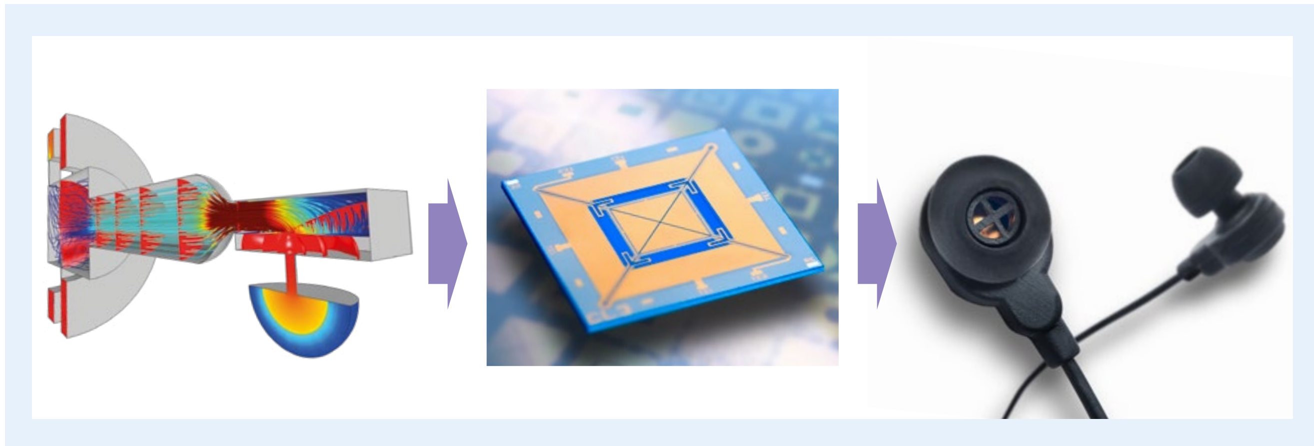
Figure 4: Illustration of ISIT's service offering using the example of MEMS loudspeakers: From concept and simulation to MEMS manufacturing to application

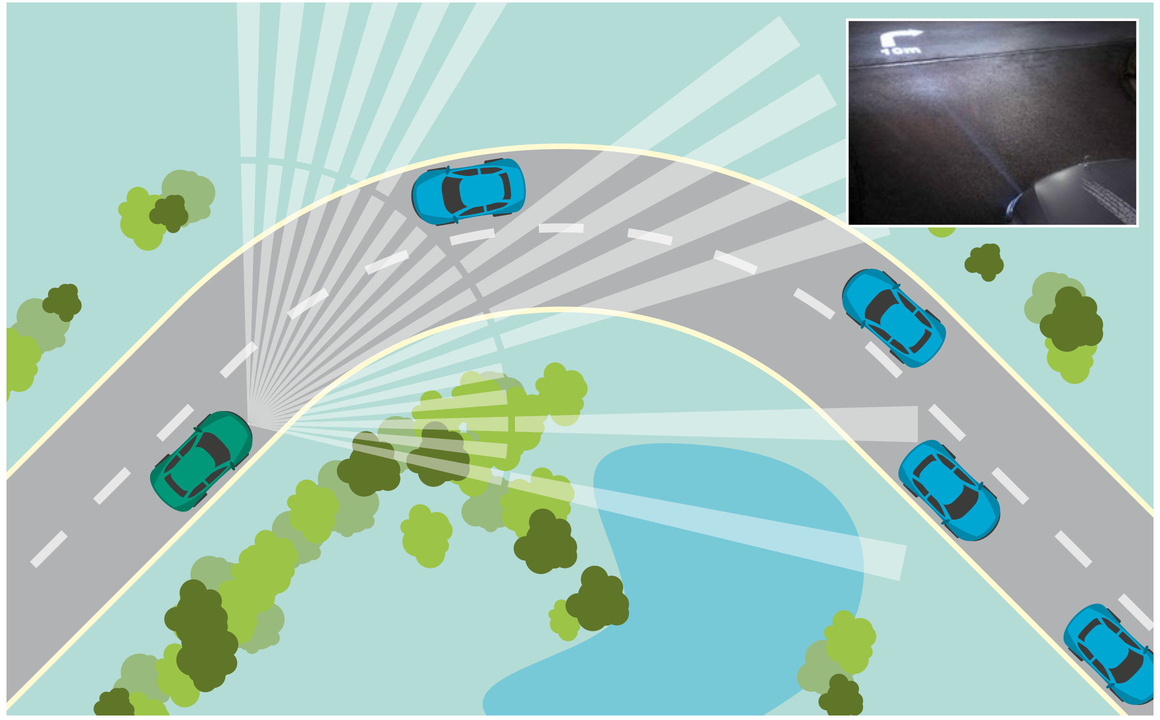


SMART HEADLIGHTS – LASER PROJECTION FOR COOPERATIVE DRIVING

Smart vision concepts for automobiles have found their way into the market with adaptive and glare-free headlights. But the development still goes on: Enabling cars to project adaptive light patterns, signals and symbols around them has the potential to further improve traffic security as a means for interactive communication between vehicles and traffic participants (figure 1). As a possible approach for projecting fine-resolution patterns in front of a car, headlights with scanning MEMS micromirrors have been developed and tested within the German public funded project KOLA (Kooperativer Laserscheinwerfer).

A white laser light source produces a power of up to 1 W, which is deflected by a resonant 2D MEMS scanner that has been designed and fabricated by Fraunhofer ISIT. With its circular aperture of 5.5 mm, the scanner will reflect sufficient light power and keep eye safety at the same time. A wafer-level vacuum package limits gas damping effects of the resonant system, hence large scanning angles are achieved. The manufacturing process involves four different wafers: the MEMS device wafer itself, a spacer, an upper glass lid with AR coating and a bottom wafer. After bonding all these wafers, the mirrors are hermetically encapsulated. They are diced into single devices and mounted on a PCB for characterization and demonstration (figure 2).

Figure 1: Visualization of different smart headlight approaches. –
Light patterns for masking out the oncoming cars
Small picture: Laser projected signs on street for communication between vehicles



A noteworthy detail - in particular for harsh automotive conditions - is the scanner technology: While most MEMS actuators use fragile electrostatic comb drives, ISIT's piezoelectric driving unit greatly enhances the mechanical robustness under shock and vibration constraints. The piezoelectric actuators consist of an active layer of thin-film Aluminum nitride (AlN) and a passive layer of polysilicon. Since the mirror plate is quite large and the chip size has to be as small as possible, the actuators have been tightly arranged around the mirror plate. Two actuator rings are responsible for x- and y-movement, respectively.

At the given light intensity, the mirror plate significantly heats up, thus the frequency ratio of the two axes has to be minimized. On the other hand, the frequency difference has to be large enough for avoiding mechanical coupling. The design values obtained from simulation were closely achieved in the fabrication with fx = 2244 Hz and fy = 2270 Hz, respectively. Both axes are driven by voltages of ± 40 VAC and the maximum scanning angles obtained for both axes are 55° x 35°, which will be reduced to 40° x 20° for a rectangular projection field without pincushion distortion (figure 3).

During oscillation, the highest mechanical stress occurs in the mirror hinges at largest deflection. These maximum stress values were optimized in FEM simulations and do not exceed 1 GPa (figure 4), which is still far below the breakdown stress of the polysilicon used here, according to former experiences.

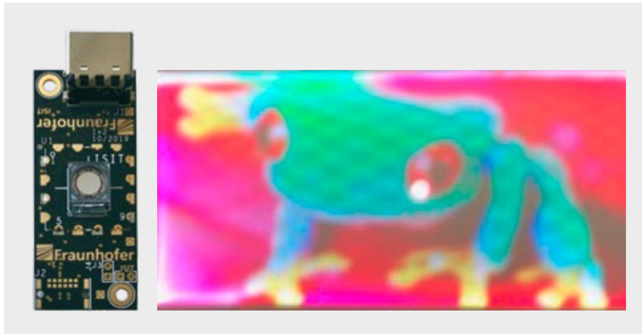


Figure 2: Left: Vacuum packaged MEMS mirror mounted on a PCB for closed-loop driving. Right: Laser projection picture based on Lissajous scanning using double resonant axes

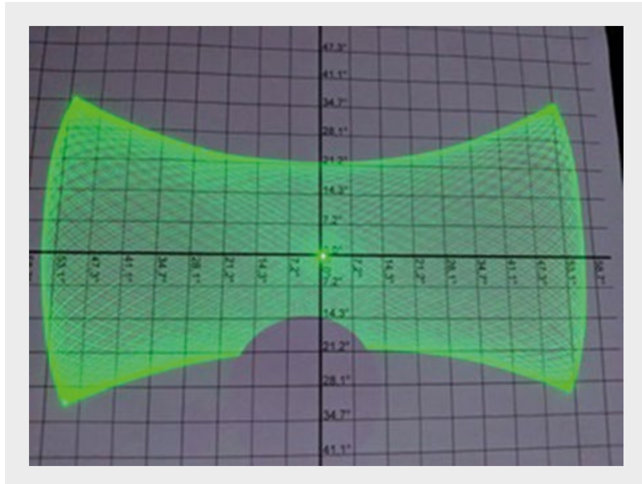


Figure 3: Result of biaxial scanning angles driven by ±40 V_{AC} at f_x = 2.26 kHz and f_y = 2.3 kHz, respectively. The maximum total optical scanning angles are $\vartheta_{opt,x}$ = 55° and $\vartheta_{opt,y}$ = 35°, where a distortion less rectangular field of view has an area of 50° x 20°

SMART HEADLIGHTS – LASER PROJECTION FOR COOPERATIVE DRIVING

Our MEMS scanner solution opens a perspective for customers to develop robust and compact projection modules for harsh environments like in automotive use. Owing to the maturity of the essential process techniques, i.e. MEMS containing AlN actuators and multiple wafer bonding, the manufacturing has a short runtime and provides a high yield of up to 98 %.
In the present smart headlight application, our gimbal-less, two-dimensional MEMS mirror design fulfills all needs regarding mechanical robustness, reliability and the scanning angles. A redesign is targeted for raising the resonance frequencies as well as the frequency difference, in order to optimize the functional robustness.

Authors:
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Dr. Thomas Knieling

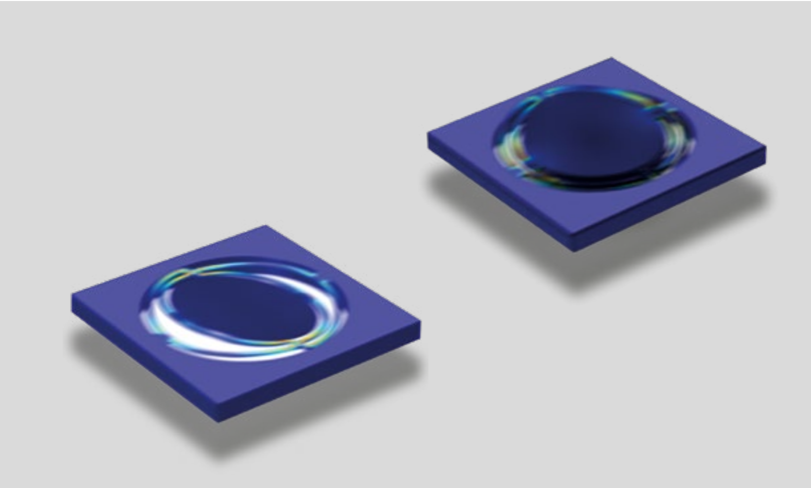
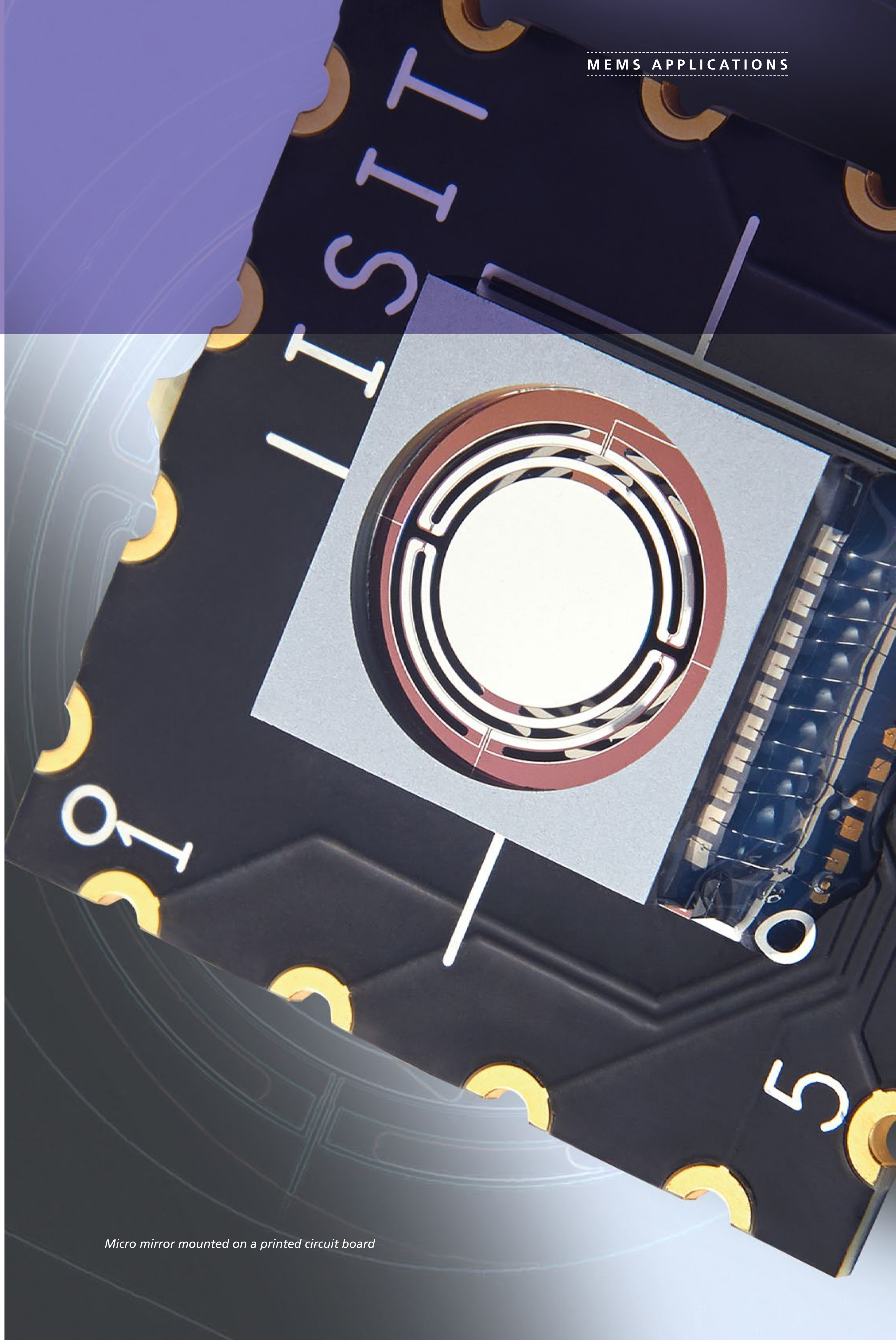
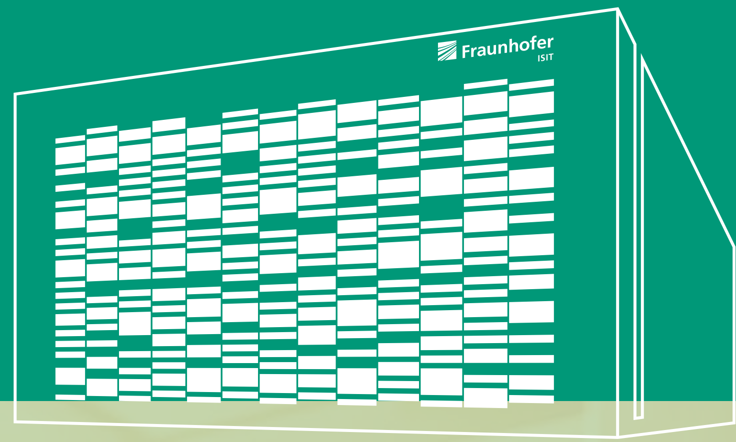


Figure 4:
FEM simulation results for Von-Mises stress (intentionally blurred; red color denotes the maximum stress).
Left: In the rotation mode about y-axis, the maximum Von-Mises stress is 0.99 GPa.
Right: In the rotation mode about y-axis, the maximum Von-Mises-stress is 0.65 GPa

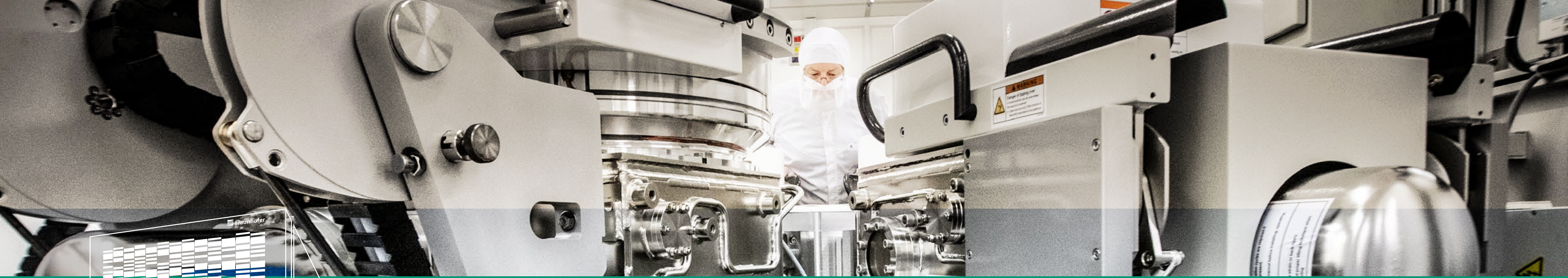


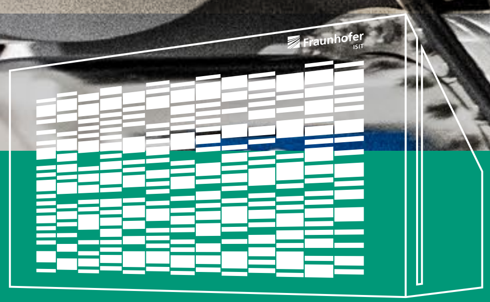
Micro mirror mounted on a printed circuit board



TECHNOLOGY

ISIT cleanroom: lithography area





TECHNOLOGY

Fraunhofer ISIT is running a 200 mm Silicon technology line for front-end processes such as MOS and PowerMOS. Specific processes for MEMS and NEMS as well as for packaging are implemented in a special 1000 m² cleanroom which includes wet etching, dry etching, DRIE, deposition of non-IC-compatible materials, lithography with thick-resist layers, electroplating, microshaping and wafer bonding. Further cleanroom laboratories are set up for CMP and post-CMP processing. Extra laboratories are dedicated to electrical and mechanical characterization of devices, assembly and interconnection technology, and reliability testing. We also operate and offer a pilot production line for Li-polymer batteries. *

*The institute's facilities have been certified to ISO 9001:2015.

Services at metal deposition equipment

TECHNOLOGY PLATFORMS

ISIT has a wide portfolio of qualified single process technologies available, which were combined to five specific technology process platforms. They form a kind of tool box to realize various applications.
In addition, Fraunhofer ISIT has further technology offers, e.g. for the development of lithium batteries.

POLY SILICON TECHNOLOGY PLATFORM (PSM-X2)

The technology platform PSM-X2 features a low stress 10–30 µm thick poly silicon layer for the realization of mechanical active and passive MEMS structures.
The use of high resolution lithography allows minimal structure dimension down to 0.5 µm.

An additional electrode layer beneath the active polysilicon layer is implemented. This gives the opportunity for out-of-plane signal detection or sensor stimulation. Additive functional layers enhance reliability and robustness of the MEMS devices (anti stiction, high-g shock). For the wafer scale bonding of the sensor device and the protective encapsulation a dedicated multi pressure wafer level packaging process is applied using a gold silicon eutectic process at about 400°C.

The metallic bond frame induces a hermetic encapsulation of the cavity and the pressure applied during the bond process will persist.

Integrated getter films allow cavity pressure levels down to 10-6 bar and a pressure ratio within adjacent cavities of up to 1:400. The application range of PSM-X2 platform includes e.g. inertial sensors, micro mirrors or electro-optic deflection devices. Recently, Fraunhofer ISIT has developed an innovative process technology for the manufacturing of sophisticated MEMS scanners ($^{2}\varepsilon$ Process), called "Dual-Layer EpiPolySilicon Process".

Following the success of the well established surface micromachining technology PSM-X2 for inertial sensors, the $^{2}\varepsilon$ process is based on structuring two 30 microns thick epitactically grown polysilicon layers. This allows the realization of staggered finger combdrives for mirror actuation and detection and the design of suspension.

Above: Fabrication of packages for laser diodes
Right: Various structured glass wafers

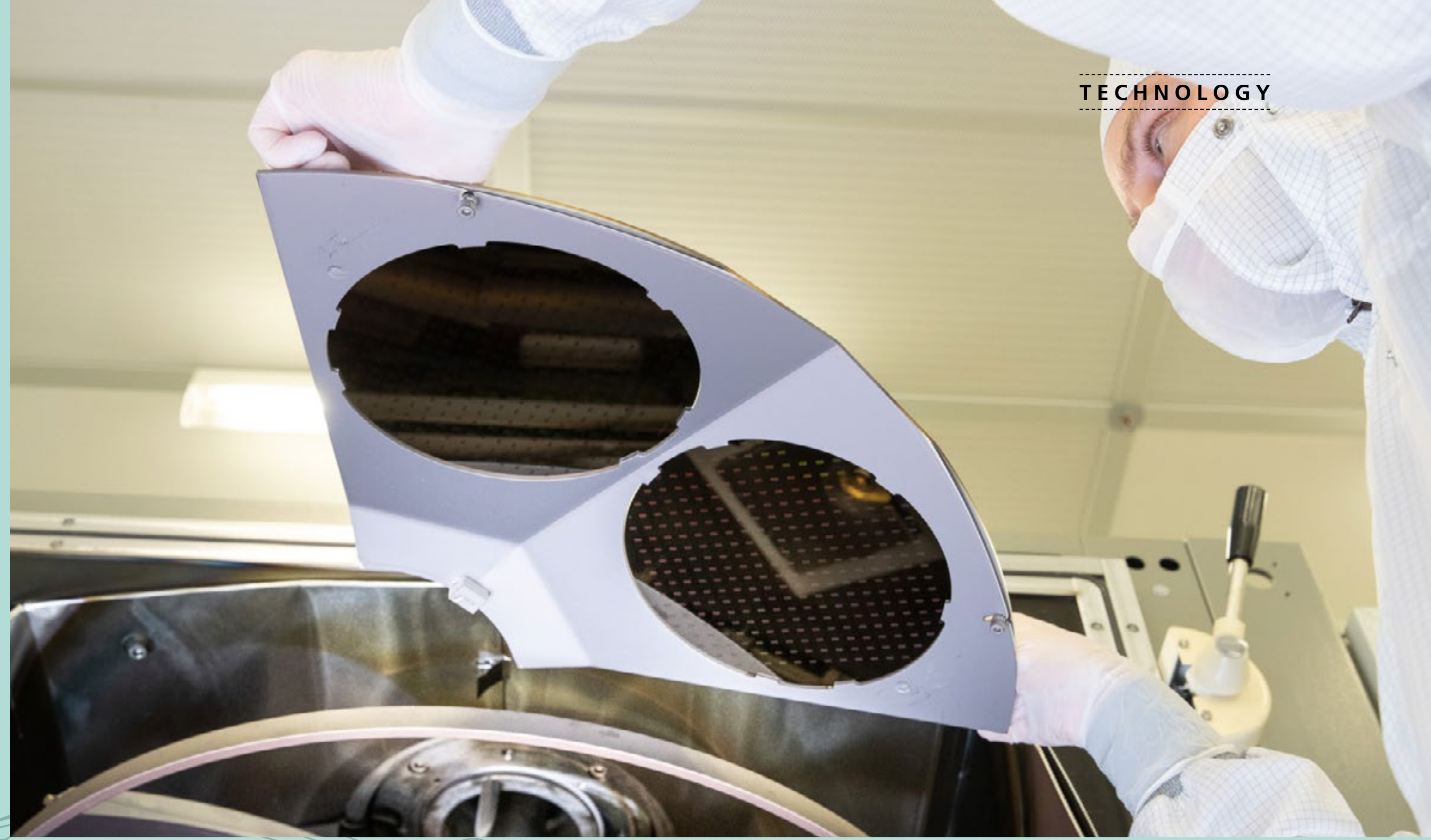
GLASS MICROMACHINING

The Fraunhofer ISIT developed a process based on hot temperature viscous glass micromachining. It is mainly used for the production of micro-lenses and glass packages with inclined window surfaces. Using this process, it is possible to structure glass wafers with high aspect ratios on wafer level. A structured silicon wafer is chosen as so-called primitive form, so glasses must be used whose softening temperature is well below that of silicon. This has the advantage that the standardized methods to structured silicon wafers of a clean room can be used. The etched structures or cavities correspond later the molded areas in the glass. The structured silicon wafer is then anodically bonded to a glass wafer. In this case, a defined pressure within the cavities is enclosed. When a relative vacuum is enclosed the cavities and the heat treatment takes place under atmospheric pressure, the glass is pressed into the cavities. If an atmospheric pressure is enclosed and the heat treatment takes place under vacuum then the glass is forced out of the cavities. Depending on the application, the glass may now be further processed by grinding and polishing.

1200 V IGBT with NiAu surfaces

PIEZO MODULE

The Fraunhofer ISIT has been working for more than 10 years on the deposition of thin films of the piezoelectric materials aluminum nitride (AlN) and lead zirconium titanate (PZT). Currently, sputtering processes with film thicknesses of up to 4 μm for AlN and up to 3 μm for PZT are available. The integration into MEMS structures is typically realized via unimorphs consisting of a piezoelectric layer embedded between two metal electrodes on top of a passive support layer made from mono- or polycrystalline silicon. PZT is mainly used for actuator applications, as its high piezoelectric coefficients enable particularly large deflections and high forces with only low drive voltages. The PZT actuators are integrated for their utilization in MEMS scanners and loudspeakers. For sensory applications, AlN is preferred due to its considerably better signal-to-noise ratio. At ISIT it is currently used in ultrasonic transducers, MEMS microphones and vibrational energy harvesters. In addition to these established materials scandium-doped AlN (AlScN) is being developed in cooperation with the Kiel University. Despite the higher piezoelectric coefficients compared to pure AlN, this material retains the advantageous properties (high dielectric strength, IC-compatible, low dielectric losses) of the AlN and is therefore suitable for both sensor and actuator MEMS components. In the long term, it is intended to completely replace the lead-containing PZT. Among other things, a highly sensitive magnetoelectric sensor and MEMS scanners based on AlScN are currently being developed.



Operator loading wafers into the evaporation chamber

POWDER MODULE

At Fraunhofer ISIT a novel technology has been developed which allows the integration of nearly any material onto planar substrates. It is based on the agglomeration of micron-sized powder (particles) by atomic layer deposition (ALD).

Like for the fabrication of ceramics, firstly a mold, in this particular case a silicon substrate with dry etched micromold pattern, is filled with loose powder. However instead of sintering the particles together with high pressure at high temperatures, the silicon substrate is subjected to an ALD process at temperatures below 300° C. Thanks to the outstanding coating capability of ALD the loose particles in the micromolds are fixated to porous 3D structures over the whole mold depth (up to 600 μm) by a layer with a thickness of only 75 nm. These porous 3D structures are shrinkage-free and stable mechanically as well as thermally. Lateral dimensions between 50 μm and several mm can be realized with high precision. The nearly perfect envelopment of each particle by the ALD layer ensures an excellent protection against environmental influences. Substrates with embedded porous 3D structures can be post-processed in a cleanroom using standard processes of IC and MEMS fabrication at up to 400 °C.

That opens up a unique range of applications. One of the evaluated ones is the fabrication of integrated permanent micromagnets from NdFeB powder. Strong magnetic fields on small scale are of interest for many MEMS sensors and actuators. The focus at ISIT is currently on magnetically driven vibrational energy harvesters and microscanners. Other promising applications of the novel technology are miniaturized organic-free phosphor converters for solid state lighting (SSL) or the thermal isolation of mass flow and gas sensors by evacuated porous 3D structures, which is comparable to conventional super vacuum insulation.

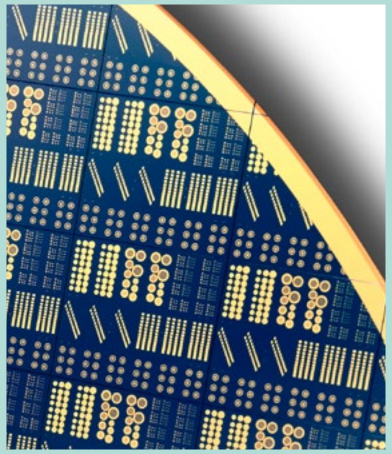
NdFeB micro-magnets based on innovative powder technolgy

GaN TECHNOLOGY

In addition to the research of new high voltage silicon devices the ISIT is developing high voltage devices with gallium nitride (GaN) substrates. This material is used to replace silicon because of higher electric strength, higher switching speed and higher possible working temperature. These benefits lead to a higher efficiency.

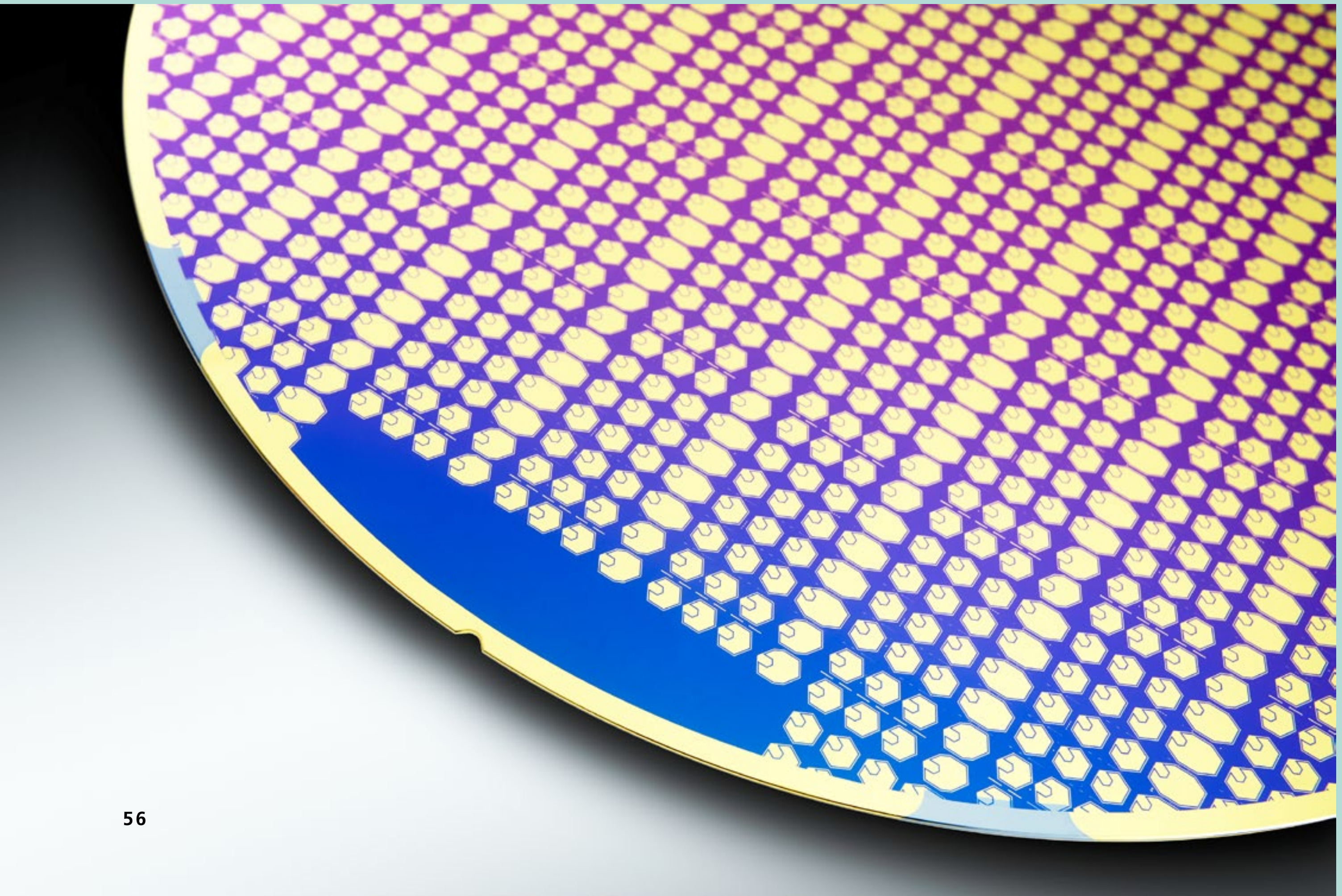
While lateral HEMT devices can be purchased today, the research objectives of the ISIT are vertical transistors on 8" wafer. The substrates of these wafers are made of silicon, only the top layers where the power device is placed in are epitaxial grown GaN.

To achieve the goal, the equipment and know-how of the newly built MEMS cleanroom will be used. Technology is and has been adapted to meet the requirements of the new material. Supplemental equipment to avoid silicon contamination of GaN material (Si is a dopant for GaN) is going to be ordered in the project "Research FAB Microelectronics Germany". That includes tools for e.g. dry etching, wafer cleaning and annealing.



Left: GaN on Si wafer with test structures for measurement of n-type and p-type contact

Bottom: GaN wafer with semi vertical diodes of different size and geometry

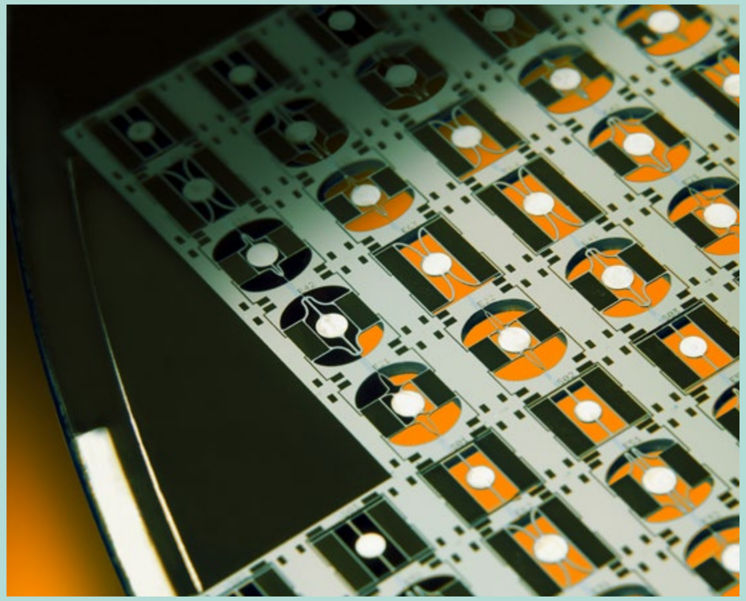


FURTHER TECHNOLOGY OFFERS

METAL SURFACE MICROMACHINING

Metal surface micromachining is an alternative way to build up complete MEMS systems or a part of them. By using mainly electroplating and lithography in combination with PVD, PECVD and etching processes it is possible to fit the requirements for a variety of applications.

The low CMOS/ASIC compatible temperature budget makes this process suitable for the monolithical integration of a complete MEMS system. Additional a high flexibility in design and thickness is given. Additional fields of application are electrodes for electrostatic actuation/deflection, bondframes for waferlevel packaging, metal wiring, bondpads, bumps and high-Q inductors.



Scanning micro mirrors with experimental suspensions

Lithium polymer cells for electric automotive application in cooling fixation

POUCH CELL TECHNOLOGY

Based on the lithium ion battery technology, Fraunhofer ISIT provides a flexible manufacturing platform enabling technical realization of accumulator development. The production of cells can be divided in two main steps:

- Manufacturing of electrodes and separators
- Assembling of cells

The electrodes can be produced with laboratory equipment up to pilot line level with a maximum speed of 2 m/min. In this context the proprietary separator concept developed by Fraunhofer ISIT is an integral part of the cell technology. It is exactly matched to the assembling process (lamination) for the production of cells.

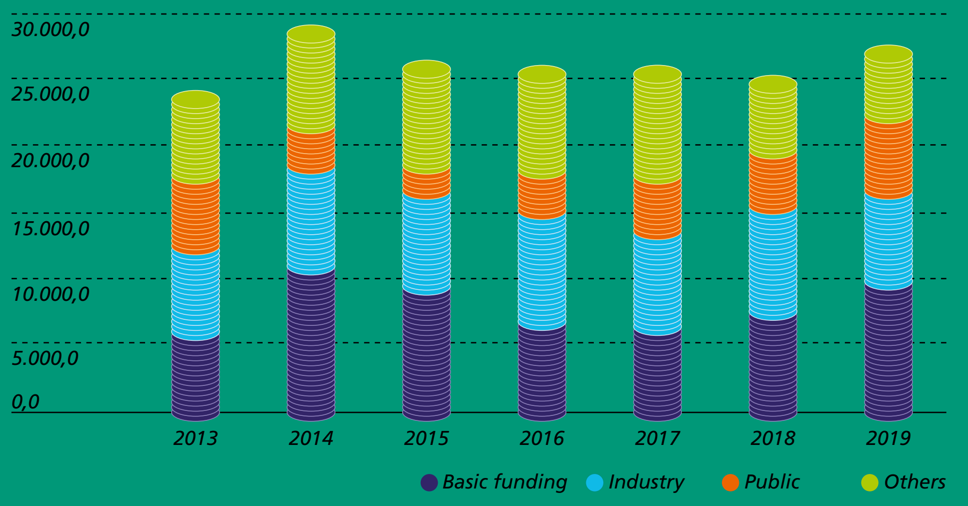
By variation of materials in the lithium accumulator its performance can be controlled within a wide range. In addition, the pouch casing enables an adaption of the cell design in a wide format range to predetermined dimensions. By continuous introduction of new materials a considerable „electrochemical system module" was generated over the years. It is adjusted continuously to increasing requirements.

REPRESENTATIVE FIGURES

BUDGET

Income of Fraunhofer ISIT from 2013 up to 2019
The budget 2019 was financed by proceeds of projects of industry/industrial federations/small and medium sized companies amounting to 7.073,6 T€, of government/project sponsors/federal states amounting to 5.117,4 T€ and of others amounting to 5.118,7 T€. Furthermore there were Fraunhofer projects and basic funding with 9.735,6 T€.

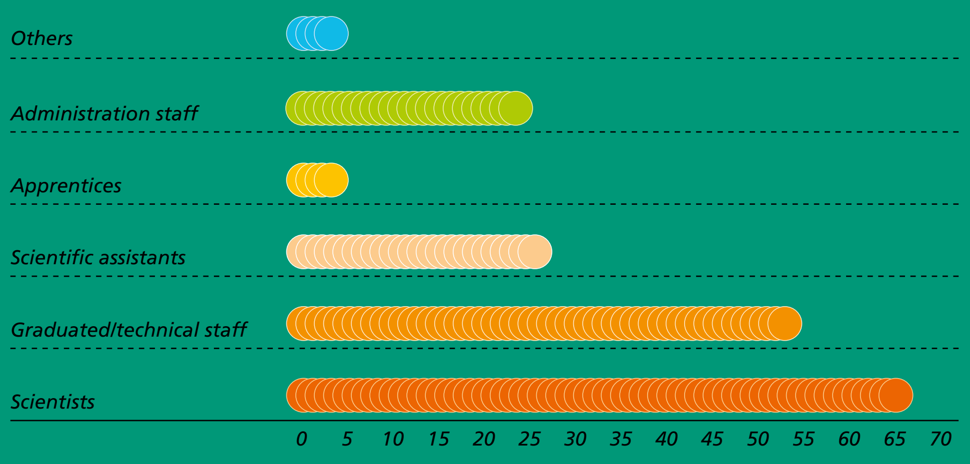
Budget [T€]



STAFF

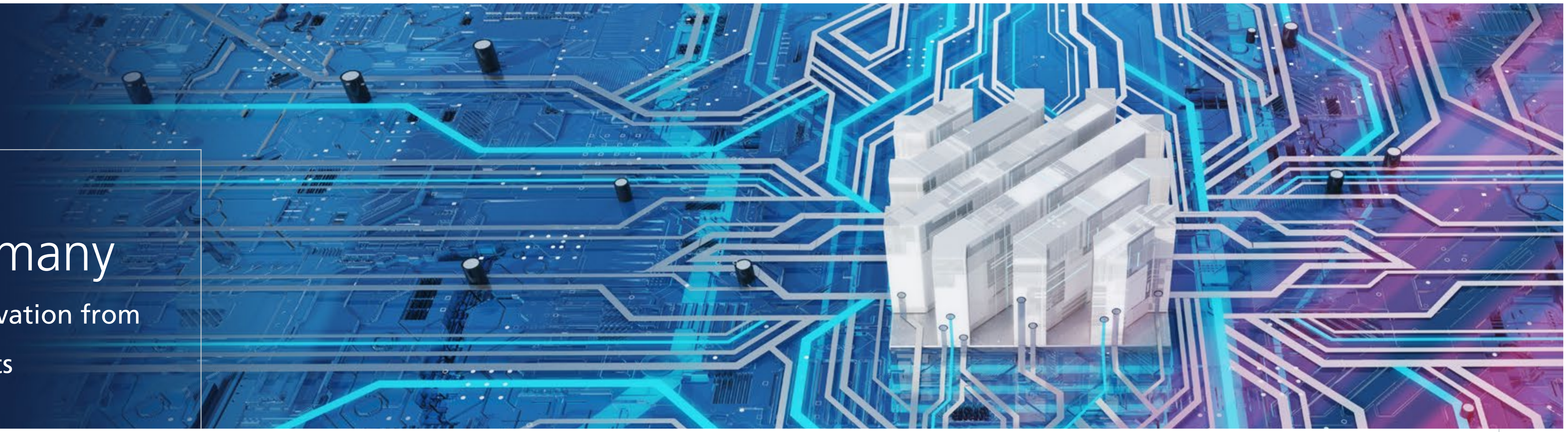
Staff Development
At the end of 2019 the staff consisted of 139 employees. 63 were employed as scientific personnel, 52 as graduated/technical personnel and 24 worked within organization and administration. The employees were assisted through 24 scientific assistants, 4 apprentices and 4 others.

Staff Development



Research Fab Microelectronics Germany

One-Stop-Shop: Microelectronics innovation from fundamental research to pilot products



Since April 2017, Fraunhofer ISIT is part of the Germany-wide Research Fab Microelectronics Germany (FMD). With 13 member institutes and over 2000 active researchers, this research network represents Europe's largest R&D collaboration for micro- and nanoelectronics.

The investments in FMD are paying off

Within the last two and a half years, successful project ventures have been established and numerous contracts completed in cooperation with the FMD. In 2019, projects with a combined volume of € 66.8 million were made possible as a result of investments into the FMD. Pure industry projects accounted for more than € 17 million in 2019, underlining the importance of this unique cooperation in German microelectronics research.

FMD – a promising model for major project initiatives

In 2020, the final set-up phase for the Research Fab Microelectronics Germany is being initiated. The innovative concept's great potential for cross-site cooperation has already been proven e.g. in the "miniLIDAR" project, a major initiative (with a volume of € 5.65 million) supported by the FMD's business office since its launch in late 2019. The project will design miniaturized LIDAR components for robotic applications with the aid of an industry partner actively scouted for and won over by the FMD business office. Four FMD institutes – the Ferdinand Braun Institute FBH in Berlin, the Fraunhofer Institue for Microelectronic Circuits and Systems IMS in Duisburg, the Fraunhofer Institute for Photonic Microsystems IPMS in Dresden, and the Fraunhofer Institute for Reliability and Microintegration IZM in Berlin – are involved in the project.

Founders' dreams come real in the FMD-Space

The start-up support concept FMD-Space – first proposed at the very start of the FMD's set-up – has continued to make headway in 2019 in several successful pilot projects. Technology-driven start-ups are thus provided efficient and ready access to the technologies and facilities of the member institutes. The enterprising minds behind the start-ups team up with the institutes' research staff to produce working demonstrators of their product concepts. The services of the FMD-Space are, for instance, being used by the founders of "Ghost - feel it", the "OQmented GmbH", and "nxtbase technologies GmbH". Two further project ideas won their places in the FMD-Space in late 2019: "Quantune Technologies" and "Twenty-One Semiconductors".

Modernizing the FMD's facilities at full speed

The FMD vision of successful research and development work happening collaboratively at locations across Germany is supported by Germany's Federal Ministry of Education and Research, with approx. € 350 million in funding set aside until late 2020. This investment into the FMD fuels the future viability of applied microelectronics research in Germany. Practically, this primarily takes the form of updated and modernized research facilities at the 13 participating institutes from the Fraunhofer-Gesellschaft and Leibniz Association. By the end of 2019, 157 new pieces of equipment have already been delivered and are, in the main, already up and running – a great step forward in substantially expanding the institutes' technological capabilities.

Fraunhofer ISIT
is participant of the

Forschungsfabrik Mikroelektronik Deutschland

THE FRAUNHOFER-GESELLSCHAFT

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

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

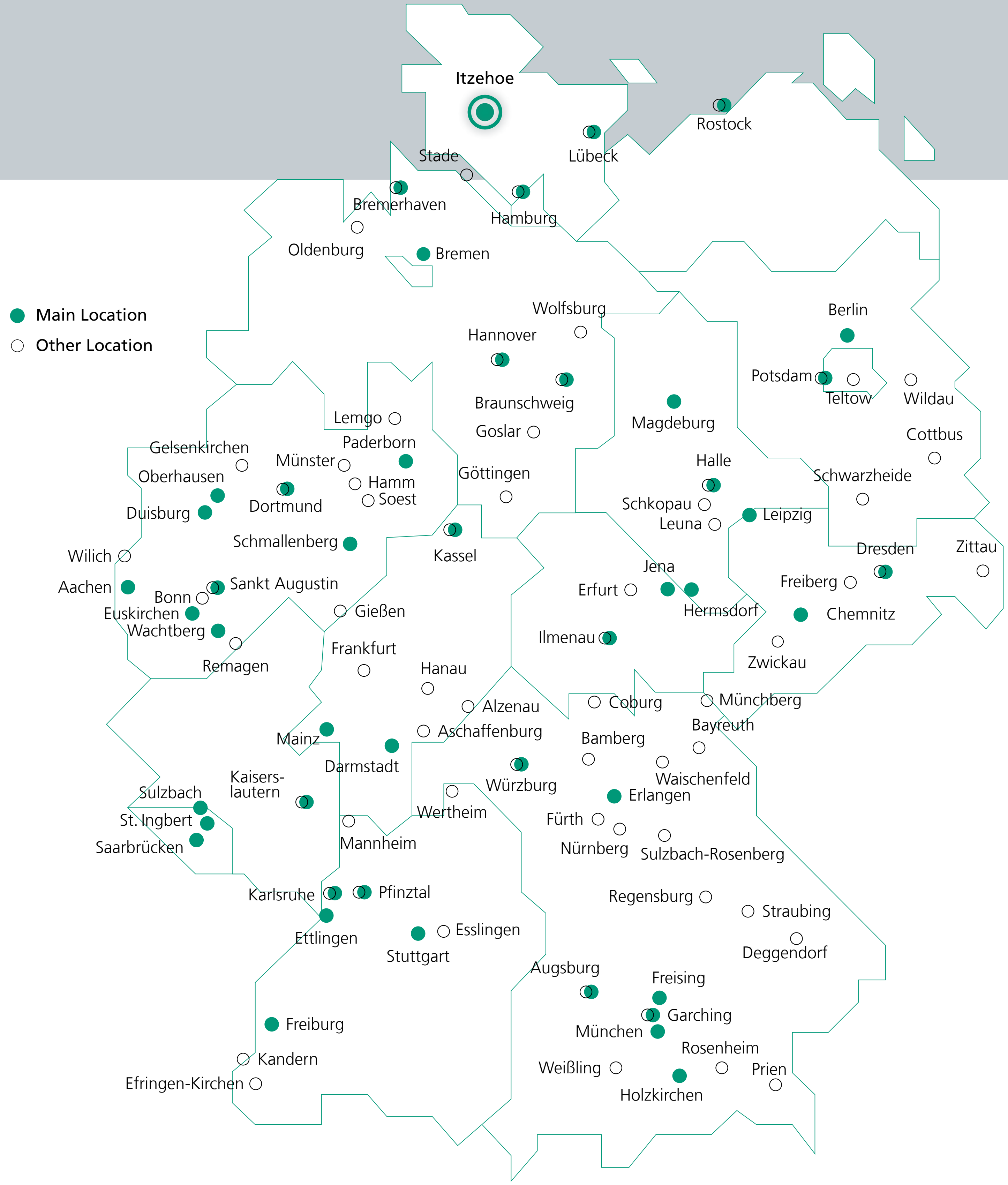
Founded in 1949, the Fraunhofer-Gesellschaft currently operates 74 institutes and research institutions. The majority of our 28,000 staff are qualified scientists and engineers, who work with an annual research budget of 2.8 billion euros. Of this sum, 2.3 billion euros is generated through contract research. Around 70 percent of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining 30 percent comes from the German federal and state governments in the form of base funding. This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future.

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

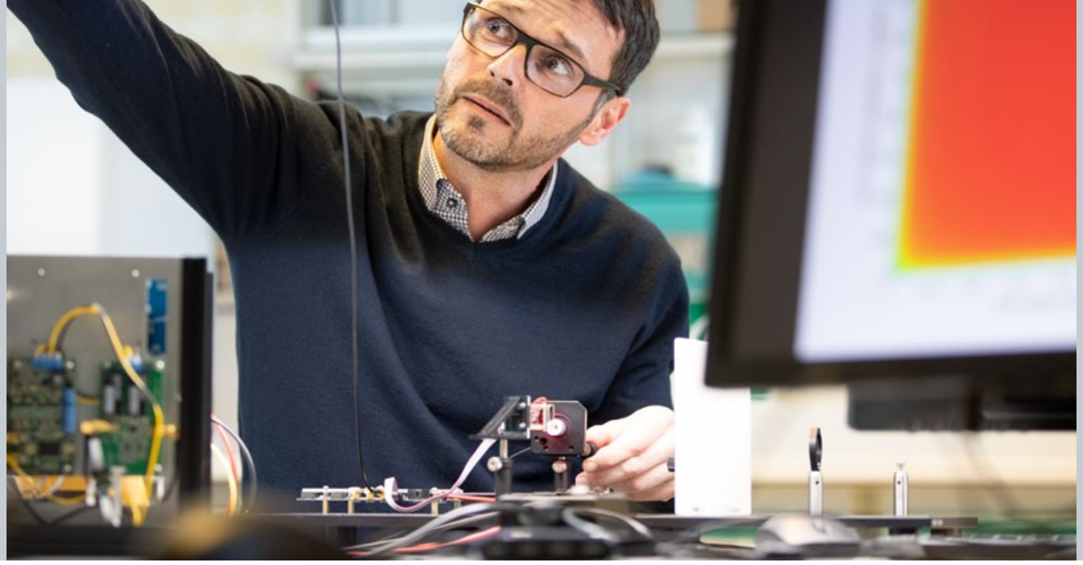
Our highly motivated staff, working at the cutting edge of research, are the key factor in our success as a scientific organization. Fraunhofer offers researchers the opportunity for independent, creative and, at the same time, targeted work. We therefore provide our employees with the chance to develop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

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.

LOCATIONS OF THE RESEARCH FACILITIES



IMPORTANT
NAMES, DATA, EVENTS



Cooperation with Institutes and Universities

Technische Universität Dresden, Dresden

Nanoelectronic Materials Laboratory (namlab), Dresden

Hochschule Flensburg, Flensburg

Albert-Ludwigs-Universität, Freiburg

Hochschule für Angewandte Wissenschaften, Hamburg

Fachhochschule Westküste, Heide

Christian-Albrechts-Universität, Technische Fakultät, Kiel

Fachhochschule Kiel, Kiel

University of Southern California, Los Angeles, USA

Fachhochschule Lübeck, Lübeck

Syddansk Universitet (SDU), Sonderburg, Dänemark

Lecturing Assignments at Universities

W. Benecke
Lehrstuhl Technologie Siliziumbasierter Mikro- und Nanosysteme, T*echnische Fakultät, Christian-Albrechts-Universität zu Kiel*

R. Dudde
Mikrotechnologien (8168), Fachbereich Technik, *FH Westküste, Heide*

F. Haase
Professur für Leistungselektronik und Grundlagen der Elektrotechnik, Department Informations- und Elektrotechnik, *HAW Hamburg*

H. Kapels
Professur Halbleiterbauelemente der Leistungselektronik, *Technische Fakultät, Christian-Albrechts-Universität zu Kiel*

F. Lofink
Prozesse und Materialien der Nanosystemtechnik, Micro- and Nanosystem Technology, *Technische Fakultät, Christian-Albrechts-Universität zu Kiel*

G. Pangalos
Advanced Control Systems: Simulation and Optimization Tools, *Lehrauftrag an der HAW Hamburg*

O. Schwarzelbach
Mikrosystementwurf, Fachbereich Technik, *FH Westküste, Heide*

O. Schwarzelbach
Mikroelektromechanische Systeme (MEMS), Institut für elektrische Messtechnik und Mess-Signalverarbeitung, *Technische Universtität Graz, Austria*

B. Wagner
Lehrstuhl Prozesse und Materialien der Nanosystemtechnik, Micro- and Nanosystem Technology, Technische Fakultät, Christian-Albrechts-Universität zu Kiel

Memberships in Coordination Boards and Committees

L. Bertels
Member of DGQ kooperative Firmenmitgliedschaft

L. Bertels
Member of DGQ-Qualitätsleiterkreis Hamburg

L. Bertels
Member of DGQ-Regionalkreis Hamburg and Schleswig-Holstein

L. Bertels
Member of Network „Qualitätsmanagement“ of the Fraunhofer Gesellschaft

J. Eichholz
Member of GMM/GI-Fachausschuss EM „Entwurf von Mikrosystemen“, VDE / VDI-Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik

J. Hagge
Member of GfKORR Arbeitskreis „ Korrosionsschutz in der Elektronik und Mikrosystemtechnik“

T. Knieling
Technologienetzwerk Körpernahe Systemtechnik (Body Tec)

T. Knieling
Member of Organic and Printed Electronics North (OPEN)

M. Kontek
Member of AG 2.4 Drahtbonden

J. Lähn
Member of Hamburger Lötzirkel

F. Lofink
Member of Kiel Nano, Surface and Interface Science (KiNSIS)

R. Mörtel
Member of BVES

R. Mörtel
Member of Fraunhofer-Allianz Energie

R. Mörtel
Member of Fraunhofer-Allianz Batterien

R. Mörtel
Member of Subsea@Fraunhofer

A. Müller-Groeling
Member of „NiNA“ - Norddeutsche Initiative Nanotechnologien e. V.

A. Müller-Groeling
Member of Förderverein Technische Fakultät Kiel e. V.

W. Reinert
Member of DVS-Fachausschuss FA10 ”Mikroverbindungstechnik“

W. Reinert
Member of IMAPS Deutschland

W. Reinert
Member of Technical Committee of Electronics Packaging Technology Conference (EPTC)-Singapore

W. Reinert
Member of GMM Workshop Packaging von Mikrosystemen

W. Reinert
Member of Wafer Bond Technologie Konferenz

K. Reiter
Member of DGM, Arbeitskreis Probenpräparation

K. Reiter
Member of Metallographie Nord

K. Reiter
Member of „Preparation-Board“ Praktische Metallographie

H. Schimanski
Member of Arbeitskreis „Systemzuverlässigkeit von Aufbau- und Verbindungstechnologie“ des Fraunhofer IZM

H. Schimanski
Member of VDE/VDI Arbeitskreis „Prüftechniken in der Elektronikproduktion“

H. Schimanski
Member of ZVEI Fachverband Arbeitsgruppe „Zuverlässigkeit von Leiterplatten“

H. Schimanski
Member of Hamburger Lötzirkel

H. Schimanski
Member of FED Arbeitskreis „Baugruppe“

H. Schimanski
Member of FED Regionalgruppe Hamburg

H. Schimanski
Member of DVS Fachausschuss FA10 „Mikroverbindungstechnik“

H. Schimanski
Member of GfKORR Arbeitskreis „Korrosionsschutz in der Elektronik und Mikrosystemtechnik“

S. Schröder
AG 2.4 Drahtbonden

S. Schröder
IMAPS Deutschland

V. Stenchly
IVAM – Member of IVAM

V. Stenchly
Senior Advisor GMM VDE/VDI- Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik

B. Wagner
Member of GMM-Fachausschuss 4.1 „Grundsatzfragen der Mikrosystemtechnik und Nanotechnologie“, VDE/VDI-Gesellschaft für Mikroelektronik, Mikro- und Feinwerktechnik

A. Würsig
Member of Fraunhofer-Allianz Batterien

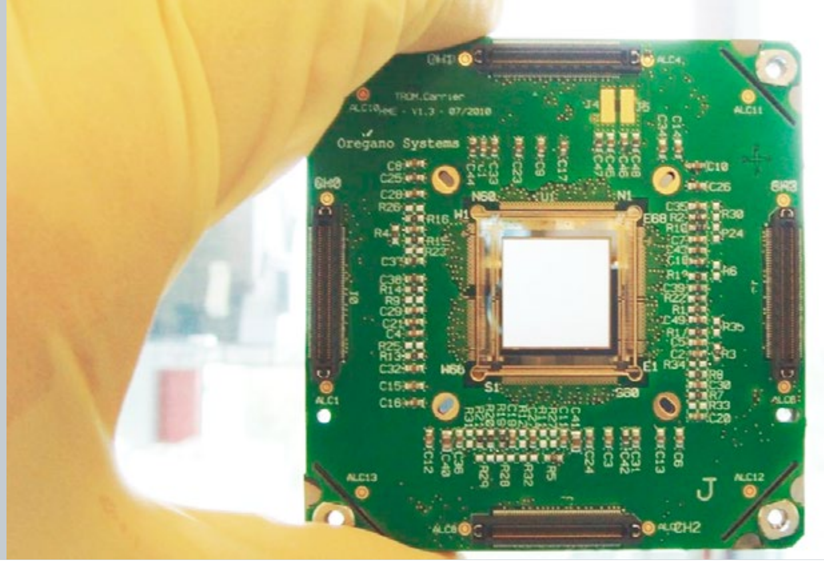
A. Würsig
Member of Fraunhofer-Allianz Energie

A. Würsig
Member of Bundesverband Energiespeicher (BVES)

A. Würsig
Member of Kompetenznetzwerk Lithium-Ionen-Batterien (KLiB)

A. Würsig
Member of Subsea of the Fraunhofer-Gesellschaft

H. Zeller
Member of Fraunhofer-Allianz Energie



Trade Fairs and Exhibitions

SPIE 2019
Photonics West Exhibition,
February 02–07, 2019,
San Francisco, USA

Mobile World Congress
February 25 – 27, 2019,
Barcelona, Spain

DAGA 2019
45. Jahrestagung für Akustik
March 18–21, 2019,
Rostock

Hannover Messe 2019
Leading Trade Show for
Integrated Energy Systems for
Industry, Heating and Mobility,
April 01–05, 2019, Hannover

PCIM Europe 2019
International
Exhibition & Conference,
Power Conversion Intelligent
Motion,
May 07–09, 2019,
Nürnberg

SMT/Hybrid/Packaging 2019
Hybrid Packaging System
Integration in Micro Electronics,
May 07–09, 2019,
München

ees Europe 2019
May 15–17. Mai, 2019,
München

Nordjob Unterlebe Westküste 2019
Trade Fair for
Education and Study,
May, 22–23, 2019,
Brockdorf

Transducers 2019
June 23–27, 2019,
Berlin

Laser 2019
Micro-Actuators for Optical
Applications,
June 24 – 27, 2019,
München

AES Headphone Technology 2019
August 27 – 29, 2019,
San Francisco, USA

AzubIZ 2019
Regional Recruiting Fair,
September 20, 2019,
Itzehoe

Husum Wind 2019
The German wind trade fair
and congress,
September 10–13, 2019,
Husum

microtec nord 2019
September 11, 2019,
Fraunhofer ISIT,
Itzehoe

AES Convention 2019
October 15–19, 2019,
New York, USA

Mikrosystemtechnik Kongress 2019
MEMS, Mikroelektronik,
Systeme,
October 28–30, 2019,
München

Productronica 2019
Development and Manufacture
of Electronic
November 12–15, 2019,
München

Miscellaneous Events

ISIT Presentation in Framework of „Macht mit bei MINT – Zukunftsberufe für Frauen“
Information Day for Schoolgirls,
initiated by Volkshochschulen
Kreis Steinburg,
February 26, 2019,
Fraunhofer ISIT, Itzehoe

ISIT Participation at Parlamentarischer Abend Nanotechnologie
April 10, 2019
Vertretung des Landes
Schleswig-Holstein, Berlin

11th European Wet Users Meeting
April 4, 2019,
Donaueschingen

40th European CMP Users Meeting
April 5, 2019,
Donaueschingen

ISIT Participation at press conference "Bewerbung Schleswig-Holsteins um die Forschungsfabrik Batteriezelle"
Speakers: State Secretary for
Technology Dr. Thilo Rohlfs,
Head of Fraunhofer ISIT
Dr. Axel Müller-Groeling
May 24, Kiel

Workshop Netzwerk Leistungselektronik Schleswig Holstein
Expert workshop to discuss
initial study results of
"Leistungselektronik in
Schleswig-Holstein – Stand und
Perspektiven"
June 17, 2019, FH-Kiel, Kiel

ISIT Presentation in the Framework of Sommer des Wissens 2019
June 22–23, 2019,
Rathausmarkt, Hamburg

On-Site Lithium-Ion Cell Production Technology
Custom Cells Seminar
July 3, 2019,
Fraunhofer ISIT, Itzehoe

ISIT presentation as part of an information trip for journalists, organized by the Cluster Erneuerbare Energien Hamburg (EEHH)
Speakers: Dr. Axel Müller-
Groeling, Prof. Holger Kapels,
Dr. Andreas Würsig
September 05, 2019,
Fraunhofer ISIT Itezehoe

Workshop Netzwerk Leistungselektronik Schleswig Holstein
Study Presentation "Leistungs-
elektronik in Schleswig-Holstein
– Stand und Perspektiven"
September 12, 2019,
Husum Wind, Husum

International Conference on Planarization/ CMP Technology ICPT
September 16–18, 2019, Hsin-
chu, Taiwan

ISIT Participation at ECPE Workshop „Advanced Power Packaging“
October 09–10, Hamburg
ISIT Presentation at Firmen-
kontakttag,
Fachhochschule Kiel

Northern Germany's largest job fair organized by students
October 23, 2019,
Kiel

12th European Wet Users Meeting
October 24, 2019,
Dresden

41st European CMP Users Meeting
October 25, 2019,
Dresden

Workshop Netzwerk Leistungselektronik Schleswig Holstein
Energiewende in der Praxis
November 22,
2019 Fraunhofer ISIT, Itzehoe

Science Match – Future Energies
December 03, 2019,
Sparkassenarena, Kiel

Patents

W. Reinert
Vorrichtung zur Zündung und Reaktionsübertragung in reaktiven Mehrschichtsystemen
DE 102012110549 B4

F. Stoppel, B. Wagner
MEMS having micromechanical piezoelectric actuators for realizing high forces and deflections
SG 11201701748W
AU 2015310896 B9
CN ZL201580060521.9

S. Gu-Stoppel, H. J. Quenzer, U. Hofmann
Vorrichtung mit einer Feder und einem daran aufgehängten Element und Verfahren zum Herstellen desselben
EP 2803635 B1

Z. Yu, H. Kapels, K. Hoffmann
Vorrichtung zum Steuern eines schaltenden Gleichspannungswandlers, schaltender Gleichspannungswandler und Verfahren zum Steuern eines geschalteten Gleichspannungswandlers
EP 3347978 B1

T. Lisec, H.-J. Quenzer, T. Reimer
Verfahren zum Herstellen einer Vorrichtung mit einer dreidimensionalen magnetischen Struktur
EP 3234968 B1

T. Lisec, F. Lofink
Verfahren zum Herstellen eines Hohlraums mit poröser Struktur
EP 3284714 B1

W. Reinert, H.-J. Quenzer
Verfahren zur Herstellung eines Deckelsubstrats und gehäustes strahlungsemittierendes Bauelement
EP 3078089 B1
US 10,283,930 B2

T. Lisec, F. Stoppel
Mikro-elektro-mechanisches System und Verfahren zum Herstellen desselben
EP 3105770 B1
US 10,373,790 B2

S. Gu-Stoppel, H.-J. Quenzer, J. Janes, F. Heinrich
Piezoelektrischer Positionssensor für piezoelektrisch angetriebene resonante Mikrospiegel
DE 102014217799 B4
CN ZL201510560162.5

L. Blohm, E. Nebling, J. Albers, G. Piechotta
Integrated disposable chip cartridge system for mobile multiparameter analyses of chemical and/or biological substances
US 10,261,041 B2

T. Thönnessen, G. Neumann
Verfahren zum Befüllen elektrochemischer Zellen
DE 102012109032 B4

N. Laske, A. Kulkarni, A. Schulz-Walsemann
Verfahren zur Herstellung von Linsenelementen und von gehäusten, strahlungsempfindlichen Bauelementen auf Waferebene
KR 10-2033228

Doctoral Theses

Simon Fichtner
Development of High Performance Piezoelectric Al1-xScxN for Microelectromechanical Systems: Towards a Ferroelectric Wurtzite Structure.
Cristian-Albrechts-Universität zu Kiel,
August 2019

Diploma, Master's and Bachelor's Theses

Christoph Bauerschäfer
Entwicklung und Evaluierung eines Time-to-Digital (TDC) HF-Boards zur hochauflösenden Time-of-Flight-Messung eines gepulsten Laserstrahls
Master's thesis,
FH Westküste &
HAW Hamburg, 2019

Lars Boie
Entwicklung und Evaluierung von aktiven optischen Komponenten für eine 3D-LIDAR Kamera
Master's thesis,
FH Westküste &
HAW Hamburg, 2019

Tallal Majeed Butt
Simulative Investigation and Evaluation of Measures to Reduce the DC-Link Capacitance in a Three-Phase Inverter
Master's thesis,
Albert-Ludwigs-Universität Freiburg, December 2019

Shahbaz Hasan
Accelerated, Multi-Core MCU Implementation of Model-Based Control for Soft Switching Inverter Including Resonant Current Controller
Master's thesis,
TU Dortmund, 2019

Christoph Kaufmann
Frequency Measurement Methods for the Supply of Synthetic Inertia
Master's thesis,
HAW Hamburg,
November 2019

Julian Lange
Charakterisierung und Evaluierung von MEMS-Energy-Harvestern mit integrierten Mikromagneten für autarke Sensoranwendungen
Master's thesis,
FH Westküste, July 2019

Marcel Metschulat
Entwicklung eines Datenverarbeitungs- und Speicherkonzeptes für ein Time-of-Flight LIDAR-System in VHDL
Master's thesis,
FH Westküste &
HAW Hamburg, 2019

Naveen Krishnan Murugesan
Electronics for Deep Diving Autonomous Underwater Vehicle for Exploration
Master's thesis,
TU Chemnitz, January 2019

Marlene Nötzhold
Untersuchungen hinsichtlich der Einsetzbarkeit von SiC-MOSFETs innerhalb eines 2-Level-Wechselrichters für den Antrieb einer E-Maschine
Bachelor´s thesis,
FH-Flensburg, 2019

Ilhami Özen
Untersuchung verschiedener High-Side-Gate-Treiber Ansätze relevant für Zero Voltage Switching (ZVS) Anwendungen für Halbleiter mit breitem Bandabstand
Bachelor´s thesis,
CAU zu Kiel, 2019

Yimei Zhang
Entwicklung eines neuartigen Herstellungsverfahrens für elastische Glasmembran für Drucksensoren
Master's thesis,
FH Kiel, June 2019

Journal Papers, Publications and Contributions to Conferences

H. Hanssen, D. Friedrich, W. Benecke
Technology and Electrical Characterization of MemFlash Cells for Neuromorphic Applications.
Journal of. Physics. D: Applied Physics. 51 (2018) 324003

A. Kulkarni, P. Malaurie, V. Stenchly, H. J. Quenzer, N. Laske, R. Dudde
Silicon Lens Arrays for Wafer Level Packaging of IR-Sensors.
TechConnect Briefs 2018, Informatics, Electronics and Microsystems, p.p. 147–150, 2018, ISBN: 978-0-9988782-1-8

F. Manthey, A. Gorodnichev, E. Langnes, G. Pangalos, F. Haase
Model-Based Control of an Inverter for Wide Range Soft-Switching Operation.
PCIM 2018, 2018, Nuremberg

A. Männchen, F. Stoppel, D. Beer, F. Niekiel, J. Nowak, B. Wagner
Zwei-Wege-Lautsprecher basierend auf MEMS-Technologie.
44. Deutsche Jahrestagung der Akustik, DAGA 2018, March 19–22, 2018, Munich

A. Männchen, F. Stoppel, D. Beer, F. Niekiel, B. Wagner
In-Ear Headphone System with Piezoelectric MEMS Driver.
Audio Engineering Society, Convention e-Brief 469, October 07, 2018

J. Ophey[a], S. Reuber[b], J. Seeba[b], C. Heubner[c], N. Junker[c]
[a]Fraunhofer ISIT, [b]Fraunhofer IKTS, [c]Technische Universität Dresden.
Umweltfreundliche Hoch-Energie-NCM 622-Kathoden mit optimierter Speicherkapazität. ProZell Industrietag 2018, September 10, 2018, Braunschweig

M. Päsler
Highly Integrated Traction Inverter for a Modular Drive Concept.
PCIM Paper, 2018, Nuremberg

M. Päsler, J. Hinz, H.-J. Schliwinski, U. Schümann, J. Schnack, R. Eisele, D. Hilper, C. Mertens, P. Heumann, M. Kamprath, A. Zastrow, H. Beer, F. Osterwald, T. Ebel, S. Brückner, H. Wolff, H. Reese, S. Schikowski
Highly Integrated Traction Inverter for a Modular Drive Concept. PCIM Europe 2018, June 05–07, 2018, Nuremberg

H. Schimanski
Elektrochemische Migration auf elektronischen Baugruppen durch kombinierte Lötprozesse.
DVS-Berichte Band 340, S. 350–356, 2018

H. Schimanski, J. Hagge
Risikopotenziale mit der richtigen Flussmittel- und Lötpastenkombination minimieren.
All-Electronics.de – Entwicklung, Fertigung, Automatisierung, April 18, 2018

H. Schimanski, J. Hagge
Elektrochemische Migration in Nacharbeits- und Reparaturlötprozessen. All-Electronics.de – Entwicklung, Fertigung, Automatisierung,
April 18, 2018 and Productronic, May, 2018

H. Schimanski
Nutzentrennung – Fluch und Segen zugleich? All-Electronics.de – Entwicklung, Fertigung, Automatisierung, infoDIREKT 322 pr 118 and Productronic, November, 2018

S. Schröder, H. Schimanski
Lötmaterialien auf dem Prüfstand. All-Electronics.de – Entwicklung, Fertigung, Automatisierung,
April 19, 2018

S. Schröder, H. Schimanski
Mit mikro- und niedrig Ag-legierten Loten die Lötsicherheit erhöhen.
All-Electronics.de – Entwicklung, Fertigung, Automatisierung, April 19, 2018 and Productronic, April, 2018

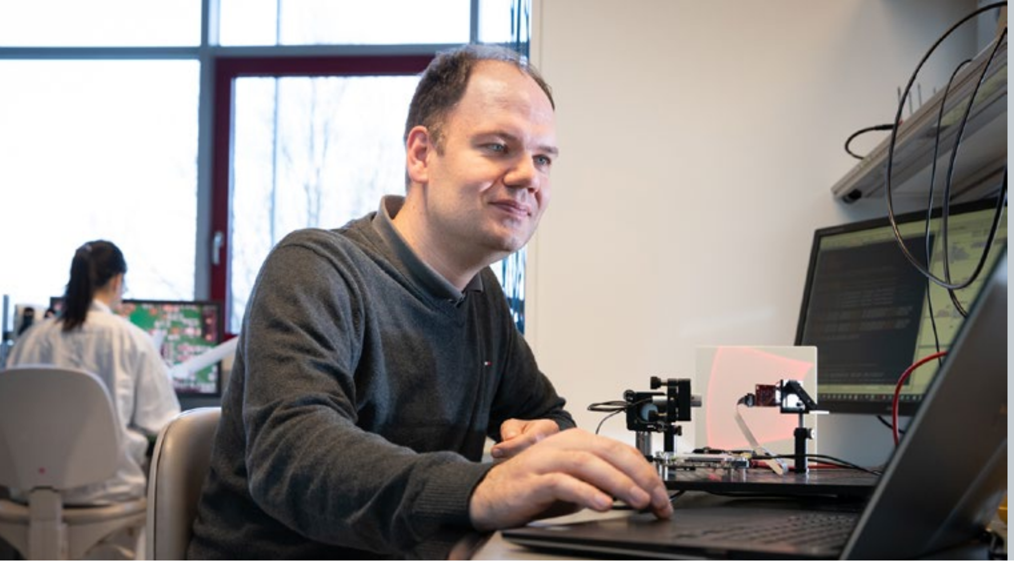
F. Stoppel, A. Männchen, F. Niekiel, D. Beer, T. Giese, B. Wagner
New Integrated Full-Range MEMS Speaker for In-Ear Applications.
2018 IEEE Micro Electro Mechanical Systems (MEMS), pp. 1068–1071, 2018 and Proc. MEMS 2018 – The 31st IEEE International Conference on Micro Electro Mechanical Systems, January 21–25, 2018, Belfast, Northern Ireland, UK

F. Stoppel, A. Männchen, F. Niekiel, D. Beer, B. Wagner
Leistungsfähiger integrierter MEMS-In-Ear-Lautsprecher mit piezoelektrischem Antrieb.
44. Deutsche Jahrestagung der Akustik, DAGA 2018, March 19–22, 2018, Munich

N. Wagner, J. Häcker, B. Sievert, R. Richter, T. Danner, M. Fichtner, Z. Zhao-Karger, M. Hahn, H.-G. Bremes, C. Wolter, F. Kampmann
Development of Magnesium-Sulfur Batteries: From Fundamental Research to Application.
Conference Paper, 2nd International Symposium on Magnesium Batteries, September, 2018, Ulm

K. Weihe, C. C. Yáñez, G. Pangalos, G. Lichtenberg (HAW)
Comparison of Linear State Signal Shaping Model Predictive Control with Classical Concepts for Active Power Filter Design. Simultech 2018, Porto, Portugal

C. C. Yáñez, G. Pangalos, G. Lichtenberg (HAW)
An Approach to Linear State Signal Shaping by Quadratic Model Predictive Control.
ECC18, Konferenz in Limassol, Zypern



Talks and Poster Presentations

S. Bette, S. Fichtner, S. Bröker, L. Nielen, T. Schmitz-Kempen, B. Wagner, C. Van Buggenhout, S. Tiedke, S. Tappertzhofen
Infrared-Laser Based Characterization of the Pyroelectricity in AlScN Thin-Films.
Thin Solid Films 692 (2019) 137623, 2019

M. Bodduluri, T. Lisec, L. Blohm, F. Lofink, B. Wagner
High-Performance Integrated Hard Magnets for MEMS Applications.
MikroSystemTechnik Kongress 2019, 150–153, October 28-30, 2019, Berlin

S. Bröker, S. Fichtner, S. Bette, S. Tiedke, S. Tappertzhofen B. Wagner
Al1-xScxN Thin Films for Pyroelectric IR Detectors.
MikroSystemTechnik Kongress 2019, 424-427, October 28-30, 2019, Berlin

J. Eichholz
Künstliche Intelligenz und Digitalisierung in Verkehr und Logistik.
Projekt „Smart Window", Schiff und Hafen, June 2019 and Journals für Mobilität und Verkehr 4, November 2019

S. Fichtner, N. Wolff, F. Lofink, L. Kienle, B. Wagner
AlScN: A III-V Semiconductor Based Ferroelectric.
Journal of Applied Physics 125, 114103, 2019

S. Fichtner, D. Kaden, F. Lofink, B. Wagner
A Generic CMOS Compatible Piezoelectric Multilayer Actuator Approach Based on Permanent Ferroelectric Polarization Inversion in Al1-xScxN.
Proc. IEEE Transducers 2019, 289-292, June 23-27, 2019, Berlin

J. Franz, H. Zeller
Stabilizing the Frequency in Power Systems with High Penetration of Renewable Energy
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Journal of Microelectromechanical Systems, 28 (2019) 1019–1031, 2019

GENERAL VIEW ON PROJECTS

Power Electronics

Hocheffiziente Leistungstransistoren

- Netzwerk Leistungselektronik – Netzwerk LE
- Integrierte Umrichter für modularverteilte Elektroantriebe hoher Drehzahl; Teilvorhaben: Simulation, Technologische Sonderprozesse und Zuverlässigkeitsuntersuchungen für integrierte Umrichter – InMOVE
- Entwicklung einer schnellen Leistungsdiode – Fast Recovery Diode
- Backside coating of IGBT-wafer – VISHAY-IGBT backside coating
- Sub-Mikrometer Mikroplastik Partikel in der marinen Umwelt – Size is important

Leistungselektronik für regenerative Energiesysteme

- Fraunhofer Anwendungszentrum Leistungselektronik für regenerative Energiesysteme, ALR, Standort Hamburg – ALR
- Schaufenster intelligente Energie – SINTEG: Norddeutsche Energiewende 4.0; Systemdienstleistungen mit Speichern, Algorithmen-Entwicklung, Modellbildung und Simulation zur Systemintegration – NEW 4.0
- Vertikale GaN-Transistoren für effiziente Leistungselektronik im Niederspannungsbereich – VERTIGO
- Elektrische Antriebsmaschine mit in das Lagerschild integrierter SiC-Leistungselektronik – LaSiC
- Synthetic inertia from hybrid power plants – Study hybrid power plants

Batteriesysteme

- Schnellladefähige Lithium-Energiespeicher mit verbesserter Energiedichte für den Einsatz in modularen Unterstützungs- und Antriebskonzepten – HiPoLit
- Kostensenkung und Qualitätssteigerung bei der Lithium-Ionen-Batterie-Elektrodenfertigung durch quantitative, optische inline-Messtechnik – Q-LIB
- Cell for High Temperature/ Shock – AIF-CHiTS
- Umweltfreundliche Hoch-Energie-NCM 622-Kathoden mit optimierter Speicherkapazität – HiLo
- Hochleistungsladesystem mit integriertem Pufferspeicher – Power400
- Optimierung von Magnesium-Schwefel Batterien durch innovative Materialentwicklung – MagSiMal
- Hochstromfähiges Lithium-Batteriemodul, Entwicklung einer Hochleistungs-Lithium-batterie – AIF-Hochleistungsbatterie
- Lithium-Ionen-Zellen zur Integration mit erweiterter Sensorik – LImeS
- Doppelseitige Beschichtung von Elektrodenfolien - Beschichtete Elektrodenfolien
- Elektrolyt-Charakterisierung / Zellbau – Elektrolyt-Charakterisierung
- Tailored Battery for Wind Energy Applications – Tailored Battery
- Entwicklung eines Verfahrens zur Herstellung von Magnesium-Ionen-Zellen – Magnesium-Ionen-Zellen
- Analysis of customer specified coated and uncoated electrode foil – Armor LFMP cathode
- Analysis of primered foils due to different cell-chemistries versus pure collector development of cell chemistry, assembly of cells and analysis – Armor-AL-Collector
- Forschung zur Einführung neuer Materialien – Materialeinführung
- Erstellen einer Technologieübersicht im Bereich der Lithium-Festkörperbatterien – Traktionsbatterie
- Calcium Rechargeable Battery Technology – CARBAT
- High energy lithium sulphur cells and batteries – HELIS
- Optimised and systematic energy management in electric vehicles – OPTEMUS

Micro Manufacturing Processes

- Herstellung von Faserjustierplatten und Interposern – Faserjustierplatten Sicoya

Prozessintegration und Pilotfertigung

- Entwicklung einer Plattform für funktionelle Glasgehäuse für die Integration mikrooptischer und -mechanischer Systeme auf Waferebene – PRISMA
- Miniaturisierte IR-basierte Sensorsysteme - Teilvorhaben: Optische Waferlevel-Integration von FIR-Sensoren und innovativen pyroelektrischen Sensormaterialien – MIRS-PENTA – MFV
- Entwicklung eines CMP-Prozesses für TEOS-Oxid mit Stopp auf Epi-Poly – Vishay
- Entwicklung eines 3D-Gyro basierend auf der EPI-Poly-Technologie
- Optimierung und Herstellung von Elektrischen Array-Chips
- Transfer of fabrication process for switchable e-beam mask – TROM
- MEMS Mirror Based 3D-Camera Module feasability study project – 3D-Camera
- Pilot production of ISIT test wafer – Testwafer
- Multifunktionale Sensorintegration auf anwenderspezifischen ICs – MUSIC
- Voll integrierte, ungekühlte Wafer-level FIR-Kamera für Wärmestrahlung – ATAIR
- Silizium- und Oxidpolierprozesse – Polierprozesse

Modul Services

- Untersuchung der Auswirkung ionischer Verunreinigungen in dünnen Spalten an realitätsnahen Aufbauten mit neuen miniaturisierten Bauelementen – AIF-Ionische Verunreinigungen
- Lebensdauerprüfung an Elektrolytkondensatoren – Lebensdauerprüfung

MEMS Applications

- FlexFunds Biomarkers – Rapid-Mal
- Ferroelektrizität in ScAlN: von der Entdeckung des Effekts zu disruptiven Bauelementen – SALSA
- Nykteris II – Nykteris II
- Kompetenzzentrum Nanosystemtechnik – Kompetenzzentrum Kiel

Optische Systeme

- Aufbau eines LIDAR-Demonstrators – LIDAR-Demonstrator
- Industrietaugliche UKP- Laserquellen und systemweite Produktivitätssteigerungen für hochdynamische Bohr- und Schneidanwendungen – InBus
- MEMS-basiertes Laserstrahl-Ablenksystem für einen Laser-Projektions-Scheinwerfer – KOLA
- Labor zur Integration poröser 3D-Hochleistungswerkstoffe in Bauelemente der Mikrosystemtechnik und Leistungselektronik – LAB 3D
- MEMS-Scanner basiertes Laserprojektionssyetem für Maritime Augmented Reality - Smart Window
- Miniaturisierte IR-basierte Sensorsysteme – Teilvorhaben: Optische Waferlevel-Integration von FIR-Sensoren und innovativen pyroelektrischen Sensormaterialien - MIRS-PENTA – MEMS
- Entwicklung und Herstellung eines sensorgesteuerten Ozongenerators – MIKROOZON
- Entwicklung einer adaptierbaren, modularen Strategie zur Qualitätskontrolle zellbasierter Therapien – ZellTherQC
- Optoelektronisch-mikrofluidisches System zur Detektion von fluoreszenzmarkierten Nukleinsäuren – OPTOCHIP
- Fertigung eines passiven MEMS-Spiegels mit kuppelförmigem Deckel – Oqmented MEMS-Spiegel
- Fabrication of 3000 additional MEMS scanning mirrors – MEMS scanning mirrors
- Design- and process-development for a 3D MEMS gyro – 3D-Gyro MF
- Development of 2D quasi-static MEMS-Mirrors – 2D quasi-static MEMS-Mirrors
- Pilot Line for Micro-Transfer-Printing of functional components on wafer lavel – MICROPRINCE
- CIMD Entwicklung eines Schnelltest-Systems zur frühen und versorgungsrelevanten Detektion immun-vermittelter muskoloskelettaler Erkrankungen – CIMD Schnelltest
- Cluster of Excellence Advanced Photo Sources – CAPS

Akustische Systeme und Mikroantriebe

- Generative Herstellung effizienter Piezo-MEMS für die Mikroaktorik-TVB-Auslegung und Herstellung gedruckter Mehrlagen-Piezzoaktuatoren – Generator
- Resonant magnetoelectric sensors – SFB 1261-A3
- MEMS magnetoelectric sensor fabrication – SFB 1261-Z1
- Process module development and sample fabrication of piezoelectric MEMS microphones on CMOS – X-FAB-Lippmann
- Feasibility study and development work for a MEMS fabrication of a Mass Air Flow Sensor – ZEPHYR
- AIN-based Ultrasonic Transducers – X-FAB Ultrasonic Transducers
- Preparation phase for Printhead – X-FAB Printhead
- Unterstützung bei Entwicklungsarbeiten im Projekt Solenoid-Treiber – Trinamic-Dongbu
- Entwicklung eines In-Ear-Demonstrators – EF SpeakTronic
- Towards Zero Power Electronics – ZePowEl
- Smarte MEMS-Lautsprecher für mobile Anwendungen – SmartSpeaker
- Extrem breitbandiger Stromsensor mit höchster Dynamik für hocheffiziente Leistungswandlung – mAgnes-MAVO
- AHEAD-MEMS Loudspeaker– AHEAD Phase 1

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