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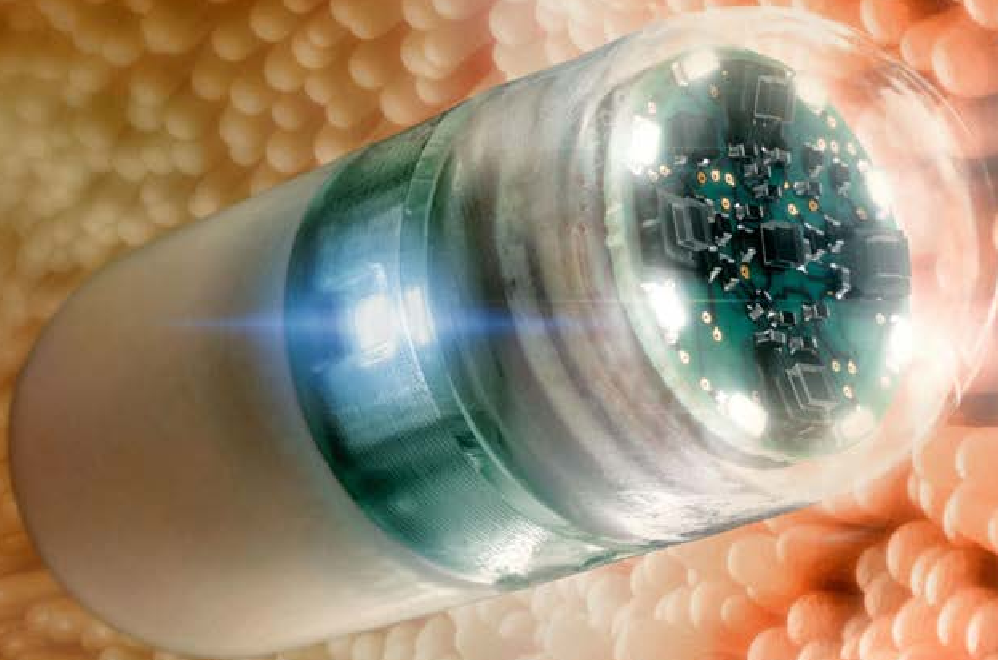
FRAUNHOFER INSTITUTE FOR RELIABILITY AND MICROINTEGRATION IZM



# ANNUAL REPORT 18/19

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# PREFACE

## APPLICATION-ORIENTED RESEARCH, RELIABLE DEVELOPMENT

### Dear readers!

The Fraunhofer Institute for Reliability and Microintegration IZM remains the first port of call for the development of miniaturized electronics systems that function robustly and reliably in even the most extreme conditions. Many companies draw on our know-how and seek support for designing and assembling custom-fit electronic systems, whose functionality is then tested in relevant specialized application areas. Fraunhofer IZM focuses above all on pioneering applications like the Internet of Things, autonomous systems, 5G technology, bioelectronic innovation and hardware security-related systems. As part of this, the special application requirements are already taken into account at the very beginning of the development. To optimally 'meld' electronic systems with the end product, Fraunhofer IZM provides a broad spectrum of solutions, from system integration through to fabrication optimization using wafer, package and panel technologies.

Of the year's many outstanding projects, several deserve special mention:

- The EndoTrace project has developed a miniaturized, modular capsule camera for small bowel endoscopy. Equipped with imaging software and storage, the camera is no bigger than a tablet and is easy to swallow.
- Self-driving vehicles are set to play a huge role in future mobility. The KameRad project has developed a radar- and camera-based system that promises to improve the safety of autonomous driving. The aim is developing a miniaturized module with combined 79-GHz MIMO radar and stereo camera system.
- One technology highlight has been the second phase of the international industry consortium implementing panel level packaging in industry. The promising results will make a significant contribution to helping the technology take hold, as well as raising the profile of Fraunhofer IZM.
- The efforts of the German federal ministry for education and research (BMBF) junior research group »Obsolescence as challenge for sustainability« should also be spotlighted. For several years now the interdisciplinary group has been researching the causes of the short life-cycle of electronic products, as well as developing strategies for more durable products and sustainable consumption of products. Fraunhofer IZM is participating in the group as cooperation partner.

Other important cooperations were also continued and extended in 2018:

- The »Research Fab Microelectronics Germany« is being implemented, with the first devices already being deployed in projects.
- The centers of excellence in Berlin and Dresden were successfully evaluated and approved for continued operation. In Dresden, the cooperation includes four Fraunhofer institutes and focuses on micro-nano integration, while the Berlin center of excellence is working in the area of digital networking.
- The startup incubator »Start-a-Factory« saw further expansion and raised its public profile. The modular development and fabrication laboratory is in high demand – the first startups have already moved in and a number of demonstrators have been assembled according to industry conditions and quality.
- The flagship projects eHarsh and ZEPOWEL also took great strides forwards. The eHarsh project is developing sensor systems for extremely harsh conditions, while the ZEPOWEL project, led by Fraunhofer IZM, is focusing on the development of highly integrated, extremely power efficient modules for the Internet of Things.
- Apart from our cooperation with the TU Berlin, we were able to expand our activities with other universities and technical colleges. Together with the TU Berlin, we are developing new interconnection technologies for wafer-level packaging, while with the Berlin University of Applied Sciences, we are focusing on aspects of sensor packaging, and with the Brandenburg University of Technology, on high-frequency technology.

Moreover, a strategy audit was performed in autumn. Here, a high-profile team of auditors from industry and academia assessed the overall strategy of Fraunhofer IZM for the next three to eight years as extremely successful.

A particularly pleasant highlight in 2018 has to be mentioned – Fraunhofer IZM's 25th anniversary celebrations. Approximately 500 guests attended an international symposium and celebrated 25 years of outstanding research history at Berlin's Kulturbrauerei.

All that's missing now in our round-up of the year 2018 is a look at the turnover, which was also extremely positive. The operating budget again increased, reaching 33.7 million euros in 2018. The institute counts as accomplishment a 45.4 percent proportion of revenue from industry. All in all, Fraunhofer IZM is continuing on an upward course.

I am very much looking forward to 2019 – Fraunhofer IZM will again host an extensive program of workshops. Exciting and forward-looking research projects are being continued, and last, but not least, a host of new project ideas will be launched.

On that note, I'd like to thank all our partners in industry and research, as well as the funding bodies and implementing organizations on federal-, Länder- and EU-level.

Above all, my thanks of course go to our staff, without whom Fraunhofer IZM would be unthinkable and whose efforts above-and-beyond ensured 2018 was such a successful year for Fraunhofer IZM.

I hope all of you enjoy catching up on Fraunhofer IZM's achievements in 2018 with this annual report.

Prof. Dr.-Ing. Dr. sc. techn. Klaus-Dieter Lang
Fraunhofer IZM 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.

Over 400 institute staff are dedicated to developing these 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**

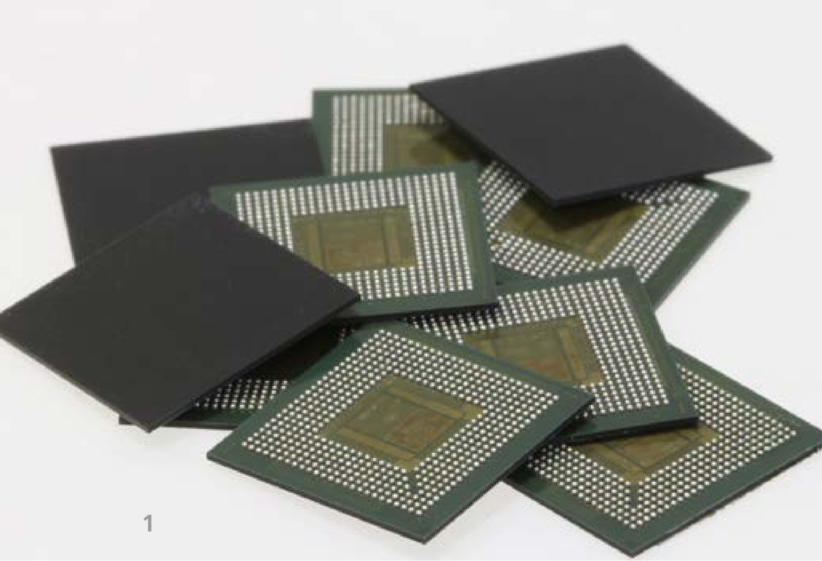
Fraunhofer IZM's research results are highly relevant to industries such as the automotive industry, medical engineering, industrial electronics and even lighting and textiles. Semiconductor manufacturers and suppliers of related materials, machines and equipment, but also small companies and start-ups 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 Technische Universität Berlin and the Berlin University of Applied Sciences (HTW), to ensure that the preparation for future cooperation with industry is optimal.



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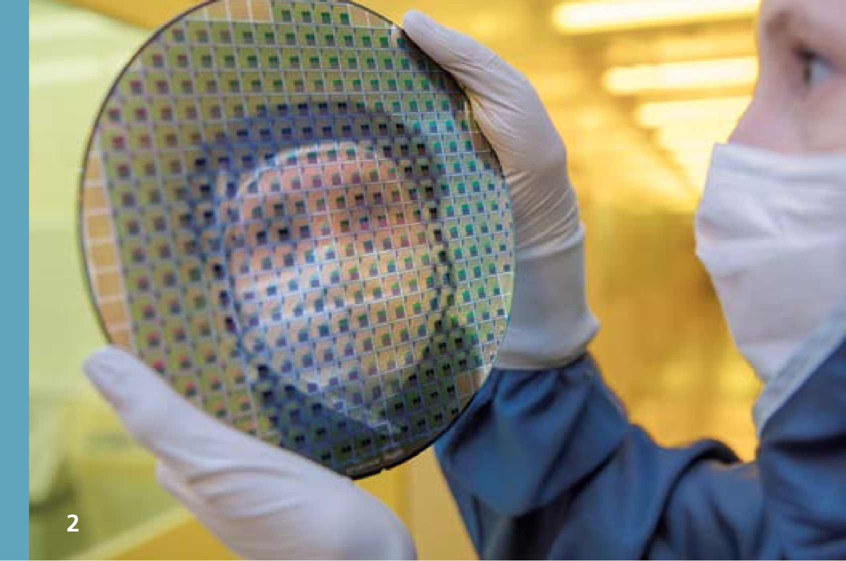

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# SYSTEM INTEGRATION & INTERCONNECTION TECHNOLOGIES

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. Approx. 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.



# 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 Fan-out panel level packaging yields ultra-thin, highly integrated multi-die packages*

*2 Back-end of line processing on CMOS wafer*

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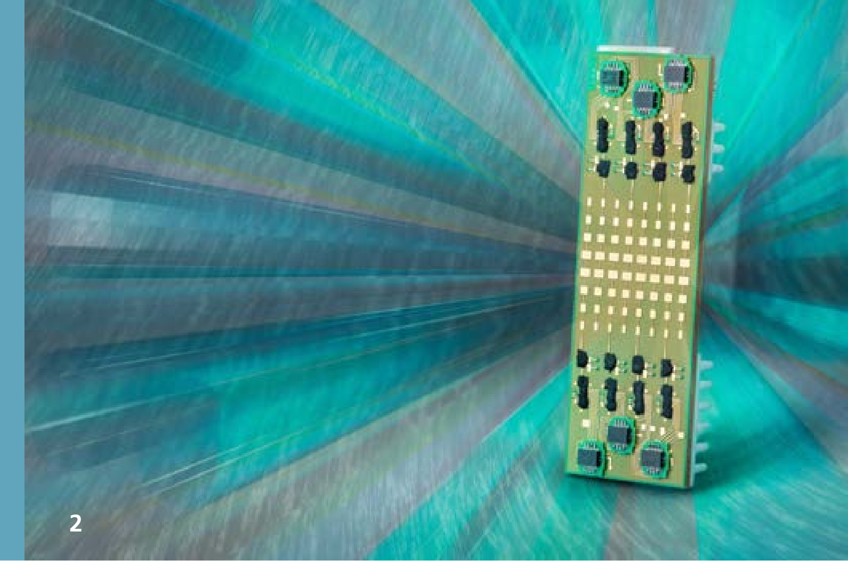

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# ENVIRONMENTAL & RELIABILITY ENGINEERING

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 a team of 40 people from science and technology, processes and models are developed and applied to 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. In this way, our partners can minimize costs and risks while taking advantage of the special opportunities offered by new system integration technologies.

The following processes are currently in particular demand:

- For the latest technological trends, we can perform environmental, resource, and cost analyses as we have access to process details that can be incorporated into the environmental assessment.
- Such practice-proven detailed evaluations are integrated into application scenarios in order to adequately optimize modular product concepts, sensor-based IT services, or future network infrastructure according to environmental parameters.
- For the reliability assurance of system integration technologies, Fraunhofer IZM has all relevant test methods at its disposal in house. This enables us to offer our partners holistic solutions and bring together the best combination of skills.
- With our »physics-of-failure« approach, we analyze the interaction of materials, technology, failure mechanism and application scenario in our projects with regard to reliability and are thus able to consider all relevant aspects of the value creation chain of electronics production and application.

The following fields of application are primarily addressed:

- Mobile end devices
- Information and communication technology (ICT) and network technology
- Autonomous sensors
- Power electronics
- Photonics and lighting

# RF & SMART SENSOR SYSTEMS

Self-sufficient sensor technology, radar sensors, 5G mobile radio or 60 GHz communication systems – despite great differences at first glance, research and development of all these applications share many similarities. All have to meet the fundamental requirements of any wireless networking technology, including large bandwidth, ruggedness, safety and energy efficiency. Safety aspects are increasingly gaining importance. Additional functional gains are expected from controllable antennas. System design is assuming an ever- greater role in these technologies: tight integration of circuit design with technology development (hardware package codesign) is becoming as essential as hardware software code design. For this reason, the department has always sought to draw on the broad technological know-how of Fraunhofer IZM as a whole, in addition to delivering cutting edge expertise in firmware and software development. In particular, we focus on:

- RF design and characterization of materials, packages and components (up to 220 GHz)
- RF system integration and module design, including in terms of signal and power integrity
- Development of micro batteries, power supply and management
- 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 combination of practical know-how gained in a wide variety of projects, state-of-the-art equipment, a sophisticated grasp of modeling tools and a systematic approach characterize the work of the department.

A particular specialty is RF systems. Material and structure characterization of high frequency-related assembly and connection technology in terms of high-frequency properties has vast potential, and we have translated this into a comprehensive, scientifically rigorous design approach, known as M3 (methodology, modeling, measures). The latter allows meeting the individual requirements of customized design in a relatively short time, i.e. without expensive and time-consuming iterations. Beyond purely functional optimizations, the approach facilitates multi-criteria optimization of electrical, optical, technological and economic parameters, so that the best performance for each application can be achieved. M3 is applied in the design of innovative high-frequency systems up to 110 GHz and sensor systems for harsh operating conditions in various research and industrial projects.

All our research and development relies on the department's cutting-edge technology and infrastructure. For example, in the HF laboratory, non-destructive determination of dielectric material parameters is available. Test structures can be measured up to 500 GHz. A screen cabin allows the 3D characterization of antenna modules. In the microelectronics laboratory, autarkic sensor nodes can be assessed and placed into operation. For the manufacture of micro batteries, a battery development and assembly line with a precision screen printer, substrate bonding device and microfluidic electrolyte filling device is available. The entire manufacturing process of a battery is carried out under argon boxes in pure gas conditions.

*1 Research focus: repair and longevity of electronics in the framework of circular economy*

*2 Ka-band transmitter modules for planar SATCOM terminals with beamforming antennas*

# BUSINESS UNITS & INDUSTRY SECTORS

# FRAUNHOFER – A STRONG NETWORK

**Fraunhofer-Gesellschaft**

The Fraunhofer-Gesellschaft is the leading organization for applied research in Europe. Its research activities are conducted by 72 institutes and research units at locations throughout Germany. The Fraunhofer-Gesellschaft employs a staff of more than 26,600, who work with an annual research budget totaling more than 2.6 billion euros. Of this sum, more than 2.2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

**Research Fab Microelectronics Germany (FMD)**

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.

Within this new type of cooperation, the advantages of two strong and decentralized research organizations – the Fraunhofer-Gesellschaft and the Leibniz Association – are combined with the synergies of a central organization to form the world's most capable provider of applied research, development, and innovation within microelectronics and nanoelectronics. The close intermeshing and the uniform public face allow the FMD to serve not only customers from heavy industry, but also to offer SMEs and startups more comprehensive and simpler access to the next generation of technology.

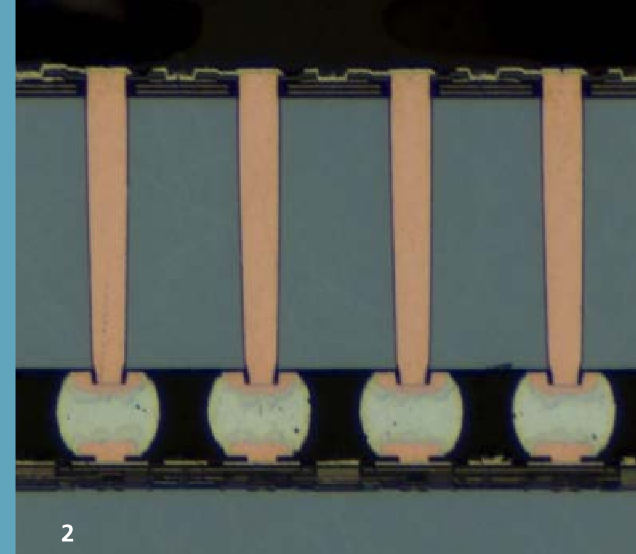
The German Federal Ministry of Education and Research (BMBF) is funding the setup of the FMD to the tune of 350 million euros, largely for the modernization of the institutes' research equipment. A year and a half after the project started on April 6, 2017, 45 percent of the planned investments for the FMD have been successfully fulfilled.

The FMD offers research facilities from a single provider along the entire innovation chain. In 2017, successful project involvements were set up and orders were completed in combination with the FMD. For 2018, projects based on the FMD investments with a volume of 41.1 million euros can already be identified, which represents a significant success at such an early stage. The industrial share of this project volume is already at 30 percent.

**Centers od Excellence**

The goal of the Functional Integration of Micro-/Nanoelectronics Center of Excellence 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.

# 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.*

**Sensor fusion for fully autonomous driving**

Radar and camera systems for autonomous driving – two promising technologies with specific advantages and disadvantages. One of the systems may be superior when it comes to image recognition, say, while the other provides information that is reliable independently of the light conditions. By combining an innovative 79 GHz MIMO radar system with a stereo camera system in one package, and the fusion of the sensor data, a high-performance sensor system for autonomous driving is being created in a consortium sponsored by the German Federal Ministry of Education and Research (BMBF). Fraunhofer IZM is developing the hardware components (stereo camera, radar front end, MIMO antennas) in conjunction with its partners. The radar front end is being implemented in an innovative glass interposer technology that can also be used for other high-resolution applications in the future thanks to a scalable approach.

**Platform concept for controllable 5G antennas**

Millimeter-wave systems addressing future key market applications, such as 5G wireless communication and automotive radars, increasingly rely on large active antenna arrays and electronic-beam steering to overcome high attenuation losses in the transmitted signal and exhibit high resolution and a broad field of view. As such, they pose the challenge of achieving high performance without sacrificing cost effectiveness. The EU-funded SERENA consortium is currently developing a heterogeneous integration platform based on gallium nitride-on-silicon (GaN-on-Si) technology and state-of-the-art volume packaging, as well as a hybrid analog/digital signal processing architecture, to improve output power, efficiency, form factor, data rate, and affordability of mm-wave beam-steering systems. An integration platform of this type will be demonstrated with a proof-of-concept scalable prototype for 5G mm-wave radio access operating in the 37 GHz to 41 GHz band.

**Development of a LIDAR sensor 3D-SiP using high density TSV, bumping and flip chip technologies**

For the build-up of these sensor modules, Fraunhofer IZM performed all packaging-related tasks such TSV and RDL formation, micro-solder bumping, flip chip assembly, as well as chip and wire bonding. Each module consists of a single photon avalanche diode (SPAD) array with 256 x 256 = 65,536 pixels (pitch 40 µm) which is implemented on a 10 x 10 mm² silicon die (total thickness: 88 µm). Each SPAD cell includes a TSV (diameter: 8 µm, depth: 88 µm) which routes the electrical contact to the back of the SPAD array where micro-solder bumps (diameter: 25 µm) connect each pixel to the read-out ASIC (12 x 12 mm², thickness: 725 µm). The 3D-SiP module was finally die bonded to a PCB and the peripheral IOs along the four sides of the ASIC were connected to it by wire bonding.

**Services:**

We provide the following services for the automotive and transportation sector:

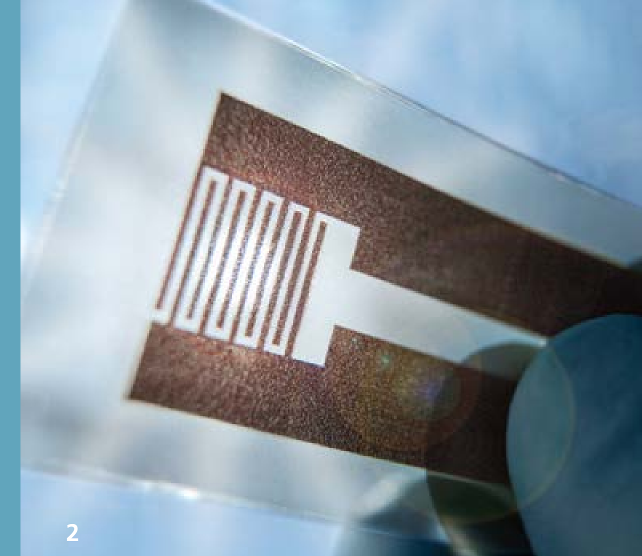
- Power electronics
- Sensor and actuator technology
- Reliability management and assurance
- Robust design

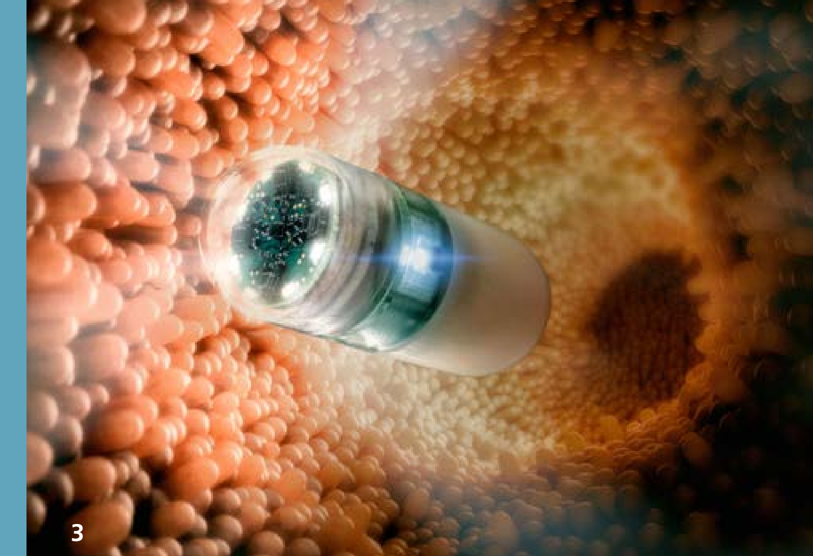
1 *LIDAR-sensor as 3D system-in-package developed at Fraunhofer IZM*

2 *88 µm thin silicon chip with 256 x 256 SPAD array and TSVs mounted on ASIC*

3 *Sensor fusion for autonomous driving: integration of camera- and radar module*

# MEDICAL ENGINEERING





*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, bio-compatibility assessments, as well as the risk assessment according to ISO 14971 standards, which is required for the development of new products.*

**Camera pill provides new insights**

In the BMBF-funded EndoTrace project, a highly integrated, pill-shaped camera system was developed for medical diagnosis of the small intestine. The pill is moved through the body by natural peristalsis for several hours and takes high-resolution images of the stomach wall. The images are recorded by five partially tilted cameras to enlarge the field of view and are stored in the capsule. The lighting, camera, μ-chip for image compression, memory, and battery components are linked by a combination of embedding technology, module stacking, and semiflex PCB in a compact, miniaturized system.

**All-inkjet-printed photo-sensor on flexible plastic substrate for the detection of ultraviolet radiation**

Within a joint project between Fraunhofer IZM and the University of Applied Sciences Berlin, a 2D-printed photo sensor for the detection of ultraviolet radiation in the wavelength range of 310-390 nm has been developed. This interdigitated electrode sensor was completely realized by applying inkjet printing technology to nanoparticle-based inks. It detects electromagnetic radiation by a change of resistance in the semiconductor material used. Despite the limited sensitivity due to the chosen printing approach, the sensors realized hold a great potential, especially considering the ability to realize such photo sensors on flexible substrates with a low cost inkjet printing process.

**Optofluidic biochip integration**

Photonic integrated circuits with microfluidics are emerging as a potential platform for highly sensitive point-of-care testing that enables rapid clinical decision making in diagnosis of cardiovascular diseases and infectious diseases. Within the EU-Project PHOCNOSIS Fraunhofer IZM used bi-layer adhesive impregnated film for bonding, because of its biocompatibility, low cost, and rapid prototyping from chip to panel level. An assembly process at room temperature was developed where both chips were bonded using laser-micro-structured adhesive film. This innovative assembly approach allows the development of a functional hybrid optofluidic biochip with optical, fluidic, and electrical interfaces. A chip cartridge has also been fabricated by means of 3D printing in order to facilitate its handling and reading.

**Emergency battery system of the future**

In an EU-project, aluminum ion batteries are being developed at Fraunhofer IZM as a promising and cost-effective successor generation to lithium ion batteries. Carbon-based cathodes have a very high cycle stability and current-carrying capacity, but have a low energy density. In a further development, carbon-sulfur nanocomposites were synthesized by means of a high-energy ball mill, which is characterized by a higher energy density. A capacity of 220 mAh/g was attained, although this drops during cyclization.

**Services:**

- Packaging and reliability analyses for miniaturized medical devices/implants
- Lab-on-substrate for patient-oriented laboratory diagnostics
- Improved functionalities for smart prostheses
- Wearables for medical use
- Textile- and structure-integrated electronics functionalities to support the digitization process in every field of medical diagnostics and treatment

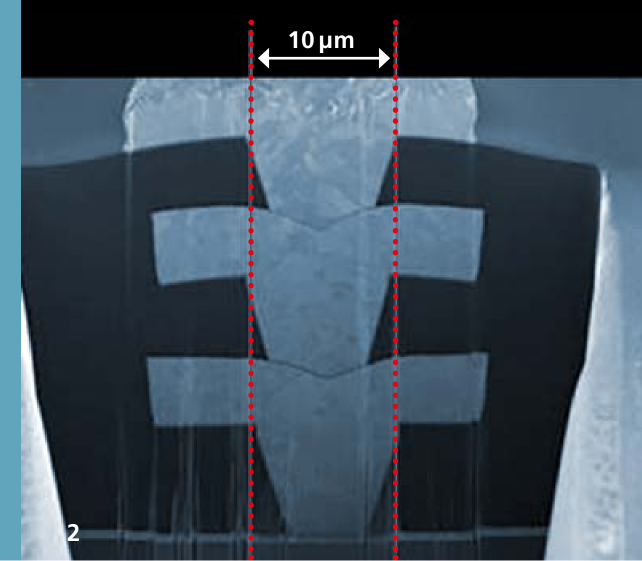
1 *Hybrid chip cartridge for point-of-care tests*

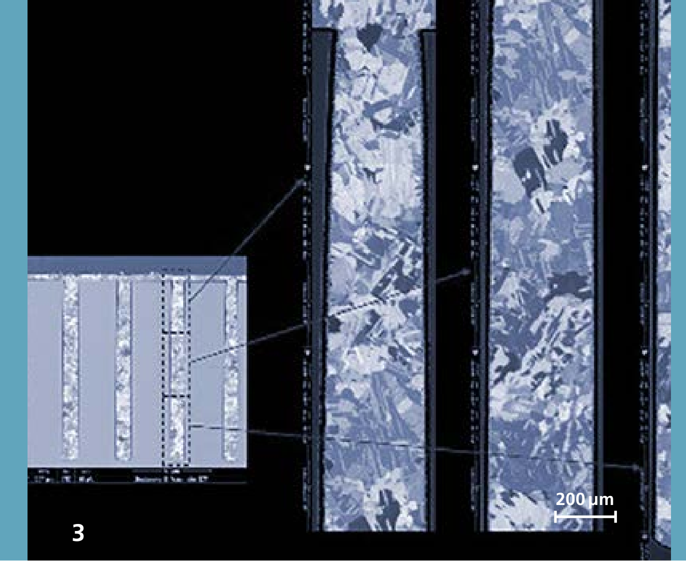
2 *Inkjet printing of a photo sensor*

3 *Highly integrated, pill-shaped camera system*

# SEMICONDUCTORS

*This business unit has a focus on the integration and development of new sensors. Besides that 3D integration allows the realization of complex, heterogeneous system-in-package (SiP) solutions. Fraunhofer IZM offers its customers a closed implementation chain – from concept, process development, and characterization to reliability validation and prototyping of new sensors, hermetic sensor packages, and 3D systems. All processes necessary to the realization of sensors and wafer-level packages are available, including the formation of through-silicon vias (TSVs).*




**Development of a via-in-via technology for polymer-based multi-layer fine pitch RDL**

The requirements in the fine pitch capability of multi-layer wiring technologies are increasing steadily. While routing lines can already be fabricated in a very fine pitch below 10 µm, the via feeds through the inter-dielectric polymer layers require diameters above 20 µm and a staggered arrangement to be able to use standard direct photo structuring processes. Fraunhofer IZM has developed a technology for the formation of vias with 10 µm diameter into 10 µm-thick polymer layers, which allows a stacked configuration in a multi-layer setup. Based on that, the area consumption of the vias is dramatically reduced. This technology is based on direct ablation of the vias into the polymer, utilizing an excimer laser and a pre-structured hard mask followed by high speed copper filling.

**Preparation techniques for 3D stacks**

The evaluation of 3D interconnects in silicon is commonly done by time-consuming and extensive FIB cuts that usually visualize a single TSV only. Funded by the EU, Fraunhofer IZM has developed a new preparation technique that allows the simultaneous precise cutting and polishing of large areas of any number of TSVs. With this approach, the etch profile in silicon, isolation layer, barrier and seed layer, and the microstructure along the whole via can be captured representatively with high contrast and a very detailed resolution.

**Reliability assessment and EBSD of hybrid bonding with Cu and $SiO_2$**

The reliability and grain structure of fine-pitch hybrid bond interconnects based on Cu and $SiO_2$ were investigated within a collaboration between Fraunhofer IZM-ASSID and TU Dresden. The temperature cycling test (-40 °C / +125 °C, 1,000 cycles), high temperature storage test (150, 300, 400 °C) and multiple bonding cycles did not cause any structural defects in Cu / Cu interconnects. Different grain structure phenomena (orientation, growth, and boundaries) were investigated in detail by electron-backscattered diffraction (EBSD). The material investigation with EBSD is essential for the process evaluation, miniaturization of interconnects and reliability assessment.

**Direct bonding technology**

Within a joint project with the Xperi Corporation, the wafer-wafer direct bonding process was further developed. Particular attention was paid to the realization of defect-free bonding interfaces and a related higher yield. With a suitable analysis method (CSAM), reproducible, defect-free interfaces could be verified. Furthermore, bonding processes for low-temperature oxides were developed that are compatible with sensitive components. Here, oxides were deposited at temperatures as low as 125 °C and successfully bonded with a defect-free interface.

**Services:**

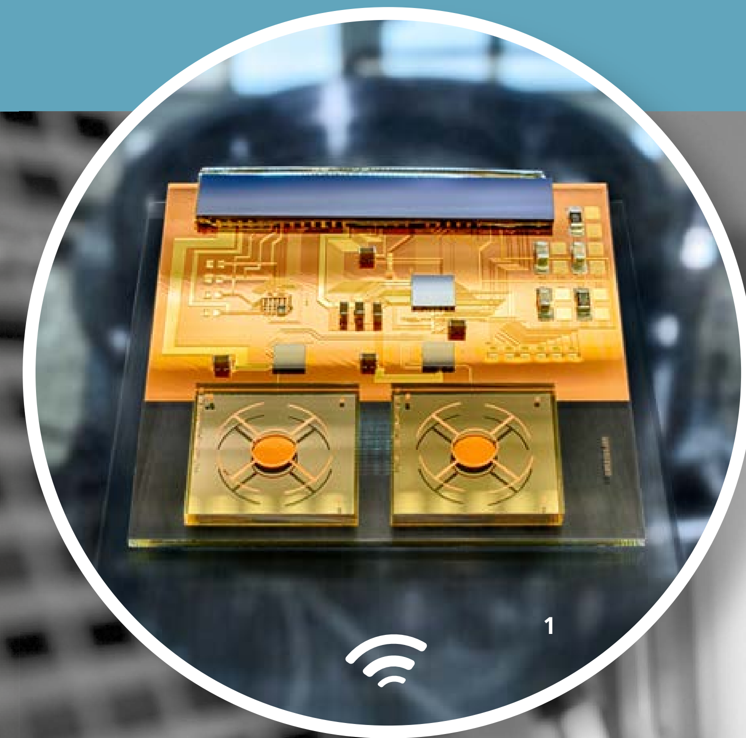
- TSV formation in CMOS wafers (via-middle, via-last)
- Reverse-side contacting (BS via-last) for sensors
- Silicon and glass interposers
- 3D assembly (die-to-wafer, wafer-to-wafer)
- 3D integration of optical connectors
- Hybrid 3D pixel detector modules
- Hermetically sealed MEMS packages with TSVs
- Material and equipment evaluation and qualification
- Prototype manufacture and pilot series
- Pressure sensors

*1 Electron backscatter diffraction mapping of hybrid bond interconnect*

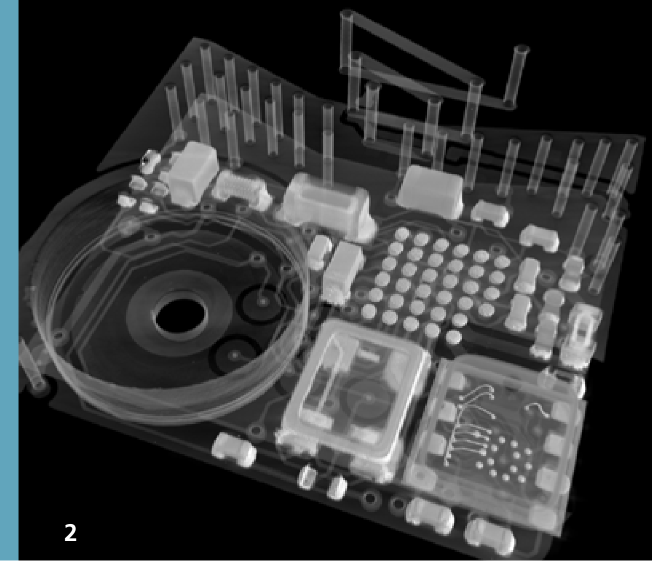
*2 Stacked micro-vias with 10µm diameter in 10µm thick polymer layers*

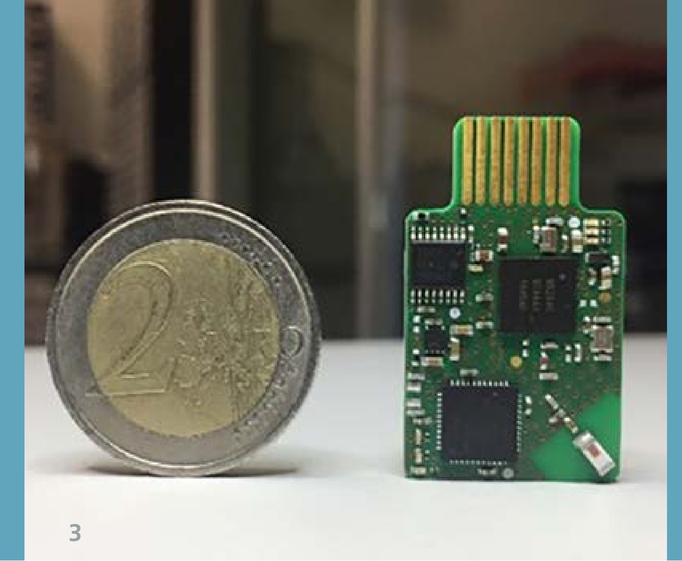
*3 Preparation of full-length TSV cross section and analysis by means of ion channeling*

# INDUSTRIAL ELECTRONICS



*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.*





**Wireless localization of systems in production and assembly lines**

The continuous tracking of tool positions and transport means is an important factor in terms of efficiency and tracking of safety relevant production steps. The BMBF-research project »Wireless Localization of Systems in Production and Assembly Lines« (NaLoSysPro) investigated a miniaturized 24 GHz radar positioning system in order to determine the distance, angle, and velocity of objects by signal time-of-flight measurement. The project includes the RF chip set and antenna integration on a thin-film multilayer module, which was finally integrated into the mobile transponder system.

**Industrie 4.0 in micro integration**

In the BMBF-funded PCB 4.0 project, Fraunhofer IZM is working in the area of Industry 4.0 together with Siemens, EnOcean, TU Berlin, Sensorik Bayern, WIBU, and KSG on the issue of process monitoring and interlinking in microelectronics manufacturing. In various scenarios, networked miniaturized radio sensor nodes [RSNs] are used, for example, to document the manufacturing history of a high-quality assembly in a forgery-proof manner or to optimize process control by means of RSN-integrated sensor technology, as well as to monitor loads on the assembly in use and thus ensure preventive maintenance. At Fraunhofer IZM, the automated SMT production line has been equipped with distributed gateways for this purpose, enabling the simulation of a wide variety of industry 4.0 scenarios.

**Modular and configurable sensor kit**

Would you like a quick way to check if an idea is any good? In the case of wireless sensor technology, the path to the first industrial test sample has often been long and costly. The »sensor kits« available on the market are not suitable either in terms of robustness or form factor. That is why, in a project funded by the BMBF, Fraunhofer IZM has developed a modular and configurable sensor kit for industry. By freely combining hardware and software modules for sensor technology, communication, and data processing, different power supply and communication concepts for a wide range of sensors can be implemented and quickly tested on production machines.

**Automated adaptation of reference designs**

In circuit design, reference circuits and design recommendations from the manufacturers are often applied. Since these are usually available as data sheets in pdf format, the circuit must be manually transferred to the current design. This is a time-consuming and, most importantly, superfluous work step. Supported by the BMBF, Fraunhofer IZM has developed a design tool that supports the automated adaptation of reference designs in pdf format within the design process.

**Services:**

- Design, technology development and optimization, reliability tests, and technology transfer for highly integrated modules on circuit board substrates, flex-rigid, flex, and metal or ceramic substrates
- Packaging and interconnection technology for industrial electronic products
- Integration of (active and passive) electronic components in fabrics or compound materials and embedding technology for ultra-thin systems and high-security applications (invisible electronics)
- Antenna and circuit designs for industrial electronics
- Design and prototype manufacture of autonomous multi-channel radio sensors for automation solutions

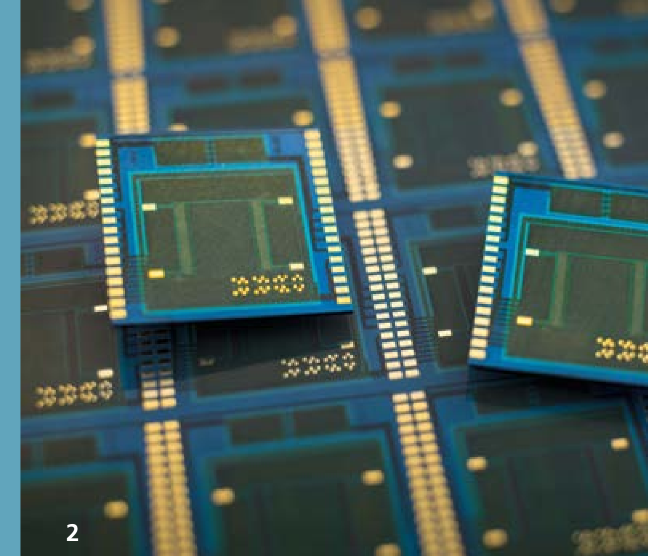
*1 Miniature mobile transponder helps localize tools at assembly stations*

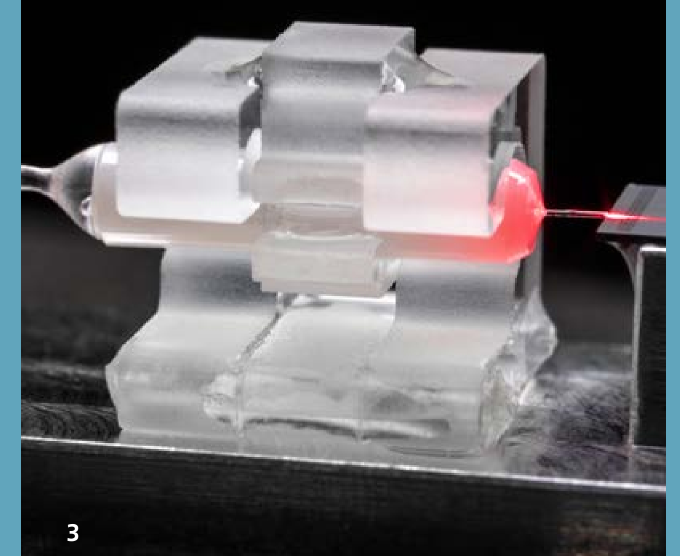
*2 Miniaturized RF sensor node for process monitoring in an industrial environment*

*3 Sensor module with temperature, moisture, and acceleration sensor as well as Bluetooth v5 as a wireless interface*

# INFORMATION & COMMUNICATION

*The new era of increasing connectivity and digitalization creates new challenges for the design and construction 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.*





**CloseWEEE – Circulating raw materials**
One of the first Horizon 2020 projects on recycling management has been successfully completed, coordinated by Fraunhofer IZM: a high-quality ABS with a recyclate share of over 70% has been obtained from plastic fractions from electrical scrap recycling, which is suitable for demanding applications with high-gloss, black surfaces. Thanks to the CreaSolv process from Fraunhofer IVV, antimony trioxide can be separated from flame-retarded plastics for the first time and used again as a synergist for flame retardancy. With lithium batteries as the starting material, a recycling process for cobalt and, for the first time, graphite was demonstrated on a plant scale.

**L3MATRIX: Reducing the energy consumption of switch ASICs**
The EU-project L3MATRIX aims to demonstrate feasibility for co-packaging optics, flip-chip assembling the biggest silicon photonics matrix on the market today on an electric switch ASIC that handles the entire chip I/O. The development of the next generation of switch ASICs with 25 Tbps or 50 Tbps is challenging due to power consumption: Currently, one third to half of the power on the chip is consumed by I/Os. This is the main impediment to the scalability of switch ASICs. L3MATRIX co-packaging enables the disaggregation of chip I/Os from the main ASIC and the vision of the L3MATRIX project is completely in line with the roadmap of the main companies driving the switching sector.

**Simulation of process-induced warping for wafer/panel level fan-out packaging**
The processing of fan-out wafer level packages on different formats and sizes (wafers, panels) shows that warping during these processes is a problem that needs to be quantified and narrowed down in order to achieve feasibility. The Fraunhofer IZM team has revised the associated procedure so that panels with a side length of more than 30 cm can be simulated at a speed that allows complete design studies to be conducted. This makes it possible to analyze and optimize influences of the geometry of the package and selection of the mold material.

**Cost analysis for wafer/panel level fan-out packaging**
The switchover of manufacturing processes in the area of wafer/panel level fan-out packaging is leading to significant changes in cost structures within production. In order to be able to identify potential cost and resource savings in a targeted manner, Fraunhofer IZM has developed a new cost model that enables the quantitative evaluation and analysis of detailed influences of production volume, investment costs, process parameters and package design characteristics (RDL layer structure, chip arrangement, panel size, etc.). The basic input data was established in cooperation with the Panel Level Packaging Consortium and the results were successfully transferred to the partners.

**Services**
- Design of integrated, miniaturized, autonomous, and robust sensor systems and wireless networks
- Assembly of high-frequency systems and electro-optical components
- Optimization of processes and transfer of assembly technologies for highly integrated systems
- Reliability testing and lifetime estimation
- Consulting and eco-design services for sustainable ICT products

*1 L3MATRIX: the next generation of data center infrastructure*

*2 Panel level packaging: Fraunhofer IZM provides not only the technology, but also the corresponding cost analysis*

*3 Stacked glass block connectors for fiber-chip modules*

# LABS & SERVICES

## SYSTEMINTEGRATION

**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-, via-last-, backside-via process)
- Silicon plasma etching – DRIE (TSV, cavities)
- Thin-film deposition (sputter, CVD)
- Photolithography (incl. photo resists, polymers)
- High-density thin-film-multilayer (Cu-RDL)
- Wafer-level bumping (Cu-Pillar, SnAg, Ni, Au, In, AuSn)
- Wet-chemical processes (etching, cleaning)
- Wafer thinning und thin wafer dicing (blade & stealth)
- Wafer bonding – permanent and temporary (support wafer, thin-wafer handling)
- Wafer level assembly (D2W)
- AOI, metrology

**Substrate Line**
In the substrate area panel-size substrates with a size of 460 x 610 mm² 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 PCBs 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

## WERKSTOFFANALYTIK

**Moisture Lab**

- Comprehensive simulation-based reliability assessment of humidity-induced phenomena in micro-electronic 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**

- Characterization of power modules and power electronic devices
- 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 THz system for HF material characterization
- Semi-automatic sample station with thermal chamber (-60 °C to 300 °C)
- EMC and antenna measuring chamber up to 40 GHz, experimentally up to 110 GHz (shielded)
- Antenna measuring system 40 GHz to 325 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
- 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 & WORKSHOPS

**25 Years of Fraunhofer IZM**

On November 27, Fraunhofer IZM celebrated its 25th birthday. The occasion was marked with an international symposium – entitled »Status & Future of Electronic Packaging« – that took a look into the future with 200 guests from science and business. The proceedings were opened with a presentation on novel smart systems by Deputy Director Rolf Aschenbrenner, followed by high-profile representatives from industry speaking about the importance of microelectronics now and in the future, as exemplified by the new developments in 5G telecommunications or driverless cars. Together, they formed one narrative of progress and opportunity, from the new interest in »chiplets« to Intel's Next Generation Computing roadmap and the newest ideas at Audi.

In the afternoon, there was a spectacular ceremony in the movie theater of Berlin's Kulturbrauerei venue. The head of the institute presented the technological and organizational development projects in store at Fraunhofer IZM. Well-known names from government and science took the podium one by one and talked about their history with the institute. The culmination of festivities was the presentation of the Fraunhofer IZM Research Award, which, in 2018, went to Dr. Henning Schröder for developing thin-glass technology. After the official part was over, the celebrations moved to the Palais and Kesselhaus, where the fun continued – with dancing – into the early hours.

**Mayor Michael Müller visits the Berlin Center for Digital Transformation**

As part of his summer science tour, the Governing Mayor of Berlin and Senator for Higher Education and Research, Michael Müller, visited the IoT Lab at the Berlin Center for Digital Transformation operated by Fraunhofer FOKUS on August 15, and was able to learn about the many projects being pursued in conjunction with Berlin's business community. Company representatives from ALBA Group, CONTACT Software GmbH, and SAP SE & CO KG were able to tell the mayor about existing and future collaborations with the Center.

The mayor's visit was closely related to the announcement by the Fraunhofer-Gesellschaft that the Berlin Center for Digital Transformation is now entering its second phase, two years after its foundation. Within the Center, the four Berlin-based Fraunhofer institutes – FOKUS, HHI, IPK, and IZM – pool their expertise in information and communication technologies, data processing, production, and microelectronics. The Center is being funded by the state of Berlin, the Fraunhofer-Gesellschaft, and by monies from the European Regional Development Fund (ERDF) to the tune of €6 million until the end of 2020. In the second phase, which has now begun, cooperation with partners from industry, medium-sized enterprises, and start-ups is set to intensify.

At the end of his visit, Michael Müller stressed the Center's importance to Berlin. He particularly praised the fact that the Fraunhofer institutes and the Center – together with their collaborative and network partners – were turning the capital into an international hotspot for digitalization and were thus an important location factor in Berlin's economic development.

*1 State Secretary Steffen Krach speaks at Fraunhofer IZM's 25th anniversary ceremony*

**Panel Level Packaging Symposium in Dresden and Berlin**
To develop very thin, cost-effective packages with extremely good RF properties and low thermal resistance, Fraunhofer IZM in 2016 initiated a consortium that promoted the industrialization of fan-out panel level packaging processes. After an extremely successful presentation of the development results in Berlin on May 17 and 18, 2018, the consortium showed the almost 100 participants at the fourth project symposium in Dresden at the end of January 2019 where the journey is heading: Towards the packaging technology of tomorrow.

**Innovation Day at the Research Fab Microelectronics Germany**
On September 27 and 28, the Research Fab Microelectronics Germany (FMD) held its first Innovation Day. Europe's largest research cooperation in microelectronics invited attendees to lectures and expert discussions on the issue of smart microsystems. In an accompanying exhibition, futuristic technologies such as self-sufficient microsystems and smart sensors were presented. Experts came to Fraunhofer IZM's premises to discuss the current state of research and the latest technological opportunities presented by microelectronics.

The first Innovation Day saw high-ranking guests from government and science arrive at Fraunhofer IZM to give their joint green light to interdisciplinary work and to discuss future research plans. September 28 was also the opening of the first FMD integration line. The scientific lectures were accompanied by a ceremony with visual highlights and insights into the day-to-day research at all member institutes. Dr. Michael Meister, Parliamentary State Secretary to the Federal Minister of Education and Research, highlighted the unique character of the Research Fab's concept in Germany, before officially opening the FMD's first integration line.

**Expert discussion about device discontinuation as a driver of obsolescence**
The research group Obsolescence as a Challenge to Sustainability (OHA) is a joint project of TU Berlin and Fraunhofer IZM and is being funded by the German Federal Ministry of Education and Research (BMBF). Since 2016, up-and-coming researchers have been investigating the phenomenon of obsolescence from various points of view: they are looking at business models, consumer behavior, and product features. One driver of obsolescence in the area of products is device discontinuation. As semiconductor technology develops at breakneck speed, individual components quickly become obsolete and are discontinued. If, however, suitable spare parts are no longer being produced, this may affect the availability of the entire system. That is why, on September 25, the OHA research group hosted an expert discussion on the topic of device discontinuation as a driver of obsolescence among products.

| Fraunhofer IZM at trade shows (selection) | |
|---|---|
| **SPIE Photonics West** | Jan / Feb, San Francisco, USA |
| **6. Anwenderforum SMART TEXTILES** | February / March, Berlin |
| **LOPEC** | March, Munich |
| **CIPS 2018** | March, Stuttgart |
| **Smart Systems Integration** | April, Dresden |
| **IEEE ECTC** | May / June, San Diego, USA |
| **PCIM Europe** | June, Nuremberg |
| **SMT Hybrid Packaging** | June, Nuremberg |
| **Sensor+Test** | June, Nuremberg |
| **Semicon West** | July, San Francisco, USA |
| **ESTC** | September, Dresden |
| **InnoTrans** | September, Berlin |
| **Photonic Days** | October, Berlin |
| **IWLPC** | October, San José, USA |
| **Compamed** | November, Düsseldorf |
| **electronica** | November, Munich |
| **SEMICON EUROPA** | November, Munich |
| **Semicon Japan** | Dezember, Tokio, JPN |

**Science journalists welcomed at Fraunhofer IZM**
The Berlin Center for Digital Transformation is the shared home of Berlin's Fraunhofer Institutes for a plethora of research and development activities, ranging from information and communications technology, data processing, the realization of novel electronic systems to production technology and microelectronics.

Sixteen science journalists had a chance to experience what this means in practice at a special press conference hosted on May 25 at Fraunhofer IZM. Alongside the world's thinnest speaker or an intelligent posture-correcting vest brace, the many solutions on show included wiretapping-proof fiber optic cables and revolutionary 3D printing technologies.

**Workshops at Fraunhofer IZM**
In 2018, once again, numerous workshops organized by IZM researchers took place at the institute. The event season kicked off in February with a radar workshop held under the auspices of the Berlin Center for Digital Transformation. Here, the current state-of-the-art in the field of innovative radar technologies and new packaging technologies for radar applications were presented. In the lab course that followed, participants were given the opportunity to develop and test their own radar system.

Spring saw as many as three workshops on the topic of packaging. Around 50 people attended an introduction to »New Trends and Technologies in Advanced Packaging« in April. An international workshop about photonic packaging at the beginning of June was also very well attended. The workshop focused on automatic assembly technologies for optoelectronics at the sub-micro level. An event about embedding SMD devices in circuit boards was targeted specifically at German medium-sized enterprises. The intention here was to improve understanding of the design principles and setup concepts in the area of SMD embedding.

After the summer break, the institute's wafer experts offered a workshop that covered all areas of wafer level packaging and sensor integration, from materials science and 3D and hermetic packaging to fan-out technologies for sensors and power modules. The series was rounded off in November, suitably enough by a workshop about the core expertise of Fraunhofer IZM, and the one that gave it its name: the reliability of electronic systems. As every year, many industry representatives attended in order to find out about application-specific assurance of the reliability of electronic systems.

**»Keeping research up and running« – Fraunhofer IZM at the Berlin intercompany race**
By now, it has become a tradition of its own and the team event every summer: Berlin's Intercompany Race (»Firmenlauf«). Almost 190 runners from the six Fraunhofer institutes in Berlin and Brandenburg met on May 30 last year to cover the 5.5 km distance and then relax at the barbecue with sausages and beer. The annual workout is really worth it: the Fraunhofers came 35th in the team ranking. In the individual ranking, one student even came fourth in skate-boarding! Well done to all participants!

*1 Dr. Michael Meister, Parliamentary State Secretary at BMBF, Prof. Matthias Kleiner, President of the Leibniz-Gemeinschaft, Prof. Georg Rosenfeld, Fraunhofer Board, Prof. Hubert Lakner, Head of the FMD Steering Board*

*2 Science journalists visiting Fraunhofer IZM*

1

2

**Her Majesty's Treasury at Fraunhofer IZM**

On 23 March 2019, Fraunhofer IZM welcomed most distinguished visitors from Britain: Jon Sell, Deputy Director Corporate Finance, Business, Energy and Industrial Strategy at Her Majesty's Treasury, accompanied by several of his department heads working on science policy and innovation. After a brief introduction to the work of Fraunhofer IZM by the Institute's Director Professor Klaus-Dieter Lang, the British delegation toured the IZM's very own »founder's garage« Start-a-Factory. The unique facilities give exciting startups working with highly miniaturized electronics and sensor technology access to top-modern production equipment and scientific know-how to accelerate their products' journey to industrial production.

| Selection of events organized by Fraunhofer IZM | |
|---|---|
| **DELL visits Fraunhofer IZM: Cloud Service Provider Summit 2018** | January, Berlin |
| **European 3D Summit** | January, Dresden |
| **Industry Working Group: System Reliability in Assembly and Interconnection Technology** | Feb/Jun/Oct, Berlin, Nuremberg |
| **Industry Working Group: Compliant Environmental Management in the Electronics Industry** | Feb/Jun/Nov, Berlin |
| **IMAPS Seminar 2018: Reliability is no Accident! Design, Material, Technology, Simulation, Test** | March, Berlin |
| **Tutorial: Autarkic Wireless Sensor Networks** | March, Berlin |
| **Workshop: New Trends and Technologies in Advanced Packaging** | April, Berlin |
| **Workshop: Panel Level Packaging** | May, Berlin |
| **2018 ECTC/ ITherm Women's Panel** | May, San Diego |
| **SME Innovation Day** | June, Berlin |
| **Workshop: Photonic Packaging – Sub-micron Assembly** | June, Berlin |
| **Workshop: Learning Factory for Ecodesign** | June, Berlin |
| **Workshop: SMD Component Embedding into PCBs** | June, Berlin |
| **Symposium: 6th Optical Interconnect in Data Centers** | September, Rom |
| **Workshop: Wafer Level Packaging & Sensor Integration** | October, Berlin |
| **Workshop: Reliability Assessment of Microelectronic Systems** | November, Berlin |

# PROMOTING YOUNG TALENT AT FRAUNHOFER IZM

The future of our industry is based on the next generation of scientists. Fraunhofer IZM has been supporting up-and-coming scientists for over 20 years and has long been reaping the rewards. To recruit the brightest minds, the institute makes use of dual vocational training. In 2018, four trainees succeeded in completing their apprenticeships in microtechnology and office communication. Fortunately, Fraunhofer IZM was able to offer positions to the three microtechnologists once their apprenticeships were completed.

But other opportunities such as internships also provide an insight into the training and study opportunities for scientific (MINT) professions. In 2018, eight pupils took part in a two- to three-week internship at the Fraunhofer IZM laboratories. In addition, in order to motivate the next generation to work in research, a career information day was offered for pupils from the Gabriele-von-Bülow-Gymnasium, a partner school of Fraunhofer IZM.

**Fraunhofer Talent Take Off – All Aboard!**

The study orientation program »Fraunhofer Talent Take Off – All Aboard!« offers pupils and students who are enthusiastic about natural sciences, technology, mathematics, or computer science the opportunity to find out more about what »applied research« actually means. On March 29, Fraunhofer IZM welcomed numerous interested young people, who were given exciting insights into research life and answers to all questions about professional practice at Fraunhofer. They also had the opportunity to try out glove boxes in the battery laboratory, examine chip samples in the grinding laboratory, and experience reliability tests first hand in the ECM laboratory. Finally, they were able to demonstrate their own spirit of research and build and test a flying machine. Needless to say, there was also plenty of opportunity to exchange ideas with other MINT talents.

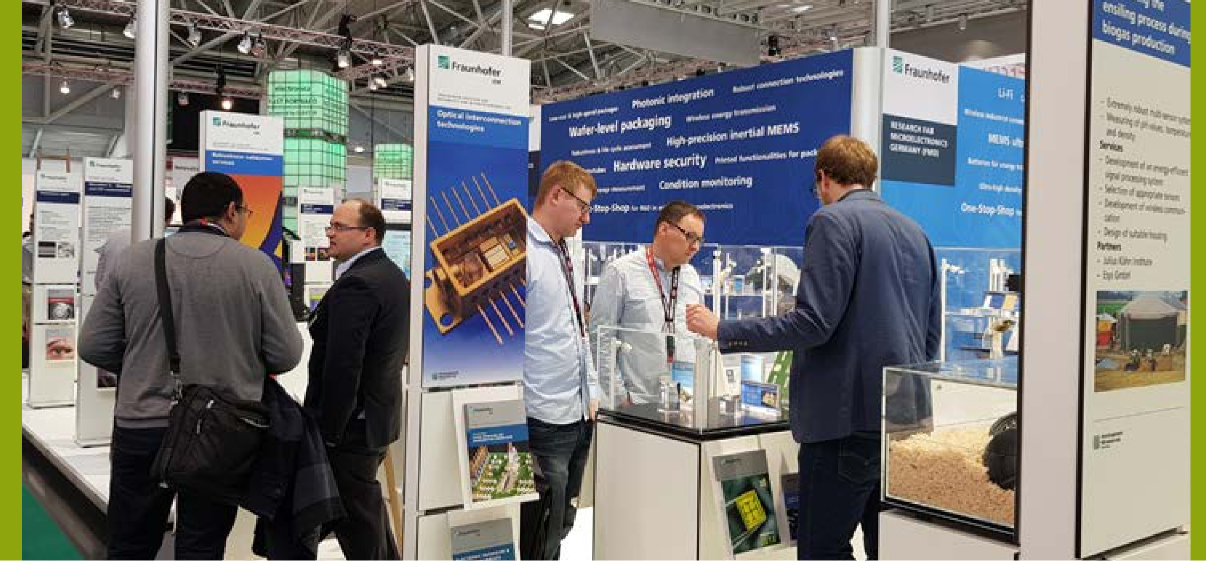
**Girls' Day 2018 – what can you find in a smartphone?**

On Girls' Day, which took place on April 26, twelve female high-school students from Gabriele-von-Bülow-Gymnasium visited Fraunhofer IZM and gained an insight into the world of microelectronics. The girls were able to visit the Fraunhofer IZM laboratories and learned how new elements or functions can be developed for an electronic device and how a smartphone can be made to function reliably despite frost and summer sun – or if it is accidentally dropped. In addition, the pupils were table to look at the inner workings of a cellphone and learn more about its individual elements. They didn't just look over the scientists' shoulders, however, but also lent a hand themselves. They had an opportunity to prove their scientific abilities in a competition: The aim was, with little material, to build an »egg flying machine« with which a raw egg could survive a drop from a height of four meters without damage. Girl's Day is an integral part of Fraunhofer IZM's promotion of young researchers and took place in 2018 for the 15th time in a row.

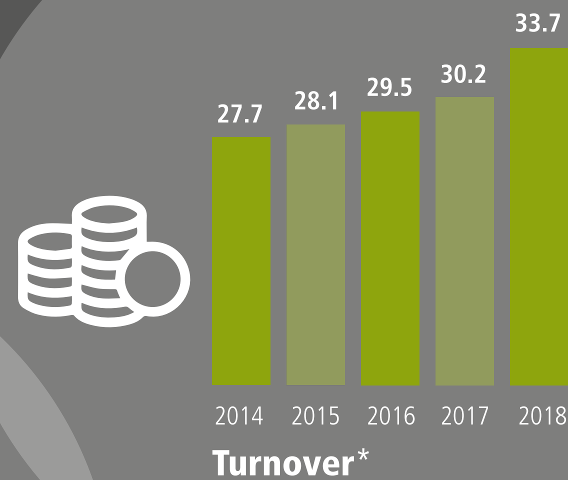
*1 A delegation from Her Majesty's Treasury visits Fraunhofer IZM*

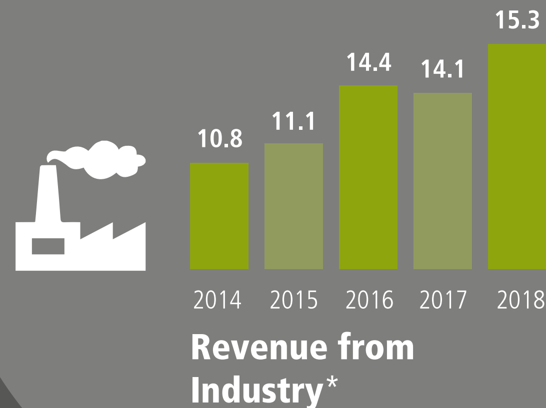
*2 A student explains her concept for an »egg flying machine«*

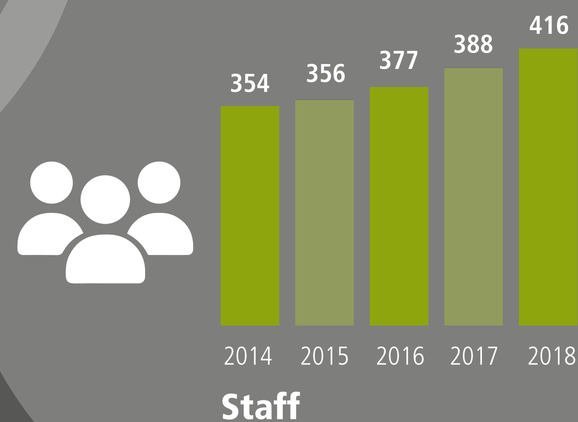
# FACTS & FIGURES




## 2014 – 2018
at a Glance




* in Mio. Euro

# FRAUNHOFER IZM IN FACTS AND FIGURES

**Financial situation**

2018 was another successful year for Fraunhofer IZM. The investments made in infrastructure and equipment over recent years have been successfully leveraged to expand the range of services on offer to support industry in research and development. Earnings from German and international industrial companies and trade associations rose by 11.6 percent over the last year to 15.3 million euros. Fraunhofer IZM was thus able to cover 45.4 percent of its costs through direct orders from industry. The volume of publicly funded projects increased by 12.5 percent compared to the previous year, with a project volume of 12.6 million euros. Fraunhofer IZM's turnover rose by 11.6 percent to 33.7 million euros. In 2018, the institute covered 83.6 percent of its operating budget with external income. Projects totaling 27.9 million euros were financed externally.

**Investments in equipment**

1.6 million euros of the institute's own money were spent on ongoing replacement and renewal investments in 2018. These funds were used to improve Fraunhofer IZM's equipment with a large number of targeted individual measures and to increase the efficiency of existing systems. A further 2,1 million euros were invested in carrying out various smaller construction measures. These included detailed improvements and adjustments that were made in order to increase the performance of Fraunhofer IZM and to implement new occupational safety requirements.

The establishment of the Research Fab Microelectronics Germany (FMD) continues apace. Another 17.7 million euros were spent on equipment and systems in 2018. This measure was made possible thanks to funding from the German Federal Ministry of Education and Research (BMBF).

**HR development**

The expansion in the range of services is reflected in personnel development. The IZM sites in Berlin and Dresden/Moritzburg employed 260 people, that is 27 more than in 2017. Fraunhofer IZM offers students the opportunity to combine their degree with practical scientific work. At the end of 2018, 147 interns, bachelor students, master students, and student assistants were being supervised at the institute and nine apprentice micro technologists and office managers were in training.

| Fraunhofer IZM in 2018 | |
|---|---|
| **Turnover** | 33.7 million euros |
| **External revenue** | 27.9 million euros (83.6 percent of total turnover) |
| **Sites** | Berlin and Dresden/Moritzburg |
| **Laboratories** | >8.000 m³ |
| **Number of staff** | 416 (including 147 student assistants, master students, interns and 9 apprentices) |

1

2

3

# AWARDS

**Institute Director Klaus-Dieter Lang named IEEE Fellow**
To mark the new year 2018, Professor Klaus-Dieter Lang has been offered the fellow grade of the Institute of Electrical and Electronics Engineers (IEEE). With this honor, the world's leading engineers' association recognizes Professor Lang's long track record of excellent scholarship in the field of packaging and the heterogeneous integration of microelectronics. Lang already headed the German chapter of one of the IEEE's societies – today's Electronics Packaging Society (EPS) – between 2008 and 2014 and continues to play a substantial role in the successful development of the IEEE with his scholarly contributions and international networking efforts. Fellowships at the IEEE have been proffered by the Board of Directors for over a century; only 0.1 percent of its many members around the world are chosen for this prestigious honor every year.

**Fraunhofer IZM is »Innovator of the Year«**
The readers of DESIGN & ELEKTRONIK have named Fraunhofer IZM »Innovator of the Year«. In the competition, which aims to make the »stars behind the products« visible, the development of a chip cooling system by Fraunhofer IZM as part of the EU CarriCool project was recognized in the category »Chip Production«. The award was presented to M. Jürgen Wolf and Dr. Hermann Oppermann in Munich on October 25.

**IHK Research Transfer Award for flexible circuit boards**
Dr. Thomas Löher and his team have been awarded the IHK Research Transfer Award for their design of an elastic circuit board. Endowed with a prize of €10,000, the award celebrates the »TWINflex Stretch« project, conducted in cooperation with Würth Elektronik GmbH & Co. KG to develop and ready a flexible circuit board for industrial production. Fraunhofer IZM worked on the technological underpinnings of the project, while Würth Elektronik investigated the required manufacturing processes. The flexible circuit board can be employed e.g. in wearable electronics or in medical technology, and it is already actively being used in a specialized diagnostic chest-strap for infants.

**Young Researcher Award for Felix Fischer**
In 2018, the EBL symposium in Fellbach, Germany, presented its first Young Researcher Award (Nachwuchsforscherpreis). Felix Fischer, student assistant at Fraunhofer IZM, prevailed against five competitors in the finals with a presentation of his master thesis in which he examines the aging behavior of aluminum wire bonds on an innovative nickel-gold layer system – known as electroless nickel immersion gold (ENIG) – on printed circuit boards. The award was presented to him by Prof. Mathias Nowottnick from the University of Rostock.

**Fraunhofer IZM named Research Institute of the Year**
Fraunhofer IZM is very excited about coming in first place among the »Research Institutes of the Year« honored at the 3DInCites Awards 2018. Every year, the 3DInCites Awards are given to individual and institutional recipients for their exceptional contributions to the hetero system integration of semiconductors in a range of categories, e.g. for work in the fields of 3D or Fan-Out Wafer-Level Packaging. The Institute's researchers are particularly proud of winning the award in the important category »Research Institute of the Year«, as its winners are chosen by the packaging community as an expression of genuine appreciation among the packaging professionals of the world.

**Best Paper of Session Award for SATCOM research**
Fraunhofer IZM researchers (Dr. Ivan Ndip, Christian Tschoban and Professor Klaus-Dieter Lang) received a Best Paper of Session Award at the 51st International Symposium on Microelectronics, which took place in Pasadena from October 8–11, 2018, for their paper entitled, »Systematic Design of Ka-band Transmitter Modules using the M3-Approach«. The paper is based on the results of the AVISAT project, a research project on satellite communication (SATCOM), funded by the German Federal Ministry of Economic Affairs and Energy (BMWi), and led by Dr. Ivan Ndip at Fraunhofer IZM. In this project, Fraunhofer IZM researchers apply their M3-approach to systematically design, fabricate, test and optimize miniaturized and high-performance transmitter and receiver modules which operate in the K/Ka and Q/V bands. Fraunhofer IZM collaborates in the AVISAT project with two industry partners namely IMST GmbH and HISATEC GmbH.

**Dr. Henning Schröder receives the Fraunhofer IZM Research Award 2018**
As part of the celebrations for the 25th anniversary of Fraunhofer IZM, Henning Schröder received the IZM Research Award on 27 November 2018. The physicist adapted integrated optics processes for use with thin glass. With the unique thin glass technology developed by Dr. Henning Schröder, optical circuit paths can be brought into the chips themselves. No more throttling: the time is right for high-speed optical signals on circuit boards. Thin glass offers countless advantages over the polymers that are also used to integrate circuit paths. It is all about glass now: circuit boards, photonic modules, fiber coupling, or micro-optical benches – Schröder's team has been employing and refining the thin glass technology everywhere for the last 15 years.

**Best Academic Paper Award for Kai Zoschke**
The Institute of Electrical and Electronics Engineers (IEEE) honored Kai Zoschke's contribution to the topic »Full Wafer Redistribution and Wafer Embedding as Key Technologies for a Multi-Scale Neuromorphic Hardware Cluster« with a Best Academic Paper Award at the Electronics Packaging Technology Conference 2017 (EPTC 2017). The paper deals with technology developments for high-density wiring of chips on semiconductor wafers and the integration of such wafers in large-format printed circuit boards. The technologies are used in the Human Brain Project to build a computer with highly integrated circuits based on neuronal models. The award was presented at EPTC 2018 in Singapore in December.

*1 Dr. Thomas Löher (3rd from right) receives the IHK Research Transfer Award*

*2 Frank Riemenschneider, editor in chief of DESIGN & ELEKTRONIK (left), presents the »Innovator of the Year« Award to Fraunhofer IZM's Jürgen Wolf*

*3 Institute Director Prof. Klaus-Dieter Lang with this year's IZM Research Award recipient Dr. Henning Schröder and the head of the award committee, Prof. Martin Schneider-Ramelow*

# BEST PAPER, EDITORIALS, DISSERTATIONS

### Further Best Papers

**IWLPC 2017: »Best of Conference Paper« und »Best of 3D Track Paper« for Wolfram Steller**
»Dual Side Chip Cooling Realized by Microfluidic Interposer Processing on 300mm Wafer Diameter«
Wolfram Steller, Frank Windrich, Philipp Heilfort, Jessica Kleff, Raúl Mroßko, Jürgen Keller, Thomas Brunschwiler, Gerd Schlottig, Hermann Oppermann, M. Jürgen Wolf and Klaus-Dieter Lang

**Smart System Integration 2018: Best Poster Award for Lena Goullon**
»Die Attach for High Power VCSEL Array Systems«
Constanze Weber, Matthias Hutter, Martin Schneider-Ramelow

### Editorials

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

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

### Dissertations

**Brückner, John**
»Elastizitätsmodul und Bruchfestigkeit von Poly-Silizium-Membranen kommerzieller MEMS-Mikrofone«

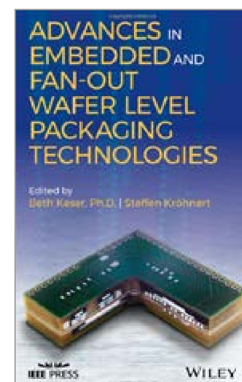
**Brincker, Mads**
»Reliability of Metal Films and Interfaces in Power Electronic Devices«

**Kaya, Burcu**
»Concept Development and Implementation of the Online Monitoring Methods in Transfer Molding Process for Electronic Packages«

**Mukhopadhyay, Biswajit**
»Realisierung eines piezo-resistiven Niederdruck-Sensors in der SOI-Technologie zum Einsatz in Hochtemperatur- und aggressiver Umgebung«

**Windrich, Frank**
»Charakterisierung der thermischen Reaktionen von Dünnfilm-Polymeren bei der Anwendung für das Microelectronic Packaging«

### Publication Highlights




**Töpper, Michael; Ostmann, Andreas; Braun, Tanja; Lang, Klaus-Dieter**
History of Embedded and Fan-Out Packaging Technology, in: Advances in Embedded and Fan-Out Wafer Level Packaging Technologies (2019), ISBN- 978-1-119-31413-4, John Wiley & Sons, Inc., Hoboken, NJ, USA, S. 1-38

# LECTURES

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

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

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

### Technische Universität Berlin

**Dr. B. Curran**
- Design, Simulation and Reliability of Microsystems

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

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

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

**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

**Dr. T. Tekin**
- Antennas

### Technische Universität Dresden

**Jun.-Prof. Dr. I. Panchenko**
- Micro-/ Nanomaterials and Reliability Aspects

### University of Aalborg

**Prof. Dr. E. Hoene**
- Design of Modern Power Semiconductors Components

# COOPERATION WITH UNIVERSITIES (SELECTION)

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

To effectively realize its research targets Fraunhofer IZM has formed strategic networks with universities in Germany and abroad. This page provides an overview of our most important cooperation projects. Close collaboration between Fraunhofer institutes and universities throughout Germany and internationally has always been a cornerstone of Fraunhofer's ongoing success. Universities bring their innovativeness and their expertise and know-how in basic research to the table, while 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**
Fraunhofer IZM's close relationship with the TU Berlin's Research Center for Microperipheric Technologies is proof-positive of this collaborative model and dates back to the institute's very founding in 1993. In the 1990s, the institute became one of the world's leading research institutes for packaging technology.

Since 2011, the traditional double appointment of Fraunhofer IZM Director and Head of the Research Center for Microperipheric Technologies has been held by Professor Klaus-Dieter Lang. Both institutions research and develop smart system integration with a joint goal, namely to integrate components that may have been manufactured using very different technologies on or in a single carrier substrate.

**Fraunhofer IZM-ASSID cooperates with the Electronic Packaging Laboratory (IAVT ) at TU Dresden**
Within the framework of the joint Assistant Professorship between Fraunhofer IZM-ASSID in Dresden Moritzburg and TU Dresden (Electronic Packaging Laboratory, IAVT), junior professor Iuliana Panchenko and her research group work on new materials and technologies for fine-pitch interconnects in 3D/2.5D Si assemblies.



# COOPERATION WITH INDUSTRY (SELECTION)

| Company | Location |
|---|---|
| **AEconversion GmbH & Co. KG** | Bad Sassendorf |
| **AEMtec GmbH** | Berlin |
| **Ajinomoto Group** | Tokio (J) |
| **Amkor Technology, Inc.** | Chandler, Arizona (USA) |
| **AMO GmbH** | St.Peter / Hart (A) |
| **ams AG** | Premstätten (A) |
| **Apple Inc.** | Cupertino, Austin (USA) |
| **Asahi Glass Co., Ltd.** | Tokio (J) |
| **ASM Pacific Technology Ltd.** | Singapur (SG) |
| **AT&S AG** | Leoben (A) |
| **Atotech Deutschland GmbH** | Berlin |
| **AUDI AG** | Ingolstadt |
| **Baker Hughes INTEQ GmbH** | Celle |
| **BMW AG** | Munich |
| **BrewerScience** | Rolla (USA) |
| **Broadcom Ltd.** | Regensburg |
| **Bundesdruckerei GmbH** | Berlin |
| **Continental AG** | Regensburg |
| **Daimler AG** | Stuttgart |
| **Deutsches Elektronen-Synchroton DESY** | Hamburg |
| **DISCO Corporation** | Tokyo (J) |
| **DResearch Digital Media Systems GmbH** | Berlin |
| **Ericsson** | Stockholm (SE) |
| **EV Group (EVG)** | St. Florian a.I. (A) |
| **Evatec AG** | Trübbach (CH) |
| **Finisar Cooperation** | D, USA |
| **First Sensor AG Berlin** | Berlin, Dresden |
| **Fujifilm Electronic Materials** | EU, USA |
| **Fujitsu Technology GmbH** | Augsburg |
| **GLOBALFOUNDRIES INC.** | Dresden |
| **HELLA GmbH & Co. KGaA** | Lippstadt |
| **Hitachi Chemical Company, Ltd.** | Tokio (J) |
| **Hitachi Metals Europe GmbH** | Düsseldorf |
| **Infineon Technologies AG** | D |
| **InnoSent GmbH** | Donnersdorf |
| **Intel Corporation** | USA |
| **Invensas** | Santa Clara (USA) |
| **Isola USA Corp.** | Chandler (USA) |
| **Jenoptik Power System** | Jena |
| **Johnson & Johnson** | New Brunswick (USA) |
| **Magneti Marelli** | I |
| **MED-EL GmbH** | Innsbruck (A) |
| **Meltex Inc.** | Tokio (J) |
| **Merck KGaA** | Darmstadt |
| **Mitsubishi Electric Corporation** | J |
| **Mitsui Chemicals Tohcello, Inc.** | Tokio (J) |
| **MITNETZ Strom mbH** | Kabelsketal |
| **Olympus Surgical Technologies Europe** | Hamburg |
| **Osram Opto Semiconductors GmbH** | Regensburg, Munich |
| **PANalytical B.V.** | Almelo (NL) |
| **Philips Technology GmbH** | Aachen |
| **Robert Bosch GmbH** | Reutlingen, Stuttgart |
| **Semsysco GmbH** | Salzburg (A) |
| **Sensitec GmbH** | Lahnau |
| **Shin-Etsu Chemical** | Tokio (J) |
| **Siemens AG, Siemens Healthcare** | D |
| **SPTS Technologies Ltd.** | Newport (UK) |
| **Süss MicroTec SE** | Garching, Munich |
| **Suzuki Corporation** | J |
| **Swissbit Germany AG** | Berlin |
| **TDK-EPCOS AG** | Munich |
| **TRUMPF Laser GmbH** | Berlin |
| **Unimicron Technology Corporation** | Taoyuan (TW) |
| **Valeo** | Creteil (FR) |
| **VINOTECH srls** | Ceppaloni (I) |
| **Volkswagen AG** | Wolfsburg |
| **Würth Elektronik GmbH & Co. KG** | Niedernhall, Rot a.S. |
| **ZF Friedrichshafen GmbH** | Friedrichshafen |

# MEMBERSHIPS (SELECTION)

| | | |
|---|---|---|
| **AMA Fachverband Sensorik, Wissenschaftsrat** | H. Pötter | Member |
| **Cluster Optik Berlin/Brandenburg**<br>Photonik für Kommunikation und Sensorik | Dr. H. Schröder | Spokesman |
| **Deep Tech Award Berlin** | Prof. K.-D. Lang | Member |
| **Deutsche Forschungsgemeinschaft** | Prof. K.-D. Lang | Reviewer |
| **Deutscher Verband für Schweißtechnik DVS** | Prof. K.-D. Lang | Executive 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 |
| **Heterogeneous Integration Roadmap (HIR)** | R. Aschenbrenner | Chair Technical Working Group SiP |
| **IEEE Electronics Packaging Society**<br>Technical Committees:<br>Green Electronics<br>Photonics - Communication, Sensing, Lighting<br>IEEE CPMT German Chapter<br>IEEE EPS TC Material & Processes | R. Aschenbrenner/Prof. K.-D. Lang<br><br>Dr. N. F. Nissen<br>Dr. T. Tekin<br>R. Aschenbrenner<br>Dr. T. Braun | Fellow<br><br>Technical Chair<br>Technical Co-Chair<br>Chair<br>Member |
| **IMAPS International Microelectronics Assembly and Packaging Society**<br>IMAPS Europe/IMAPS Deutschland<br>IMAPS Signal/Power Integrity Committee<br>IMAPS Executive Council | <br>Prof. M. Schneider-Ramelow<br>Dr. I. Ndip<br>Dr. I. Ndip | <br>Past President/President<br>Chair<br>Director |
| **IVAM Fachgruppe Wearables** | E. Jung | Technical Chair |
| **MikroSystemTechnik Kongress 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, Erik 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**
Sensoren und Messsysteme – 19. ITG/GMA-Fachtagung, June 2018, Nuremberg, Germany

*Bönisch, S.; Hoffmann, S.; Hoene, E.; Schmidhuber, M.*
**Characterization of Ferrite Core Properties for FM-Band Filtering in Automotive Applications**
Proceedings of CIPS 2018, March 2018, Stuttgart, pp. 500-505

*Braun, T.; Becker, K.-F.; Hölck, O.; Kahle, R.; Wöhrmann, M.; Böttcher, L.; Töpper, M.; Stobbe, L.; Aschenbrenner, R.; Voges, S.; Schneider-Ramelow, M.; Lang, K.-D.*
**Panel Level Packaging - A View Along The Process Chain**
Proceedings of ECTC 2018, May/June 2018, San Diego, CA, USA

*Brunschwiler, T.; Steller, W.; Oppermann, H.; Kleff, J.; Robertson, S.; Mroßko, R.; Keller, J.; Schlottig, G.*
**Dual-Side Heat Removal by Silicon Cold Plate and Interposer With Embedded Fluid Channels**
Proceedings of ITherm 2018, May/June 2018, San Diego, CA, USA, pp. 331-338

*Curran, B.; Reyes, J.; Tschoban, C.; Höfer, J.; Grams, A.; Wüst, F.; Ndip, I.; Lang, K.-D.*
**Development and Validation of a Chip Integration Concept for Multi-Die GaAs Front Ends for Phased Arrays up to 60 GHz**
IEEE Transactions on Components, Packaging and Manufacturing Technology, Vol. 8, Nr. 7, July 2018, pp. 1231-1240.

*Emmerich, J.; Binnemans, P.; Chancerel, P.; Chanson, C.*
**What the Urban Mine Teaches us on Waste Batteries Availability and Closing of Material Loops**
23rd International Congress for Battery Recycling 2018, September 2018, Berlin, Germany

*Engin, A. E.; Ndip, I.; Lang, K.-D.; Aguirre, G.*
**Nonoverlapping Power/Ground Planes for Suppression of Power Plane Noise**
IEEE Transactions on Components, Packaging and Manufacturing Technology, Vol. 8, Nr. 11, 2018, pp. 50-56

*Greco, G.; Tatchev, D.; Hoell, A.; Knumney, M.; Raoux, S.; Hahn, R.; Elia, G. A.*
**Influence of the Electrode Nano/Microstructure on the Electrochemical Properties of Graphite in Aluminum Batteries**
Journal of Materials Chemistry A, October 2018, DOI: 10.1039/c8ta08319c

*Hackbart, R.; Kostelnik, J.; Kuschan, J.; Schmidt, H.; Krüger, J.; Vieroth, R.; Lang, K.-D.*
**SmartSensX – Ein Konzept für vernetzte tragbare Sensoren zur Anwendung in der Softrobotik und Mensch Maschine Interaktion**
»Technische Unterstützungssysteme, die die Menschen wirklich wollen«, December 2018, Hamburg, pp. 289-296

*Hahn, R.; Ferch, M.; Kyeremateng, N. A.; Höppner, K.; Marquardt, K.; Elia, G. A.*
**Characteristics of Li-ion Micro Batteries Fully Batch Fabricated by Micro-Fluidic MEMS Packaging**
Springer Nature Microsystem Technologies (2018), doi.org/10.1007/s00542-018-3933-z

Kallmayer, C.; Schaller, F.; Löher, T.; Haberland, J.; Kayatz, F.; Schult, A.
**Optimized Thermoforming Process for Conformable Electronics**
13th MID Congress, September 2018, Würzburg, Germany

*Kolbinger, E.; Wagner, S.; Gollhardt, A.; Rämer, O.; Lang, K.-D.*
**Corrosion Behaviour of Sintered Silver under Maritime Environmental Conditions**
Microelectronics Reliability (2018), Vol. 88-90, pp. 715-720

# PUBLICATIONS (SELECTION)

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

*Kuttler, S.; Walter, H.; Grams, A.; Schneider-Ramelow, M.; Huber, S.*
**Determination of Stress-Strain Properties Combining Small-Depth Nanoindentation and Numerical Simulation**
Proceedings of ESTC 2018, September 2018, Dresden, Germany

*Leverenz, E.; Becker, K.-F.; Koch, M.; Straube, S.; Pötter, H.; Lang K.-D.*
**Energy Autarkic Wireless Sensor Node for Reliable Long-Term Exposure to Domestic Waste Water in a Sewage System**
Sensoren und Messsysteme – 19. ITG/GMA-Fachtagung, June 2018, Nürnberg, Germany

*Maaß, U.; Hefer, J.; Brockmann, C.; Reinhardt, D.; Lang, K.-D.*
**CoDesign for the Integration of Energy Harvesters and Antennas for Highly Integrated CPS**
Proceedings of Smart System Integration 2018, April 2018, Dresden, Germany

*Mackowiak, P.; Abdallah, R.; Wilke, M.; Patel, J.; Ashraf, H.; Buchanan, K.; Lang, K.-D.; Schneider-Ramelow, M.; Ngo, H.-D.*
**Electrical Characterization of Low Temperature PECVD Oxides for TSV Applications**
Proceedings of IMAPS 2018, October 2018, Pasadena, CA, USA

*Manier, C.-A.; Klein, K.; Wuest, F.; Gernhardt, R.; Oppermann, H.; Cussac, P.; Andzouana, S.; Mitova, R.; Lang, K.-D.*
**Wafer Level Embedding Technology for Packaging of Planar GaN Half-Bridge Module in High Power Density Conversion Applications**
Proceedings of PCIM Europe 2018, Juni 2018, Nuremberg, Germany, pp. 951-958

*Ndip, I.; Lang, K.-D.*
**Roles and Requirements of Electronic Packaging in 5G**
Proceedings of ESTC 2018, September 2018, Dresden, Germany

*Ndip, I.; Lang, K.-D.; Reichl, H.; Henko, H.*
**On the Radiation Characteristics of Full Loop, Half-Loop and Quasi Half-Loop Bond Wire Antennas**
IEEE Transactions on Antennas and Propagations, Vol. 66, Nr. 11, 2018, P. 5672-5688

*Ngo, H. D.; Ehrmann, O.; Schneider-Ramelow, M.; Lang, K.-D.*
**Piezoresistive Pressure Sensors for Applications in Harsh Environments – A Roadmap**
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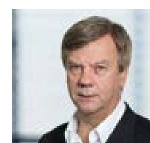

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Miniaturized modular encapsulated camera for endoscopy, equipped with integrated image capture and storage, developed in the EndoTrace project (cf. description on p. 17)