Fraunhofer
IZM

FRAUNHOFER INSTITUTE FOR RELIABILITY AND MICROINTEGRATION IZM

# ANNUAL REPORT 19/20

# CONTENT


Preface Page 4

**FRAUNHOFER IZM**

Core Competencies Page 7
Fraunhofer – a Strong Network Page 12
Automotive and Transportation Page 14
Medical Engineering Page 16
Semiconductors Page 18
Industrial Electronics Page 20
Information and Communication Page 22
Labs & Services Page 24

**EVENTS**

Events and Workshops Page 27
Promoting Young Talents Page 31

**FACTS & FIGURES**

Fraunhofer IZM in Facts and Figures Page 33
Awards Page 34
Best Papers, Editorials, Dissertations Page 36
Lectures Page 37
Cooperation with Universities Page 38
Cooperation with Industry Page 39
Memberships Page 40
Publications Page 41
Patents and Inventions Page 46
Advisory Board Page 47
Contacts Page 48
Imprint Page 50

# PREFACE

## RESEARCHING FOR APPLICATION, DEVELOPING FOR RELIABILITY

### Dear Readers!

The research year 2020 is dedicated to a vision of bioeconomic change. We are tasked with developing and supporting a new way of living and a new type of economy built on renewable resources that will secure humanity a future worth living on a healthy Planet Earth. As a scientific enterprise, we will do our part and take on the challenges of the new decade. On top of their other duties, all four departments of Fraunhofer IZM are already working on important technological solutions. Our shared mission is to equip our society with high quality electronics that offer a viable way forward for the many pressing issues facing our world: resource efficiency, sustainability, climate protection, and much more.

Fraunhofer IZM is committed to expanding its technology and system capabilities. One example of this is our new working group on »Bioelectronics«, which was constituted to develop and integrate custom bioelectronics systems for use on and in our bodies and to get us a decisive step closer to the medical technology of the future. Other focus areas for us are miniaturization and system integration strategies for 5G and 6G communication, neuromorphic and quantum computing, artificial intelligence, and the sustainability of electronics. The newly formed working group on »Transdisciplinarity for Sustainable Electronics« will zero in on these aspects and add an essential new facet to the portfolio of Fraunhofer IZM. All of this allows our institute to offer more R&D services in technological, functional, and social fields, using smart process flows and optimized interfaces to enable a vast range of use cases.

Our efforts allow us to give our research and development partners even better support and assistance in our shared work on developing, constructing, and integrating the robust and reliable electronics that will make the impossible possible.

With so many excellent projects to choose from in 2019, it was hard to pick only the following examples that show the enormous capabilities of all of the people working here at Fraunhofer IZM:

- We developed an autonomous system for monitoring the power electronics in wind turbines, developed in cooperation with our project partners (AMWind).

- Using optical biosensors, our colleagues have designed a diagnostic system that can recognize Lyme disease at a crucially early stage (PoC-BoSens).

- We are continuing to build up our Research Fab Microelectronics, and have already completed a first set of successful projects.

- »Start-a-Factory Reloaded« marked the establishment and launch of Start-a-Factory, the modular development and research lab built for start-ups.

- One particular highlight of the year was the formation and launch of the iCampus project group. This »Innovation Campus Electronics and Microsensors Cottbus« will produce high-resolution HF sensor systems.

- Communication and shared expertise can open new paths for our future together: Fraunhofer IZM has launched its first blog. Follow »RealIZM« to get the latest news and stories from our teams, complete with exclusive insights, exciting ideas, and promising solutions.

A quick look at our facts and figures shows that 2019 was a memorable year for Fraunhofer IZM. We have been able to increase our operating budget again to a full 37 million euros, while maintaining the share of revenue from industry of 39 percent.

I would like to say thank you for the excellent cooperation with various universities. Together we have developed the technological basics and made groundbreaking discoveries. At the risk of forgetting other partner institutions, I need to name the Technical University of Berlin, the Berlin University of Applied Sciences (HTW), the Technical University of Dresden, and the Brandenburg University of Technology Cottbus-Senftenberg.

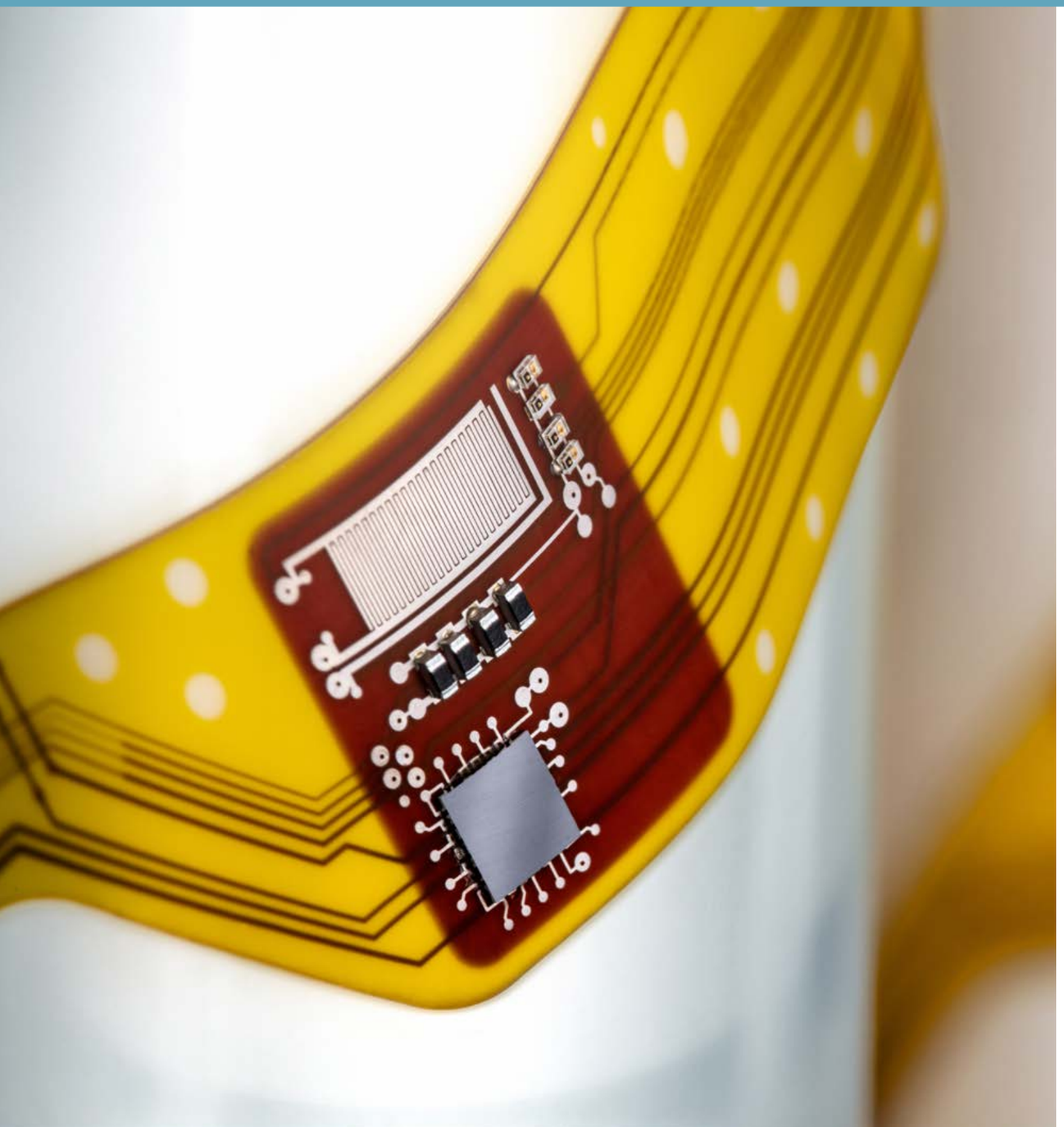
It would be remiss of me to not mention our exceptional work in the Fraunhofer Group for Microelectronics and with our many partners from science and industry, our sponsors and supporters at the federal and state level, and our project clients. All of these cooperative ventures are characterized by genuine trust and the shared pursuit of scientific and technical excellence.

On a personal note, I need to thank all of my colleagues for their exceptional achievements. Their work is what makes this institute successful. Without them, the remarkable developments at Fraunhofer IZM would not have been possible – which is something I am keenly aware of in these exceptional circumstances.

I hope this report will offer you an enjoyable read and lots of interesting and exciting insights.

Prof. Klaus-Dieter Lang
Institute Director

# CORE COMPETENCIES



## FROM WAFER TO SYSTEM

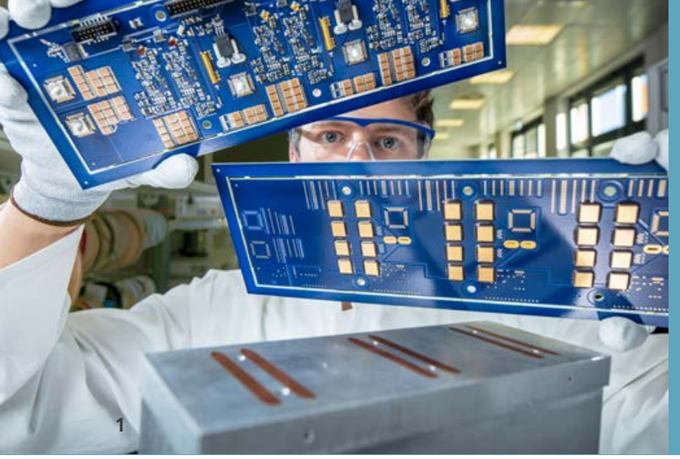
Intelligent electronic systems – available everywhere and to everyone! In order to make this possible, components need to have exceptional properties. Depending on the application, they need to function reliably at high temperatures, be extremely miniaturized and moldable to individual build spaces or even flexible, and have outstanding lifetime. The Fraunhofer Institute for Reliability and Microintegration IZM helps companies around the world develop and assemble robust and reliable electronics to the very cutting edge and then integrate them into the required application.

With more than 430 employees, the Institute develops adapted system integration technologies on wafer, chip and board level. Research at Fraunhofer IZM means designing more reliable electronics and making reliable lifetime predictions.

**Working together with Fraunhofer IZM**
Fraunhofer IZM's research results are highly relevant to industries such as the automotive industry, medical engineering, industrial electronics and even lighting and textiles. Semiconductor manufacturers and suppliers of related materials, machines and equipment, but also small companies and start-ups can choose the approach that best suits their needs – from easily accessible standard technologies through to high-end disruptive innovation. As partners, our customers profit from the advantages of contract research, by selecting between exclusive release of a product innovation, improving a workflow or qualifying and certifying a process.

**Contract research**
Often a successful cooperation project begins with a preliminary consultation phase that is usually free-of-charge. Fraunhofer only begins billing for its research and development services once the parameters of the cooperation have been defined. Customers retain ownership of the material project outcomes developed within their contract, as well as the applicable usage rights to the produced inventions, property rights and the know-how.

**Project funding**
Some development challenges require pre-competitive research. In these cases, teaming up with companies and research institutes and public funding support is more effective than operating solo. The institute cooperates closely with numerous universities, including the Technical University of Berlin and the Berlin University of Applied Sciences (HTW), to ensure that the preparation for future cooperation with industry is optimal.




**Rolf Aschenbrenner**
rolf.aschenbrenner@izm.fraunhofer.de

**Dr.-Ing. Andreas Ostmann**
andreas.ostmann@izm.fraunhofer.de


# SYSTEM INTEGRATION & INTERCONNECTION TECHNOLOGIES

The »System Integration and Interconnection Technologies« (SIIT) department is the largest in the institute. Its work focuses on heterogeneous system integration. The combination of various materials, devices, and technologies opens up a wide range of application areas such as medical engineering, automobile production, aviation, industrial electronics, or communication technology. Highly integrated electronic and photonic systems, modules, and packages are developed and manufactured for specific individual requirements. The complete value creation chain of the individual products from conception, design, and technology development to industrializable production is covered. The department focuses on the design, implementation and analysis of power electronic and photonic systems.

Our scope of services includes, for example:

- Electronic and photonic circuit carriers: multilayer conventional, rigid, and flexible printed circuit boards, partly with integrated components; mold packages with rewiring; integration of optical waveguides in printed circuit boards
- Conformables: stretchable, thermoplastic, and textile assemblies
- Assembly: high-precision chip placement, automated SMD assembly, flip-chip technology, automated optical fiber coupling, and micro-optics assembly
- Interconnection technologies: soldering; sintering; transient liquid phase bonding (TLPB) and bonding of components; micro-optics and chips; wire and ribbon bonding; galvanic metal deposition and sputtering; screen printing, stencil printing, and contactless material dosing by jets; application of polymer lenses; integrated optical waveguides in thin glass; development of new bonding technologies
- Encapsulation: embedding of printed circuit boards; transfer and compression molding; potting and protective lacquering; underfilling and glob-top
- Processed materials and techniques: fiber composites; encapsulation compounds; soft solders; sintered materials; glass structuring; mechanical and chemical metalworking

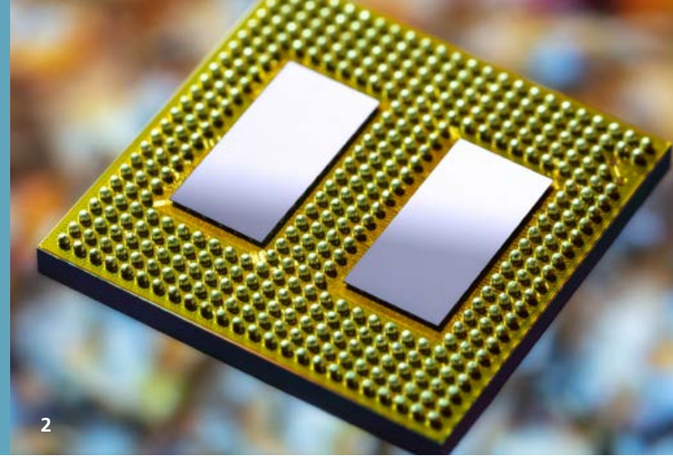
Our employees' many years of experience in combination with state-of-the-art equipment for processing large-format manufacturing in the entire production process (610 x 457 mm²; 18" x 24") is unique worldwide. Approximately 2,500 m² of laboratory space are available, 600 m² of which are cleanrooms of ISO classes 5 - 7. Here, the production of complex electrical or photonic circuit carriers, the assembly of components on and embedding in circuit carriers or housings, as well as the bonding and encapsulation of the components, is carried out.

The finished systems are electrically and mechanically tested and evaluated. For documentation and analysis purposes, we use imaging techniques for structure resolution down to the nm range, optical function measurement techniques, and chemical analysis down to the sub-ppm range.




**Dr.-Ing. Michael Schiffer**
michael.schiffer@izm.fraunhofer.de

**M. Jürgen Wolf**
juergen.wolf@izm.fraunhofer.de

# WAFER LEVEL SYSTEM INTEGRATION

The department »Wafer Level System Integration« (WLSI) focuses its research activities on the development of advanced packaging and system integration technologies and offers customer-specific solutions for microelectronic products used in smart systems. Around 60 scientists at two sites – Fraunhofer IZM in Berlin and the institute branch ASSID – All Silicon System Integration Dresden (IZM-ASSID) – conduct research in the following key areas:

- 3D integration
- Wafer-level packaging and fine-pitch bumping
- Hermetic MEMS and sensor packaging
- High density assembly
- Sensor development and integration
- Hybrid photonic integration

At both sites, the department operates leading-edge process lines that permit a high degree of processing flexibility, particularly for 200 – 300 mm wafers. The lines are characterized by a high adaptability and compatibility between the individual sub-processes and are particularly equipped for production-related and industry-compatible development and processing. Both sites have a completely ISO 9001:2015-certified management system to guarantee highest quality standards in project and process work.

The department's already outstanding technological expertise is continuously extended within numerous research projects and the gained know-how can be transferred at development stage to SME partners.

WLSI has established a broad cooperation network with manufacturers and users of microelectronic products, as well as tool suppliers and material developers in the chemical industry.

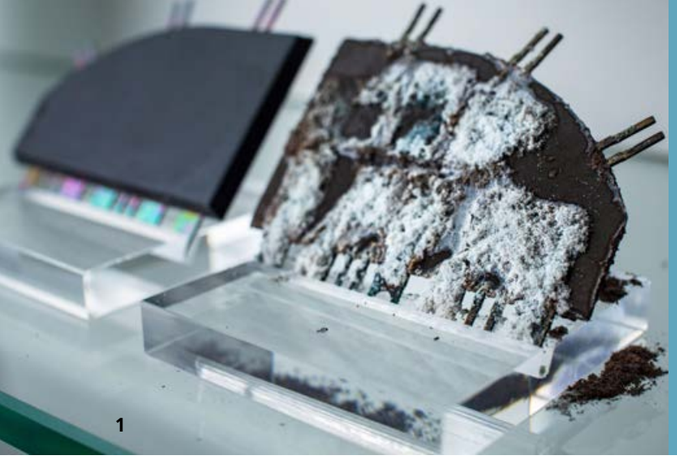
The department's technological know-how is focused on the following areas:

- Heterogeneous wafer-level system integration
- 3D wafer-level system in package (WL SiP, CSP)
- Application-specific Cu-TSV integration: via middle, via last, backside TSV
- Cu-TSV interposer with multi-layer RDL and micro cavities
- Glass interposer with TGV
- High-density interconnect formation micro bump or pillar (Cu, SnAg, CuSn, Au, AuSn)
- Pre-assembly (thinning, thin wafer handling, singulation)
- 3D assembly (D2D, D2W, W2W)
- 3D wafer-level stacking
- Wafer bonding (adhesive, soldering, direct)
- Direct bond interconnects (DBI) – W2W (12")
- Micro sensors
- MEMS packaging (hermetic)

The service portfolio for industrial partners comprises process development, material evaluation and qualification, prototyping, low-volume manufacturing and process transfer. Newly developed technologies can be adapted to customer-specific requirements.

1 *Traction inverter with insulated single GaN packages*

2 *Fan-in wafer-level package (10 mm x 10 mm) with flip chips assembled face-down*




**Dr.-Ing. Nils F. Nissen**
nils.nissen@izm.fraunhofer.de

**Dr.-Ing. Olaf Wittler**
olaf.wittler@izm.fraunhofer.de


# ENVIRONMENTAL & RELIABILITY ENGINEERING

New microelectronics systems have to cope with more demanding functional requirements and working conditions. At the same time, they are expected to be cost-efficient and environmentally friendly in production and in active use. The »Environmental and Reliability Engineering« department supports new technical developments on their way to the market with environmental performance and reliability checks ranging from nano-characterization to system-level evaluation and optimization.

The department offers services in the areas:

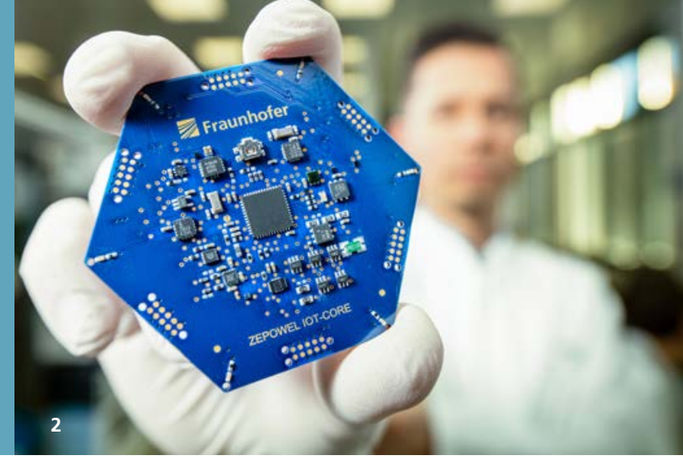
- Environmental assessments and eco-design
- Resource efficiency, circular economy, and obsolescence research
- Reliability standards and testing procedures
- Failure mechanisms, lifetime models, and materials data
- Simulations for reliability analyses and optimization

With an interdisciplinary team processes and models are developed and applied that enable our partners to integrate environmental and reliability relevant criteria in the design and development process. We thus help to identify weak points and potentials at an early stage during the introduction of new technologies, materials, processes, components, and applications and to react appropriately.

Stemming the tide of electrical and electronics waste and reining in the resource hunger of the industry is one of the key challenges faced by all of society. Modern life has become unthinkable without electronics. A boon and a bane alike, electronics contribute to making climate change worse, but they can also be the key to saving resources and reducing our carbon footprint. More and more companies are committing themselves to finding innovative and sustainable solutions, for which they turn to the professional advice and services of Fraunhofer IZM. Recent analyses and studies conducted in the department have covered important aspects of the problem, ranging from the environmental balance of electronics manufacturing to product design for reliability and long life or the resource efficiency of the coming 5G networks. Green technologies and product designs can have a real effect, but only if their users' behaviour also changes. This human aspect is a particular focus of the newly founded working group on »Transdisciplinarity for Sustainable Electronics«.

A longer life for microelectronics is made possible by the physics-of-failure concept. Electronic components often fail because of the adverse effects of humidity. To capture these quantitatively, Fraunhofer IZM has bundled its technical facilities and competences in the new Corrosion Analysis Lab. It has become the newest part of a comprehensive portfolio that covers all essential sources and mechanisms leading to fatigue, wear, and tear in electronic components, including vibration, heat and temperature changes, humidity, and electrical forces.







**Dr.-Ing. Dr.-Ing. habil. Ivan Ndip**
ivan.ndip@izm.fraunhofer.de

**Harald Pötter**
harald.poetter@izm.fraunhofer.de


# RF & SMART SENSOR SYSTEMS

What do so seemingly unrelated applications like radar sensing, 5G, 60 GHz communication systems, or autonomous sensors have in common? They share a tendency towards technological extremes: large bandwidths, ruggedness, and a commitment to maximum energy efficiency. Controllable antennas, beamforming, and protections against signal deterioration are also attracting increasing attention among researchers. Meeting these exacting standards needs the tight integration of circuit design and technology development (hardware/package co-design) just as much as genuine cooperation between software and hardware developers (hardware/software co-design). With this in mind, the department combines the intensive technological know-how of Fraunhofer IZM with our in-depth expertise in firmware and hardware development.

Our work is focused on:

- RF design and characterization of materials, packages, and components (up to 220 GHz)
- RF system integration and module design, with due consideration for signal and power integrity
- Development of micro batteries, power supply, and power management systems
- Design and implementation of self-sufficient wireless sensor systems for industrial use
- Tools for the optimized design of microsystems and server-client software architectures

The work of the department is characterized by its effective combination of the practical insights won from our many successful projects, our extensive range of state-of-the-art equipment, our wealth of experience with modelling tools, and our unfailing dedication to a systematic approach.

1 *Electronic components failing due to humidity – a case for the Corrosion Analysis Lab*

2 *Highly efficient IoT-core for the Internet of Things*

# FRAUNHOFER – A STRONG NETWORK

**The Fraunhofer-Gesellschaft**
The Fraunhofer-Gesellschaft, headquartered in Germany, is the world's leading applied research organization. With its focus on developing key technologies that are vital for the future and enabling the commercial exploitation of this work by business and industry, Fraunhofer plays a central role in the innovation process. As a pioneer and catalyst for groundbreaking developments and scientific excellence, Fraunhofer helps shape society now and in the future. Founded in 1949, the Fraunhofer-Gesellschaft currently operates 74 institutes and research institutions throughout Germany. The majority of the organization's 28,000 employees 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.

**Research Fab Microelectronics Germany**
Fraunhofer IZM is one of 13 members of the Research Fab Microelectronics Germany (FMD) – Europe's largest cross-location R&D collaboration for microelectronics and nanoelectronics, with over 2,000 scientists.

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. In this project the Fraunhofer institutes IZM, IMS and IPMS as well as the Ferdinand-Braun-Institut 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.

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 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 for updated and modernized research facilities at the participating institutes from the Fraunhofer-Gesellschaft and Leibniz Association.

**High-Performance Centers**
The goal of the High-Performance Center Functional Integration for Micro-/Nanoelectronics is above all to support SMEs in Saxony with sensor and actuator technology, measurement technology, and mechanical engineering and construction by rapidly transferring research results into innovative products. The Fraunhofer institutes ENAS, IIS, IPMS, and IZM, as well as the TU Dresden and Chemnitz and the HTW are also members. The Berlin Center for Digital Transformation is a cooperation between the four Berlin Fraunhofer institutes FOKUS, HHI, IPK, und IZM. Its work focuses on technologies and solutions that advance increasing digitalization and networking in all areas of life.



# BUSINESS UNITS & INDUSTRY SECTORS

**Complex project initiatives move across the boundaries of disciplines and competencies. They benefit from the business expertise of Fraunhofer IZM's dedicated Business Development Team that represents the industry's specific needs in all functional areas of the institute and coordinates the work on innovative solutions. We are here to assist you in the strategic development of innovative areas with complex and ground-breaking technologies.**

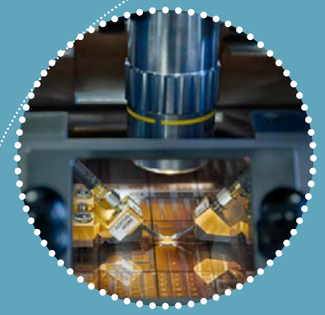
AUTOMOTIVE AND TRANSPORTATION

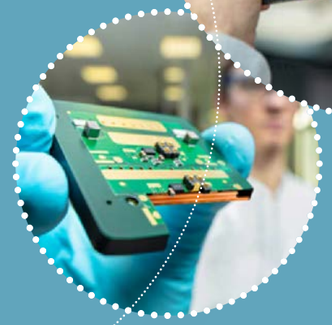
MEDICAL ENGINEERING

SEMICONDUCTORS

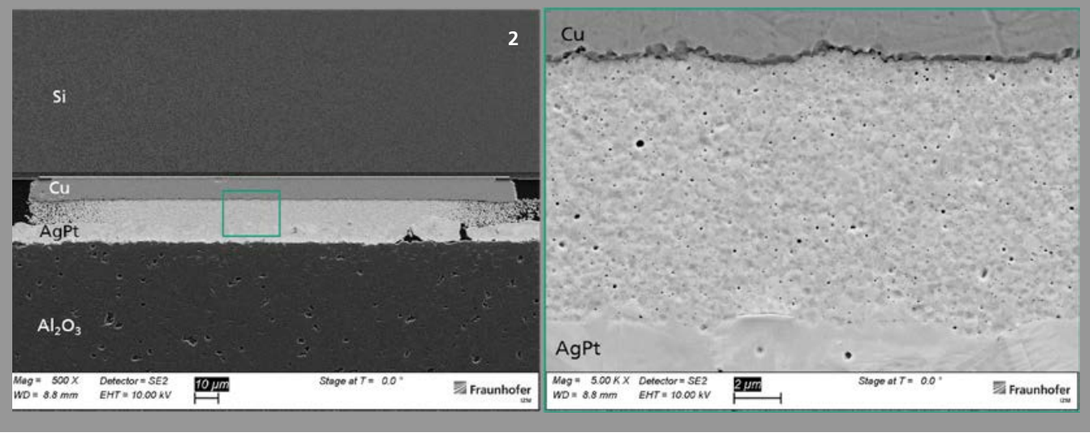
INDUSTRIAL ELECTRONICS

INFORMATION AND COMMUNICATION



# AUTOMOTIVE AND TRANSPORTATION




**Modern traffic systems have to be safe, environmentally friendly and cost-efficient. High-performance, reliable and, in some cases, highly miniaturized systems are key goals for developers creating innovative forms of transport and traffic systems for road, rail, sea and air. Transportation has been a key priority and competence area across Fraunhofer IZM departments since the institute's very beginning. The institute helps OEMs, Tier1 companies and particularly their suppliers integrate the latest electronics into vehicles quickly and efficiently. We develop future-proof, reliable solutions, including prototypes, which improve the safety and comfort of conventional, hybrid and electric engines and systems.**


1

**Process evaluation and optimization through simulation and metrological verification**

Warping and mechanical tension are an urgent concern in all electronics manufacturing processes. To address this issue, existing models simulating the entire production process were refined and verified both in laboratory and real-life industrial conditions. The emphasis was placed on polymer-based substrate and encapsulation materials and, in particular, on semiconductors embedded in a system-in-package assembly. The model pinpointed and optimized the process steps affecting reliability, paving the way for low-warpage and low-tension designs for highly complex systems. The model had to consider several challenging factors, ranging from the sheer number of process steps to be included to the thin layers, copper structuring, complex compounds, and chemical shrinkage in the simulated products.

**Silver sintering – a reliable interconnection for many applications**

Silver sintering promises far greater reliability than other soft soldering options (up to a hundredfold increase in the part's life expectancy). With a high melting point of 962 °C, silver is a suitable choice for environments above 150 °C, with its response to temperatures of up to 300 °C currently being tested.

Current silver sintering is used mostly for the planar bonding of power semiconductors or between larger substrates and cooling components, not least due to the positive thermal conductivity of the material at 430 W/(m·K). The same approach can be used for opto-electrical components like semiconductor lasers or LEDs.

Research is also underway for flip-chip silver sintering, looking into flip-chip LEDs with only two, but also Si chips with more than 40 bumps. Transferring silver sintering into industrial production processes is one of Fraunhofer IZM's services for its industry clients.

**State monitoring of power electronics with intelligent monitoring technology and combined tests**

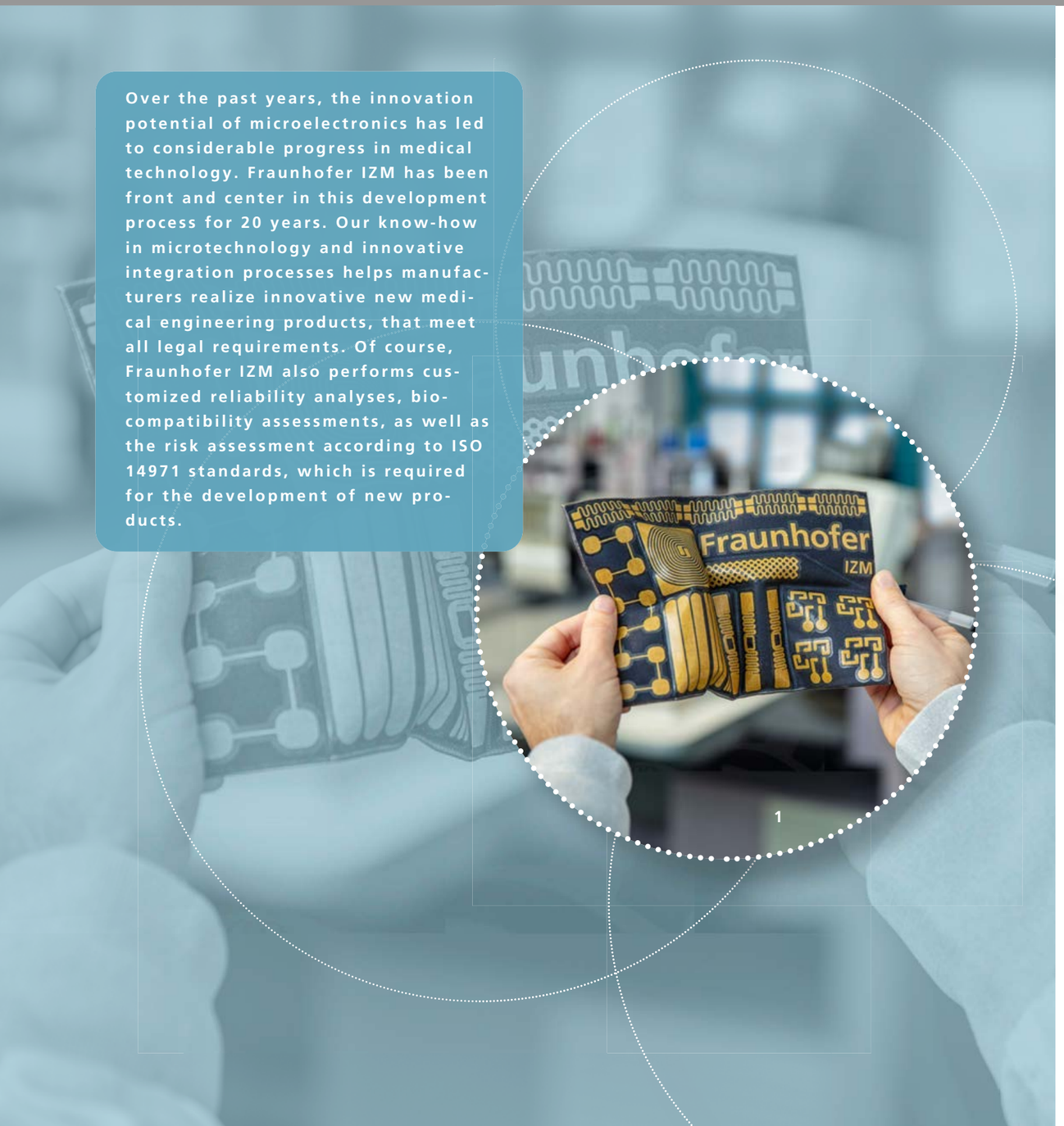
Power electronics are expected to maintain an extreme level of functional reliability even in increasingly rugged environmental conditions that expose them to adverse forces like substantial humidity. To ensure their reliable operation, in-situ state monitoring is introduced to allow targeted maintenance measures at the point of need. For the solution, existing metrological concepts were refined to monitor a relevant group of damage indicators and combined stress tests conducted to evaluate the system's reliability.

The challenges that had to be overcome for this purpose included the implementation of smart monitoring technology and the analysis of suitable damage indicators.

1 *Combined camera-radar module for next-generation autonomous driving*

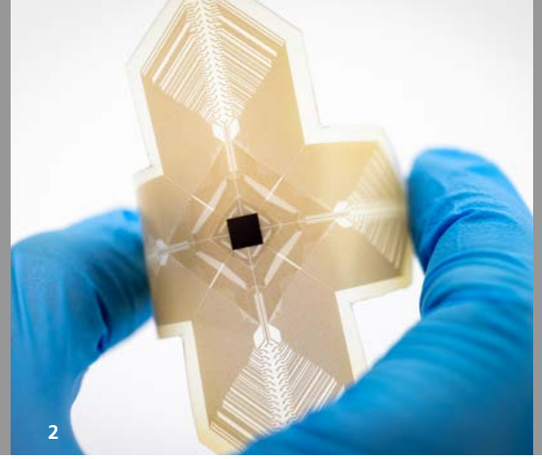
2 *Flip-chip Ag sintering (eHarsh project)*

# MEDICAL ENGINEERING

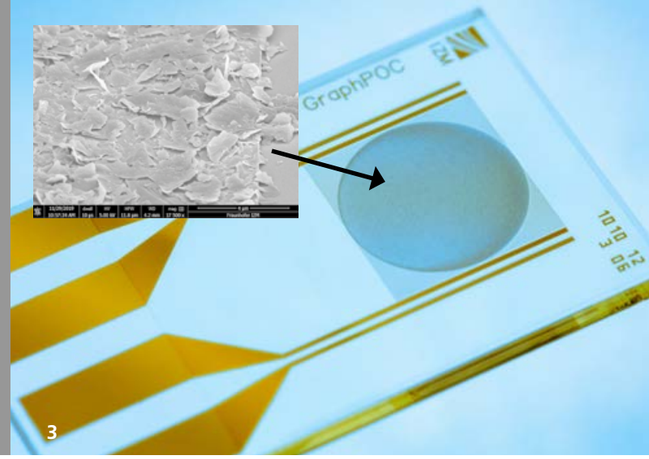



1

**Over the past years, the innovation potential of microelectronics has led to considerable progress in medical technology. Fraunhofer IZM has been front and center in this development process for 20 years. Our know-how in microtechnology and innovative integration processes helps manufacturers realize innovative new medical engineering products, that meet all legal requirements. Of course, Fraunhofer IZM also performs customized reliability analyses, biocompatibility assessments, as well as the risk assessment according to ISO 14971 standards, which is required for the development of new products.**



2




3

**Flexible implant with embedded electronic components for peripheral nerve stimulation**

Electronic components in the form of application-specific integrated circuits (ASICs), establishing the interaction between the body and the implant, have become essential elements for implantable devices, as medicine is looking into substituting its traditional pharmaceuticals with electroceuticals. As part of the EU project POSITION-II, Fraunhofer IZM is developing one of the first devices of its kind: a small and flexible bioelectronic medical system with embedded electronic components for peripheral nerve stimulation. An embedding process using biocompatible polyurethane protects the ASICS, ensuring the longevity and reliable performance of the device. This allows miniaturization, flexibility, and good mechanical tissue interaction and avoids the need for a conventional titanium case.

**Wireless neurostimulation implant to study the recovery of motor response after spinal cord injury**

Within the Fraunhofer ATTRACT »Technologies for Bioelectronic Medicine« project, Fraunhofer IZM is developing an autonomous neurostimulation implant for the purpose of restoring locomotion after spinal cord injuries. An electrode array consisting of 13 electrodes and the required driver electronics, together with a control unit to supply power and handle stimulation data, form the core of the implant. The tailored implementation allows for the electrical stimuli to be delivered to different locations on the spinal cord, and the quick responses of the custom-designed electronics ensure a rapid change of the stimulation parameters, which is paramount for facilitating a real-time motor-response. The stimulation parameters and electrode configuration are adjusted through a graphical user interface (GUI).

**Graphene-based diagnostic platform**

The BMBF-funded project »GraphPOC« is working towards a point-of-care diagnostic platform based on graphene technology. The ambition of the project is to design a purely electrical system that can recognize certain biomarkers in human blood and distinguish between bacterial, viral, or fungal infections. The concept developed in cooperation with the Technical University of Berlin relies on the high-precision deposition of organic, reduced graphene oxide, its biological application by means of catcher molecules, and the embedding of sensors in a disposable package, using microfluidics and RDL. The system has the potential for use with other biomarkers in the future as well.

**DAISY – Radar technology in nursing care**

Dementia is fast becoming a fact of life for many people in our aging society. To ensure individual and dignified care and support for those affected, the DAISY project has turned to using radar technology in a sophisticated interactive table designed to accompany and assist the active care services. The table is used as an ergotherapeutic tool for dementia sufferers. It can engage and communicate with its users by voice, sound, and image, recognize and interact with individual patients, and track and respond to their gestures.

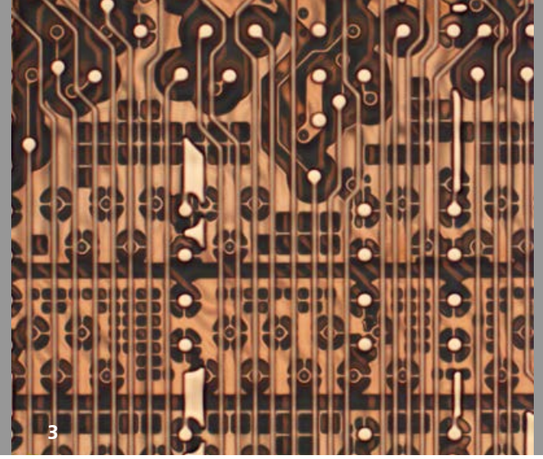
As member of a consortium of care specialists, a furniture manufacturer, and software and hardware professionals, Fraunhofer IZM is developing the hardware for the radar sensor as well as the wireless communication and charging capabilities. Its activities in the project include revising the system concept, selecting the components, and designing and characterizing the planned modules as well as developing and testing the firmware for the finished radar system.

1 *Pneumatically formed textile circuit board*

2 *Flexible implant with 324 electrodes and integrated electronics to stimulate neural activity on the brain's surface*

3 *Graphene-based biosensor with REM image of the sensor surface*

# SEMICONDUCTORS



**This business unit specializes in the integration of semiconductor elements and the production of sensors for the assembly of complex heterogeneous system-in-package (SiP) solutions. Fraunhofer IZM offers its clients holistic services – from developing the original concepts and designing the processes to characterizing and testing the reliability of the finished systems. The institute's facilities cover all relevant processes for manufacturing sensors and wafer-level packages, allowing the production of hermetically sealed sensor packages and even entire 3D systems.**

**TSV last technology and Si interposer cavity integration**

Fraunhofer IZM-ASSID is working in the publicly funded Admont project to develop a technology for the reverse-side through-silicon via (TSV) integration of micro-mechanical (CMUT) and opto-electronical (OLED) components. Based on a Si interposer, the proposed system-in-package approach allows four ASIC readout chips and passive devices to be connected to the CMUT. The ASICs are assembled using wire bonding, while flip chip technology is used to bond the CMUT with TSVs to the interposer. The thick ASICs are embedded into cavities to keep the CMUT as the highest point in the assembly.

The project has achieved the development of an Si interposer with TSV-last integrated CMUT or other devices. The chosen SiP approach enables the combination of different assembly and bonding technologies for Si interposers, leaving future product designers considerable freedom when integrating components.

**Chip-first fan-out approach for multi-chip applications with high-density wiring**

As its contribution to the EuroPAT-MASIP project consortium, Fraunhofer IZM has developed an assembly concept placing the dies directly onto a glass carrier with a die adhesive. The resulting temperature-stable bond avoids any die shift during embedding and allows the integration of chips with a denser pitch and higher I/O count. After the carrier is removed, the adhesive remains on the device and serves as the first passivation layer, on which pad contacts can be generated by laser drilling. This hybrid fan-out concept combines the cost efficiency of the chip-first face-down technique with the non-shifting chip-first face-up approach.

**Flex and rigid/flex polymeric interposers**

Fraunhofer IZM introduces a novel wafer-level high-density multi-layer wiring technology for manufacturing polymeric interposers. The technology enables thin foils to be produced with multi-layer routing, using copper tracks of ≤ 5 µm thickness and line width and spacing of ≥ 7 µm. The polymer dielectric layers have a thickness of ≤ 10 µm and can accommodate vias of ≥ 10 µm diameter. The resulting flex circuits containing up to three internal routing layers as well as contacts on the front and back measure ≤ 60 µm, with local reinforcements added to bolster their mechanical robustness during chip attachment or other assembly processes. The circuits can be used for I/O feeding and the interconnection of assembled or embedded ICs. By 3D stacking, the technology allows modules with unprecedented numbers of wiring layers to be produced.

**SERENA – Platform for GaN-on-silicon mm-wave modules**

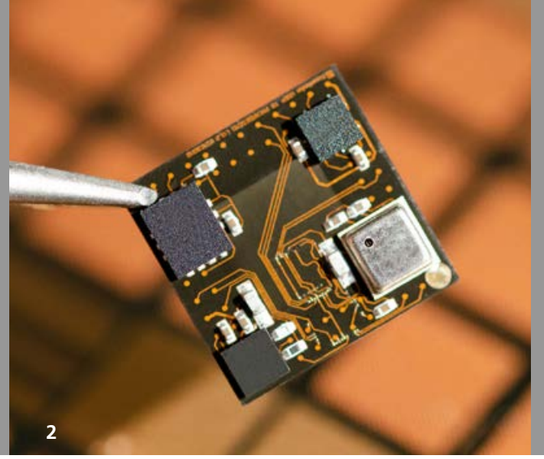
Conventional silicon has hard technological limits. The European SERENA project is developing a platform that aims to overcome those limitations with the hybrid integration of gallium nitride on silicon, while keeping the costs at a manageable level. Compared to silicon-germanium, the technology is expected to lead to a tenfold increase in efficiency and maximum output. SERENA will empower developers with a complete system architecture and integration platform to design mm-wave components for use in radar sensors and wireless 5G communication. As its contribution to the project, Fraunhofer IZM has taken over the RF design and the assembly and testing of the system integration platform.

1 *Electrical characterization of semiconductor materials*

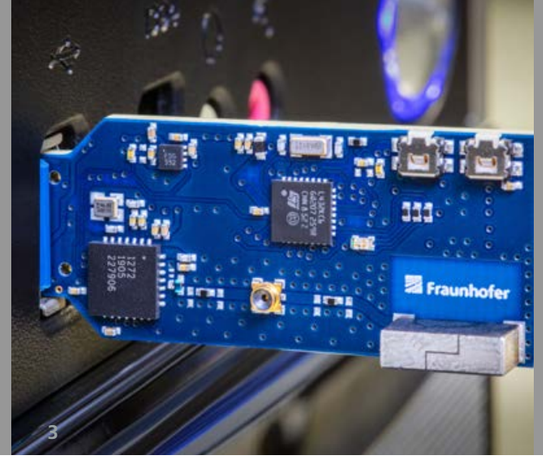
2 *Semi-automatic wafer prober for the electrical characterization of substrates and components of up to 500 GHz in the temperature range of -40°C to 180°C*

3 *Example of a multilayer flex with fine-pitch RDL (7 µm lines/space)*

# INDUSTRIAL ELECTRONICS



2




3

**In recent years Fraunhofer IZM's industrial electronics specialists have concentrated on the visionary concept of Industrie 4.0. Particular emphasis was placed on the work on cyber physical systems (CPS) and autonomous, specifically high-reliability radio sensors that record and process the relevant monitoring and / or video data on site and distribute it via standard interfaces when and where the user needs it. Industrie 4.0 means much more than CPS integration: Flexible access to monitoring data is particularly vital both for location-bound controlling and management processes and ERP systems and for on-demand access via mobile devices in inspection, maintenance, or repair scenarios.**

1

**Sensor packaging for IoT systems**

Supported by public funding, the members of the »USeP« project consortium are working on a modular universal platform for innovative, highly integrated, and customizable IoT systems specifically designed to meet the requirements of SMEs and aspiring startups. In its contribution, Fraunhofer IZM is developing an economical and flexible high-density housing (packaging) to accommodate a range of sensors. The solution uses a fan-out wafer-level package, containing a highly integrated SoC with multiple analog and digital sensor interfaces, integrated data conversion, storage, processing, and encoding capabilities, as well as a choice of communication interfaces. It can be tailored to the client's specifications with additional wiring on the surface of the package and the placement of additional sensors/actuators. Using GLOBALFOUNDRIES' energy-efficient 22 nm FDX technology, the IoT system's core elements can be cost-effectively manufactured and flexibly adapted to application-specific requirements.

**Low-power platform for exceptional energy efficiency**

As the vision of an increasingly connected society is becoming reality, there are concerns about how energy intensive the new digital way of life will be. But it also has real potential to reform our resource hungry ways – if used intelligently. The electronics making this vision possible need to be resource efficient when they are made and when they are used in order to avoid rebound effects. The Fraunhofer flagship project »Towards Zero Power Electronics« was set up to create the technologies and methods to develop highly integrated and extremely energy efficient modules for the Internet of Things.

Fraunhofer IZM has designed a scalable and modular low-power platform (IoT Core) with intelligently controlled interfaces for sensors, actuators, or other infrastructures and contributes its expertise as a system integrator to form individual components into miniaturized modules.

**Field testing the ASTROSE® server ice load warning system**

Fraunhofer IZM has been spearheading the development of autonomous sensor systems for monitoring powerlines. After successful field tests for power load tracking on overhead lines, 2019 brought two new pilot projects testing the ice load warning system built around the wireless sensors of the Astrose® family.

Placed on the lines and fed by energy harvesting, the sensors track the lines' tilt, temperature, and current. The sensors send the resulting data via the license-free 2.4GHz frequency to the Astrose® server, where specialized software clients process it for the relevant applications. The standard transmission protocols IEC 60870-5-101 and IEC 60870-5-104 are used to put the aggregate monitoring data directly at the disposal of the grid operator's controllers.

*1 Low-inductance SiC power module in mold technology with direct cooling*

*2 USeP demonstrator with sensors (acceleration, vibration, rotation, inclination, air temperature/humidity/pressure)*

*3 IoT gateway for a modular sensor kit with LoRo- and bluetooth LE V5 interface*

# INFORMATION & COMMUNICATION

**The new era of increasing connectivity and digitalization creates new challenges for the design and assembly of ICT systems: The efficient sharing and storing of data needs ever larger data centers and the means to transmit electric and optical signals. Digitalization itself brings its own challenges: There is increasing demand for highly dynamic networks that can transport, process, and analyze data. Fraunhofer IZM offers comprehensive solutions for these challenges with more than two decades of experience in the field of system integration.**

1

2

3

**Applied research on electrical and electronics devices strengthens Circular Economy policy making**
We play a key role as part of the European Commission's first Circular Economy Action Plan: The new Ecodesign Directive includes material efficiency requirements such as the availability of spare parts, ease of repair, and recyclability. We have been at the core of defining ecodesign criteria for servers, adopted into law in March 2019.

The European Commission reinforces protections for consumers against premature obsolescence with a testing program managed by Fraunhofer IZM.

In line with the EU Strategy for Plastics in a Circular Economy, we recently completed research on post-consumer ABS in new appliances. Another current project is implementing concepts of Design for Recycling and the use of recycled materials in industry.

**Textile circuit boards**
There has been a spike in interest in pliable and stretching electronic systems or »Conformable Electronics« that can be bent and shaped in all three dimensions. Fabric-integrated electronics (e-textiles) have to withstand extremely strong mechanical forces on the embedded components and connections, as they are exposed to constant dynamic stress and the considerable mechanical impact of during cleaning and laundering.

Adding a new dimension to the technology portfolio of Fraunhofer IZM, textile circuit boards (TexPCBs) are formed on special silvered fabric and embedded in a thin thermoplastic elastomer matrix. The resulting textile can be processed to route conductor paths or accommodate sensors by means of laser cutting.

**Modular products as a model for ecodesign**
Modular product design is an enabler for longer product lives and repair, and it facilitates their reuse and upgrade, making it a promising approach for more sustainable product concepts.

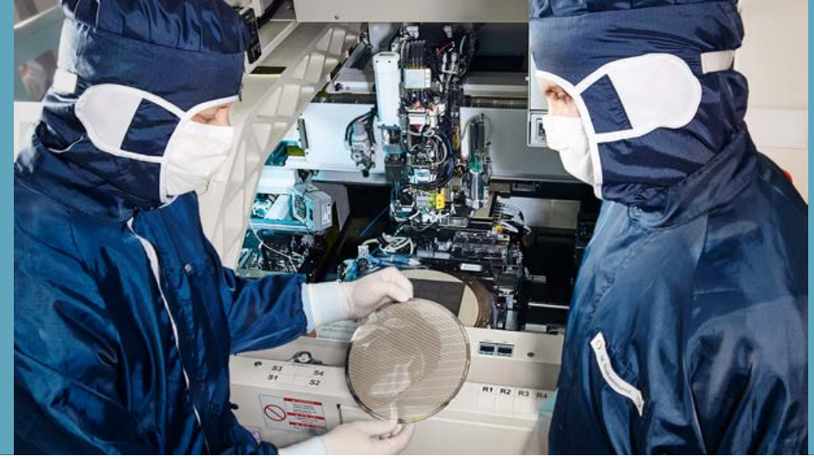
Several environmental lifecycle assessments conducted for different technologies, including the embedding of components, connectors, and smartphones, reveal the additional environmental impact coming from the production of modular components. Only if use patterns change towards keeping products in use for longer can modularity really pay off. Embedding technology can, under certain conditions, help to improve the environmental record of smart devices.

1 *Fully transparent polycarbonate bonding of LEDs*

2 *Textile circuit board, developed at Fraunhofer IZM*

3 *Board-level modularization: Digital voice recorder with embedded components in modules*

# LABS & SERVICES



Forschungsfabrik Mikroelektronik Deutschland

## SYSTEM INTEGRATION

**Wafer-Level Packaging Line**

Fraunhofer IZM operates two process lines (cleanroom class 10 – 1000) in Berlin (975 m²) and Dresden (ASSID, 1000 m²), that offer our customers various wafer-level packaging services from development stage to prototyping and small volume production. Different substrate materials (e. g. silicon, III/V, ceramic and glass) and wafer sizes (4" –12") can be processed. Project and process work on both lines is executed in compliance with ISO 9001:2015 management standards.

**Process Modules:**

- Cu-TSV integration (via-middle and via-last-processes)
- Silicon and SiC plasma etching – DRIE (TSV, cavities)
- Thin-film deposition (sputter, CVD, photolithography, reactive ion beam etcher)
- PECVD process chamber (200/300 mm) for the deposition of TEOS oxide, Silane oxide and Silane nitride
- High-density thin-film multilayer (Cu/polymer RDL)
- Wafer-level bumping (Cu-Pillar, SnAg, Ni, Au, In, AuSn)
- Wafer thinning und thin wafer dicing (blade, laser grooving and stealth dicing)
- Wafer bonding – permanent and temporary
- Wafer level assembly up to 300 mm (D2W)
- Automatic inline wafer measurement system (200/300 mm) for layer thickness, topographies, roughness as well as TTV/warpage/bow
- Fully automated electric wafer measurent system

**Substrate Line**

In the substrate 460 x 610 mm² area panel-size substrates can be prepared for resist and PCB lamination, solder resist and cover lays can be applied and developed after exposure.

In our bonding lab high-precision module assembly is carried out under inert gas. New equipment in the 480 m² cleanroom allows surface preparation for assembly at reduced bonding temperatures.

Our services include:

- Embedding of passive and active components
- Multilayer lamination of PCB substrates
- Realization of smallest vias, mechanically as well as with a laser
- Quality assessment and X-ray microscopical analysis

**Mold Encapsulation Lab**

The lab offers various encapsulation processes, related material and package analysis and reliability characterization tools as a one-stop-shop. The focus is on FO-WLP/PLP on sensor packages with freely accessible surface and on power SiPs.

- Precision assembly and compression molding on wafer and panel level (610 x 460 mm²)
- Redistribution in 2D (PCB-based and thin film) and 3D (TMV)
- Transfer molding of SiPs for sensors and power
- Process simulation and analysis of material models

Transfer to industrial production is guaranteed due to use of production equipment.

**Wire Bonding Lab**

- Processing of Au-, Al- and Cu-based bonding wire materials for thin and heavy wire bonding
- Assembly of power modules using Al/Cu- and Cu-heavy wires for quality and reliability analyses
- Assembly of sensor packages using Cu-ball/wedge bonding for lead frames and Au/AlSi1 wires for COB processes

**Soldering Lab**

- Vapor phase soldering with vacuum enables manufacturing of voidless large area solder joints for power electronics
- Fluxless soldering of printed circuit assemblies using active gas in oxygen free Nitrogen or vapor phase atmosphere



- Hermeticity test
- Leak testing including Helium bombing up to a pressure of 10 bar

**Photonics Lab**

- Laser structuring of glass layers with optical waveguides for electro-optical boards (EOCB)
- Shack-Hartmann-characterization of micro lenses and micro lense arrays
- Optical and thermal characterization of LEDs and LDs
- Research and development of optical packaging processes with an accuracy of up to 0.5 µm

## MATERIAL ANALYSIS

**Moisture Lab**

- Comprehensive simulation-based reliability assessment of humidity-induced phenomena in microelectronic components and systems
- Surface analysis through atomic force microscopy
- Analysis methods for sorption, permeation and diffusion of water in materials
- Molecular-dynamic simulation

**Long-term Testing and Reliability Lab**

- Fast temperature cycling tests in the range from -65 °C to 300 °C
- Temperature storage up to 350 °C

**Power Lab**

- Testing of hetero highly integrated of power modules
- Active cycling of power modules for lifetime assessment
- Calorimetric measurement of the effectiveness of highly efficient devices

## DESIGN

**High Frequency Lab**

- Free-space measuring station up to 170 GHz, Fabry-Perot resonators up to 140 GHz and THz system for HF material characterization
- Semi-automatic sample station with thermal chamber (-60 °C to 300 °C)
- EMC and test environment for wireless communication systems in the multi-gigabit and terabit-range
- Antenna measuring system for up to 330 GHz
- Test lab for mm wave modules for radar and communication, signal source (AWG) and spectrum analyzer up to 325 GHz
- Time range measuring station (sample oscilloscope up to 70 GHz/BERT up to 64 Gbit/s)

**Microelectronics Lab**

- Development and qualification of mechatronics systems and energy-efficient wireless sensor systems
- PXA for range calculation, conformity checks, and failure analyses; allows the recording of very fast signals (from 162 µs)

**Further laboratories include:**

- Micro Battery Lab with 10-meter battery development and assembly line
- Laboratory for Textile-integrated Electronics (TexLab)
- Photoelectron spectroscopy and electron spectroscopy for chemical analysis (ESCA)
- Corrosion Lab
- Electronics Condition Monitoring Lab (ECM) for functional tests of electronic systems under environmental stress, salt spray, shaker
- Qualification and Test Center for Electronic Components (QPZ)
- Thermo-mechanical Reliability Lab
- Thermal & Environmental Analysis Lab

# EVENTS





# EVENTS & WORKSHOPS

**Symposium Panel Level Packaging in Dresden and Berlin**
Almost 100 participants gathered on January 30, 2019 for the fourth symposium »Status & Trends in Panel Level Packaging« at the Hilton Hotel in Dresden. International experts from industry and science showcased the latest research results in the field of panel level packaging. In half-hour lectures, they presented market and application trends, the latest technology results, material, equipment and process developments for large-area and fine-scale processing as well as cost analyses.

On the following day the members of the Panel Level Packaging Consortium met at Fraunhofer IZM in Berlin. The institute's expertise in wafer-level packaging and substrate technology was the seed for the founding of the consortium in 2016 with 17 industrial partners from Europe, the USA, Japan, Korea and Taiwan. At the meeting in Berlin, a conclusion on the existing consortium was drawn and at the same time the follow-up work on the project was initiated.

**The 3rd PLATE Conference was a resounding success!**
More than 200 participants from all over the world met in Berlin from 18–20 September 2019 for the 3rd Product Lifetimes and the Environment (PLATE) Conference. As usual, the event, which this year was organized by Fraunhofer IZM in cooperation with the Technical University of Berlin, offered a strong scientific program with three keynotes, 11 workshops, 105 lectures and 20 poster presentations.

The biennial conference once again brought together science, industry, NGOs and political decision-makers, who discussed the topic of product lifetimes in the context of sustainability on all three days of the event. This year's conference focused on hot topics such as recycling management, eco-design and collaborative consumption.

A highlight of the conference were the practical workshops, which took place over two days. In the 11 workshops, different approaches to make products more sustainable were presented. From proactive obsolescence management and the sustainable smartphone of the future to strategies for extending the life of fashion products and testing for premature obsolescence – there was something of interest for everyone.

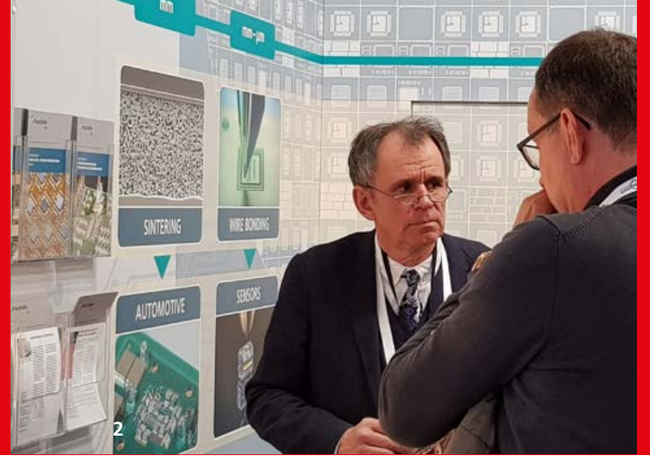
**»Keep research up and running«: Fraunhofer IZM at the Berlin company run**
It has become a small tradition and the summer team event: the company run. Almost 190 runners from the six Berlin and Brandenburg Fraunhofer Institutes met on May 22 to first cover the 5.5 km distance and then recover from the exertions at a barbecue with sausage and beer. The training really paid off this year: In the team ranking the Fraunhofer Institutes reached an excellent 2nd place. Congratulations to all participants!

**700 participants at the Microsystems Technology Congress**
For the first time since 2009, the Microsystems Technology Congress, the largest German-language event in the field of electronics and microsystems, was held in Berlin again in 2019. From 28–30 October, around 700 experts from politics,

1 *Ringing in the next round of panel level packaging – Fraunhofer IZM's Dr. Tanja Braun at the PLP Symposium in Dresden*

2 *PLATE 2019: Vocal support for the global climate strike on 20 September*

1




2


3

research and industry met up to discuss current trends in microsystems technology under the chairmanship of IZM Institute Director Prof. Klaus-Dieter Lang.

The congress not only offered its participants a platform for networking, but also provided plenty of new input on current developments, opportunities and challenges in microsystems technology: a total of four keynotes, more than 100 lectures, two extensive poster sessions, a discussion round, a workshop and guided tours of three scientific institutions. The program was rounded off by an accompanying exhibition where 44 companies and institutes presented their latest products and developments. Fraunhofer IZM also had a stand at the exhibition and showcased current developments in the field of electronic packaging.

The congress was also a great opportunity for young talents. High school and university students were not only able to find out about career opportunities in high-tech technologies of the future, but also to submit their own projects for the »COSIMA« and »Invent a Chip« competitions.

**IZM research at SMTconnect and PCIM 2019**
Soldered and sintered interconnects, but also bumping technologies and life cycle issues – these topics were in particularly high demand at Fraunhofer IZM's booth at SMTconnect.

Europe's leading trade fair for system integration in microelectronics was the focus of discussions on design, PCB production, components, assembly and interconnection technologies and test equipment, not least thanks to the »Future Packaging« production line.

Fraunhofer IZM was also represented at PCIM (Power Conversion Intelligent Motion) Europe at the same time. Here, visitors were introduced to Fraunhofer IZM's complete range of services in the field of power electronics: from system design, packaging and interconnection technology for power electronic systems and reliability aspects to cooling concepts. A special highlight was a live demonstration in the form of a measuring chamber, which measures switching losses of widebandgap semiconductors under real conditions and without additional parasitic effects.

**Start-up assistance for hardware start-ups**
Start-ups, partners and interested parties from the industry and hardware sector came together in September for a special kind of workshop: a tech safari, in which the participants could trace the path from idea to product at individual stations. Under the title »Start-A-Factory Reloaded«, 40 participants experienced the mix of lab infrastructure and work environment, which is specially designed to meet the needs of hardware start-ups. In project-based cooperations and with state-of-the-art equipment, the SAF environment enables development teams to quickly realize new products from the initial idea to the professional prototype – embedded in a network of Fraunhofer IZM specialists and other partners.

Now that all the elements have been set up and are ready for use, SAF's creators have invited to a »walk-around« event. In addition to workshops on the different stages of microelectronic hardware development, the keynotes were a particular highlight. Mike Richardson, founder and technical advisor, but also container user at SAF, explained to the audience what the nerds of the future will look like: »The special thing about a tech dork is the mix of a nerd and a communicative and social person.«

**To Mongolia by bike in 21 days**
Riding as many bike kilometers as possible within 21 days as a team – to this 20 colleagues swapped the car and the train for the bike and cycled 5,556 km, covering a distance from Berlin to Mongolia.

The »City Cycling« campaign is running throughout Germany to encourage people to rethink their ways. 80 percent of all households own a bicycle, but rarely use it. In a team the incentive is much higher. In an app, the kilometers ridden can be entered or tours can be recorded. These recorded routes are analysed anonymously by the TU Dresden and made available to the local authorities in order to optimize the cycling infrastructure. Thus, the possibilities for cycling should be improved bit by bit. For a better climate, for a good balance to the daily work routine and for the team spirit among colleagues.

**iCampµs in Cottbus takes up work**
At the »Innovation Campus Electronics and Microsensor Technology Cottbus«, 40 scientists will develop new types of sensors and systems based on them, including colleagues from the Cottbus IZM High-Frequency Sensor Systems branch under the direction of Dr. Dr. Ivan Ndip. Also on board are the Leibniz Institute for Innovative Microelectronics, the Ferdinand-Braun-Institut für Höchstfrequenztechnik and the Fraunhofer Institute for Photonic Microsystems IPMS as well as 10 chairs of the Brandenburg Technical University (BTU) Cottbus-Senftenberg.

The aim of the Innovation Campus, also known as iCampµs, is to identify the unctionality and performance requirements of sensors in concrete terms and to address them by combining the competencies of all partners.

The joint project »Innovation Campus Electronics and Microsensor Technology Cottbus«, which is funded by the German government to the tune of around 7.5 million euros, officially began its work on November 15, 2019.

**Fraunhofer IZM at trade shows (selection)**

| | |
|---|---|
| **3D & Systems Summit** | January, Dresden |
| **SPIE. Photonics West** | February, San Fran., USA |
| **embedded world** | February, Nuremberg |
| **Smart Systems Integration** | April, Barcelona, ESP |
| **PCIM Europe** | May, Nuremberg |
| **SMTconnect** | May, Nuremberg |
| **connecticum** | May, Berlin |
| **ECTC** | May, Las Vegas, USA |
| **LASER World of Photonics** | June, Munich |
| **Sensor+Test** | June, Nuremberg |
| **Semicon West** | July, San Francisco, USA |
| **FMD Innovation Days** | September, Frankfurt (Oder) |
| **ELIV** | October, Bonn |
| **IWLPC** | October, San José, USA |
| **Productronica** | November, Munich |
| **SEMICON Europe** | November, Munich |
| **COMPAMED** | November, Düsseldorf |
| **SEMICON Japan** | December, Tokyo, JPN |

1 *»Stadtradeln« cycling initiative – team Fraunhofer IZM*

2 *Deep in conversation: the IZM booth at SMTconnect*

3 *From left to right: Prof. Tillack (Leibniz), Prof. Wehrspohn (Fraunhofer Board), Prof. Hipp (BTU), Dr. Münch (MWFK), Prof. Schieferdecker (BMBF), Prof. Schenk (project leader), Prof. Tränkle (FBH), Holger Conrad (Fraunhofer IPMS), Dr. Dr. Ndip (Fraunhofer IZM)*


1

2

**70 years of Fraunhofer –**
**the institute celebrates with an open day**

On September 6, Fraunhofer IZM celebrated a party in honor of the Fraunhofer-Gesellschaft's 70th anniversary. Under the motto »70 Years of Future – #WHATSNEXT«, IZM employees revived memories of the past and together took a look at the future. At the opening, Institute Director Prof. Klaus-Dieter Lang addressed the guests and thanked not only the researchers themselves, but also their families. Relatives, alumni, long-standing partners and employees had the opportunity to try out a variety of activities at numerous stands on the historic site in Berlin Wedding: From a steep climbing wall with a 25 degree overhang for the sportsmen and women, to a station for painting cups for the more creative guests, to culinary delicacies, there was something for every taste.

| Selection of events organized by Fraunhofer IZM | |
|---|---|
| **Panel Level Packaging Symposium** | January, Dresden, Berlin |
| **Industry Working Group: System Reliability in Assembly and Interconnection Technology** | February, May, October, Berlin, Nuremberg |
| **Industry Working Group: Compliant Environmental Management in the Electronics Industry** | March, June, November, Berlin |
| **Girls' Day 2019** | March, Berlin |
| **Workshop: Ecodesign Learning Factory** | March, Berlin |
| **6th GMM Workshop: Packaging of Microsystems** | March, Berlin |
| **Lab Course: EMC Optimized Design – Parasitics in Power Electronics** | April, Berlin |
| **Start-A-Factory Reloaded** | September, Berlin |
| **7th Optical Interconnect in Data Centers Symposium** | September, Dublin, IRL |
| **Workshop: Polymer Ageing and Microelectronic Package Reliability** | September, Berlin |
| **Workshop: Modern Power Semiconductors and their Packaging** | October/November, Aalborg, SWE |
| **Workshop: Reliability of Electronic Systems** | November, Berlin |
| **Lab Course: Autarkic Radio Antennas** | November, Berlin |



# PROMOTING YOUNG TALENTS AT FRAUNHOFER IZM

Two trainees started their dual vocational training in the field of microtechnology at Fraunhofer IZM in 1999. Since then, the institute has enabled almost 40 young people to successfully complete their training in this exciting and promising profession.

Many of them now form an important part of the technical staff in Fraunhofer IZM's laboratories and clean rooms. In 2019, two trained microtechnologists were once again rewarded with an employment contract for their excellent performance. Since 1999, the range of training opportunities has been expanded: apprenticeships in precision mechanics or as office communication experts have been added. Since last year, four new apprentices have joined the IZM staff. And there are more to come: From 2020, the institute will offer training to become a surface coater. Anyone who wants to combine craftsmanship with the fun of technology is welcome to apply here. Fraunhofer IZM is pursuing its goal of increasing young people's interest in technical developments and careers in technology and research. To this end, the institute also offers internships for young people to provide an insight into the training and study opportunities for scientific (MINT) professions. In 2019, a total of 25 students were able to get to know the work in the laboratories of Fraunhofer IZM during a two- to three-week internship.

**Soldering, dismantling, calculating – Girls' Day 2019**

On March 28, 2019, Girls' Day was held at Fraunhofer IZM for the 16th time in a row, this time with 10 students from Gabriele-von-Bülow-Gymnasium – Fraunhofer IZM's Berlin partner school. The girls first visited the IZM laboratories and learned how new components or functions for an electronic device are developed and how a smartphone functions reliably despite frost, summer sun or even after a fall. They also lent a hand themselves: Dismantling mobile phones, calculating resistors, soldering – the participants had a lot to do. Finally, the girls had to build a so-called »egg flying machine« with little material, which would enable a raw egg to survive a fall from a height of four meters without damage. The highlight: All eggs remained intact and the students had every reason to be proud of their project.

**Using networks to attract young people!**

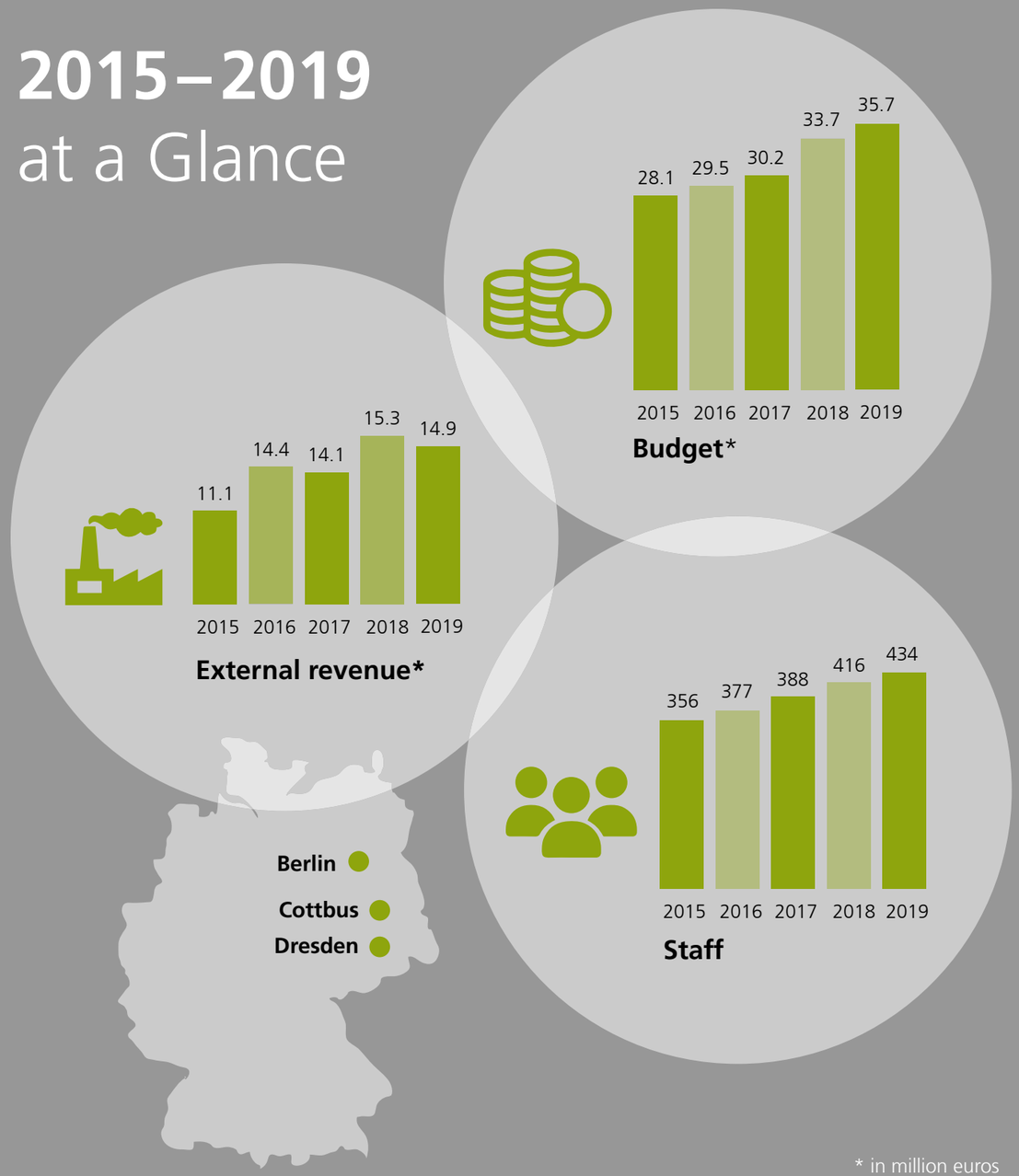
Fraunhofer IZM's dedication to supporting young people is also illustrated by the institute's joining the newly founded association for securing skilled workers in the high-tech sector proANH e. V., whose training and further education network for high technology Fraunhofer IZM hopes to use to support the recruitment of young people and securing skilled workers. Stands at training and career fairs such as the connecticum in the Arena Berlin or »Dream Profession IT & Technology« in a hall of the STATION Berlin also served to inspire young people to take up research careers.

1 *Facing an inquisitive team of junior researchers: the IZM team at connecticum*

2 *Egg flight engineers at work*

# FACTS & FIGURES

## 2015–2019 at a Glance




# FRAUNHOFER IZM IN FACTS AND FIGURES

**Financial situation**
2019 saw the continuation of Fraunhofer IZM's successful track record. The Institute's budget increased by 5.8 percent over the previous year to a total of 35.7 million euros. In total, Fraunhofer IZM covered 78.6 percent of its operating budget from external funding. All in all, projects amounting to 27.9 million euros were financed externally.

41.8 percent of Fraunhofer IZM's operating costs were covered by direct contracts from industry. Revenue has remained stable at 14.9 million euros, while the share of projects with public financing increased year-on-year at a rate of 3.3 percent. The project volume in this area amounted to a total of 13 million euros.

**New equipment**
Investments into replacing and restocking the Institute's equipment amounted to 2.1 million euros from Fraunhofer IZM's own budget. These sums were invested to optimize the Institute's technical capabilities with numerous targeted investments and to increase the efficiency of the existing facilities.

A further 3.7 million euros were invested into several small-scale construction projects; including the expansion of the cleanroom facilities at Fraunhofer IZM, also supported by funding from the State of Berlin. The Research Fab Microelectronics Germany (FMD) in Berlin is nearing completion; new equipment and facilities were procured with an investment of 5.5 million euros in 2019. These activities were made possible through the support of the Federal Ministry of Education and Research.

**HR development**
The expansion in the range of services is reflected in personnel development. The IZM sites in Berlin and Dresden/Moritzburg employed 285 people, that is 25 more than in 2018.

Fraunhofer IZM offers students the opportunity to combine studying for their degree with practical scientific work. At the end of 2019, 149 interns, bachelor students, master students, and student assistants were being supervised at the institute and eight apprentice micro technologists and office managers were in training.

| Fraunhofer IZM in 2019 | |
|---|---|
| **Budget** | 35.7 million euros |
| **External revenue** | 27.9 million euros (78.6 percent of total turnover) |
| **Sites** | Berlin, Cottbus and Dresden/Moritzburg |
| **Laboratories** | >8,000 $m^2$ |
| **Staff** | 434 (including 149 student assistants, master students, interns and 8 apprentices) |

1

2

3

# AWARDS

**GMM Award for Klaus-Dieter Lang**
At the opening of this year's Microsystems Technology Congress, IZM institute director Prof. Klaus-Dieter Lang was honored with the highest VDE award of the Society for Microelectronics, Microsystems and Precision Engineering – the GMM Award. Lang was chairman of the MST Congress in 2019 and has been associated with the GMM for many years, for example through his membership in the steering committee of the MST Congress and his work in various committees. Due to its above-average standards, the GMM Award is presented at most every three years to personalities who have rendered outstanding services to the effectiveness of the GMM in an extraordinary way and with a high level of commitment.

**Research Award »Transformative Science« for Melanie Jaeger-Erben**
This year, the research award »Transformative Science« of the Wuppertal Institute and the Zempelin Foundation in the Stifterverband was awarded to Prof. Dr. Melanie Jaeger-Erben, head of the research group »Transdisciplinarity for Sustainable Electronics« at Fraunhofer IZM.

Professor Melanie Jaeger-Erben convinced the jury with her impressive inter- and transdisciplinary profile, her previous academic success and her ability to work on and reflect current issues in sustainability research using innovative transdisciplinary methods. Melanie Jaeger-Erben is pleased about the recognition of her work: »I would like to use the prize money to intensify our work on a high-profile platform for disseminating the idea of a transformative and inclusive ‚Circular Society'.«

**Award for Fraunhofer IZM at the »Ideas Competition for International Research Marketing«**
The German Research Foundation (DFG) has awarded Fraunhofer IZM a prize in the ideas competition for international research marketing. The research prize was awarded for the concept of a scientific blog in the field of microelectronics. The platform aims to facilitate a global exchange of knowledge and increase the importance of research topics and research institutions on an international level, and is also designed to promote digital collaboration between nationally and internationally qualified researchers and interested parties.

**»Young Engineer Award« for Christoph Marczok**
IZM junior scientist Christoph Marczok was honored with the Young Engineer Award of PCIM Europe 2019 for his contribution on the topic »Low Inductive SiC Mold Module with Direct Cooling«.

In order to take advantage of the superior properties of wide-bandgap semiconductors, power modules require optimal thermal performance, good parasitic electromagnetic properties, high temperature resistance and the possibility to be easily integrated. Christoph Marczok's paper shows a new design for power modules with SiC power MOSFETs using multilayer ceramic substrates with direct water cooling of the substrate. The award ceremony took place on May 7, 2019, during the opening ceremony of the PCIM Europe Conference in Nuremberg.

**Tanja Braun elected to the IEEE EPS Board of Governors**
In December 2019, Dr. Tanja Braun was elected Member-at-Large of the IEEE EPS Board of Governors for the coming year. IEEE, the »Institute of Electrical and Electronics Engineers«, is the world's largest professional association for engineers. The Electronics Packaging Society (EPS) brings together expertise in the fields of microelectronics and packaging.

The EPS Board of Governors establishes standing committees to coordinate and oversee activities in various operational and strategic areas, including international conferences, publications and technology networks. In this context Tanja Braun is now responsible for the further development of »Women in Engineering«. The election reflects her high standing in the EPS community.

**Dominik Andrä wins 3rd place in the Fraunhofer Communication Prize 2019**
Every year, a communication prize for outstanding PR work is awarded on behalf of the Fraunhofer-Gesellschaft – as an incentive to develop and implement one's own ideas. With his video clip »Behind the scenes at Fraunhofer IZM« IZM student Dominik Andrä won 3rd place right away. He had started the project as an intern without a budget. The clip can be seen on the IZM career page and has already been viewed over 2,000 times. It gives young people a first insight into the work of the institute.

**»Think Tank Award 2019« for the Center for Digital Transformation**
The exhibit of the Center for Digital Transformation (LZDV) was awarded third place in the Fraunhofer-Gesellschaft's Think Tank Awards at the Hannover Messe 2019. With their jointly developed exhibit and the slogan »Light up your production«, the Berlin Fraunhofer Institutes FOKUS, IZM, HHI and IPK demonstrated how digital networking using optical wireless technology can efficiently meet the high demands of industrial environments. In a production technology scenario, the »Optical Wireless Communication – OWC« was presented as a future-proof alternative to radio-based wireless LAN. OWC uses light instead of radio as a wireless medium and is therefore not susceptible to radio interference. It guarantees high transmission speeds with low latency.

1 *Professor Klaus-Dieter Lang receiving the GMM Award from GMM chairman Ronald Zengerle*

2 *Professor Melanie Jaeger-Erben, group leader at Fraunhofer IZM, and recipient of the »Transformative Science« Research Award*

3 *Christoph Marczok, winner of the »Young Engineer Award« at PCIM Europe 2019*

# BEST PAPER, EDITORIALS, DISSERTATIONS

## Best Paper

**Tina Thomas awarded Best Paper of Track at IMAPS 2019**
IZM researcher Tina Thomas' paper on »Ferrites in Transfer Molded Power SiPs – Challenges in Packaging« was recognized as the best paper of its track at the IMAPS International Symposium on Microelectronics in Boston, USA, in October 2019. Thomas has specialized in the aging of encapsulation materials and transfer molding for electronics encapsulation. In their prize paper, Tina Thomas and her co-authors Marius van Dijk, Marc Dreissigacker, Stefan Hoffmann, Hans Walter, Karl-Friedrich Becker, and Martin Schneider-Ramelow round up the newest discoveries and insights concerning the epoxy encapsulation of ferrites.

**Dr. Robert Hahn wins Presentation Award at the Material Science and Nanotechnology Conference**
The Presentation Award of the 2nd International Conference on Material Science and Nanotechnology in London goes to Dr. Robert Hahn for his »phenomenal and invaluable« presentation on »Materials Process Engineering for Extremely Miniaturized Batteries«. Working at IZM, Robert Hahn is an expert for the development and construction of batteries miniaturized to a record scale of less than 1mm in length.

**Best Paper for David Schütze at the EBL Conference**
At »EBL 2020« Electronics and PCBs Conference, David Schütze was the proud recipient of the Best Paper Award. The paper »Constructing highly miniaturized and robust wireless sensor nodes with PCB embedded components«, co-authored by Schütze and Karl-Friedrich Becker, Christian Tschoban, Christian Voigt, Thomas Löher, Stefan Kosmider, Andreas Ostmann, Lars Böttcher, Martin Schneider-Ramelow, and Klaus-Dieter Lang, looks at the design of a robust and autonomous small-scale sensor module achieved by PCB embedding technology.

## Editorials

**International Journal of Microelectronics and Electronic Packaging**
Ndip, I. (Associate Editor)

**MEMS Accelerometers (MDPI)**
Ngo, Ha-Duong (Editor)

**PLUS Journal (Eugen G. Leuze Verlag)**
Lang, K.-D. (Member of the Editorial Board)

## Dissertations

**Benecke, Stephan**
»Systemverhalten von Energy Harvestern in autonomen Sensoren unter Betrachtung der Wechselwirkung von Funktionalität und Umweltverträglichkeit«

**Bicakci, Aylin**
»Thermische Untersuchung von Schaltungsträgern für leistungselektronische Halbleitermodule mit organischem Isolator«

**Hanß, Alexander Oliver**
»Zuverlässigkeitsuntersuchungen von LED-Interconnects mit Hilfe der Transienten Thermischen Analyse«

**Härter, Stefan**
»Qualifizierung des Montageprozesses hochminiaturisierter elektronischer Bauelemente«

**Heilmann, Jens**
»Lebensdauermodellierung für gesinterte Silberschichten in der leistungselektronischen Aufbau- und Verbindungstechnik durch isotherme Biegeversuche als beschleunigte Ermüdungstests«

**Hu, Xiaodong**
»Influence of Bonding Temperature and Material on Anodic Bonding for Stress Sensitive MEMS«



# LECTURES

## University of Applied Sciences for Engineering and Economics in Berlin

**Dr. G. Engelmann**
- Packaging/Heterogeneous Microsystems

**Prof. Dr. H.-D. Ngo**
- Microsystems Engineering/Microsensors and Actuator Technologies

**Dr. H. Walter**
- Materials in Microsystem Technology

**Dr. Dr. I. Ndip**
- EMC in Electronic Systems

**Prof. Dr. H.-D. Ngo**
- Manufacturing Technologies for Semiconductor Sensors

**Dr. N. F. Nissen, Dr. A. Middendorf**
- Environmentally Conscious Design of Electronic Systems

**Prof. Dr. M. Schneider-Ramelow**
- Failure Mechanisms and Failure Analysis in Hetero-Microsystems
- Basic Materials of System Integration

## Technische Universität Berlin

**Dr. R. Hahn**
- Miniaturized Energy Supply/Harvesting

**Prof. Dr. M. Jaeger-Erben**
- Sociology of Engineers I and II
- From Take-Make-Dispose to a Circular Society (in the lecture series »TU Berlin for Future«)

**Dr. J. Jaeschke, Dr. O. Wittler**
- Reliability of Microsystems

**Dr. J. Köszegi**
- Design, Simulation and Reliability of Microsystems
- High-frequency Measurement Techniques in Microelectronic Packaging

**Prof. Dr. K.-D. Lang**
- Assembly of Multifunctional Electronic Systems
- Assembly Technologies for Microelectronics and MST

**Dr. T. Tekin**
- Antennas

## Technische Universität Dresden

**Jun.-Prof. Dr. I. Panchenko**
- Materials for the 3D System Integration

## Aalborg University

**Prof. Dr. E. Hoene**
- Design of Modern Power Semiconductors Components
- EMI/EMC in Power Electronics

# COOPERATION WITH UNIVERSITIES (SELECTION)

| Some of Fraunhofer IZM's university partners |
|---|
| Aalborg University, Denmark |
| AGH University of Science and Technology, Poland |
| Binghampton University, USA |
| Delft University of Technology, The Netherlands |
| Eindhoven University of Technology, The Netherlands |
| Imperial College London, Great Britain |
| KU Leuven, Belgium |
| San Diego State University, USA |
| Tohoku University, Japan |
| University of Cádiz, Spain |
| University College London, Great Britain |
| University of New South Wales, Australia |
| University of Tokyo, Japan |
| University of Twente, The Netherlands |
| University of Utah, USA |
| University of Vienna, Austria |
| Uppsala University, Sweden |
| Albert-Ludwig University of Freiburg, Germany |
| Berlin University of the Arts, Germany |
| Chemnitz University of Technology, Germany |
| Friedrich-Alexander-University Erlangen-Nürnberg |
| Heidelberg University, Germany |
| Humboldt University of Berlin, Germany |
| Paderborn University, Germany |
| Rostock University, Germany |
| University of Bonn, Germany |
| University of Potsdam, Germany |

To effectively implement its research goals, Fraunhofer IZM has established strategic networks with universities in Germany and abroad. Close cooperation with universities is an important pillar of Fraunhofer's success model. While the universities contribute their innovative ability and competence in basic research to the cooperation, Fraunhofer contributes excellence in applied research, outstanding technical infrastructure, continuity in human resources and long-standing experience in international projects.

**Cooperation with Technische Universität Berlin**
Since its foundation in 1993, Fraunhofer IZM has benefited from the successful cooperation with the Research Center for Microperipheric Technologies of the Technische Universität Berlin. In the 1990s, one of the world's first scientific institutions in the field of packaging and interconnection technology was established here. Since 2011, the traditional double appointment of Fraunhofer IZM director and Head of the Research Center has been held by Professor Klaus-Dieter Lang.

**Fraunhofer IZM-ASSID cooperates with TU Dresden**
Within the joint junior professorship »Nanomaterials for Electronic Packaging« of Fraunhofer IZM-ASSID and TU Dresden, junior professor Iuliana Panchenko and her team are working on new materials and technologies for fine-pitch interconnects in 3D/2.5D Si structures.

**Cooperation with BTU Cottbus-Senftenberg**
Fraunhofer IZM intensifies its cooperation with BTU by opening a branch office for high-frequency sensor systems in Cottbus. The research activities within the Innovation Campus (iCampµs) Cottbus focus on the design, test procedures and characterization of integrated antennas, on the co-design of chip-package antennas as well as system integration solutions for the realization of miniaturized radio frequency sensor systems.



# COOPERATION WITH INDUSTRY (SELECTION)

| | |
|---|---|
| **AEMtec GmbH** | Berlin |
| **Ajinomoto Group** | Tokio (JP) |
| **Amkor Technology, Inc.** | Chandler, Arizona (USA) |
| **AMO GmbH** | St.Peter / Hart (AT) |
| **ams AG** | Premstätten (AT) |
| **Apple Inc.** | Cupertino, Austin (USA) |
| **ASM Pacific Technology Ltd.** | Singapore (SG) |
| **AT&S AG** | Leoben (AT) |
| **Atotech Deutschland GmbH** | Berlin |
| **AUDI AG** | Ingolstadt |
| **Baker Hughes INTEQ GmbH** | Celle |
| **BMW AG** | Munich |
| **BrewerScience** | Rolla (USA) |
| **Bundesdruckerei GmbH** | Berlin |
| **Cern** | Meyrin (CH) |
| **Continental AG** | Regensburg |
| **Daimler AG** | Stuttgart |
| **Deutsches Elektronen-Synchroton DESY** | Hamburg |
| **DISCO Corporation** | JP |
| **DResearch Digital Media Systems GmbH** | Berlin |
| **Ericsson** | Stockholm (SE) |
| **Evatec AG** | Trübbach (CH) |
| **Finisar Cooperation** | DE, USA |
| **First Sensor AG Berlin** | Berlin, Dresden |
| **Fujifilm Electronic Materials** | EU, USA |
| **GEFRAN** | Provaglio d'Iseo BS (IT) |
| **GLOBALFOUNDRIES INC.** | Dresden |
| **Hitachi Chemical Company, Ltd.** | Tokio (J) |
| **Hitachi Metals Europe GmbH** | Düsseldorf |
| **Infineon Technologies AG** | DE |
| **Intel Corporation** | USA |
| **Invensas** | Santa Clara (USA) |
| **Isola USA Corp.** | Chandler (USA) |
| **Jenoptik Power System** | Jena |
| **Johnson & Johnson** | New Brunswick (USA) |
| **Magneti Marelli** | IT |
| **MED-EL GmbH** | Innsbruck (AT) |
| **Meltex Inc.** | Tokio (J) |
| **Merck KGaA** | Darmstadt |
| **Mitsubishi Electric Corporation** | JP |
| **Mitsui Chemicals Tohcello, Inc.** | Tokio (J) |
| **Olympus Surgical Technologies Europe** | Hamburg |
| **Osram Opto Semiconductors GmbH** | Regensburg, Munich |
| **PANalytical B.V.** | Almelo (NL) |
| **POSIC S.A.** | Colombier (CH) |
| **Robert Bosch GmbH** | Reutlingen, Stuttgart |
| **Schaeffler AG** | Herzogenaurach |
| **Semsysco GmbH** | Salzburg (AT) |
| **Shin-Etsu Chemical** | Tokio (JP) |
| **Siemens AG, Siemens Healthcare** | DE |
| **Süss MicroTec SE** | Garching, Munich |
| **TDK-EPCOS AG** | Munich |
| **TRUMPF Laser GmbH** | Berlin |
| **Unimicron Technology Corporation** | Taoyuan (TW) |
| **Valeo** | Creteil (FR) |
| **Volkswagen AG** | Wolfsburg |
| **Würth Elektronik GmbH & Co. KG** | Niedernhall, Rot a. S. |
| **X-Fab** | Erfurt |
| **ZF Friedrichshafen GmbH** | Friedrichshafen |

# MEMBERSHIPS (SELECTION)

| | | |
|---|---|---|
| **AMA Fachverband Sensorik, Wissenschaftsrat** | H. Pötter | Member |
| **Cluster Optik BB, Photonik für Kommunikation und Sensorik** | Dr. H. Schröder | Spokesman |
| **Deep Tech Award Berlin** | Prof. K.-D. Lang | Award Committee |
| **Deutsche Forschungsgemeinschaft** | Prof. K.-D. Lang | Reviewer |
| **Deutscher Verband für Schweißtechnik DVS** | Prof. K.-D. Lang | Advisory Board |
| **Deutscher Verband für Schweißtechnik DVS Arbeitsgruppe »Bonden«** | Prof. M. Schneider-Ramelow | Chairman |
| **ECPE Competence Centre** | Prof. M. Schneider-Ramelow | Member |
| **EURIPIDES Scientific Advisory Board** | M. J. Wolf | Member |
| **European Network High Performance Integrated Microwave Photonics** | Dr. T. Tekin | German Representative |
| **European Photonic Industrial Consortium (EPIC)** | Dr. H. Schröder | Representative Fraunhofer IZM |
| **European Technology Platform on Smart System Integration (EPoSS)** | H. Pötter | Member Executive Committee |
| **Forschungsfabrik Mikroelektronik Deutschland (FMD)** | Prof. K.-D. Lang | Steering Committee |
| **Heterogeneous Integration Roadmap (HIR)** | R. Aschenbrenner | Chair Technical Working Group SiP |
| **IEEE Electronics Packaging Society** | R. Aschenbrenner/Prof. K.-D. Lang | Fellow |
| Green Electronics | Dr. N. F. Nissen | Technical Chair |
| Photonics – Communication, Sensing, Lighting | Dr. T. Tekin | Technical Co-Chair |
| IEEE CPMT German Chapter | R. Aschenbrenner | Chair |
| IEEE EPS TC Material & Processes | Dr. T. Braun | Member |
| **IMAPS International Microelectronics Assembly and Packaging Society** | | |
| IMAPS Europe/IMAPS Deutschland | Prof. M. Schneider-Ramelow | Past President/President |
| IMAPS Signal/Power Integrity Committee | Dr. Dr. I. Ndip | Chair |
| IMAPS Executive Council | Dr. Dr. I. Ndip | Director |
| **IVAM Fachgruppe Wearables** | E. Jung | Technical Chair |
| **Microsystems Technology Congress 2019** | Prof. K.-D. Lang | General Chair 2019 |
| **OpTec Berlin Brandenburg e. V.** | Prof. K.-D. Lang | Executive Board |
| **Organic Electronics Saxony (OES)** | K. Zoschke, E. Jung | Representatives of Fraunhofer IZM |
| **Photonics 21** | Dr. R. Jordan | Board of Stakeholders |
| **Photonics West Optical Interconnects Conference** | Dr. H. Schröder | Chair |
| **Semiconductor Manufacturing Technology Sematech** | M. J. Wolf | Member |
| **SEMI ESiPAT Group** | Dr. T. Braun | Representative of Fraunhofer IZM |
| **Silicon Saxony e. V.** | M. J. Wolf | Member |
| **SMTconnect** | Prof. K.-D. Lang | Head of Programme Committee |
| **Strategischer Arbeitskreis Silicon Germany** | Prof. K.-D. Lang | Member |
| **Wissenschaftlich-technischer Rat der Fraunhofer-Gesellschaft** | Dr. N. F. Nissen | Representative of Fraunhofer IZM |



# PUBLICATIONS (SELECTION)

*Arnold, P.; Tschoban, C.; Heuer, K.; Rochlitzer, R.; Thünen, T.; Lang, K.-D.*
**Multi Sensor Node for Long-term Wireless Measurement of Density, pH Value and Temperature in Silage for Bio Gas**
Proceedings of ITG/GMA Symposium 2018, Nuremberg

*Baeuscher, M.; Reinicke, O.; Henke, M.; Mackowiak, P.; Schiffer, M.; Schneider-Ramelow, M.; Lang, K.-D.; Ngo, H.-D.*
**Investigation of IDC Structures for Graphene Based Biosensors Using Low Frequency EIS Method**
Proceedings of DeSE 2019, Kazan, Russia

*Bickel, J.; Eberl, M.; Kaletta, K.; Ngo, H.-D.; Schneider-Ramelow, M.; Lang, K.-D.*
**Layer Analysis of Partial Atmospheric Pressure Sputtering for High Temperature Packaging Applications**
Proceedings of MST-Congress 2019, Berlin, Germany

Bickel, J.; Ngo, H.-D.; Schneider Ramelow, M.; Lang, K.-D.
**Increasing the Productivity of the Novel Atmospheric Pressure Sputtering Technology for 3D Chip Interconnection**
Proceedings of EMPC 2019, Pisa, Italy

*Böttcher, L.; Kosmider, S.; Schein, F.; Kahle, R.; Ostmann, A.*
**High Density RDL Technologies for Panel Level Packaging of Embedded Dies**
Proceedings of SMTA International 2019, Rosemont, IL, USA

*Braun, T.; Becker, K.-F.; Hoelck, O.; Kahle, R.; Graap, P.; Wöhrmann, M.; Aschenbrenner, R.; Voges, S.; Dreissigacker, M.; Schneider-Ramelow, M.; Lang, K.-D.*
**Fan-out Wafer Level Packaging – A Platform for Advanced Sensor Packaging**
Proceedings of ECTC 2019, Las Vegas, NV, USA

*Braun, T.; Becker, K.-F.; Hoelck, O.; Voges, S.; Boettcher, L.; Töpper, M.; Stobbe, L.; Aschenbrenner, R.; Voitel, M.; Schneider-Ramelow, M.; Lang, K.-D.*
**Panel Level Packaging – From Idea to Industrialization**
Proceedings of ICSJ 2019, Kyoto, Japan

*Brockmann, C.; Günther-Sorge, J.; Pötter, H.*
**Realisierung und Anwendung energieautarker miniaturisierter Funksensorik: Chancen durch IoT, 5G und Narrowband**
Technisches Messen, 86(11), 2019, pp. 630-639

*Bücheler, L.; Hillmer, I.; Reimer, V.; Jiang, Y.; Angelmahr, M.; Schade, W.; von Krshiwoblozki, M.; Pawlikowski, J.; Garbacz, K.; Stagun, L.; Fischer, M.; Guttowski, S.*
**Nicht-invasives Rehabilitationssystem für irreparable Nervenschädigungen im Handgelenksbereich**
Proceedings of MST-Congress 2019, Berlin, Germany

*Clemm, C.; Emmerich, J.; Höller, V.; Schischke, K.; Nissen, N. F.; Lang, K.-D.*
**Benefits and Pitfalls of Better Lifetime Data – The Case of Batteries in Mobile Electronic Equipment**
Proceedings of PLATE 2019, Berlin, Germany

*Dils, C.; Werft, L.; Walter, H.; Zwanzig, M.; von Krshiwoblozki, M.; Schneider-Ramelow, M.*
**Investigation of the Mechanical and Electrical Properties of Elastic Textile / Polymer Composites for Stretchable Electronics at Quasi-Static or Cyclic Mechanical Loads**
MDPI Materials, 12(3599), November 2019

*Druschke, J.; Fath, S.; Stobbe, L.; Nissen, N. F.; Richter, N.; Lang, K.-D.*
**Ecological Cost-benefit Analysis of a Sensor-based Parking Prediction Service**
Proceedings of Ecodesign 2019, Yokohama, Japan

# PUBLICATIONS (SELECTION)

// FOR FURTHER INFORMATION PLEASE GO TO
WWW.IZM.FRAUNHOFER.DE

*Fritzsch, T.; Tschoban, C.; Böttcher, M.; Phung, G. N.; Lang, K.-D.*
**Miniaturized 24 GHz Radar Positioning Transponder Module**
Proceedings of Smart Systems Integration 2019, Barcelona, Spain

*Gao, G.; Mirkarimi, L.; Workman, T.; Fountain, G.; Theil, J.; Guevara, G.; Liu, P.; Lee, B.; Mrozek, P.; Huynh, M.; Rudolph, C.; Werner, T.; Hanisch, A.*
**Low Temperature Cu Interconnect with Chip to Wafer Hybrid Bonding**
Proceedings of ECTC 2019, Las Vegas, NV, USA

*Gernhardt, R.; Wöhrmann, M.; Müller, F.; Hauck, K.; Töpper, M.; Lang, K.-D.; Hichri, H.; Arendt, M.*
**An Overview about the Excimer Laser Ablation of Different Polymers and Their Application for Wafer and Panel Level Packaging**
Proceedings of IWLPC 2019, San Jose, CA, USA

*Hahn, R.*
**Batteries for Novel Medical Applications Based on Wafer-level Processing**
Proceedings of International Battery Seminar & Exhibit 2019, Fort Lauderdale, FL, USA

*Hahn, R.; Ferch, M.; Kyeremateng, N. A.; Höppner, K.; Marquardt, K.; Lang, K.-D.*
**High-throughput Battery Materials Testing Based on Test Cell Arrays and Dispense / Jet Printed Electrodes**
Springer Microsystem Technologies , Vol. 25(2019), pp. 1137-1149

*Hu, X.; Schiffer, M.; Schneider-Ramelow, M.; Lang, K.-D.*
**Numerical Investigation of Anodic Bonding for Stress Sensitive MEMS Devices**
Proceedings of MST-Kongress 2019, Berlin, Germany

*Kahle, R.; Schein, F.-L.; Ostmann, A.*
**Evaluation of Adaptive Processes for the Embedding of Bare Dies in IC Substrates**
Proceedings of EMPC 2019, Pisa, Italy

*Kaufhold, R.; Bäuscher, M.; Ngo, H.-D.; Mackowiak, P.; Wang, B.; Ehrmann, O.; Schneider-Ramelow, M.; Lang, K.-D.*
**An All-inkjet-printed Photosensor on Flexible Plastic Substrate for the Detection of Ultraviolet Radiation**
Proceedings of Smart Systems Integration 2019, Barcelona, Spain

*Klein, K.; Hoene, E.; Lang, K.-D.*
**Power Module Design for Utilizing of WBG Switching Performance**
Proceedings of ETG-Kongress 2019 (VDE), Esslingen, Germany

*Löher, T.; Seckel, M.; Haberland, J.; Marques, J.; von Krshiwoblozki, M.; Kallmayer, C.; Ostmann, A.*
**Conformable Electronics: Integration of Electronic Functions into Static and Dynamic Free Form Surfaces**
Proceedings of IEEE CPMT Symposium Japan 2019, Kyoto, Japan

*Mackowiak, P.; Erbacher, K.; Zoschke, K.; Al-Magazachi, S.; Baeuscher, M.; Schiffer, M.; Lang, K.-D.; Ngo; H.-D.*
**Ultra Thin Force and Acceleration Sensor Embedded in Flexible Thin Film Substrates Using Thin Chip Handling, Bonding and Carrier Release Technologies**
Proceedings of DeSE 2019, Kazan, Russia

*Mackowiak, P.; Wilke, M.; Wöhrmann, M.; Gernhard, R.; Zoschke, K.; Lang, K.-D.; Scheider-Ramelow, M.; Ngo, H.-D.*
**Fabrication of High Voltage Capable TSV Using Backside Via Last Process and Laser Ablation of Dry Film BCB**
Proceedings of EPTC 2019, Singapore, pp. 83-86



*Marczok, C.; Hoene, E.; Thomas, T.; Meyer, A.; Schmidt, K.*
**Low Inductive SiC Mold Module with Direct Cooling**
Proceedings PCIM Europe 2019, Nuremberg, Germany, pp. 1-6

*Müller, O.; Stube, B.; Schröder, B.*
**Effiziente Werkzeuge zur Adaption kritischer Teil-schaltungen im Entwurfsprozess von hochkomplexen Schaltungen**
Proceedings of MST-Congress 2019, Berlin, Germany

*Murugesan, K. S.; Voigt, T.; Tschoban, C.; Rossi, M.; Ndip, I.; Lang, K.-D.; Nädele, D.; Student, R.; Dengler, D.*
**Compact Wideband Wilkinson Power Divider in Thin-Film Glass Technology for 5G Applications**
Proceedings of MST Congress, Berlin, Germany

*Nanbakhsh, K.; Kluba, M.; Pahl, B.; Bourgeois, F.; Dekker, R.; Serdijn, W.; Giagka, V.*
**Effect of Signals on the Encapsulation Performance of Parylene Coated Platinum Tracks for Active Medical Implants**
Proceedings of EMBC 2019, Berlin, Germany

*Ndip, I.; Le, T. H.; Schneider-Ramelow, M.; Lang, K.-D.*
**On the Impact of Reflector Elements of Yagi-Uda Bond Wire Antennas**
Proceedings of EuMC 2019, Prague, Czech Republic

*Neumayr, D.; Bortis, D.; Kolar, J. W.; Hoffmann, S.; Hoene, E.*
**Origin and Quantification of Increased Core Loss in MnZn Ferrite Plates of a Multi-gap Inductor**
CPSS Transactions on Power Electronics and Applications, 4(1), March 2019

*Proske, M.; Jaeger-Erben, M.*
**Decreasing Obsolescence with Modular Smartphones? An Interdisciplinary Perspective on Lifecycles**
Journal of Cleaner Production, Vol. 223(2019), pp. 57-66

*Proske, M.; Matthias F.*
**Obsolescence in LCA – Methodological Challenges and Solution Approaches**
The International Journal of Life Cycle Assessment, November 2019

*Raddo, T. R.; Cimoli, B.; Sirbu, B.; Rommel, S.; Tekin, T.; Tafur Monroy, I.*
**An End-to-end 5G Automotive Ecosystem for Autonomous Driving Vehicles**
Proceedings of SPIE. Photonics West 2020, San Francisco, CA, USA

*Rost, F.; Huber, S.; Walter, H.; Van Dijk, M.; Cramer, T.; Jaeschke, J.; Wittler, O.; Schneider-Ramelow, M.*
**Warpage Investigation of PCB Embedding Technology – Determination of Relevant Modelling Parameters by Means of FEM and Experiments**
Proceedings of EuroSimE 2019, Hanover, Germany

*Schein, F.-L.; Kahle, R.; Kunz, M.; Ostmann, A.*
**High Density Fan-out Panel Level Packaging of Multiple Dies Embedded in IC Substrates**
Proceedings of EMPC 2019, Pisa, Italy

*Schiffer, M.; Mackowiak, P; Ngo, H.-D.; Ehrmann, O.; Schneider-Ramelow, M.; Lang, K.-D.*
**Mems Mass Flow Controller for Liquid Fuel Supply to HCCI-Driven Engine**
Proceedings of Transducers 2019 – Eurosensors XXXIII, Berlin, Germany

*Schischke, K.; Proske, M.; Nissen, N. F.; Schneider-Ramelow, M.*
**Impact of Modularity as a Circular Design Strategy on Materials Use for Smart Mobile Devices**
MRS Energy & Sustainability: A Review Journal, Vol. 6(E16), 2019, pp. 1-16

# PUBLICATIONS (SELECTION)

// FOR FURTHER INFORMATION PLEASE GO TO
WWW.IZM.FRAUNHOFER.DE


*Sirbu, B.; Eichhammer, Y.; Oppermann, H.; Tekin, T.; Kraft, J.; Sidorov, V.; Yin, X.; Bauwelinck, J.; Neumeyr, C.; Soares, S.*
**3D Silicon Photonics Interposer for Tb/s Optical Interconnects in Data Centers with Double-side Assembled Active Components and Integrated Optical and Electrical Through Silicon Via on SOI**
Proceedings of ECTC 2019, Las Vegas, NV, USA

*Sirbu, B.; Hasharoni, K.; Sidorov, V.; Seifried, M.; Baumgartners, Y.; Terzenidis, N.; Brimont, A.; Lawniczuk, K.; Papatryfonos, K.; Eichhammer, Y.; Oppermann, H.; Maman, A.; Kraft, J.; Horst, F.; Offrein, B. J.; Mourgias-Alexandris, G.; Moralis-Pegios, M.; Manolis, T.; Vyrsokinos, K.; Pleros, N.; Zanzi, A.; Sanchis, P.; Broeke, R. G.; Selviah, D. R.; Tang, M.; Seeds, A. J.; Liu, H.; Tekin, T.*
**Co-package Technology Platform for Low Power and Low Cost Data Centers**
Proceedings of IMAPS 2019, Boston, MA, USA

*Sirbu, B.; Tekin, T.; Weeber, J.-C.; Dereux, A.; Markey, L.*
**Unidirectional Data Center Interconnects Enabled by the Use of Broken-symmetry Gap Plasmon Resonators (BS-GPR)**
Proceedings of SPIE. Photonics West 2019, San Francisco, CA, USA

*Sültrop, C.; Lang, T.; Rohlfs, F.; Helfrich, J.; Nogueira, P. B. A.; Weber, H.; Prüfer, U.; Bergmann, D.; Gebert, J.*
**Intelligente Netzknoten als Baustein für fehlertolerante Energiebordnetze in automatisierten Fahrzeugen**
Proceedings of EEHE 2019, Bad Nauheim, Germany

*Thomas, T.; van Dijk, M.; Dreissigacker, M.; Hoffmann, S.; Walter, H.; Becker, K.-F.; Schneider-Ramelow, M.*
**Ferrites in Transfer Molded Power SiPs – Challenges in Packaging**
Proceedings of IMAPS 2019, Boston, MA, USA

*Tschoban, C.; Rossi, M.; Reyes, J.; Ndip, I.; Lang, K.-D.*
**Development of a Glass Technology Based 79 GHz MIMO Radar Front-end Module for Autonomous Driving**
Proceedings of EPTC 2019, Singapore

*Urso, A.; Giagka, V.; van Dongen, M.; Serdijn, W. A.*
**An Ultra-high-frequency 8-Channel Neurostimulator Circuit with 68 % Peak Power Efficiency**
IEEE Transactions on Biomedical Circuits and Systems, 13(5), October 2019, pp. 882 – 892

*Vagionas, C.; Ruggeri, E.; Kalfas, G.; Sirbu, B.; Leiba, Y.; Kanta, K.; Giannoulis, G.; Caillaud, C; Cerulo, G.; Mallecot, F.; Raddo, T. R.; Mesodiakakia, A.; Gatzianas, M.; Apostolopoulos, D.; Avramopoulos, H.; Tafur-Monroy, I.; Tekin, T.; Miliou, A.; Pleros, N.*
**An End-to-end 5G Fiber Wireless A-RoF / IFoF Link Based on a 60 GHz Beamsteering Antenna and an InP EML**
Proceedings of SPIE. Photonics West 2020, San Francisco, CA, USA

*Voges, S.; Becker, K.-F.; Schütze, D.; Schröder, B.; Fruehauf, P.; Heimann, M.; Nerreter, S.; Blank, R.; Gottwald, S.; Hofmeister, A.; Schmied, M.; Kreitmair, M.; Fust, R.; Neifer, W.; Braun, T.*
**Highly Miniaturized Integrated Sensor Nodes for Industry 4.0**
Proceedings of IMAPS 2019, Boston, MA, USA

*Wagner, S.; Wuest, F.; Trampert, S.; Sehr, F.; Middendorf, A.; Wittler, O.*
**Condition Monitoring for Failure Monitoring of Power Electronic Assemblies**
Proceedings of ELIV 2019, Bonn, Germany

*Weber, C.; Hutter, M.; Schneider-Ramelow, M.*
**Silbergesinterte Flip-Chip-Kontaktierungen zur Realisierung von hochtemperaturfähigen Sensorsystemen**
Proceedings of MST-Congress 2019, Berlin, Germany

*Weichart J.; Erhart, A.; Viehweger, K.*
**Preconditioning Technologies for Sputtered Seed Layers in FOPLP**
Proceedings of ECTC 2019, Las Vegas, NV, USA

*Wittler, O.*
**Challenges of Voltage Driven Failure Mechanisms in Power Electronics Packages Proceedings of International Conference**
Automotive 48 V Power Supply Systems 2019, Berlin, Germany

*Wittler, O.; van Dijk, M.; Grams, A.; Huber, S.; Rost, F.; Walter, H.; Lang, K.-D.*
**Verwölbung in der Systemintegration – Status und zukünftige Herausforderungen**
Proceedings of MST-Congress 2019, Berlin, Germany, pp. 374-277

*Wöhrmann, M.; Ndip, I.*
**Fundamentals of RF Design and Fabrication Processes of Fan-out Wafer / Panel Level Packages and Interposers**
Proceedings of ECTC 2019, Las Vegas, NV, USA, Professional Development Course

*Wöhrmann, M.; Toepper, M.; Schneider-Ramelow, M.; Lang, K.-D.*
**Entwicklung eines neuartigen, quantitativen Adhäsionsmessverfahrens für Dünnfilmlagen in der Mikroelektronik**
Proceedings of MST-Congress 2019, Berlin, Germany

*Wolf, M. J.*
**Heterogeneous Integration – Requirements and Enabling Technologies**
Proceedings of CISES 2019, Shanghai, China

*Wüst, F.; Trampert, S.; Sehr, F.; Lang, K.-D.*
**Integrated Condition Monitoring by Measuring the Delay of Gate Turn-off**
Proceedings of EMPC 2019, Pisa, Italy

*Zanzi, A.; Vagionas, C.; Griol, A.; Rosa, A.; Lechago, S.; Moralis-Pegios, M.; Vyrsokinos, K.; Pleros, N.; Kraft, J.; Sidorov, V.; Sirbu, B.; Tekin, T.; Sanchis, P.; Brimont, A.*
**Alignment Tolerant, Low Voltage, 023 Vcm, Push-pull Silicon Photonic Switches Based on a Vertical pn Junction**
Optics Express, 27(22), 2019, pp. 32409-32426

*Zoschke, K.; Mackowiak, P.; Ngo, H.-D.; Tschoban, C.; Fritsche, C.; Ndip, I.; Kröhnert, K.; Lang, K.-D.*
**High-density Flex and Thin Chip Embedding Technology for Polymeric Interposer and Sensor Packaging Applications**
Proceedings of IWLPC 2019, San Jose, CA, USA

*Zoschke, K.; Mackowiak, P.; Ngo, H.-D.; Tschoban, C.; Fritsche, C.; Kröhnert, K.; Fischer, T.; Ndip, I.*
**High-Density Flexible Substrate Technology with Thin Chip Embedding and Partial Carrier Release Option for IoT and Sensor Applications**
Proceedings of ECTC 2019, Las Vegas, NV, USA

# PATENTS & INVENTIONS

*Braun, Tanja; Becker, Karl-Friedrich; Kahle, Ruben; Töpper, Michael*
**Method for Manufacturing an Electronic Component and an Electronic Component**
US 2017/0098611 A1

*Dietrich, Lothar; Brink, Morten; Oppermann, Hermann*
**Formulation and Method for Manufacturing Alloy Deposits of Silver and Gold**
DE 10 2019 202 899 B3

*Guttowski, Stephan; Zurwehn, Volker; Hefer, Jan; Wussow, Kai*
**Surveillance System for a Variety of Objects**
DE 10 2011 109 516 A1

*Hahn, Robert*
**Fuel Cell Arrangement**
DE 10 2007 005 232 A1

*Jung, Erik; Kallmayer, Christine; Alves Marques, Joao*
**Process for Transferring Electronic Circuits to Surfaces**
DE 10 2018 205 265 B3

*Löher, Thomas; Ostmann, Andreas; Seckel, Manuel*
**Production Method for an Electronic System, Production Method for a Free Forming Surface Including such a System, Corresponding Electronic System and Free Forming Surface Including Such a System**
EP 2 449 865 B1

*Ndip, Ivan*
**Antenna Apparatus with Bond Wires**
US 10,490,524

*Ndip, Ivan; Braun, Tanja*
**Wafer-level Package with Integrated or Embedded Antenna**
US 10,461,399

*Ndip, Ivan; Braun, Tanja*
**Wafer-level Package with at Least One Integrated Antenna Element**
EP 3 346 494 A1

*Oppermann, Hermann; Dietrich, Lothar; Engelmann, Gunter; Wolf, Jürgen*
**Method for Producing a Nanoporous Layer**
DE 10 2007 055 019 A1



# ADVISORY BOARD

## CHAIRMAN

Dr. Franz Richter
*Süss MicroTec AG, Garching near Munich*

## MEMBERS

Paradiso Coskina
*VDI/VDE Innovation + Technik GmbH, Berlin*

Gabi Grützner
*Micro resist technology GmbH, Berlin*

Martin Hierholzer
*Infineon Technologies Bipolar GmbH & Co. KG, Warstein*

Dr. Stefan Hofschen
*Bundesdruckerei GmbH, Berlin*

Ministerialrat Bernd Lietzau
*The Governing Mayor of Berlin, Senate Chancellery for Science and Research*

Johannes Stahr
*AT&S AG, Leoben (A)*

Prof. Dr. Christian Thomsen
*Technische Universität Berlin*

Prof. Dr. Bernd Tillack
*IHP GmbH, Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder)*

Dr. Markus Ulm
*Bosch Sensortec GmbH, Reutlingen*

Dr. Thomas Wille
*NXP Semiconductors Germany GmbH, Hamburg*

Ministerialrat Christoph Zimmer-Conrad
*Saxony's State Ministry for Economics, Labor and Transportation, Dresden*

Dr. Tina Züchner
*Federal Ministry of Education and Research, Department Electronics and Autonomous Driving, Bonn*

## GUESTS

Ministerialrätin Dr. Annerose Beck
*Saxony's State Ministry for Higher Education, Research and the Arts*

Christian Wiebus
*NXP Semiconductors Germany GmbH, Hamburg*

# FRAUNHOFER IZM CONTACTS

## FRAUNHOFER INSTITUTE FOR RELIABILITY AND MICROINTEGRATION IZM

Gustav-Meyer-Allee 25 | 13355 Berlin, Germany
Phone +49 30 46403-100
info@izm.fraunhofer.de

**Director**
Prof. Dr.-Ing. Dr. sc. techn. Klaus-Dieter Lang
Phone +49 30 46403-179
klaus-dieter.lang@izm.fraunhofer.de

**Deputy Director**
Rolf Aschenbrenner
Phone +49 30 46403-164
rolf.aschenbrenner@izm.fraunhofer.de

**Deputy Director**
Prof. Dr.-Ing. Martin Schneider-Ramelow
Phone +49 30 46403-172
martin.schneider-ramelow@izm.fraunhofer.de

**Director's Assistant**
Dr.-Ing. Maik Hampicke
Phone +49 30 46403-683
maik.hampicke@izm.fraunhofer.de

**Head of Administration**
Jürgen Rahn
Phone +49 30 46403-105
juergen.rahn@izm.fraunhofer.de

**Head of Administration**
Carsten Wohlgemuth
Phone +49 30 46403-114
carsten.wohlgemuth@izm.fraunhofer.de

## DEPARTMENTS

**Wafer Level System Integration**
Head: Dr.-Ing. Michael Schiffer
Phone +49 30 46403-234
michael.schiffer@izm.fraunhofer.de

Head: M. Jürgen Wolf
Phone +49 30 46403-606
Phone +49 351 7955 72-12
juergen.wolf@izm.fraunhofer.de

**System Integration and Interconnection Technologies**
Head: Rolf Aschenbrenner
Phone +49 30 46403-164
rolf.aschenbrenner@izm.fraunhofer.de

Head: Dr.-Ing. Andreas Ostmann
Phone +49 30 46403-187
andreas.ostmann@izm.fraunhofer.de

**Environmental and Reliability Engineering**
Head: Dr.-Ing. Nils F. Nissen
Phone +49 30 46403-132
nils.nissen@izm.fraunhofer.de

Head: Dr.-Ing. Olaf Wittler
Phone +49 30 46403-240
olaf.wittler@izm.fraunhofer.de

**RF & Smart Sensor Systems**
Head: Dr.-Ing. Dr.-Ing. habil. Ivan Ndip
Phone +49 30 46403-679
ivan.ndip@izm.fraunhofer.de

Head: Harald Pötter
Phone +49 30 46403-742
harald.poetter@izm.fraunhofer.de

## DRESDEN ASSID BRANCH OF THE INSTITUTE

**All Silicon System Integration Dresden (ASSID)**
Ringstr. 12, 01468 Moritzburg, Germany

Head: Prof. Dr.-Ing. Dr. sc. techn.
Klaus-Dieter Lang
Phone +49 30 46403-179
klaus-dieter.lang@izm.fraunhofer.de

Head: Dr.-Ing. Michael Schiffer
Phone +49 30 46403-234
michael.schiffer@izm.fraunhofer.de

Head: M. Jürgen Wolf
Phone +49 351 7955 72-12
Phone +49 30 46403-606
juergen.wolf@izm.fraunhofer.de

## COTTBUS BRANCH OF THE INSTITUTE

**Branch Lab for High-Frequency Sensor Systems**
Karl-Marx-Straße 69, 03044 Cottbus, Germany

Head: Dr.-Ing. Dr.-Ing. habil. Ivan Ndip
Phone +49 30 46403-679
ivan.ndip@izm.fraunhofer.de

## MARKETING & BUSINESS DEVELOPMENT

Head: Dirk Friebel
Phone +49 30 46403-278
dirk.friebel@izm.fraunhofer.de

**Business Development Team**
Dr. rer. nat. Michael Töpper
Phone +49 30 46403-603
michael.toepper@izm.fraunhofer.de

Erik Jung
Phone +49 30 46403-230
erik.jung@izm.fraunhofer.de

Dr.-Ing. Andreas Middendorf
Phone +49 30 46403-135
andreas.middendorf@izm.fraunhofer.de

**PR & Marketing**
Georg Weigelt
Phone +49 30 46403-279
georg.weigelt@izm.fraunhofer.de

# IMPRINT

**Editor:**
Prof. Dr.-Ing. Dr. sc. techn. Klaus-Dieter Lang
Fraunhofer IZM
www.izm.fraunhofer.de

**Editorial Office:**
mcc Agentur für Kommunikation GmbH
Georg Weigelt, Fraunhofer IZM

**Layout / Design:**
mcc Agentur für Kommunikation GmbH
www.mcc-events.de



**Photography:**
Fraunhofer IIS/EAS (21), BTU Cottbus-Senftenberg (29), Henning Schacht (34)

All other image rights Fraunhofer IZM or Fraunhofer IZM together with
Janine Escher (5, 25); Tim Hosman (17); Volker Mai (Titel, 6, 8, 9, 10, 11, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23, 33); MIKA Berlin (10, 11, 34, 35, 46, 47); Erik Müller (8, 48)

**Cover:**
Combined camera-radar module for next-generation autonomous driving