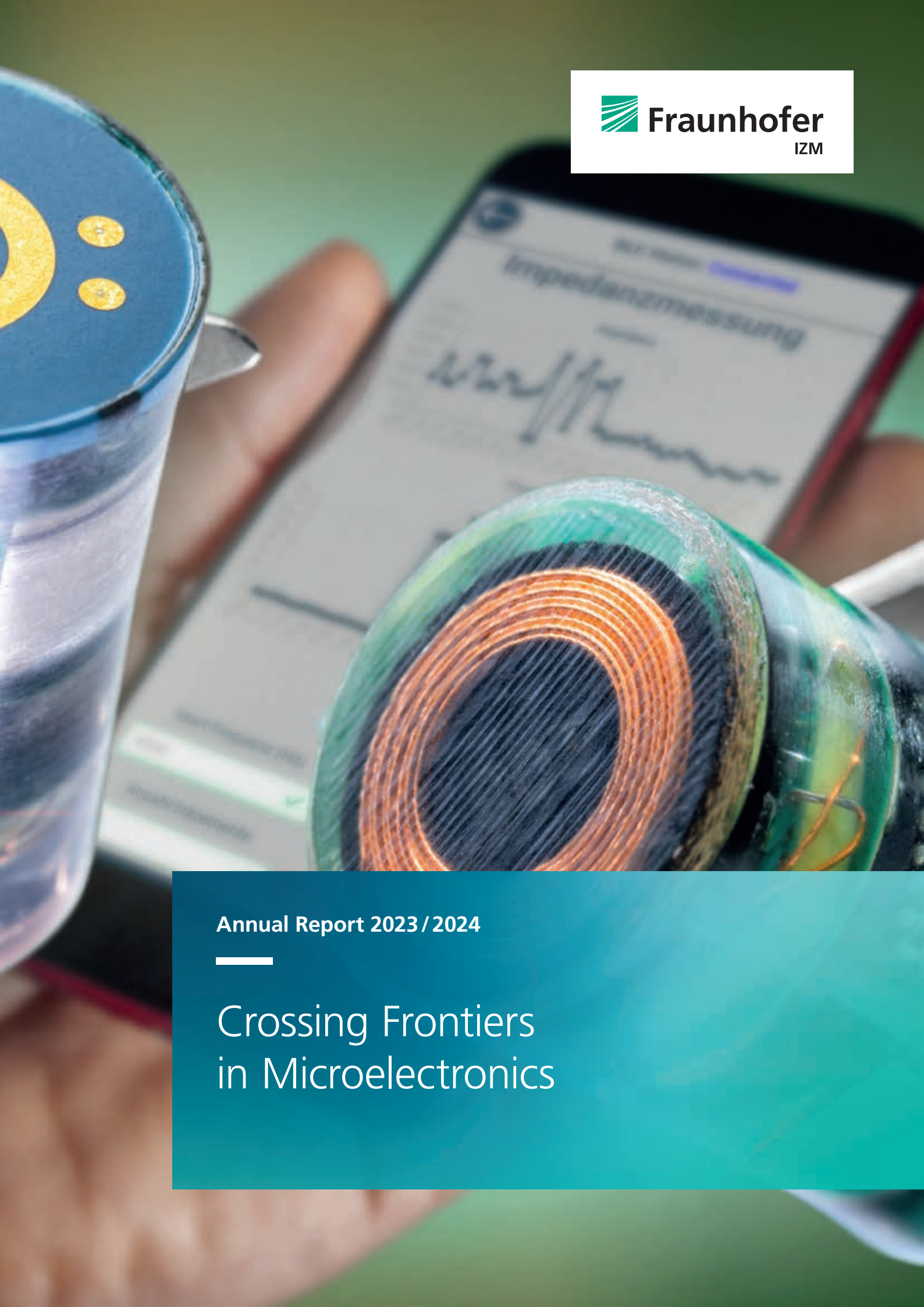


Fraunhofer IZM

Annual Report 2023 / 2024

Crossing Frontiers in Microelectronics

Annual Report 2023/2024

Crossing Frontiers in Microelectronics

Fraunhofer IZM's high-end performance packaging not only enables solutions for future industries, but also makes a vital contribution to European technological sovereignty.«

Prof. Martin Schneider-Ramelow
Director of Fraunhofer IZM

Content

Preface

Dear readers!

The aftershocks of a global pandemic, the ongoing Russian war on Ukraine, and a volatile energy market: The last year has been challenging, not least for sectors of industry as dependent on resources as microelectronics.

This makes it even more satisfying for me to be able to report that Fraunhofer IZM can look back to a very successful year indeed despite all of the headwind in the economy. The technologies developed at the Institute are in great demand in the industry and will have a major impact on our society and way of life.

Chiplet assembly, hybrid bonding, Si-interposer technologies, fan-out wafer-level packaging, cryo-packaging, integration of high-bandwidth memory (HBMs), RF characterization, or packaging for 5G/6G applications: This is only a selection of the many fundamental technologies that are needed for the microelectronics of tomorrow. Taking just one example: Cryogenic packaging is paving the way for ultrafast quantum computing, which will be essential for handling the unimaginable immense datasets used by AI systems. Or think of the Zn-H2 project, where Fraunhofer IZM is researching novel forms of energy storage using zinc-hydrogen technology.

The increasingly vocal call for more sustainable design and production processes for electronics is finding its echo in the more and more ambitious carbon reduction goals that many companies are committing to.

These are just some of the many highlights of the last twelve months:

- The »Green ICT @ FMD« project funded by the Federal Ministry of Education and Research has passed some key milestones on its way towards creating a center of competence for greener and more resource-conscious IT and communication technology.
- The »FANOPa« project (funded by the Senate of Berlin) has produced a fan-out wafer-level packaging platform for RF applications, with a pilot production line for prototypes and multi-project wafers established for the purpose.
- Within the European Chips Act, Fraunhofer IZM is part of several initiatives designed to strengthen the continent's semiconductor industry. As a contribution to the EU Chips Act, a European consortium under the leadership of the Research Fab Microelectronics Germany (FMD) plans to establish the most comprehensive and advanced pilot line for »Advanced Heterogeneous System Integration and Advanced Packaging« in the coming years.

One cornerstone of the innovative research done at Fraunhofer IZM is our close cooperation with partner universities, which we were able to intensive last year:

At the Technical University of Berlin's Research Center for Microperipheric Technologies, new DFG-funded projects were launched that will bring about an even closer connection between fundamental and applied research. Our partnership with Fraunhofer IPMS on the development of the Center for Advanced CMOS & Heterointegration Saxony is continuing apace and will contribute substantially to strengthening what has come to be called »Silicon Saxony«. We also need to mention the close partnership with the Technical University of Dresden: Working with Professor Julia Pancheko, honorary professor for »Nanomaterials for Electronic Packaging«, we are creating optimized miniature interconnects on the basis of innovative nano-materials and nano-structured surfaces.

Our cooperation with BTU Cottbus-Senftenberg is going strong as part of the iCampus, and our dedicated IZM site for »High-Frequency Sensors & High-Speed Systems« is being expanded. It has been a year now that Professor Ivan Ndip, department head at Fraunhofer IZM, has held the chair there. Bioelectronics is also attracting increasing interest, and the Institute is cooperating with the Technical University of Delft on the successful development of a neuronal interface for controlling smart and tactile prosthetics.

We like to keep our eyes fixed on the future at the Institute. But this year, we also had occasion to look back at 30 years of Fraunhofer IZM history and to mark our anniversary with a dedicated conference and a gala celebration. »Crossing Frontiers in Microelectronics« was our motto when we welcomed many representatives from academia, industry, and politics. We thank everyone who attended or sent us their best wishes for our Institute's birthday!

Alongside research and our close partnerships with the industry, we placed particular emphasis on training and young talent last year. Our ten apprentices in technical and non-technical functions were able to acquire invaluable know-how and skills to prepare them for one of the industries of the future. The Institute is also supporting students completing their master's degrees or doctorates, becoming a hothouse for scientific talent. Supporting this talent is one of our express ambitions at the Institute. We also offered young men and women the great opportunity to experience the work of Fraunhofer IZM at first hand by welcoming 24 school interns and four young people completing their voluntary environmental service year at the Institute.

We can see our positive track record of the last year reflected in our hard facts and figures as well. Roughly 450 people are working at our three sites and helped raise our commercial results to 33.9 million euros last year. Our operating budget also increased, specifically to 42.3 million euros.

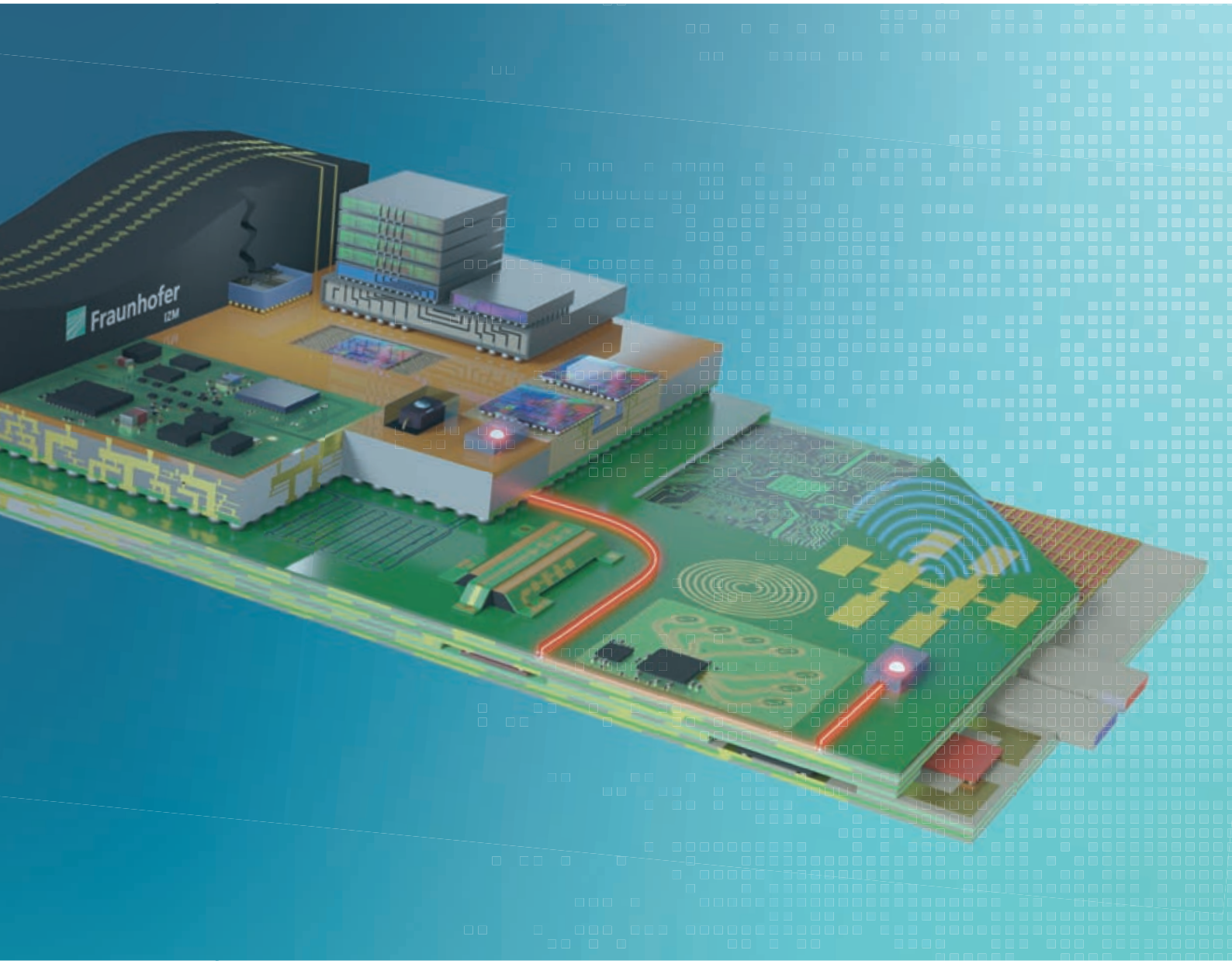
A result this positive in a market this troubled is only possible thanks to the highly motivated people of Fraunhofer IZM who deserve my particular thanks for this achievement. Without your passion and commitment, we would certainly never get the innovative and groundbreaking research we do at Fraunhofer IZM.

We also need to thank our partners in science and industry for the invaluable impulses and hands-on expertise help make Fraunhofer IUM one of the premier research institutions for system integration and reliable microelectronics.

I wish our readers an enjoyable time with our annual report and hope they can share out optimism about the future - whatever crises and uncertainties it may hold!

Yours,

Martin Schneider-Ramelow
Director



High-End Performance Packaging

High-performance systems at lower costs - that is the promise of hetero-integration and technologies like chiplet architectures. The QR code links to an interactive illustration of high-end performance packaging that shows where the technology is heading and which novel capabilities Fraunhofer IZM already has in store in its technology portfolio.

Core Competencies

From Wafer to System

Intelligent electronic systems – available everywhere and to everyone! In order to make this possible, components need to have exceptional properties. Depending on the application, they need to function reliably at high temperatures, be extremely miniaturized and moldable to individual build spaces or even flexible, and have outstanding lifetime.

The Fraunhofer Institute for Reliability and Microintegration IZM helps companies around the world develop and assemble robust and reliable electronics to the very cutting edge and then integrate them into the required application. With 450 employees, the institute develops adapted system integration technologies on wafer, chip and board level. Research at Fraunhofer IZM means designing more reliable electronics and making reliable lifetime predictions.

Working together with Fraunhofer IZM

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

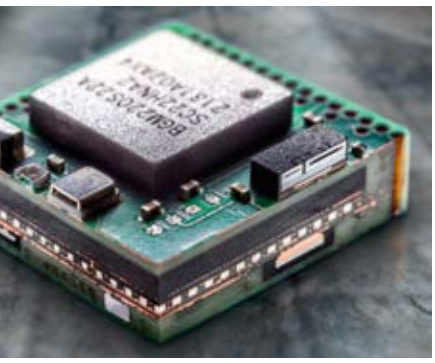
Contract research

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

Project funding

Some development challenges require pre-competitive research. In these cases, teaming up with companies and research institutes and public funding support is more effective than operating solo. The institute cooperates closely with numerous universities, including the Technical Universities of Berlin and Dresden and the BTU Cottbus-Senftenberg, to ensure that the preparation for future cooperation with industry is optimal.

System Integration & Interconnection Technologies



Highly miniaturized edge IOT module

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 interconnection technologies
- Encapsulation: embedding in printed circuit boards; transfer and compression molding; potting and protective lacquering; underfilling and glob-top
- Processed materials and techniques: fiber composites; encapsulation compounds; soft solders; sintered materials; glass structuring; mechanical and chemical metalworking

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

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

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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 80 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:

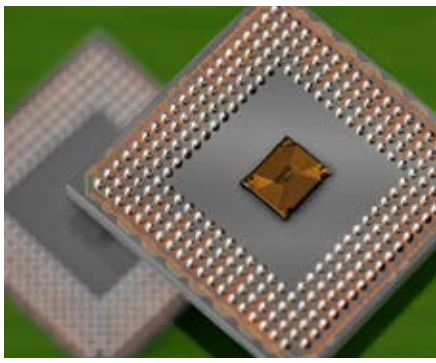
- 3D integration including Cu-TSV and wafer tacking
- Thin wafer processing and integrationtechnology
- Heterogeneous Integration
- Wafer-level packaging, fine-pitch bumping and interconnect technologies
- Hermetic MEMS and sensor packaging
- High density flip-chip assembly
- Sensor development and integration
- Hybrid photonic integration
- Photonic and plasmonic system development

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, WSI)
- 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 / nano interconnect and pillar bumps with solder cap (Cu, SnAg, CuSn, Au, AuSn, In, InSn, nano-porous Au)
- Pre-assembly (thinning, thin wafer handling, laser grooving, laser dicing, plate dicing)
- 3D assembly (D2D, D2W, W2W)
- 3D wafer-level stacking
- Wafer bonding, direct bond interconnects (DBI) - W2W (12"), (adhesive, soldering)
- Micro sensor development and integration
- MEMS packaging (hermetic)
- Simulation and characterization of photonic and plasmonic components & systems
- Photonic system integration (incl. e. g. polymer waveguides)

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



A micro RFID tag embedded in the chip rewiring layer helps identify components and forge a trustworthy supply chain

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Environmental & Reliability Engineering

Standardized power connectors and modular designs help en route to a circular economy

Reconciling progress in microelectronics with the needs of our environment has become a key priority in the industry. Fraunhofer IZM is a pioneer in this field. The »Environmental and Reliability Engineering« department has been supporting new technical developments and the innovation of more sustainable, durable, and greener electronics for over two decades. With its unique combination of environmental performance and reliability checks, the department can offer services in the areas:

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

Our interdisciplinary team develops processes and models and supports our partners in integrating environmental and reliability criteria in the design and development process. We can help identify weak points and untapped potential at an early stage in the introduction of new technologies, materials, processes, components, and applications and find suitable solutions for our partners.

Stemming the tide of electrical and electronics waste and reining in the resource hunger of the industry is one of the key challenges faced by all of society. Modern life has become unthinkable without electronics. A boon and a bane alike, electronics contribute to making climate change worse, but they can also be the key to saving resources and reducing our carbon footprint.

The environmental footprint of actual products and of the fundamental technologies that make them possible has gained considerable salience in the industry. We are also assisting suppliers and smaller enterprises in defining and meeting specific climate and resource efficiency targets.

Legislators and consumers alike are increasing pressure on manufacturers in the form of toughened standards and specifications for products that are easier to tear down, to repair, and to keep in working order for a longer overall product lifespan. Methods for application-specific reliability checks are playing an important role in these efforts to extend the lives of particularly resource-intensive electronic components.

The reliability of technologies is benefitting from constant progress and refinement in testing methods and simulation models. A lot of attention is currently aimed at warpage and corrosion, but depending on their use case, the reliability of electronic components is understood and analyzed in terms of all important fatigue mechanisms or other forces affecting the components, including mechanical vibration, heat, humidity, changes in temperature, or voltage and power loads. These tests and simulations, tailored specifically to the given use case, offer new pointers for optimization for the relevant parameters (such as the materials, geometries, and process design) to achieve the new reliability standards expected in the supply chain and in actual use.

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RF & Smart Sensor Systems

The department »RF & Smart Sensor Systems« is concerned with the research, development and industrial application of wireless sensor and communication systems. The focus of our work is on 5G and 6G communication systems, radar sensor technology and as well as wireless sensor nodes. The greatest challenge in terms of research and development and the defining criteria are large bandwidths high robustness and a commitment to maximum energy efficiency. Other features such as controllable antennas, beamforming, and protections against signal deterioration are also attracting increasing attention.

Meeting these exacting standards needs the tight integration of circuit design and technology development (hardware/package codesign) just as much as genuine cooperation

between software and hardware developers (hardware/software co-design). With this in mind, the department RF & Smart Sensor Systems combines the intensive technological know-how of Fraunhofer IZM with our in-depth expertise in firmware and hardware development.

Our activities focus on:

- RF design and characterization of materials, packages, antennas, and components (up to 220 GHz)
- RF system integration and module design- with particular attention to signal and power integrity
- Development of highly integrated radar sensor systems
- Design and construction of autonomous wireless sensor systems for industrial use
- Development of microbatteries and power supply and power management systems for autonomous devices
- Tools for the optimized design of microsystems and server-client software architectures for IOT applications

Compression-molded 3D radar antennas in a MIMO array can cover 180° of the surrounding space

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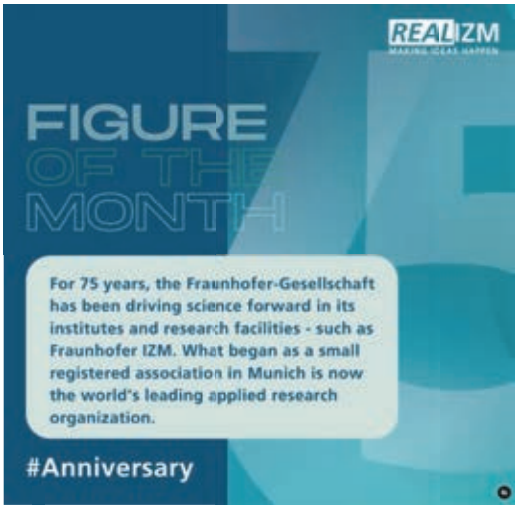
2024
Get Smarter with Fraunhofer IZM

Tutorials – Training – Expert Sessions – Blog

Fraunhofer IZM is now represented on all major social media channels and is continuously expanding its online presence. We offer further training opportunities on YouTube with online courses, while valuable contacts with industry experts are maintained on LinkedIn. We also reach both new and existing target groups on X, Facebook and Instagram with insights into our day-to-day work. Thanks to our rapidly growing number of followers, our reach is constantly expanding. You will find some examples of our work on the next page.

LinkedIn and Instagram allow a glimpse into everyday life at the Institute and make the work of our colleagues visible

Three of the seven »Green ICT@FMD« training videos produced to date for a specialist audience in science and industry



Video tutorials for green electronics

As part of the BMBF-funded »Green ICT@FMD« project, IZM's environmental experts in electronics and ICT products have created training videos that impart knowledge and skills for evaluating »green« ICT systems. This includes topics such as life cycle assessments, environmental legislation and current developments.

Fraunhofer IZM is responsible for the entire production of the training videos: conceptualization, script, creation of graphics, technical recording in the video studio and post-production. The videos are aimed at a specialist audience from the fields of science, industry and politics. The speakers in the videos are IZM colleagues, which strengthens visibility and networking in research.

https://izm.fraunhofer.de/greenICT-online

The only way is up: Four years of the RealIZM blog

With a mix of interviews, reports and videos, RealIZM, Fraunhofer IZM's science blog for microelectronics has established itself over the past four years as an online communication platform through which the Institute shares its latest research findings with the packaging community. Almost 500 people interested in microelectronics have subscribed to the blog newsletter so as not to miss an episode and 7,000 visitors visited our website in 2023 alone. Come and visit us too!

https://blog.izm.fraunhofer.de

Free and online: IZM Expert Sessions are very well received

»Heterogeneous integration - What's next?« was the name of the first workshop that IZM researchers held online in July 2020. Since then, the IZM Expert Sessions have been very popular with our customers. Around 30 seminars have been held in recent years, often with several sessions on an overarching topic such as new optical connection technologies, low-power systems, innovative substrate materials or miniaturized sensor systems.

https://izm.fraunhofer.de/workshops

In the Spotlight
Embedding for Power Electronics

Eckart Hoene

Power electronics will play a key role in decarbonizing our economic system. Their task is to convert the largely electrical energy several times on its way to the end consumer with as little loss as possible. Fraunhofer IZM has been researching for decades how this conversion can be realized as cost-effectively and efficiently as possible.

As the volume of power electronics is primarily determined by the size of the passive components, our research efforts have long focused on the sharpest sword for volume reduction: higher switching frequencies. The introduction of power semiconductors made of silicon carbide and gallium nitride quickly showed that these semiconductors are no longer limited in speed by themselves, but by the packaging of the power semiconductors. Parasitic electromagnetic effects lead to oscillations and overvoltages, which prevented the full potential of the semiconductors from being utilized.

With this in mind, Fraunhofer IZM presented power semiconductors embedded in printed circuit boards in combination with ceramic substrates to experts for the first time in 2013. The technology has created degrees of freedom for a good electromagnetic design with more wiring layers, as well as enabling the highly concentrated power loss of these semiconductors to be dissipated in a space-saving manner.

The major advantage of this compared to conventional modules is the reduction in switching losses. If you consider that, in an electric car with a SiC inverter, around 70 % of the inverter losses in the standardized driving cycle are switching losses, there is great potential here for a longer range. Over more than ten generations of power modules, IZM scientists have continued to optimize their properties so that switching losses have been reduced by a factor of four compared to the state of the art. This was achieved primarily by reducing the DC link inductance, a perfectly symmetrical current flow with 1D current flow direction and a damped primary DC link.

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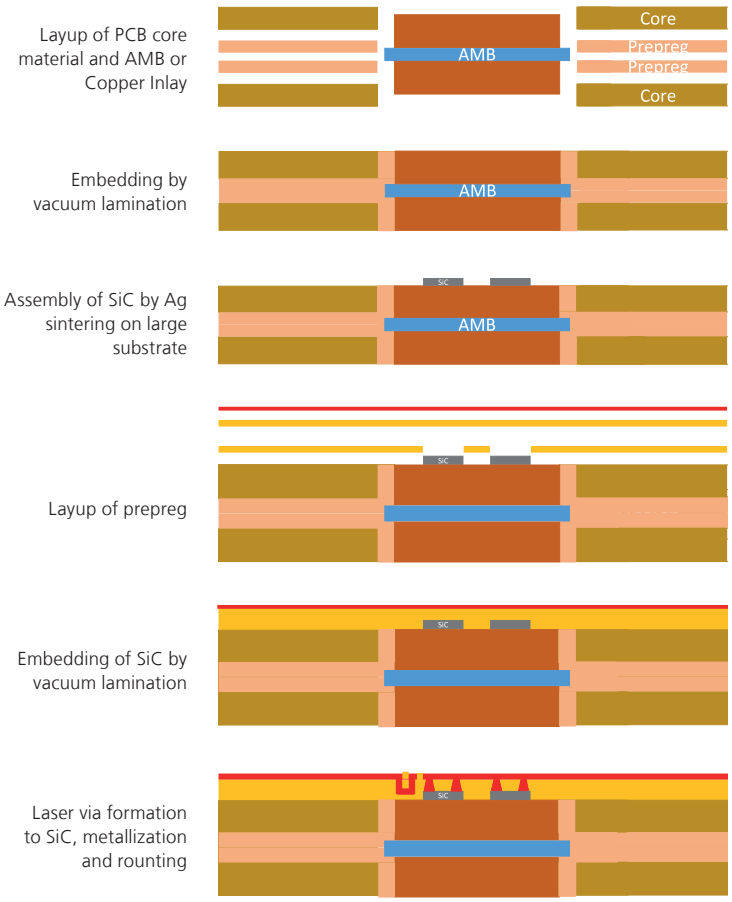

The process flow for embedding SiC power semiconductors in circuit boards

The basic structure of the assembly technology is shown in the figure above. The structure begins with the ceramic substrates, which can spread the waste heat of the semiconductors with thick copper, and the ceramic, which produces insulation with low thermal resistance. They are joined together in a lamination process to form a printed circuit board panel. The semiconductors are applied to the ceramic substrates using a silver sintering process. In the next step, the semiconductors are laminated in and the electrical contact to their top side is made possible by laser drilling. The electrical contacts are then produced in the electroplating process. Another layer is almost always laminated on top, then the module is finished. It can then be fitted with SMD components like a printed circuit board or soldered onto a heat sink. The electrical connections can be produced in a variety of ways, including the use of lasers to mount copper sheets onto the modules at Fraunhofer IZM.

Interest in the use of this technology in industry has increased significantly in the last two years and has led to a large number of projects at the Institute. Other suppliers now also offer this technology, meaning that Fraunhofer IZM is no longer the only partner for such projects. The duration and hurdles that a technology has to overcome before it can be implemented in series production are exciting. After initially having to solve production challenges in our company, which were mainly related to the combination of very different materials and their expansion coefficients, it is the proof of service life that now takes up a lot of time and resources. The lively research landscape in Germany is helpful for this, although a little more willingness to take risks in industry would be desirable.

In the Spotlight
Trusted Electronics

Jan Hefer, Karl-Friedrich Becker, Olaf Wittler, Markus Wöhrmann

1 Sensor module for in-line data capture, produced in a trustworthy manufacturing environment

2 Miniature crypto RFID chip, embedded by wafer-level thin-film technology

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With increasing globalization and more complex supply chains, electronic hardware is susceptible to tampering

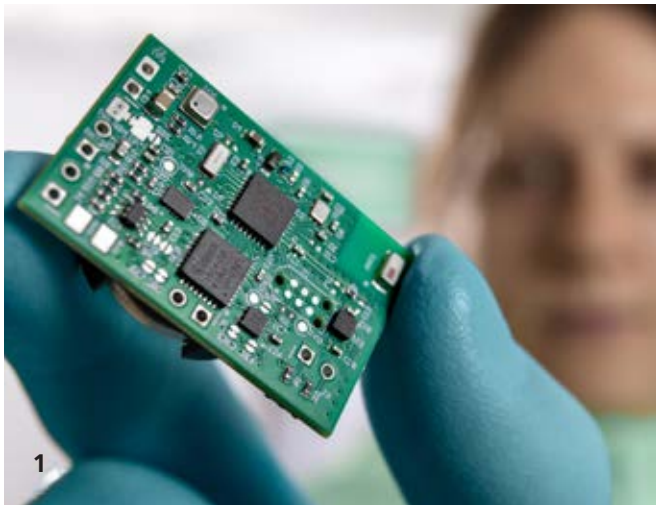
A chain is only as strong as its weakest link. This wisdom also applies to the Industrial Internet of Things (IIoT), autonomous and connected vehicles and important infrastructures, as high investments in software security alone do not guarantee a holistically secure system. Complete security for a wide range of applications based on electronic systems can only be achieved if the trustworthiness of the hardware is guaranteed.

While software vulnerabilities can often be remedied by patches or updates, correcting hardware – especially if a large number of affected devices have been placed on the market – is much more difficult, as redesigns or recalls can be very costly. The extent of damage is therefore generally greater if the hardware has been attacked or tampered with.

A risk assessment for the system or application under consideration forms the basis for deciding which measures are best suited to protect potential points of attack and minimize risks. For hardware-based critical infrastructures, for example, cost-intensive, multi-level security concepts would make sense, whereas simpler and therefore inexpensive solutions are required for consumer electronics. A cost-benefit analysis also plays an important role in the selection of protective measures.

Hardware-implemented protection mechanisms

Fraunhofer IZM's packaging technologies offer a wide range of options for helping to protect semiconductor components from physical attacks and tampering attempts. For example, shielding or concealing layers or structures can be applied to make it more difficult for attackers to access and tamper with internal elements of a component to be protected. However, such structures can also have sensory properties, so that intrusion detection is possible with their help or by embedding sensor functions in wiring or substrate levels. Integrated ID elements also serve to ensure the uniqueness of components.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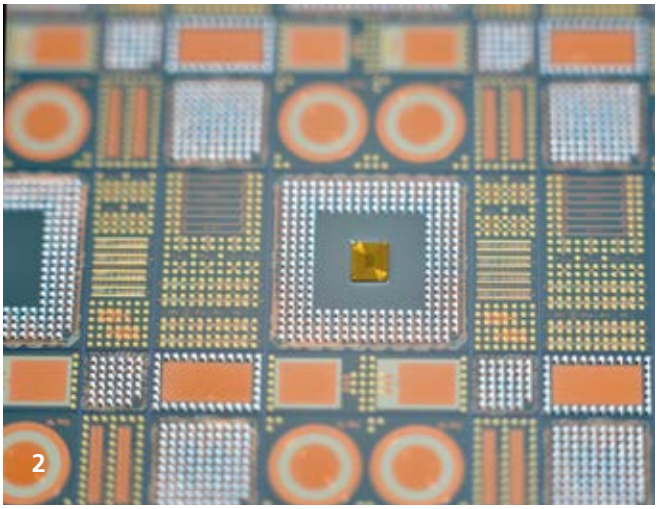
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By using technology-based protection concepts, companies can therefore increase the trustworthiness of their products and arm themselves against physical attacks and tampering attempts.

Trusted production as the basis for trusted electronics

The basis of Industry 4.0-oriented manufacturing is the networking of production facilities and the use of data to digitalize business processes. In addition to the data that production systems already supply, further process information and data directly from the workpiece and the production environment are required in order to achieve a holistic system view as a basis for production monitoring and optimization.

Current research into trusted manufacturing focuses on process digitalization for a manufacturing scenario in which high-value electronic goods are produced in a distributed manufacturing environment. The most important research topics are the implementation of a Chain of Trust (CoT) for trusted distributed manufacturing and the application of artificial intelligence and machine learning to analyze and optimize manufacturing processes.

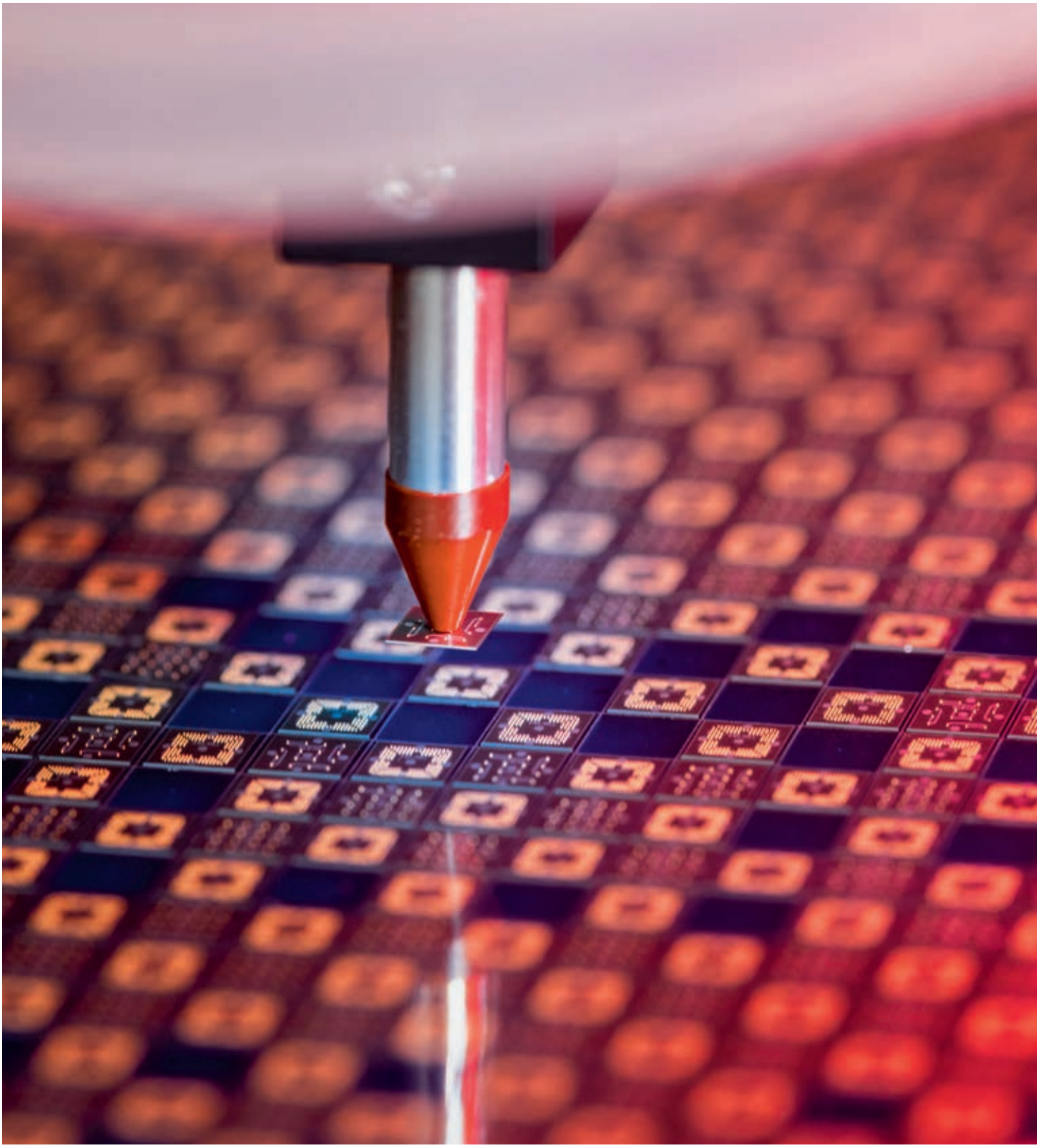
The experimental evaluation of these concepts in two assembly lines – including data acquisition, data processing and AI processing – has already been achieved with the aim of optimizing production in terms of higher production yield and product quality.

Evaluation of trustworthiness through a combination of analysis methods

The trustworthiness of all sub-components forms the decisive basis for the safety and reliability of a product. If components other than those originally approved for the product are installed, this results in incalculable risks.

Fraunhofer IZM has pooled its resources and expertise in order to reduce the risks posed by irregularly marketed components, counterfeits or tampering, so that suspected cases can be thoroughly investigated. IZM's specific knowledge in the design, process technology, analysis and testing of electronic components, assemblies and systems comes into play here.

This allows design and production differences to be identified and evaluated with the company concerned, so that conclusions can be drawn about production processes or production locations. Electrical characterization, in turn, helps to describe system behavior and detect malfunctions. All of the information obtained can provide a valuable insight into the reliability of the tested component or assembly.



Handling thinned chips

World Leader in Applied Research

A Strong Network

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft, based in Germany, is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. A trailblazer and trendsetter in innovative developments and research excellence, it is helping shape our society and our future. Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Almost 32,000 employees, predominantly scientists and engineers, work with an annual research budget of approx. 3.4 billion euros. Fraunhofer generates about 3.0 billion euros of this from contract research.

Research Fab Microelectronics Germany

In 2017, Fraunhofer IZM became part of the Research Fab Microelectronics Germany, also known as the FMD or Forschungsfabrik Mikroelektronik Deutschland. The FMD is a cooperation venture of the Fraunhofer Group for Microelectronics and the Leibniz Institutes FBH and IHP. It is the go-to place for all issues concerning microelectronics and nanoelectronics in Germany and across Europe. The FMD offers technologial solutions in numerous areas, such as sensor systems, power electronics, MEMS actuators, microwave und Terahertz, extended CMOS, chip- and chiplet design, optoelectronic systems as well as multi-project technologies. Furthermore, the FMD facilitates research cooperations on topics like resource efficiency, next generation computing, security, mobility, production and communication.

Along with the range of technological solutions and the coordination of large collaborative projects, the FMD also runs special formats for start-ups, SMEs and research groups, like the funding programs »Green ICT Space« and »QNC Space«.

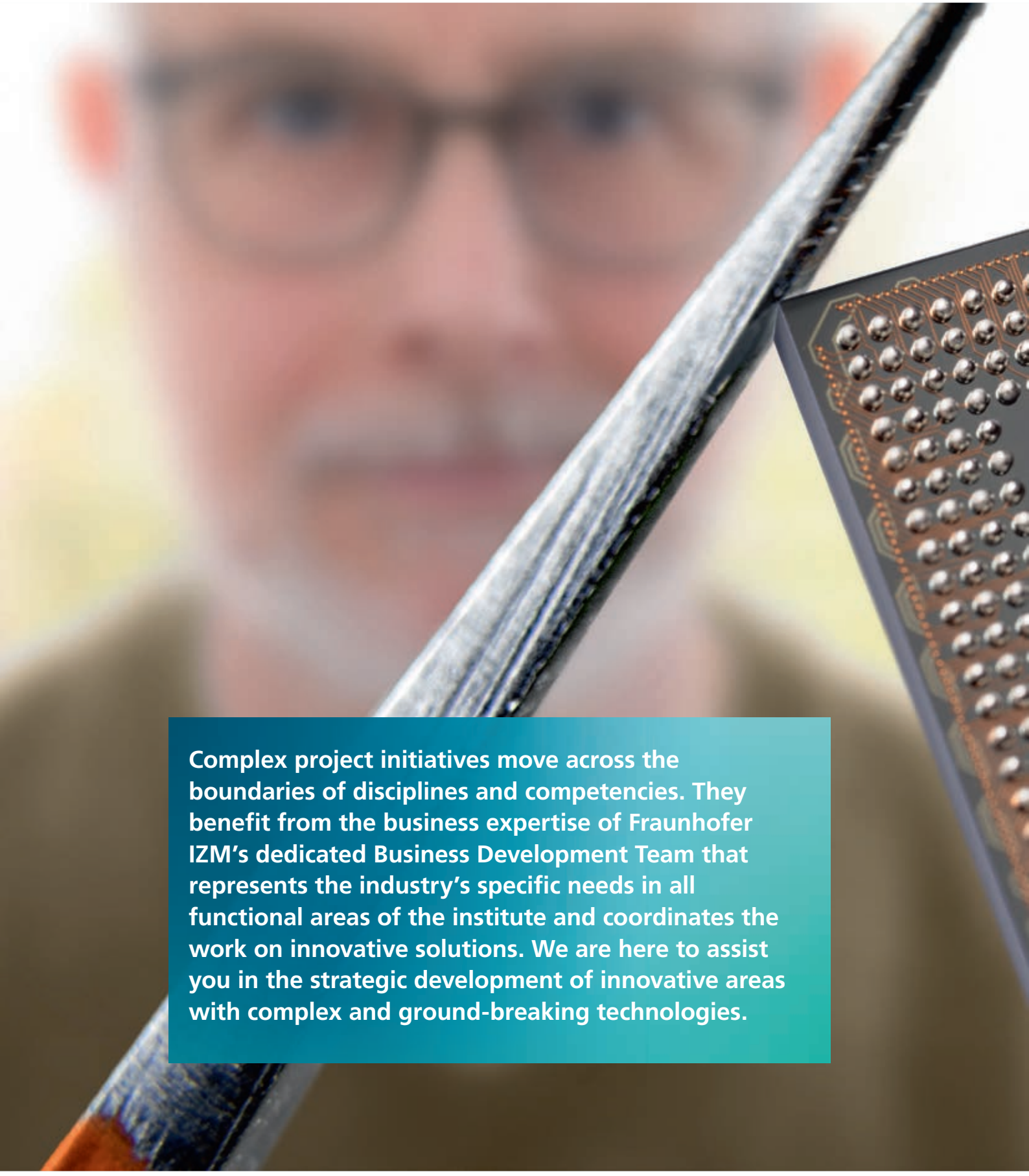
Over the coming years, the FMD intends to build the most comprehensive and advanced pilot line dedicated to chip integration for innovative, robust and trustworthy heterogeneous systems as a contribution to the EU Chips Act. This pilot line for Advanced Heterogeneous System Integration will enable state-of-the-art system design, interconnection and assembly technologies, and promote the innovative potential of the whole industrial spectrum in Europe.

High-performance Centers

The High-Performance Center »Functional Integration of Micro- / Nanoelectronics« supports SMEs in Saxony with know-how in 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-ASSID, as well as the Technical Universities Dresden and Chemnitz and the HTW Dresden are members of the Center.

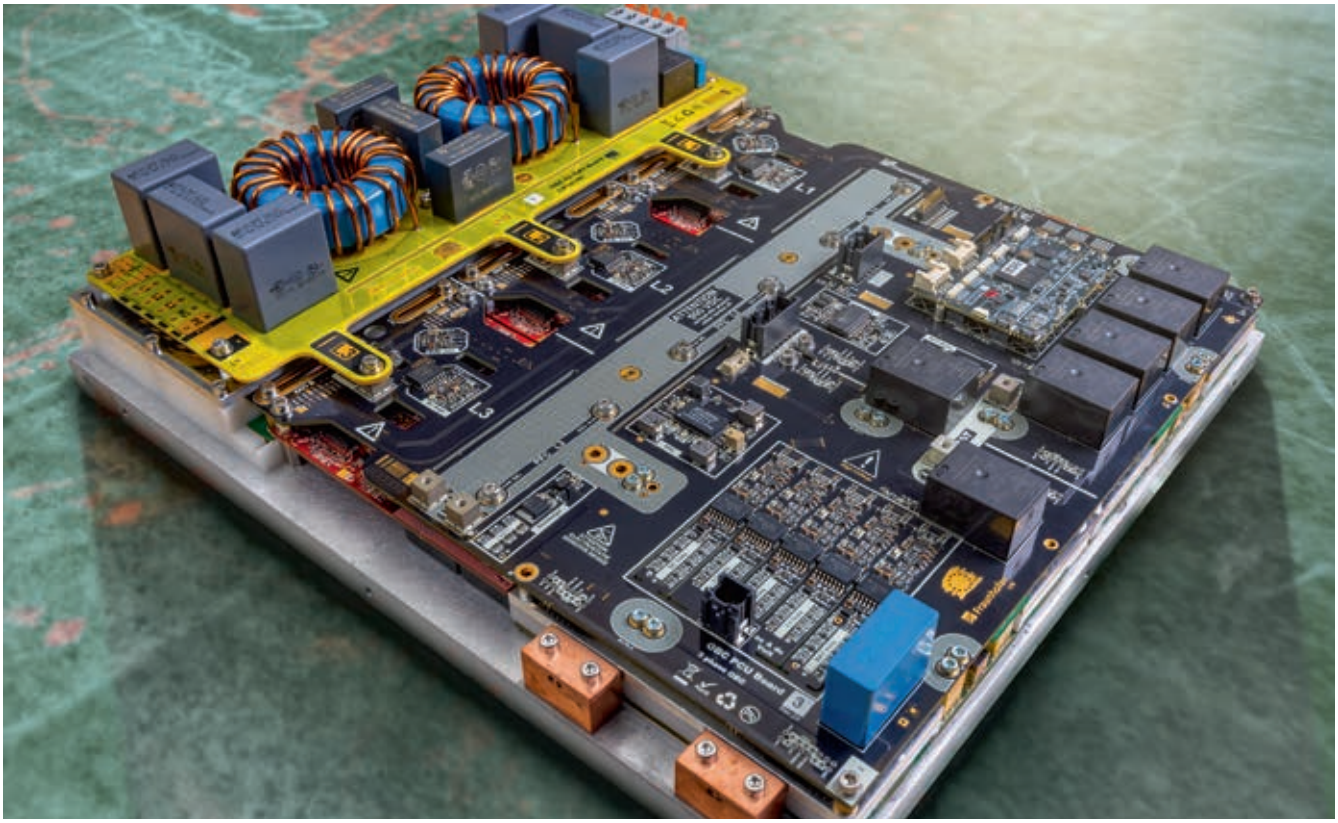
The »Berlin Center for Digital Transformation« is a collaborative venture involving the four Berlin-based Fraunhofer institutes FOKUS, HHI, IPK und IZM. Its work focuses on technologies and solutions that advance increasing digitalization and networking in all areas of life.



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

Business Units & Industry Sectors

Automotive and Transportation



Innovative 22 kW on-board charger developed at Fraunhofer IZM

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.

Fraunhofer IZM develops cost-efficient bidirectional charging unit for electric vehicles

On-board chargers (OBC) are indispensable in modern electric vehicles. To minimize production costs, Fraunhofer IZM is developing an innovative bidirectional 22 kW system based on planar transformers and coupled inductors. The inductive components built using established PCB technology are optimized with regard to the uniform current distribution in the windings as well as the flux density distribution and the macroscopic eddy currents in the magnetic core using 3D field simulations. The OBC works worldwide in 3-phase and 1-phase networks in a very wide input voltage range and can be used for both 400 V and 800 V batteries. This achieves an efficiency of over 97 % with a volume of three liters.

Radar-based 3D environment detection for safe collaboration between man and machine

In a factory, man, machine and the connecting intralogistics system must work together safely. The PLATON project is developing an integrated sensor and data processing platform that evaluates 3D radar data both on different time scales and spatially distributed using AI. The functionality is to be tested through the interaction of several automated guided vehicles (AGVs). A MIMO radar is combined with a SAR radar for safety-compliant detection of the environment. Fraunhofer IZM is developing the integrated front-end modules and also the signal processing for the MIMO radar. By merging the data from the two radar systems as well as the data from the various AGVs, the environment can be recorded with the required level of certainty. Fraunhofer IZM developed the hardware for this. The project is funded by the Federal Ministry of Education and Research.

Development of a dynamically adaptable radar front end for monitoring and controlling air traffic

Studies see the use of airspace by UAS (unmanned aircraft systems) as the future of regional passenger and goods transportation. The resulting intensive use of airspace, particularly in conurbations, requires efficient monitoring and control of traffic flows. In the AKIRA-UTM project, Fraunhofer IZM is working with Fraunhofer FHR to develop scalable ground-based radar systems for locating and positioning the UAS and for communication between the UAS and between the UAS and the UAS traffic management system (UTM). The radar systems are distributed over a wide area. The networking of the individual ground radar systems ensures interference-free radar and communication functionality. Fraunhofer IZM is developing an adaptable MIMO radar front end with a detection range of 180°, whose angular resolution can also be adapted horizontally and vertically during operation. The project is funded by the Bavarian State Ministry of Economic Affairs, Regional Development and Energy.

A coupled RadCom sensor network for monitoring the airspace

Medical Engineering

The REMEDIA sensor bracelet keeps track of 40 environment factors to see which affect respiratory diseases

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.

Non-contact patient monitoring – ECG by radar

Rural areas suffer from a lack of medical care, particularly when it comes to high-quality diagnostics. The situation is to be improved by adapting sensor concepts from the context of Industry 4.0 to medical diagnostics. Example ECG: By using radar technology, monitoring can be carried out contact-free and from a distance, and the data can be made available to the attending physician or telemedicine service providers via a secure data interface. The developed radar sensor can detect heart and respiration values through clothing, comforters and even mattresses and transmit them to the monitoring devices. The sensors emit electromagnetic waves that are reflected by the body. In practice, it works something like this: The blood ejected by the heart runs along the vessels in the form of a pulse wave, which appears as a vibration on the surface of the body. This is measured using the sensors. The project is a joint project as part of the Innovation Campus Electronics and Microsensor Technology Cottbus.

Wafer-level technologies enable novel brain implants

The MINIGRAPH project focuses on developing a groundbreaking neuroelectronic therapeutic method that uses a new generation of brain implants with closed-loop capabilities. This is made possible with a flexible electronics unit and high-density arrays of graphene micro-electrodes implanted in the patient's head. The highly miniaturized system features high spatial resolution and optimal biocompatibility with brain tissue. Wafer-level technology allows the production of entire implant systems with e. g. electrodes, sensors, and signal processing capabilities on a single wafer substrate. The wafer-level approach that embeds thin dies in redistribution layers boosts functionality, while minimizing size and keeping power consumption and manufacturing costs down. Moreover, the inherent repeatability of wafer-level processes ensures consistency and reliability across devices, which is crucial for medical applications. Hermetic sealing is achieved by e. g. thin-film encapsulation using biocompatible coatings. Such sealing is crucial for the device's performance and biocompatibility. It protects the delicate electronic components from external forces like fluctuating temperatures or the corrosive effects of bodily fluids and lowers the risk of infection.

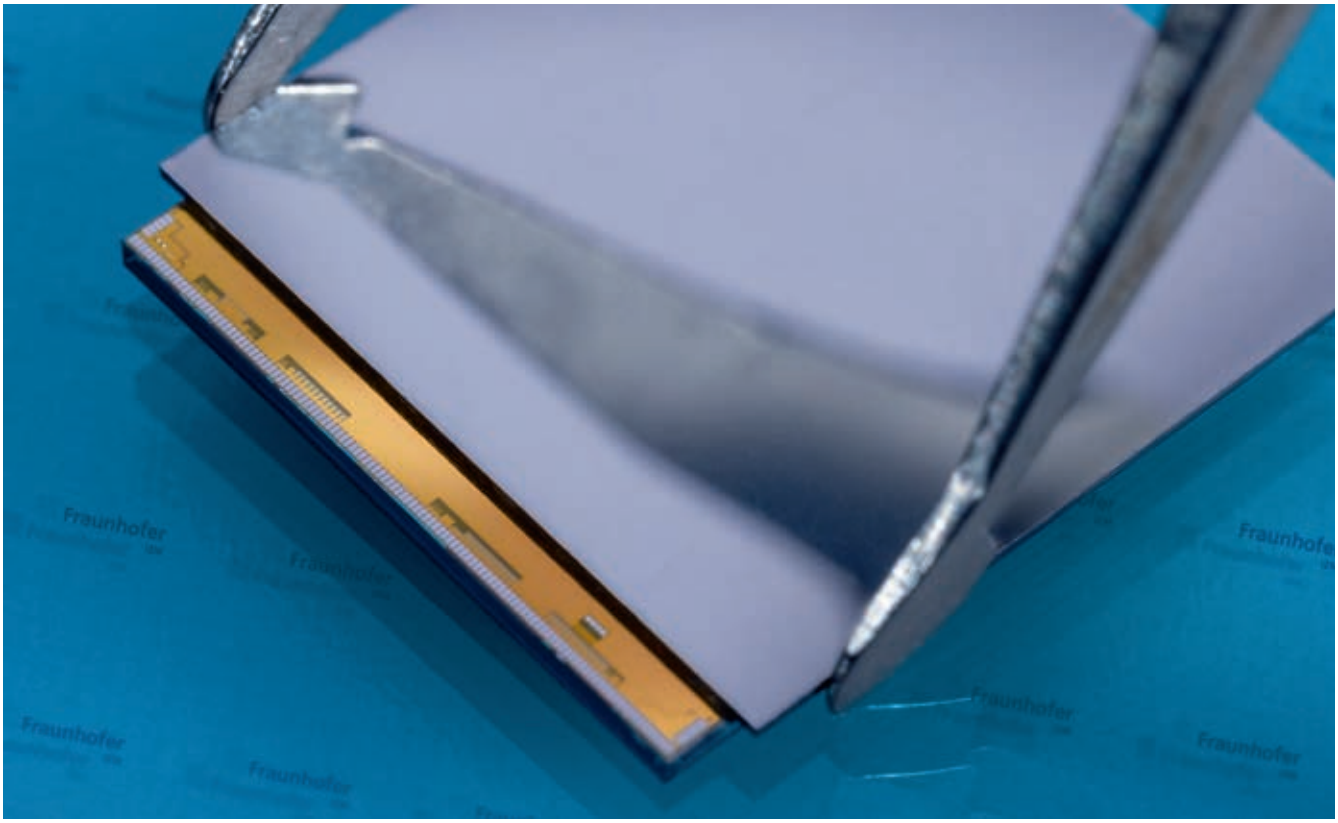
REMEDIA - wearable multi-sensor system bracelet

From birth, people are exposed to a variety of external environmental influences, such as fine dust and toxic gases. These external factors, known as the exposome, have long-term effects on human health. Within the EU-Projekt REMEDIA, the impact of the exposome on the progression of lung diseases is being investigated. IZM researchers have developed a wearable multi-sensor system in the form of a bracelet that can digitally record and document over 40 different harmful substances, even in the lowest concentrations. These devices are used by subjects in their everyday living environments for research studies.

Simultaneous energy and data transmission for deep implants by means of ultrasound

The Technologies for Bioelectronics group at Fraunhofer IZM, together with partners from the EU-wide consortium Moore4Medical were the first to demonstrate ultrasonic delivery of instantaneous mW-range DC power to deep implants. This was achieved using micromachined ultrasound transducers and a dedicated microchip which are part of an open platform developed as part of the project. The scientists also developed a robust scheme for ultrasound communication from deep implants based on backscattering and frequency-shift-keying and demonstrated its superior performance over the conventional on-off-keying during movement.

Semiconductors



Hybrid pixel detector module with silicon sensor for use in X-ray exams

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

Environmental improvement in semiconductor production through wafer recycling

The »GreenICT@FMD« project investigates and promotes sustainable processes in the context of microelectronics and assesses their potential for reducing greenhouse gases. Fraunhofer IZM has developed a process for recycling monitor wafers. Monitor wafers are test wafers that go through the same steps as »real« wafers. These can be recycled using a process at the institute and reused as interposers. During recycling, existing photoresist and several metal layers are removed in three process steps (stripping, copper etching and TiW etching). The SiO2 layer remains on the wafer for the next application. Such recycling means that new production and the associated environmental impact of a wafer can be avoided. This was demonstrated by the ecological assessment of the processes based on chemical and water consumption.

Packaging of high-performance computing modules

Fraunhofer IZM has levelled up its advanced packaging portfolio with a special focus on wafer-level packaging (WLP) for high-performance computing (HPC) modules. Silicon interposers using through-silicon vias and ultra-fine pitch multi-layer wiring for connecting chips and routing signals has proven itself as the major platform for chiplet integration.

The well-established multi-layer copper redistribution technology has been scaled down to enable routing schemes at 4 µm line/space (8 µm pitch) and less. Wafer-level packaging of HPC modules also uses flip chip assembly, underfilling, compression molding, ball soldering for second level IO formation.

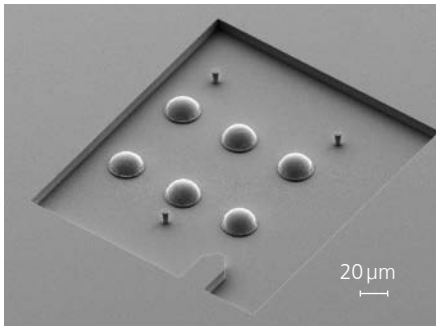
Development of a photonic electronics platform

The BMBF-funded »Silhouette« project (Silicon Photonics for Trusted Electronic Systems) aims to develop a heterogeneous, standardized, and modular electro-optical platform for open processor systems for use in communication and data transfer security solutions in the field. This is meant to allow photonic components to be flexibly connected to open processor systems via optical and electrical interfaces. The focus is on converting sensitive electrical into tap-proof optical signals using photonic encryption hardware to enable secure communication.

Fraunhofer IZM's key contribution to the project lies in developing the conceptual design and processing technology and subsequently manufacturing the electro-optical interposer and assembly of optical and photonic components, with particular attention to the precise alignment of electro-optical interfaces. With a diameter of less than one micrometer, waveguides on optical integrated circuits are extremely small. Fraunhofer IZM is developing a passive alignment system based on solder-supported self-alignment with integrated mechanical stops

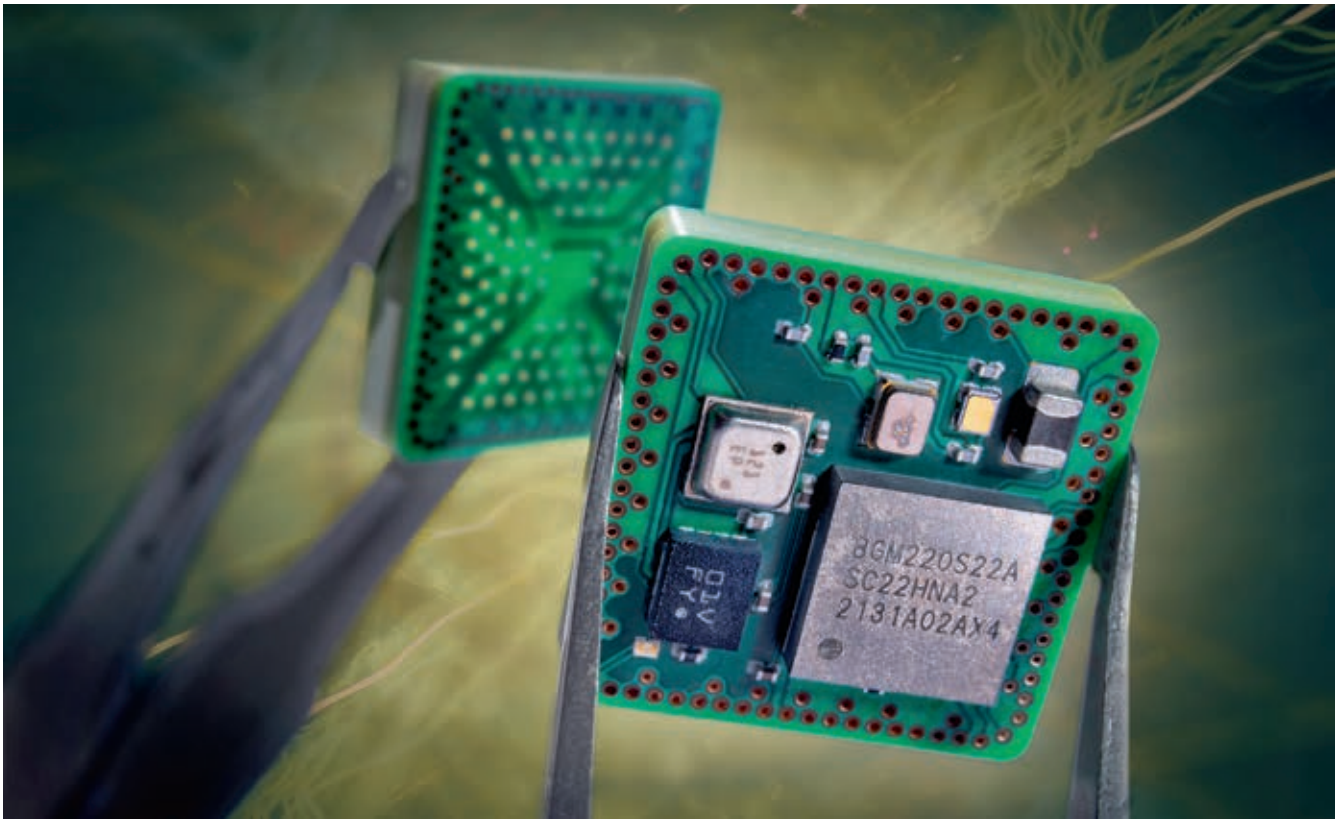
Know-how protection for trustworthy, heterogeneous electronic systems with chiplets

For the BMBF-funded VE-REWAL project, a platform for trusted electronics is being developed and demonstrated in action in the form of a 77 GHz radar MIMO system using a chiplet design. Fraunhofer IZM's work happens on the »RDL-1st for Trusted Chiplet Packaging« sub-project, where the essential process blocks for the RDL-1st FOWLP technology are being refined and the functional demonstrator is constructed. The new work addresses novel materials, wiring densities, and failure mechanics, and thermomechanical simulation models are created and verified. Technology demonstrator packages with five chiplets have already been successfully manufactured and electrically tested.



Etched cavity on a photonic IC with silicon stops and flip-chip solder bumps for passive laser alignment

Industrial Electronics



Highly miniaturized edge IOT module

In recent years Fraunhofer IZM's industrial electronics specialists have concentrated on the visionary concept of Industry 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. Industry 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.

New condition monitoring concept for humidity stress

In the internal Fraunhofer project »power4re« (reliable converters for regenerative energy supply), a new type of condition monitoring concept was developed for monitoring assemblies exposed to moisture. For this purpose, a circuit was implemented that monitors specially designed status indicators. The results of this monitoring enable targeted maintenance activities to reliably maintain the operational capability of applications in environments exposed to moisture.

Plug & play radar – Fraunhofer IZM radar platform

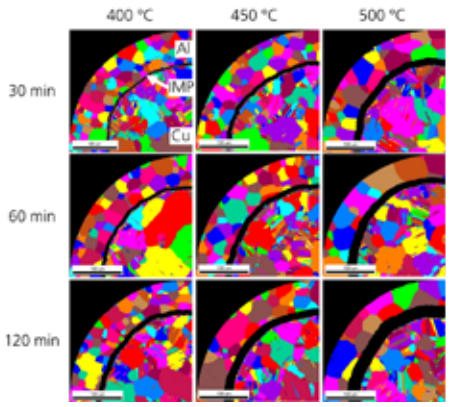
The increasing availability and large selection of commercially available radar sensors makes non-contact radar technology interesting for many applications. The radar platform offers a solution-oriented introduction to this technology. Unlike evaluation boards, the radar platform, consisting of a smaller radar sensor board with minimal circuitry, a mainboard and software libraries, allows users to either use the sensor unchanged in their project or use it as a starting point for their own development. The ISM bands (industrial, scientific and medical) are available at 24 GHz (0.25 GHz BW) and 61 GHz (0.5 GHz BW) as well as the automotive short-range radar (SRR) at 79 GHz (4 GHz BW).

EBSD analyses on the successful completion of the »AlCuBo« project

The »AlCuBo« project (»aluminum copper bonding wires for power electronic modules«) was successfully completed with intensive and informative EBSD (electron backscatter diffraction) analyses. These analyses make it possible to visualize the changes in the microstructure of the wire materials as well as the change in the average grain size and the intermetallic phases after different heat treatments. In addition, the combination with EDX (energy-dispersive X-ray spectroscopy) made it possible to distinguish the face-centered cubic materials, which are difficult to differentiate by EBSD, very well.

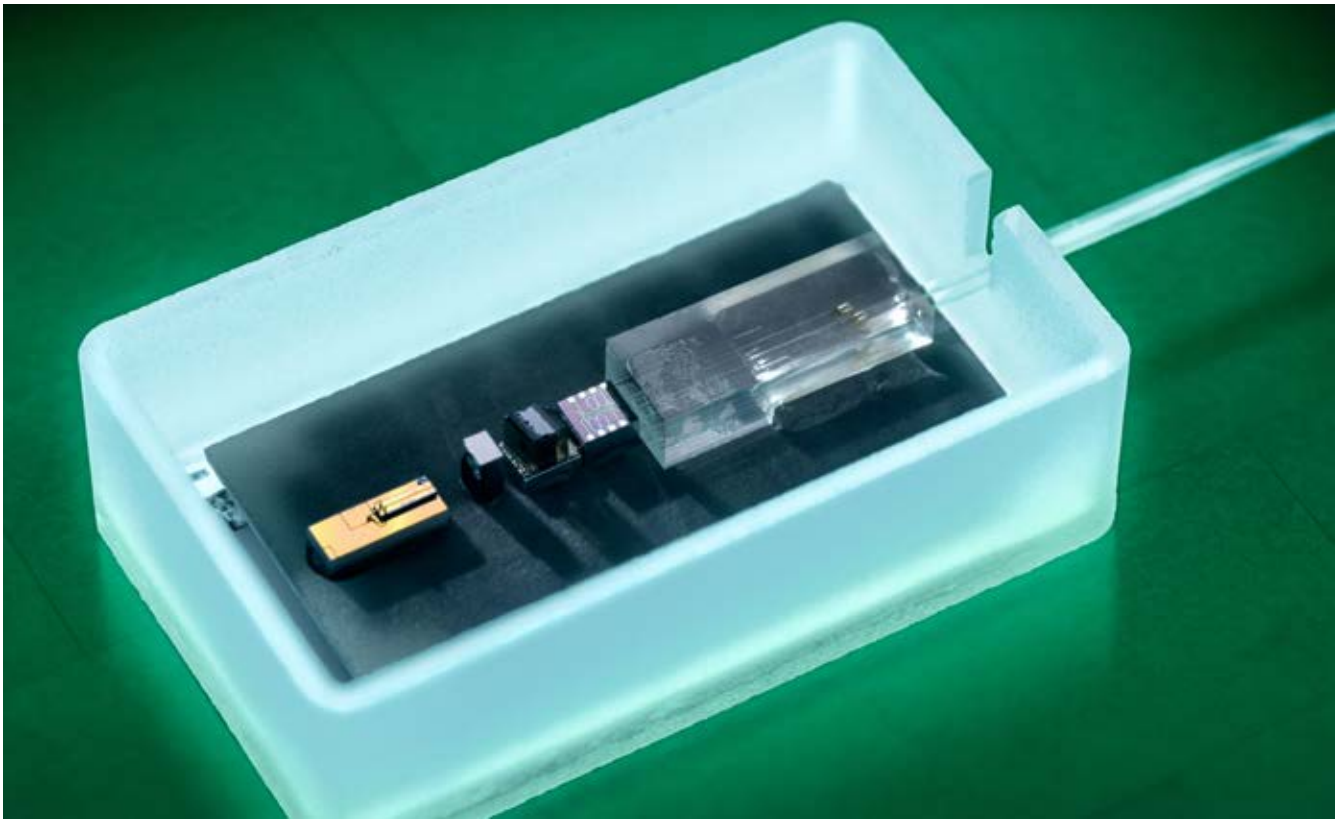
AI at the Edge – condition monitoring for construction machinery

Fraunhofer IZM is working together with colleagues from BTU Cottbus-Senftenberg and Fraunhofer IPMS to record the current machine condition of construction machinery. A particular challenge is the early detection of wear conditions under harsh operating conditions. In some cases, the use signals are orders of magnitude lower than the signal levels resulting from normal operation. Multi-parameter measurements provide the basis for detecting changes in system behavior at an early stage. The signals are merged and pre-evaluated in an energy-efficient data processing system. In the event of anomalies, high-performance AI-based data processing is activated. The results are transmitted to the operator.



EBSD image of the heat-treated wire lengths (annealing temperature and time on the X and Y axes), each showing a quarter of a 500 µ AlCu wire. The black ring represents the intermetallic phase

Information and Communication



Glass-based package for semiconductor lasers coupled to a photonic chip (PIC)

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

Environmental forecast for 5G networks in Germany

The study »Environmental Technology Impacts Assessment for Mobile Communications in Germany« (UTAMO) was carried out by Fraunhofer IZM on behalf of the Federal Environment Agency and includes a rough ecological assessment of the German mobile networks for the baseline year 2019 as well as forecasts of developments up to 2030. To this end, a life-cycle-oriented inventory model was developed that quantifies the carbon footprint of device manufacturing and the electrical power requirements of radio access and aggregation networks. To minimize the future environmental impact of mobile networks, the study also developed packages of measures that specify, for example, network and site planning, aspects of system modernization and options for active load and energy management.

Packaging for cryogenic quantum computing

The technological realization of quantum computing depends on the number of available quantum bits or qubits. Integrating the control electronics into a cryogenic environment is a promising avenue towards this goal. It needs high-density superconducting lines and connections between the quantum processing unit (QPU) and the control electronics (QCI) and a thermal decoupling at the same time. For this purpose, IZM-ASSID is developing a scalable packaging solution based on a rigid-flex interposer. The integration technologies used for the purpose include superconducting TiN lines (sc RDL) and in-bump bonds (sc bump bonds).

Ecological assessment of a modular laptop

Modular end devices offer the possibility of easier repair and more precise fitting and have experienced a small revival in recent years in the context of »right to repair«, among other things. As part of a life-cycle assessment, Framework's modular laptop was examined and its carbon footprint and abiotic resource consumption evaluated. The greenhouse gas potential is mainly driven by the display module and the resource consumption by the gold contacts, especially on the RAM module.

Quantum system packaging

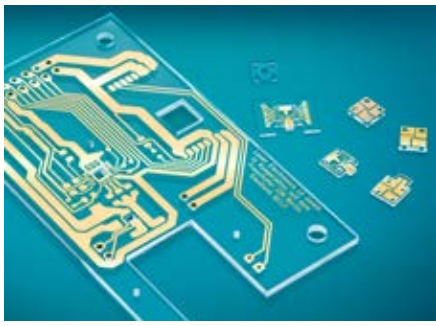
At Fraunhofer IZM, innovative quantum chips were embedded in laser-structured thin glass packages and optically/electrically coupled using large-format structuring and assembly systems procured as part of the ERDF project »QPLa«.

The starting material for this are large-format thin glass panels, which can be laser-etched with a precise structure or metallized. The individual packages, which are almost freely scalable in terms of size and quantity, can also be operated at low temperatures and in a vacuum for applications in quantum computing and quantum sensor technology thanks to hermetization.

6GKom research for the mobile communications of tomorrow

While the fifth generation of mobile communications (5G) is currently being launched on the market, Fraunhofer IZM is working on the hardware basis for the next 6G mobile communications standard in the »6GKom« project with partners from TU Berlin, TU Dresden, Ulm University and the IHP in Frankfurt/Oder. The central element is a »massive MIMO antenna module« for the frequency range from 110 to 170 GHz, which allows active control of the antenna beam. This allows data rates of several Tbit/s to be achieved and enables very precise localization applications. Based on an innovative system integration platform, a new type of co-design approach is being implemented that encompasses the chip, package and antennas together. In addition, new baseband architectures and test procedures for the metrological verification of the 6G application are being researched, taking into account the parasitic THz effects.

A modular laptop made by Framework with a lifecycle assessment produced by Fraunhofer IZM



Bare thin-film circuit carriers on different thin glas formats, laser structured and ready for fs laser etching to accommodate photonic components with micrometer precision

Labs & Services

System Integration

Wafer-Level Packaging Line

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

Process Modules (up to 12")

- Cu-TSV integration (via-middle and via-last-processes)
- Silicon and SiC plasma etching – DRIE (TSV, cavities)
- Multilayer thin-film deposition (PVD, CVD, ECD, lithography (resolution up to 0.5 µm), mask aligner, reactive ion beam etcher)
- PECVD process chamber (200/300 mm) for the deposition of TEOS oxide, Silane oxide and Silane nitride
- High-density thin-film multilayer (Cu/polymer RDL, Cu-Demascene)
- Wafer-level bumping (Cu-Pillar, SnAg, Ni, Au, In, UnSn, AuSn, Cu-nano interconnects, nanoporous Au)
- Wafer thinning und thin wafer dicing (blade, laser grooving and stealth dicing)
- Wafer bonding – permanent and temporary
- Wafer-level assembly up to 300 mm (D2W)
- Automatic inline wafer metrology for layer thickness, topographies, roughness as well as TTV / warpage / bow
- Fully automated electric wafer measurement system (8" / 12")

Substrate Line

In the substrate area panel-size substrates (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. Track geometries with down to 2 µm width are under development.

Our services include:

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

Mold Encapsulation Lab

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

- 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

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
- Hermeticity test
- Fluxless soldering of printed circuit assemblies using active gas in oxygen free nitrogen or vapor phase atmosphere
- 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 microlense 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
- Fs writing processes and thermal ion exchange for integrated optics in glass

Quantum Lab

- 3D glass structuring with selective fs laser etching
- 2PP printing of microoptical interconnects / lenses
- Laser sealing for hermetic cavities (vacuum / gas)
- Automated coupling for quantum chips / PICs
- Characterization of optical fields (SNOM)

Material Analysis

Moisture Lab

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

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
- Component and assembly qualification in acc. with AEC, IPC, JEDEC

Power Lab

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

Design

High Frequency Lab

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

Microelectronics Lab

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

Further laboratories include:

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

The speakers at the gala celebrating 30 years of Fraunhofer IZM (left to right): Dr. Axel Kaschner (Robert Bosch GmbH), Dr. Roland Krüppel (BMBF), Professor Martin Schneider-Ramelow (Fraunhofer IZM), Secretary of State Dr. Henry Marx (State of Berlin), Professor Geraldine Rauch (TU Berlin) and Professor Axel Müller-Groeling (Fraunhofer Society)

Events & Promoting Young Talents

Happy Birthday, Fraunhofer IZM!

Fraunhofer IZM turned 30 this year! From the first groundbreaking invention, electroless nickel bumping, to current research into chiplets and autonomous functions, we look back on three decades of pioneering research in the field of microelectronic packaging. We celebrated the milestone birthday in September with many guests.

There were also many other IZM activities at trade fairs, conferences and workshops. 2023 will be remembered as the year in which our event activities returned to »business as usual«. Colleagues once again presented their research findings at conferences around the world and the Institute presented itself at trade fairs in Germany and abroad. But even though the majority of all the events were able to take place live again, online formats have maintained their firm place in Fraunhofer IZM's event repertoire even after the pandemic. This year there were two online session series, that were very well received and drew over 450 interested parties to their screens in a total of seven sessions.

On the following pages you will find a selection of events that Fraunhofer IZM organized itself in the past year or in which IZM colleagues were involved. In 2023, as in the previous year, this included a particularly large number of events aimed specifically at young people.

Events

30 years of Fraunhofer IZM - Around 200 guests attended the symposium and gala event on 28 September 2023

30 years of Fraunhofer IZM

Fraunhofer IZM celebrated its 30th anniversary in 2023. To celebrate this milestone in style, a specialist symposium was held at the main site in Berlin on September 28, 2023. Under the title »Crossing Frontiers in Microelectronics«, the researchers showed how they intend to tackle the major challenges of our time such as chip shortages, increasing data rates, and the energy crisis in the coming decades. The presentation topics ranged from high-performance computing and sensor technology to mobility and sustainability. The symposium, which was attended by renowned industry partners, was followed by a ceremony with high-ranking representatives from politics and research.

Fraunhofer IZM was founded three decades ago by a visionary group of German scientists. Today, the Institute employs over 400 people at three locations and has made a significant contribution to the future viability of microelectronics with 6,000 publications and 350 patents over the last 30 years.

Network meeting »Women at Fraunhofer IZM«

Last year, Fraunhofer IZM held four events, each with 30 to 50 female participants from all three Institute locations, to specifically promote networking among female employees and train them on overarching topics such as social media, networking, presentation techniques, and further training opportunities.

The feedback on the events was extremely positive and was mostly associated with the desire to extend the format. The participants particularly praised the opportunity for exchanging ideas and the growing support among the participants – even after the events in everyday business. The successful initiative

The IZM birthday bash went on long into the night

is already being adapted by other Fraunhofer Institutes, which underlines the relevance and added value of these events.

Lab Week 2023

Lab Week takes place annually and enables interested IZM employees to become acquainted with the diversity of research at their own Institute in all four departments. Everyone should have the opportunity to expand their horizons and get a taste of the lab! Various laboratories open their doors and dedicated colleagues show and explain clearly what is being investigated, researched and developed there. Lab Week 2023 was particularly impressive: A total of 33 guided tours took place over five days, conducted by 24 lab guides and co-organizers and attended by 172 colleagues.

Learning from Fraunhofer experts

Last year, we were once again able to reach a large number of interested parties with our free Online Expert Sessions. Two free lecture series looked at different areas of micro-electronics. In the spring, the »Low Power Systems« series offered an introduction to the complex world of particularly energy-efficient systems, such as those required for outdoor devices where the battery cannot be replaced regularly. Our experts recorded over 130 registrations in three compact sessions. In return for the great interest in this important field of research, our experts offered a thorough introduction to the topic and an outlook on Fraunhofer research in this area.

The »Materials for Electronic Innovations« series was launched in the fall, focusing on innovative base materials for semiconductor production and their environmentally friendly use. Research into new substrate materials for state-of-the-art packaging processes is one of Fraunhofer IZM's core competencies, which

Events organized by Fraunhofer IZM (Selection)

Session Series »Low-Power Systems«	March 2023
Fachsymposium »Crossing Frontiers in Microelectronics«	September 2023, Berlin
Expert Talks »Materials for Electronic Innovations«	October – December 2023
Radar Signal Processing Based on TI-Ecosystem	November 2023
Materials for RF Applications – Understanding Requirements and Material Characterisation	November 2023
Neuro-Technology Symposium	December 2023

was reflected in the large number of registrations: More than 320 registered interested parties wanted to be convinced by the collective expertise of our researchers.

Kick-off meeting for the »AGRARSENSE« project at Fraunhofer IZM

At the kick-off meeting in early 2023, the various representatives of the European »AGRARSENSE« project gathered at Fraunhofer IZM in Berlin to jointly define the work packages for the first project phase and set goals for the collaboration.

The project is driving forward urgently needed digital innovations for sustainable management in agriculture and forestry. It supports the implementation of aspects of Industry 4.0 and »Smart Farming« as well as sustainability aspects through the targeted use of energy and resources for healthy, sustainable production.

The »AGRARSENSE« project initiative is coordinated by the Swedish partner KOMATSU and the Fraunhofer Institutes EMFT and IZM. As part of the project, the corresponding ICT and the data management level are being developed. The project is funded as part of the EU Key Digital Technologies Joint Undertaking (KDT JU) and brings together 52 partners from 15 EU countries.

Neurotechnology Symposium at Fraunhofer IZM

Multidisciplinary collaboration is one of the cornerstones of successful research. For this reason, the »Bioelectronic Technologies« group organized a neurotechnology symposium at Fraunhofer IZM in Berlin in December 2023.

Laboratory tours, networking and specialist presentations were on the agenda. IZM colleagues Vasiliki Giagka, Andreas Ostmann and Christine Kallmayer as well as Wouter Serdijn and Achilleas Savva from the Bioelectronics Group at Delft University of Technology presented their current research findings in the fields of bioelectronics, neural interfaces, miniaturization, and system integration technologies.

From Berlin to Australia for the climate

Last year, numerous colleagues again took part in the City Cycling campaign with great success and were able to set a new record. City Cycling is a nationwide initiative to promote cycling, in which small teams compete against each other within or across Institutes: The aim is to cover as many kilometers as possible on the saddle in 21 days, either alone or on shared bike tours, and thus promote cycling and climate-friendly mobility. The Fraunhofer IZM team topped last year's good result once again: 75 colleagues from all locations cycled over 20,000 kilometers. They could have easily made it to Australia and even a little further. Congratulations on this great success!

Events with Fraunhofer IZM participation (Selection)

SPIE Photonics West 2023	January, San Francisco (USA)
embedded world 2023	March, Nuremberg (D)
IMAPS Seminar	March, Illmenau (D)
PCIM Europe 2023	May, Nuremberg (D)
SMTconnect 2023	May, Nuremberg (D)
SENSOR+TEST 2023	May, Nuremberg (D)
ECTC 2023	May, Orlando, Florida (USA)
EMPC 2023	September, Hinxton (UK)
FMD.iDays 2023	September, Berlin (D)
MikroSystemTechnik Kongress 2023	October, Dresden (D)
Compamed 2023	November, Düsseldorf (D)
SEMICON Europa 2023	November, Munich (D)

The Long Night of the Sciences had something in store for old and young alike

Hands-on research – Long Night of the Sciences 2023

On June 17, 2023, Berlin's research institutions opened their doors to the Long Night of the-Sciences for the 21st time and, for the first time since 2015, Fraunhofer IZM was once again represented with various hands-on highlights. Some of the activities were aimed specifically at very young visitors. They were able to decorate a bag with fabric flowers and LEDs in the textile lab, for instance. Once they'd got warmed up, they were allowed to pick up a soldering iron in the Start-a-Factory laboratory and make a mini metal detector.

Young and old alike were very determined when it came to generating energy on a bicycle. Depending on how hard the pedals were pushed, the energy generated could be used to keep a coffee warm or power a blender, for example.

Our colleagues from the environmental department taught the visitors how to extend the service life of high-tech devices and minimize their environmental impact. Under the heading of »modular design«, it was shown how smartphones could be made repairable and recyclable and how recyclable high-tech devices could be manufactured locally.

With around 400 interested guests, the Long Night of the Sciences was a complete success for Fraunhofer IZM.

IZM researchers at IMAPS 2023 in the USA

The 56th International Symposium on Microelectronics (IMAPS 2023) took place from October 2-5, 2023, in San Diego, California, and attracted nearly 800 participants from around the world. A highlight of the symposium were the 14 Professional Development courses, which looked at the latest research findings in microelectronics. In these courses, two of which were led by IZM researcher Prof. Dr. Ivan Ndip, participants had the opportunity to take a deep dive into areas such as design, manufacturing optimization, and wafer-level and panel-level technologies. In addition, IZM colleagues gave several presentations on wafer-level and panel-level packaging topics at the symposium.

Fraunhofer IZM at trade fairs

Fraunhofer IZM on the road... the Institute traveled to trade fairs and congresses in San Francisco, Cambridge and Dresden in 2023. It all started in February with Photonics West in San Francisco, where IZM researchers presented the latest developments in the field of photonic packaging.

This was followed in May by the trade fair trio of Sensor + Test, PCIM and SMTconnect in Nuremberg – a logistical challenge for everyone involved every year. The undisputed highlight of the SMT for many years has been the Future Packaging production line, supervised and masterfully staged by IZM colleague Ulf Oestermann. This year, IZM had another crowd-puller in store – a ten-meter-wide graphic on high-end performance packaging illustrated new integration solutions in advanced packaging and attracted many curious visitors to the stand. You can also find the graphic on page 6 of this annual report.

The IZM trade fair year was rounded off in autumn with the MST Congress in Dresden, where the Institute not only had a stand, but also contributed several papers to the congress program. The focus here was on meeting and exchanging ideas with customers and project partners.

High-end performance packaging exhibited at SMTconnect in Nuremberg

Promoting Young Talent at Fraunhofer IZM

The future of science lies in the hands of young people. For this reason, Fraunhofer IZM has made it its mission for many years to promote young talent and introduce young people to scientific careers.

The Institute promotes its numerous offers by participating in Girls' Day, but also events such as the TalentTakeOff with 30 STEM students or a tour of the research institute with Jugend-forscht alumni. (School) internships, apprenticeships or places for a Voluntary Ecological Year – promoting young talent is a top priority for us, for which Fraunhofer IZM was recently awarded the IHK seal for »Excellent Training Quality« by the Berlin Chamber of Industry and Commerce. Fortunately, the advertising measures were very well received: The Institute welcomed numerous new apprentices and interns in 2023.

Supervision of interns and apprentices

Ten apprentices in the fields of microtechnology, surface coating, and office communication as well as one external group apprentice learned at Fraunhofer IZM in 2023. Dual training programs enable young people to work in a practical and interdisciplinary way. After the collaboration with the Gabriele-von-Bülow-Gymnasium, Fraunhofer IZM's partner school, was strengthened in 2023 and the cooperation agreement extended, 24 student interns were hosted by twelve different working groups at the Institute's locations in Berlin and Dresden. The students had the opportunity to get to know various professional fields and laboratories at the Institute, learn about the world of microelectronics, and get an idea of scientific research.

In addition, Fraunhofer IZM once again took part in the Berlin project EnterTechnik. As only 10.7 % of apprentices in the STEM sector in Germany are female, the cooperation with EnterTechnik is particularly important to the Institute. As part of the one-year program, girls can get a taste of up to four different technical professions. After the technical year, 75 % of participants decide to enter the STEM field. Around half of the apprentices at Fraunhofer IZM are female.

Voluntary Ecological Year in the field of sustainability

Whether smartphones, laptops or airbag sensors – microelectronics have become an integral part of our lives. The increased use of technology also has an impact on the environment. The »Environmental and Reliability Engineering« department, in which a Voluntary Ecological Year (FÖJ) can be completed at the Institute, looks at precisely this topic. In 2023, two FÖJ students had the opportunity to play an active role in developing concepts to increase the environmental compatibility and energy efficiency of electronic devices.

Girls' Day 2023

Twelve schoolgirls from Gabriele-von-Bülow-Gymnasium learned more about microelectronics and the components of smartphones on Girls' Day 2023. Together with researchers from Fraunhofer IZM, they learned how smartphones manage to function reliably in highly fluctuating temperatures, what microelectronics actually means, and where they are used. Of course, there was also a tour of the cleanroom – a highlight of every Girls' Day.

A perennial highlight of the Girls' Day – A tour of the cleanroom

Facts & Figures

Fraunhofer IZM in Facts and Figures

Financial situation

In 2023, Fraunhofer IZM was able to build on the success of previous years, but was not spared the general effects of inflation, particularly in terms of energy costs. Turnover increased significantly by 6.9 percent to 42.3 million euros. In 2023, Fraunhofer IZM was able to cover 80 percent of its operating budget with external income. In total, the volume of externally financed projects increased to 33.9 million euros. Income from German and international industrial companies and trade associations remained stable at 13.5 million euros in 2023. Fraunhofer IZM covered 31.9 percent of its costs through direct orders from industry.

Equipment investments

More than 2 million euros of equity capital were used for ongoing replacement and renewal investments in 2023. The equipment at Fraunhofer IZM has been improved through a number of targeted individual measures and the efficiency of existing systems has been increased. A further 1.1 million euros were used for various smaller construction measures to boost Fraunhofer IZM's efficiency.

The Institute is participating in the establishment of the Research Fab Microelectronics Germany – Module Quantum and Neuromorphic Computing (FMD-QNC). The aim of this consortium is to build a bridge between basic research and the industrial production and application of QC/NC technologies in the future. Services ranging from preliminary research and technology development to pilot production will be offered. Fraunhofer IZM will procure equipment and systems for a total of 11 million euros; investments of 2.5 million euros have already been realized in 2023. The establishment of the Laboratory for Bioelectronic Systems was continued with the support of the State of Berlin. A further 0.6 million euros were invested here in 2023. The aim of the laboratory is to develop and establish a universal technology platform and laboratory infrastructure for the production of bioelectronic systems. With support from the Fraunhofer Strategy Fund, a high-precision system for assembly in heterogeneous system integration worth 0.8 million euros was put into operation. Also together with the Fraunhofer Strategy Fund, 1.0 million euros were invested in the establishment of a laboratory for the development of architecture and operating concepts for robust, energy-efficient electronics with a focus on industrial electronics and sensor technology.

Personnel development

The number of employees at the IZM sites in Berlin, Cottbus and Dresden/Moritzburg remains stable at around 450 at the end of 2023. This figure also includes 136 interns, bachelor's and master's students and student assistants who received comprehensive support at Fraunhofer IZM. The Institute offers students the opportunity to combine their studies with practical scientific work in the Institute's offices and laboratories. In addition, ten apprentices were trained at the Institute in 2023 as microtechnologists, surface coaters and office management assistants.

Fraunhofer IZM in 2023

Budget	42.3 million euros
External revenue	33.9 million euros (80 percent of total turnover)
Sites	Berlin, Cottbus und Dresden/Moritzburg
Laboratories	> 8,000 m²
Staff	450 (including 136 student assistants, master students, interns and 10 apprentices)

Awards, Dissertations, Editorials

Awards

»Elektronik« magazine picks Fraunhofer innovation as its Product of the Year
Simply pop a pill to identify a fault - researchers at Fraunhofer IZM, in cooperation with Micro Systems Technologies (MST), Sensry GmbH and TU Berlin, have made this a reality. The waterproof IoT sensor is as small as a piece of candy and can reliably measure the properties of liquids even in places that are difficult to access. This can not only help with the identification of diseases, but also significantly simplify the maintenance of industrial machinery.

In this method, a frequency spectrum is sent from one electrode through a medium to a second electrode. A spectrum, i. e. a specific fingerprint of this medium, can be derived from this. If changes in material or fluid properties become apparent, this can be an indication of both the progressive corrosion of a component and the presence of a specific clinical picture. Until now, impedance analyzers have not been small and mobile enough to be used for these purposes. Researchers at Fraunhofer IZM in Berlin, with the support of MST and Sensry, have therefore developed a compact and modular IoT sensor for these applications that can measure impedances and transmit them wirelessly. As a result, it is not only waterproof, but also biomedically compatible.

Readers of the trade journal »Elektronik« voted the impedance spectroscopy capsule developed at Fraunhofer IZM one of the three best products of the year out of over 2,500 innovations. The world's smallest component of its kind was awarded one of the coveted audience prizes in the »Medical« category by the Elektronik readers, which TU project manager and research associate Basel Adams accepted at the award ceremony in Munich.

Dissertations

Franieck, Erik
Development of Inlinecure Characterization Methods of Epoxy-based Packaging Materials for Electronic Packages via Dielectric Analysis

Martins da Ponte, Ronaldo
IC-MEMS Co-fabrication; Enabling Smart-seamless Microsystem Integration for Emerging Biomedical Technologies

Proske, Marina
Ecodesign Concepts and Environmental Assessments Addressing Product Obsolescence

Rickert, Wilhelm
An Investigation of the Electromagnetic Coupling Problem by Means of a Rational Framework and Selected Experiments

Vermeer, Wiljan
Integration of Energy Storage in Solar-power Electric Vehicle Smart Charging System

Editorials

Bioelectronic Medicine Journal
Giagka, V. (Associate Editor)

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

Lectures

BTU Cottbus-Senftenberg

Prof. Dr. M. Jaeger-Erben
- BTU4Future – Climate Protection and Sustainable Development
- Colloquium »Transdisciplinary Sustainability Research«
- Introduction to Technology and Environmental Sociology
- Sociology
- MOOC Global Studies
- Summer School »Circular Economy«
- Transdisciplinary Sustainability Research

Delft University of Technology

Prof. Dr. V. Giagka
- Active Implantable Biomedical Microsystems
- Bioelectricity
- Neurostimulation

Dresden University of Technology

Prof. Dr. J. Panchenko
- 3D System Integration and 3D Technologies
- Micro-/Nanomaterials and Reliability Aspects

Technical University of Berlin

Dr. P. Mackowiak, Dr. M. Schiffer
- Technologies and Materials for Microsystems Technology

Prof. Dr. W. H. Müller
- Hands-on Project to Finite Element Analysis (Projekt)
- Structural Engineering and Basic Strength of Materials

Dr. N. F. Nissen, Dr. A. Middendorf
- Ecodesign for Electronic Systems

Prof. Dr. M. Schneider-Ramelow
- System Integration Technologies
- System Integration Materials

Dr. O. Wittler, Dr. J. Jaeschke
- Reliability of Integrated Electronics Systems

Universität Aalborg

Prof. Dr. E. Hoene
- Design of Modern Power Semiconductor Devices
- EMC in Power Electronics

weißensee kunsthochschule berlin

S. Rotzler
- Soft Hard Smart – an Interactive Introduction into Textile Electronics

University of Applied Sciences for Engineering and Economics in Berlin

M. Bäuscher, M. Hubl
- BioMEMS

S. Rotzler
- Industrial Laundering, Textile Labeling

Dr. H. Walter
- Materials in Microsystem Technology 1
- Materials in Microsystem Technology 2

Cooperation with Universities (Selection)

Some of Fraunhofer IZM's university partners

Aalborg University, Denmark
Aalto University, Finland
AGH University of Science and Technology, Poland
Binghampton University, USA
Delft University of Technology, Netherlands
Eindhoven University of Technology, Netherlands
KU Leuven, Belgium
Michigan State University, USA
Tohoku University, Japan
University College London, UK
University of Quebec in Trois-Rivières, Canada
University of Tokyo, Japan
University of Utah, USA
University of Zurich, Switzerland

Berlin University of the Arts
Bielefeld University
Bundeswehr University Munich
Chemnitz University of Technology
Heidelberg University
Humboldt University of Berlin
Otto-von-Guericke University Magdeburg
Rhenish Friedrich Wilhelm University of Bonn
Technische Hochschule Ingolstadt
University of Erlangen-Nuremburg
University of Freiburg
University of Mainz
University of Münster
University of Rostock
Weißensee Academy of Art Berlin

To effectively implement its research goals, Fraunhofer IZM has established strategic networks with universities in Germany and abroad. Close cooperation with universities is an important pillar of Fraunhofer's success model. While the universities bring their innovative ability and competence in basic research to the table, Fraunhofer contributes excellence in applied research as well as outstanding technical infrastructure.

Cooperation with the Technical University of Berlin

Ever since its foundation in 1993, Fraunhofer IZM has drawn a lot from its productive cooperation with the Research Center for Microperipheric Technologies at the Technical University of Berlin, forming one of the world's first research institutions for packaging and interconnection technologies in the 1990s. Since 2021, Professor Martin Schneider-Ramelow has been heading not just Fraunhofer IZM, but also the Research Center for Microperipheric Technologies.

Fraunhofer IZM-ASSID cooperates with TU Dresden

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

Cooperation with BTU Cottbus-Senftenberg

Fraunhofer IZM intensifies its cooperation with BTU in the branch office for high-frequency sensor systems in Cottbus. Since February 2023 IZM department head Prof. Ivan Ndip has held the chair for for Antennas and Radio Frequency Systems Integration. The research activities within the Innovation Campus (iCampµs) Cottbus focus on design, test procedures and characterization of integrated antennas, on co-design of chip-package antennas as well as system integration solutions for the realization of miniaturized radio frequency sensor systems.

Cooperation with Industry (Selection)

AEMtec GmbH	Berlin (D)
Ajinomoto Group	JP, USA
Allegro MicroSystems	Manchester, NH (USA)
Amkor Technology, Inc.	Tempe, AZ (USA)
AMO GmbH	St. Peter am Hart (AT)
ams AG	Premstätten (AT)
Amsterdam Scientific Instruments B.V.	Amsterdam (NL)
AnSem NV	Leuven (BE)
AT&S Austria Technologie & Systemtechnik AG	Leoben (AT)
AUDI AG	Ingolstadt (D)
Baker Hughes Inteq GmbH	Celle (D)
BASF SE	Ludwigshafen am Rhein (D)
Berliner Nanotest und Design GmbH	Berlin (D)
BMW AG	Munich (D)
Bosch Semiconductor Manufacturing	Dresden (D)
Brewer Science, Inc.	Rolla, Missouri (USA)
Carl Zeiss SMT GmbH	Jena (D)
CERN	Meyrin (CH)
Contag GmbH	Berlin (D)
Corning Inc.	Corning, NY (USA)
Delo GmbH	Windach (D)
DeltaHeat GmbH	Berlin (D)
DISCO Corporation	Munich (D), Tokio (JP)
DResearch	Berlin (D)
DuPont de Nemours, Inc.	Wilmington, DE (USA)
DuPont Electronics & Imaging	Marlborough, MA (USA)
DustPhotonics	Modi'in-Maccabim-Re'ut (IL)
Evatec AG	Trübbach (CH)
FACEBOOK TECHNOLOGIES, LLC	Menlo Park, CA (USA)
FIRST SENSOR	Berlin (D)
Fujifilm Electronic Materials	EU, USA
GEFRAN S.p.A.	Provaglio d'Iseo (IT)
GLOBALFOUNFRIES INC.	Dresden (D)
Heraeus	Hanau (D)
IMASENIC Advanced Imaging S.L.	Barcelona (ES)
InnoSenT GmbH	Donnersdorf (D)
Intel Corporation	Santa Clara, CA (USA)
KSG GmbH	Görnsdorf (D)
LTB GmbH	Radebeul (D)
Malvern PANalytical B.V.	Almelo (NL)
MENNEKES Elektrotechnik GmbH & Co. KG	Kirchhunden (D)
Micro Systems Engineering GmbH	Berg (D)
Mitteldeutsche Netzgesellschaft Strom mbH	Halle (D)
Multi Channel Systems MCS GmbH	Reutlingen (D)
Nagase ChemteX Corporation	Osaka (JP)
Nexperia	Nijmegen (NL)
NEXT FUEL R&D LTD	Neve Yamin (IL)
NKG	Nogoya (JP)
OSYPKA AG	DE
Philips	NL
Picosun Oy	Masala (FI)
Pilz GmbH & Co. KG	Ostfildern (D)
Plath	Ostfildern (D)
POSIC S.A.	Colombier (CH)
RENA Technologies GmbH	Gütenbach (D)
Resonac	Tokio (JP)
Robert Bosch GmbH Zentrum für Forschung und Vorausentwicklung	Renningen (D)
Rolls-Royce Deutschland Ltd & Co KG	Cottbus (D)
Saltec GmbH	Salzhausen (D)
Schaeffler AG	Herzogenaurach (D)
Schlumberger	Paris (FR)
Schmoll Maschinen GmbH	Rödermark (D)
Semsysco GmbH	Salzburg (AT)
sensiBel AS	Oslo (NO)
Siemens AG	Berlin, Erlangen, München (D)
SLAC National Accelerator Laboratory	Menlo Park, CA (USA)
Süss MicroTec SE	Garching, München (D)
Swissbit Germany AG	Berlin, Broschhofen (CH)
TEN Thüringer Energienetze GmbH & Co. KG	Erfurt (D)
Texas Instruments	München, London (GB)
Thales Group	Paris (FR)
The Chemours Company	Wilmington, DE (USA)
United Monolithic Semiconductors (UMS	Villebon-sur-Yvette (FR)

Memberships (Selection)

3D & Systems Summit (SEMI)	Dr. M. Junghähnel	Member Program Committee
3DInCites	Dr. M. Junghähnel	Member Advisory Board
AMA Fachverband Sensorik, Wissenschaftsrat	H. Pötter	Member
Cluster Optik BB, Photonik für Kommunikation und Sensorik	Dr. H. Schröder	Spokesman
Deutscher Verband für Schweißtechnik DVS	Prof. Dr. M. Schneider-Ramelow	Representative of Fraunhofer IZM
Deutscher Verband für Schweißtechnik DVS Arbeitsgruppe »Bonden«	Prof. Dr. M. Schneider-Ramelow	Chairman
ECPE Competence Centre	Prof. Dr. M. Schneider-Ramelow	Member
EFDS – Europäische Forschungsgesellschaft Dünne Schichten e. V.	Dr. M. Junghähnel	Member
Fachausschuss »Beschichtungstechnologien für optische und elektronische Funktionalisierung – FABF«	Dr. M. Junghähnel	Member
Wissenschaftlicher Beirat des EFDS	Dr. M. Junghähnel	Elected Member
European Photonic Industrial Consortium (EPIC)	Dr. H. Schröder	Representative of Fraunhofer IZM
European Technology Platform on Smart Systems Integration (EPoSS)	H. Pötter	Member Executive Committee, Board Member
FED Fachverband Elektronik-Design e. V.	Dr. N. F. Nissen	Member
Heterogeneous Integration Roadmap (HIR)	R. Aschenbrenner	Chair Technical Working Group SiP
IEEE Electronics Packaging Society	R. Aschenbrenner	Fellow
IEEE EPS Board of Governors	Dr. T. Braun	VP of Conferences
IEEE TC RF High-Speed Components of Systems	Prof. Dr. I. Ndip	Senior Member
IMAPS International Microelectronics Assembly and Packaging Society	Prof. Dr. M. Schneider-Ramelow, Prof. Dr. I. Ndip	Fellows
IMAPS Deutschland	Prof. Dr. M. Schneider-Ramelow	President
IMAPS Europe ELC	Prof. Dr. M. Schneider-Ramelow	Member
IMAPS Signal/Power Integrity Committee	Prof. Dr. I. Ndip	Chair
International Conference on Coatings on Glass and Plastics (ICCG)	Dr. M. Junghähnel	Board Member
IVAM Fachgruppe Wearables	E. Jung	Technical Chair
OPTICA	Dr. Gunnar Böttger	Representative of Fraunhofer IZM
Organic Electronics Saxony (OES)	E. Jung	Representative of Fraunhofer IZM
Photonics 21	Dr. R. Jordan	Board of Stakeholders
Photonics West Optical Interconnects Conference	Dr. H. Schröder	Chair
PLASMA GERMANY	Dr. M. Junghähnel	Elected Expert
SEMI ESiPAT Group	Dr. T. Braun	Member
Silicon Saxony e. V.	Dr. M. Junghähnel	Member
Strategischer Arbeitskreis Silicon Germany	Prof. Dr. M. Schneider-Ramelow	Member
Wissenschaftlich-technischer Rat der Fraunhofer-Gesellschaft	Dr. M. Hampicke	Representative of Fraunhofer IZM

Publications (Selection)

Baeuscher, M.; Henke, M.; Hoeppner, K.; Ngo, H.; Mackowiak, P.; Schiffer, M.; Schneider-Ramelow, M.
Evaluation of Upscaling the Selective Electrophoretic Deposition of Reduced Graphene Oxide on Miniaturized Au Interdigital Electrodes from Chip-to Wafer-level
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Trusted Data Acquisition in Microelectronics Manufacturing as a Basis for ML-optimized Processing
Proceedings of the 56th IMAPS International Symposium on Microelectronics (IMAPS 2023), San Diego, USA, DOI: 10.4071/001c.94507.

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Integrated Nanophotonics: Platforms, Devices, and Applications, 2023, Wiley-VCH, DOI:10.1002/9783527833030.ch1, pp. 1-52.

Billaud, M.; Clemm, C.; Sánchez, D.; Proske, M.; Jügel, M.; Stobbe, L.; Nissen, N.; Schneider-Ramelow, M.
ICs as Drivers of ICT Carbon Footprint: An Approach to More Accurate Die Size Assessment
Proceedings of Going Green CARE INNOVATION 2023, Vienna, Austria.

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Proceedings of EMPC 2023, Hinxton, United Kingdom.

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Proceedings of ECTC 2023, Orlando, USA.

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Modification of Prony Series Coefficients to Account for Thermo-oxidative Ageing Effects Within Numerical Simulations
Proceedings of EuroSimE 2023, Graz, Austria DOI: 10.1109/EuroSimE56861.2023.10100845, pp. 1-5.

Dilek, S.; Tschoban, C.
Performance Evaluation of E-band Transmit-receive Front-ends Based on Characterization of Joint Effects of IQ Imbalance and Carrier Phase/Frequency Offset
IEEE Transactions on Microwave Theory and Techniques, Vol. 71, No. 5, 2023, DOI: 10.1109/TMTT.2022.3223946, pp. 2069-2081.

Elsotohy, M.; Jaeschke, J.; Sehr, F.; Schneider-Ramelow, M.
Mission Profile-based Digital Twin Framework Using Functional Mockup Interfaces for Assessing System's Degradation Behaviour
Microelectronics Reliability, Vol. 150, 2023, DOI: 10.1016/j.microrel.2023.115086.

Erbacher, K.; Alves Marquez, J.; Mackowiak, P.
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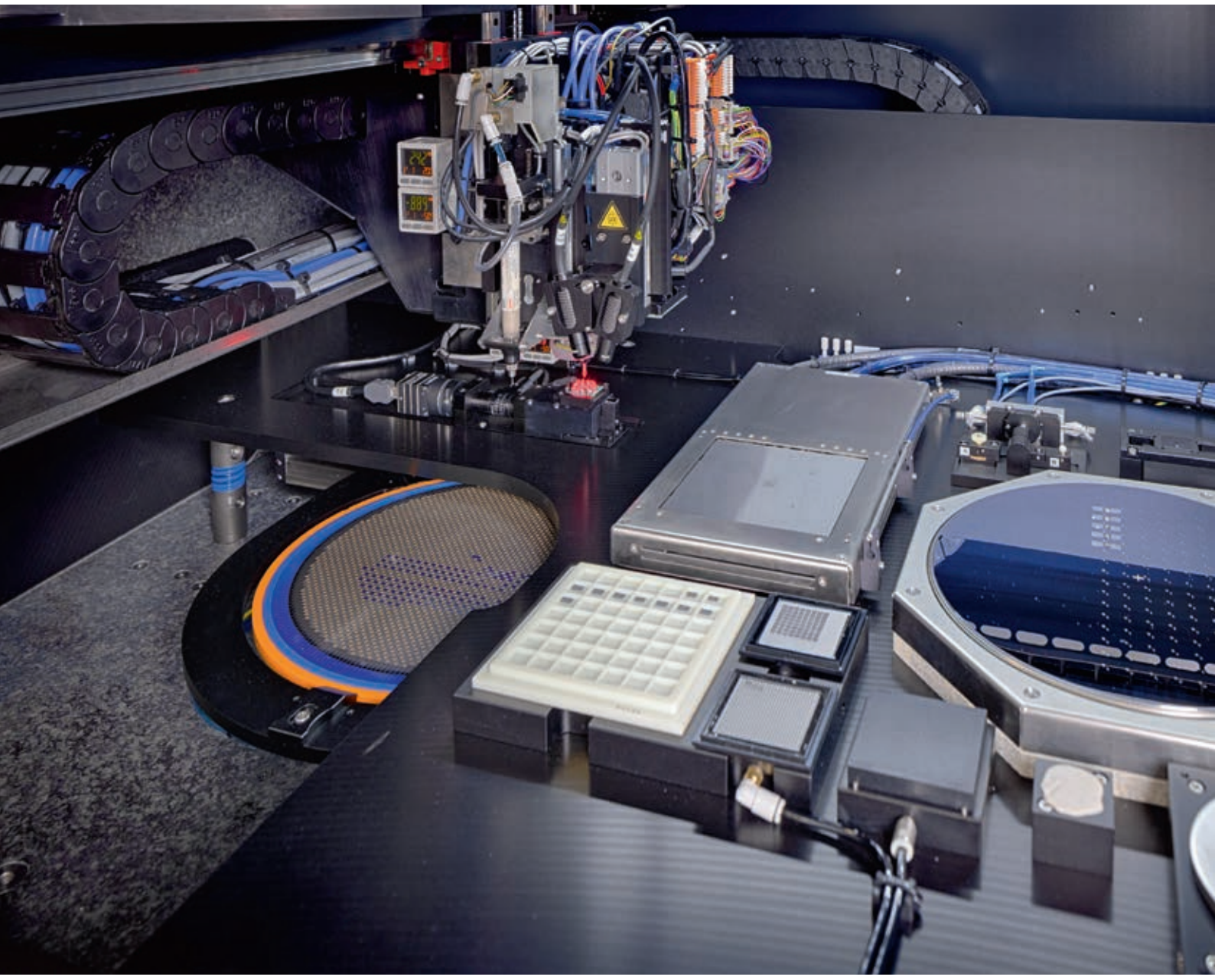

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