Fraunhofer
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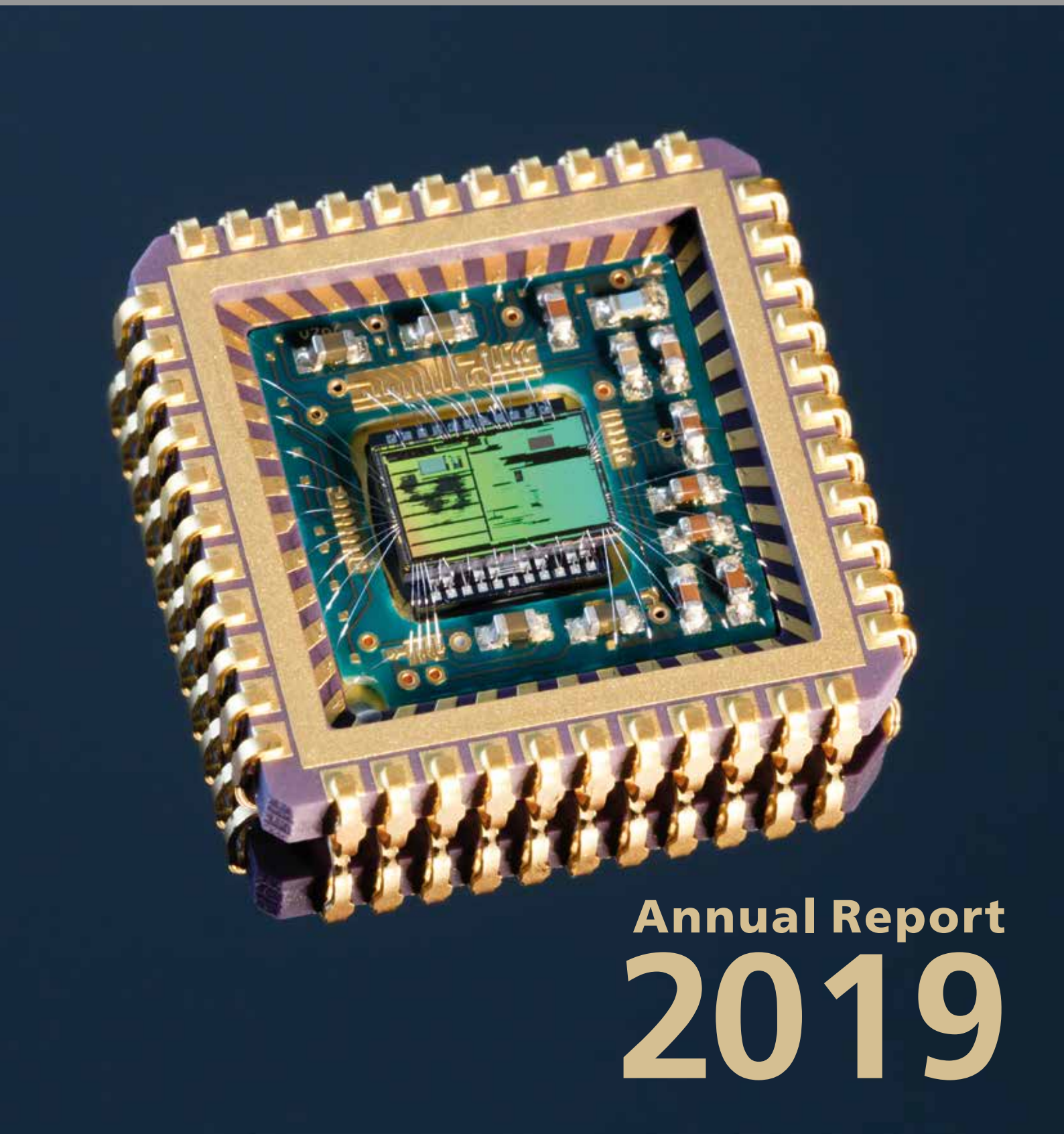
FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS



Annual Report 2019

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Front page:
The gyroscope system with MEMS, ASIC and discrete components in a ceramic package was developed in the research project KoliBriS – »compact low-power broadband sensors with integrated circuit electronics« – together with EDC Electronic Design Chemnitz GmbH (network coordinator). Another project partner was the X-FAB MEMS Foundry GmbH. You will find more about this topic on page 39.
Photo © Roman Forke, Fraunhofer ENAS

PREFACE

Photo © Ines Escherich

Progress is the realization of utopias. Oscar Wilde

Dear friends and partners of the Fraunhofer Institute for Electronic Nano Systems, dear readers,

In 2019, we have reached a major milestone, the certification according to DIN EN ISO 9001:2015 of the main site of the Fraunhofer Institute for Electronic Nano Systems ENAS. We are also recording a positive economic development. Our budget increased continuously, our achievements are recognized and appreciated. The main part of our research volume is generated by contract research, i.e. within the framework of direct orders from industry and through publicly funded projects. At this point, we would like to thank our partners and customers for their trust and support.

In the digital age with its challenges and opportunities, new product ideas can often only be implemented on an interdisciplinary basis. Division of labor and cooperation are becoming increasingly important. Therefore, together with the institutes of the Fraunhofer Group Microelectronics, Leibniz IHP and Leibniz FBI, we combine our competences as partners in the Research Fab Microelectronics Germany (FMD).

Furthermore, we put old and proven concepts to the test and further develop sustainable topics. As the portfolio of the department Back-End of Line has evolved and new topics such as memristors, technologies for 3D integration, carbon nanotubes for electronics and sensor technology as well as magnetic sensor technology based on spintronics are now located within this department, a restructuring was started in 2019. As a result, since April 2020 the department has been renamed »Nano Device Technologies«.

In our 2019 annual report, you will find a small excerpt of the topics that occupied us during the past year. Let us inspire you.

Prof. Dr. Thomas Otto
Director (acting) of the Fraunhofer Institute for Electronic Nano Systems ENAS

Photo © pixabay

STRATEGY PROCESS / FOLLOW-UP PROCESS

STRATEGY PROCESS / FOLLOW-UP PROCESS

Since its foundation in 2008, Fraunhofer ENAS can look back at a continuously positive development with high industrial revenues and a constant increase in budget and number of employees. For this, we permanently monitor trends, developments and shifts in the markets to ensure and to expand our position in the market, to open new areas of application, to further-develop our R&D portfolio and to anticipate new markets. All this is subject of our continuous strategic process at Fraunhofer ENAS.

During the strategic process, we analyzed the project portfolio, goals, customers and markets intensely. The results are the base for our goals and action plans within a period of up to five years. One of our major projects that shaped 2019 strongly, was the implementation of a quality management system in accordance with DIN EN ISO 9001:2015.

Quality Management System

The Fraunhofer Institute for Electronic Nano Systems ENAS is certified in accordance with DIN EN ISO 9001:2015 by DEKRA since December 2019. The quality management system supports our efforts to implement and execute transparent and clearly defined processes. Furthermore, it ensures the systematic and continuous improvement of our workflows.

www.enas.fraunhofer.de/en/about_us/qualitymanagement

Fraunhofer ENAS stands for:

- Customer orientation
- Satisfied employees
- Quality
- Scientific excellence
- Innovation for the benefit of customers and society
- Sustainability
- Customer satisfaction

Strategic alliances

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

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

www.forschungsfabrik-mikroelektronik.de

The investments in FMD are paying off

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

FMD – a promising model for major project initiatives

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

Founders' dreams come real in the FMD-Space

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

STRATEGY PROCESS / FOLLOW-UP PROCESS

Modernizing the FMD's facilities at full speed

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

Fraunhofer ENAS within the FMD

The cross-institutional technology portfolio of the Reasearch Fab Microelectronics Germany comprises the fields of Sensor Systems, Extended CMOS, Microwave & Terahertz, Power Electronics, MEMS Actuators and Optoelectronic Systems. Due to its broad R&D portfolio, Fraunhofer ENAS is represented in all six technology platforms as well as in the cross-technology cross-sectional topic of Advanced System Design.

USeP – Universal Sensor Technology Platform for IoT Systems of the Next Generation

www.enas.fraunhofer.de/usep

Fraunhofer ENAS, GLOBALFOUNDRIES Dresden as well as the Fraunhofer Institutes IPMS, IZM and IIS/EAS jointly work on the research project USeP (Universal Sensor Technology Platform), which focusses on the development of a new type of sensor technology platform. This platform enables the automatic generation of a wide range of innovative components and their integration into a complete system in a modular concept. The project partners focus on a central control and processing unit with numerous interfaces and a wide selection of conventional and prospective sensors and actuators. Beside a system architecture with flexible building blocks, the platform offers innovative solutions for hardware and IT security. Overall, the sensor module with its diverse design versions covers hundreds of application scenarios. The Free State of Saxony and the European Union as part of the European Regional Development Fund (ERDF) fund the project. Furthermore, Fraunhofer-Gesellschaft, GLOBALFOUNDRIES Dresden and Next Big Thing AG funded the start-up company Sensry GmbH for the marketing of the sensor platform. Sensry started operations with the goal of developing and commercializing the universal sensor platform for the development of electronic components, modules and systems.

The basis for the technology platform, which particularly benefits SMEs, is the 22FDX technology (Fully Depleted SOI) by GLOBALFOUNDRIES. Fabricated in Dresden, the technology enables highly integrated chips with energy-efficient and inexpensive properties. The participating Fraunhofer Institutes contribute their competences and expertise in the fields of innovative packaging, concept development, system design, sensor technology, data transmission as well as simulation and testing. In addition, the project USeP ensures that the results are applicable to next generations of technologies and that companies are able to use the new sensor technology platform for as long as possible.

Smart Systems Hub – Enabling IoT

www.smart-systems-hub.de

Fraunhofer ENAS actively engages in the development of the Smart Systems Hub – Enabling IoT, which aims at building a close network of Saxon experts in the key areas hardware – software – connectivity. In 2019, Smart Systems HUB GmbH has picked up speed and actively taken control of events. The hub cooperates with its three shareholders, Silicon Saxony e.V., HighTech Startbahn and 5G Lab GmbH as well as its key partners GLOBALFOUNDRIES Dresden, Infineon Technologies, SAP, T-Systems Multimedia Solutions and additional partners to systematically realize their strategy. Fraunhofer ENAS is involved in events and products of the Smart Systems Hub.

Photo © Fraunhofer-Gesellschaft

FRAUNHOFER ENAS: PROFILE

FRAUNHOFER-GESELLSCHAFT

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

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

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

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

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

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

www.fraunhofer.de/en

Last updated: January 2020

FRAUNHOFER ENAS

The Fraunhofer Institute for Electronic Nano Systems ENAS is the specialist and development partner in the field of Smart Systems and their integration for various applications. Fraunhofer ENAS has specialized on the challenge of combining micro and nano sensors, actuators and electronic components with interfaces for communication and a self-sufficient energy supply to form smart systems, thus supporting the Internet of Things and the ongoing digitalization. Application areas of our R&D services are i.a. semiconductor industry (equipment and material manufacturer), aeronautics, automotive industry, communication technology, the security sector, logistics, agriculture, process technology and medical as well as mechanical engineering.

Fraunhofer ENAS develops single components, manufacturing technologies and system concepts, system integration technologies and actively supports the technology transfer for and with its customers.

Whether start-up, SME or large enterprise, Fraunhofer ENAS offers innovation consulting and supports customer projects, starting from the idea, via design and technology development or realization based on established technologies up to tested prototypes. If standard components do not meet the requirements, Fraunhofer ENAS provides expert assistance in the realization of innovative and marketable products.

In order to focus its activities and to ensure a long-term scientific and economic success, Fraunhofer ENAS puts special emphasis on the five business units:

- Micro and Nanoelectronics
- Sensor and Actuator Systems
- Technologies and Systems for Smart Power and Mobility
- Technologies and Systems for Smart Health
- Technologies and Systems for Smart Production

The business units address different markets, different customers and different stages of the value chain depending on the required research and development services.

From an organizational point of view, Fraunhofer ENAS is subdivided into the departments Advanced System Engineering, Micro Materials Center, Multi Device Integration, Nano Device Technologies (the former department Back-End of Line), Printed Functionalities, System Packaging, and Administration. The headquarters of Fraunhofer ENAS are located in Chemnitz. The department Advanced System Engineering is located in Paderborn. In addition, a project group of the department Micro Materials Center is working in Berlin-Adlershof.

www.enas.fraunhofer.de

ORGANIZATIONAL STRUCTURE

Fraunhofer Institute for Electronic Nano Systems ENAS

Director (acting): Prof. Dr. Thomas Otto
Deputy director: Prof. Dr. Stefan E. Schulz

Department
Multi Device Integration
Acting management:
Dr. Steffen Kurth / Dr. Alexander Weiß

Department
Micro Materials Center
Prof. Dr. Sven Rzepka

Department
Printed Functionalities
Dr. Ralf Zichner

Department
Nano Device Technologies
Prof. Dr. Stefan E. Schulz

Department
System Packaging
Dr. Maik Wiemer

Department
Advanced System Engineering
Dr. Christian Hedayat

Administration
Head: Dr. Tina Kießling
Technical head: Uwe Breng

Quality Management
Dr. Martina Vogel

Marketing / Public Relations
Advisor to Institute Management
Dr. Martina Vogel

Business Unit
Micro and Nanoelectronics
Prof. Dr. Stefan E. Schulz

Business Unit
Sensor and Actuator Systems
Prof. Dr. Karla Hiller

Business Unit
Technologies and Systems for
Smart Power and Mobility
Dr. Steffen Kurth

Business Unit
Technologies and Systems for
Smart Health
Dr. Mario Baum

Business Unit
Technologies and Systems for
Smart Production
Dr. Ralf Zichner

International Offices

Fraunhofer Project Center
at Tohoku University, Japan
Prof. Dr. Shin-ichi Orimo
Prof. Thomas Otto
Assoc. Prof. Dr. Joerg Froemel
Dr. Maik Wiemer

Office Shanghai, China
SHI Min

Office Manaus, Brazil
Hernan Valenzuela

Chemnitz University of Technology

Center for Microtechnologies (ZfM)
Faculty of Electrical Engineering and Information Technology

President: Prof. Dr. Thomas Otto
Deputy director: Prof. Dr. Karla Hiller

Department
Lithography and Pattern Transfer
Dr. Danny Reuter

Department
Layer Deposition
Dr. Sven Zimmermann

Professorship of
Microtechnology
Prof. Dr. Thomas Otto

Honorary Professor of
Opto Electronic Systems
Prof. Dr. Thomas Otto

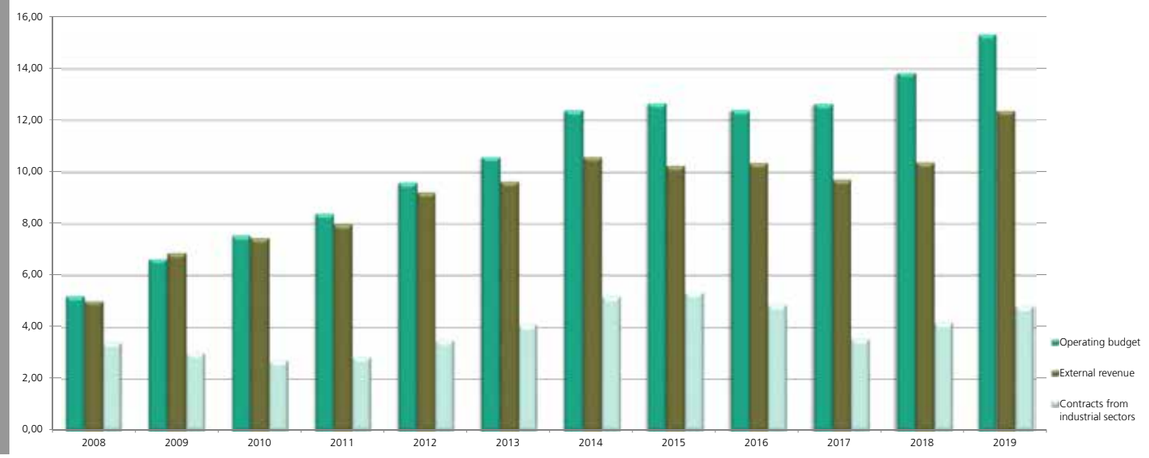
Honorary Professor of
Nanoelectronics Technologies
Prof. Dr. Stefan E. Schulz

Honorary Professor of
Reliability of Smart Systems
Prof. Dr. Sven Rzepka

Paderborn University

Professorship of Sensor Technology
Prof. Dr. Ulrich Hilleringmann

FACTS AND FIGURES



Development of the Fraunhofer ENAS

	Year											
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Operating budget (in million euros)	5.2	6.7	7.6	8.4	9.6	10.6	12.4	12.65	12.41	12.62	13.83	15.32
Increase of the budget (in relation to 2008)	–	29 %	46 %	62 %	85 %	104 %	138 %	143 %	139 %	143 %	166 %	195 %
Industrial revenues (in million euros)	3.4	3	2.8	2.8	3.49	4.1	5.2	5.24	4.85	3.54	4.18	4.8
Investment (in million euros)	0.65	5.45	6.8	1.5	1.81	1.44	7.23	2.02	1.89	2.72	1.7	1.23
Staff	63	73	91	102	104	125	129	127	132	139	157	174
Apprentices	0	2	3	5	6	7	7	6	7	6	8	8
Students and student assistants	10	10	20	40	43	51	51	43	43	35	50	50
Publications and oral presentations	61	75	114	119	112	215	198	173	176	144	141	147
Patents	7	5	13	20	8	17	9	9	12	6	9	13
Doctoral Thesis	6	0	4	2	3	3	3	5	3	5	2	2

Financial situation and investment

The year 2019 was characterized by a rapid growth of the Fraunhofer ENAS budget by 10.7 percent. The positive development of the institute is reflected above all in the external revenues of 12.37 million euros (plus 19.4 percent). The revenue quota is 80.3 percent. Orders from German and international industrial companies amount to 4.8 million euros, which represents a significant increase of 14.8 percent. The operational budget of Fraunhofer ENAS has increased by 1.48 million euros to 15.32 million euros and has tripled since its foundation.

The investments of the year 2019 were 1.23 million euros. Altogether, the total budget amounted to 16.55 million euros.

Personnel development

At the end of the year 2019, Fraunhofer ENAS employed 174 people in Chemnitz, Paderborn and Berlin. Eighteen new employees were hired, whereas ten employees left the institute.

On December 31, eight apprentices in total worked and learned at Fraunhofer ENAS. Furthermore, three apprentices successfully completed their training in summer 2019. In cooperation with Chemnitz University of Technology and Paderborn University, students and young scientists have successfully defended their graduate theses.

By the end of 2019, Fraunhofer ENAS employed 40 interns, graduate students/master's students and student aids, while during the year, more than 50 were employed. This employee base continues to prove itself as an excellent source for young scientists and technicians.

Head of administration:
Dr. Tina Kießling
Phone: +49 371 45001-210
E-mail: tina.kiessling@enas.fraunhofer.de

BOARD OF TRUSTEES

The board of trustees is an external advisory body attached to the institute. It consists of representatives fom science, industry, business, and public life. The members of the board of trustees are appointed by the Executive Board of Fraunhofer-Gesellschaft with the approval of the director of the institute. Their annual meetings are attended by at least one member of the Executive Board of the Fraunhofer-Gesellschaft.

In 2019, the members of the Fraunhofer ENAS board of trustees were:

Chairman:
Prof. Dr. Udo Bechtloff, Prof. Bechtloff Unternehmensberatung

Deputy chairman:
Prof. Dr. Hans-Jörg Fecht, Director, Institute of Micro and Nanomaterials, Ulm University

Members of the board of trustees:
MRn Dr. Annerose Beck, Head of Unit, Saxon State Ministry of Higher Education, Research and the Art
Jürgen Berger, Division Director Electronic and Micro Systems, VDI/VDE Innovation + Technik GmbH
Dr. Wolfgang Buchholtz, Manager Project Coordination, GLOBALFOUNDRIES Dresden
Dr. Stefan Finkbeiner, CEO, Bosch Sensortec GmbH
Prof. Dr. Maximilian Fleischer, Corporate Technology, Siemens AG
Dr. Arbogast M. Grunau, Senior Vice President Corporate R&D, Schaeffler Technologies AG & Co. KG
Dr. Christiane Le Tiec, CTO Ozone Products, MKS Instruments Deutschland GmbH
MR Dr. Stefan Mengel, Head of Unit, German Federal Ministry of Education and Research (BMBF)
MDirigin Barbara Meyer, Head of Department, Saxon State Ministry of Economy, Technology and Transportation
Thomas Schmidt, State Minister, Saxon State Ministry for the Environment and Agriculture
Prof. Dr. Ulrich Schubert, Director, Jena Center for Soft Matter, Jena University
Dr. Ina Sebastian, Senior Director R&D&I Policy, Infineon Technologies AG
Uwe Schwarz, Manager Development MEMS Technologies, X-FAB MEMS Foundry GmbH
Prof. Dr. Gerd Strohmeier, Rector, Chemnitz University of Technology

We thank all board members and especially the chairman Prof. Udo Bechtloff and the deputy chairman Prof. Hans-Jörg Fecht for supporting our institute.

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

As an innovative partner for our customers, Fraunhofer ENAS develops single components, processes and technologies for their manufacturing as well as system concepts and system integration technologies and helps to transfer them into production. The institute offers a research and development service portfolio, starting from the idea, via design and technology development or realization based on established technologies up to tested prototypes. If standard components do not meet the requirements, Fraunhofer ENAS assists in the realization of innovative and marketable solutions.

Interdisciplinary cooperation – key to success

Fraunhofer ENAS is an active member of different worldwide, European and regional industry-driven networks, starting from Semi and the Micromachine Center, via EPoSS – the European Technology Platform on Smart Systems Integration, Silicon Saxony and IVAM up to the Smart Systems Campus Chemnitz. The complete list is included in the attachment.

Cooperation with the Smart Systems Campus

Fraunhofer ENAS is located on the Smart Systems Campus within the »Technologie-Campus Süd«. The Smart Systems Campus is an innovative network with expertise in micro and nanotechnologies as well as in smart systems integration. The campus connects basic research (Chemnitz University of Technology in particular) and applied research with the entrepreneurial spirit of young, newly founded businesses based in the start-up building and with companies that are already fully established in the market. The Smart Systems Campus is part of the ever-expanding »Technologie-Campus Süd« in the city of Chemnitz. This

RESEARCH AND DEVELOPMENT SERVICE PORTFOLIO

- Development, design, packaging and test of MEMS/NEMS
- Methods and technologies for wafer to wafer and chip to wafer bonding
- Integration of nano functionalities, e.g. CNTs, quantum dots, spintronics, memristors
- Metallization: interconnect systems for micro and nanoelectronics and 3D integration
- Beyond CMOS technologies
- Simulation and modeling of devices, processes and equipment for micro and nano systems
- Material and reliability research
- Analytics for materials, processes, components and systems
- High-precision sensors and actuators
- Development of printed functionalities for electronic applications
- Application-specific wireless data and energy systems
- Development of microfluidic systems and biosensor integration
- Sensor and actuator systems with control units, integrated electronics, embedded software and user interface
- Reliability of components and systems
- Application-specific integration of AI methods

MARKETS AND FIELDS OF APPLICATION

- Semiconductor, semiconductor equipment and materials manufacturer
- Communication technology
- Medical engineering and life sciences
- Agriculture
- Mechanical engineering
- Process engineering
- Security
- Automotive industry
- Logistics
- Aerospace
- Internet of Things

Smart Systems Campus Chemnitz.
Photo © Biermann und Jung

also includes the latest expansion since 2018: the new building of the Center for Materials, Architectures and Integration of Nanomembranes (MAIN) that belongs to Chemnitz University of Technology.

Cooperation with industry

Within the working field of smart systems integration, Fraunhofer ENAS strongly supports the research and development of many small and medium-sized companies as well as large-scale industry. By integrating smart systems in various applications, Fraunhofer ENAS addresses the branches and markets mentioned in the green box on page 19.
The most common way of cooperating with industrial partners is contract research. However, if the tasks and challenges are too complex, we offer pre-competitive research. In those cases, teaming up with companies and research institutes, while using public funding, is more effective than operating alone.

Transfer of research and development results and technologies into industrial applications

Based on the application-oriented focus of research, Fraunhofer ENAS is able to support innovations developed together with small and medium-sized companies as well as large-scale, internationally established companies. For instance, Fraunhofer ENAS developed a modular technology platform for highly compact inertial sensors with integrated circuit electronics together with its partners EDC Electronic Design Chemnitz GmbH and X-FAB MEMS Foundry GmbH. The project is called KoliBriS and was funded by the Federal Ministry of Education and Research (BMBF). The close cooperation with MEMS foundries ensures that designs that are developed at the institute can easily be transferred into commercially available processes. Furthermore, they are made readily available to smaller businesses and research partners to enable their access to innovative solutions.

Cooperation with universities and research institutes

Fraunhofer ENAS has established a strategic network with research institutes and universities in Germany and worldwide. Long-term partnership exists with the Tohoku University in Sendai, the Fudan University Shanghai and the Shanghai Jiao Tong University.

Fraunhofer ENAS and the Tohoku University have been cooperating in the field of new materials for microelectronic systems for many years. Therefore, the Fraunhofer Project Center »NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University« was established in 2012. The perpetuation and intensification of cooperation was initiated by extending the existing cooperation agreement as early as 2018. By now, the project center is not only a platform for joint research and development activities but also a common platform for offering R&D services to industry. The joint range of services was, amongst others, presented at the Fraunhofer symposium in Sendai.

www.enas.fraunhofer.de/fraunhofer-project-center

Moreover, Fraunhofer ENAS works closely with the local universities, in particular with Chemnitz University of Technology and Paderborn University. The cooperation ensures synergies between the basic research conducted at the universities and the more application-oriented research at Fraunhofer ENAS.
The main cooperation partner at Chemnitz University of Technology is the Center for Microtechnologies at the Faculty of Electrical Engineering and Information Technology. The cooperation includes not only common research projects but also a joint use of equipment, facilities and infrastructure. Lightweight structures is a topic of the cooperation with the Faculty of Mechanical Engineering. 2018 saw the addition of a further research partner in the form of the Centre for Materials, Architectures and Integration of Nanomenbranes (MAIN), an overarching institution of the Faculties of Electrical Engineering and Information Technology and Natural Sciences at Chemnitz University of Technology and its research partners. Fraunhofer ENAS collaborates with the research center MAIN in the field of nanomembrane-based materials, one of the most modern research areas of materials engineering and sciences. The department Advanced System Engineering, located in Paderborn, continues its close cooperation with Paderborn University particularly in the field of electromagnetic reliability and compatibility, wireless energy and data transmission technology, wireless sensors nodes for mechanical engineering and application-specific integration of AI methods.

www.zfm.tu-chemnitz.de

www.uni-paderborn.de

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

Project team of the Fraunhofer Lighthouse Project »Go Beyond 4.0«.

Cooperation within Fraunhofer-Gesellschaft

Since its formation, Fraunhofer ENAS is part of the Fraunhofer Group for Microelectronics (VμE). Moreover, Fraunhofer ENAS is a member of the Fraunhofer Nanotechnology Alliance, the Fraunhofer autoMOBILE Production Alliance and the Fraunhofer Technical Textiles Alliance. Dependent on the topic, Fraunhofer ENAS also participates in the Fraunhofer Clusters 3D Integration and Nanoanalytics.

Together with the other institutes of the Fraunhofer Group for Microelectronics, Fraunhofer ENAS is part of the Research Fab Microelectronics Germany (see page 7) and participates in the Heterogeneous Technology Alliance. This alliance links the Fraunhofer Group for Microelectronics with the European research partners CEA-Leti, CSEM and VTT. Together they offer the development of microtechnologies, nanoelectronics and smart systems for next-generation products and solutions.

Fraunhofer-Gesellschaft is tackling the current challenges facing German industry by putting a strategic focus on its lighthouse projects. These projects aim at exploiting the potential for synergies within Fraunhofer-Gesellschaft by bringing different Fraunhofer Institutes and their respective expertise together. Fraunhofer ENAS manages and coordinates the lighthouse project »Go Beyond 4.0«, which was launched in December 2016, and also works in the lighthouse project »eHarsh«.

High-Performance Centers combine and link the competences of research institutes and universities within a certain region. Fraunhofer ENAS is working in two High-Performance Centers. The High-Performance Center »Smart Production and Materials« and the High-Performance Center »Functional Integration of Micro and Nanoelectronics«.

Lighthouse projects

Go Beyond 4.0

www.go-beyond-four-point-zero.de

The demand for innovative and individualized devices for the future markets automotive, aerospace, photonics and manufacturing is growing across all industries. The highly qualified functionalities of the respective devices are realized by using modern functional materials. The lighthouse project »Go Beyond 4.0« addresses mass production of future products down to batch size 1 by integrating digital manufacturing processes, such as inkjet printing as an additive process and laser processing as an ablative process, into existing mass manufacturing environments. In order to achieve this goal, the Fraunhofer Institutes ENAS, IFAM, ILT, IOF, ISC and IWU interdisciplinary combine their expertise in the fields of mechanical engineering, electrical engineering, photonics and material science. Following the concept, a reliable zero error production has been integrated systematically into the process chain to manufacture the product demonstrators.

The demonstrators address the major markets automotive engineering, aerospace and illumination: Smart Door, Smart Wing and Smart Luminaire. For this, the demonstrators, the digital production technologies (digital printing and laser processing) were adapted to the geometries of the individual demonstrators and the material properties.

In the fourth year of the project, the focus will be on the process stability of digital printing and laser technologies and component reliability. Specifically, this involves:

- Research and development of control concepts of digital prining and laser technologies for applications in industrial environments
- Research and development of reliable assembly and connection techniques for printed structures and electronic components (connectors, SMD components, wiring, moduls, ...) as well as reliability assessments of the network using functional examples from the automotive, aviation and illumination sectors.

eHarsh

www.enas.fraunhofer.de/eharsh

The lighthouse project »eHarsh« aims at developing and providing a technology platform, in which sensor systems are developed and manufactured for their application in extremely harsh environments.

The consortium, consisting of seven Fraunhofer Institutes headed by Fraunhofer IMS, addresses the growing demand for smart control and communication techniques within the industry and our society, particularly in the Fraunhofer fields of research »Mobility and Transport«, »Energy and Resources« and »Production and Supply of Services«. The technologies and competences will be developed and evaluated using two characteristic and extremely sophisticated demonstrators from the fields of engine/turbine monitoring and geothermal energy as examples.

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

Fraunhofer IWU was the Chemnitz host of the first symposiums »Smart Production« of the High-Performance Center »Smart Production and Materials« and introduces its researches during the event.
Photo © Fraunhofer IWU

Hence, robust sensors for the use up to 500 °C and MEMS sensors, integrated circuits and system components for the use up to 300 °C are developed and provided. At the same time, work on hermetically sealed encapsulations, 3D integration and encapsulations on a system level (»system-scaled package«), analytics, testing, reliability assessment and modeling is conducted. Fraunhofer ENAS is particularly working on MEMS acceleration sensors for geothermal energy (operation up to 300 °C) and the development of long-term stable hermetically sealed encapsulations with integrated ceramic windows for the sensor system as well as reliability studies.

High-Performance Centers

High-Performance Center »Smart Production and Materials«
The High-Performance Center »Smart Production and Materials« was founded as the High-Performance Center »Smart Production« by the Fraunhofer Institutes IWU and ENAS as well as Chemnitz University of Technology. It was, after a successful first funding phase, extended on July 1, 2019 by the Fraunhofer Institutes IWS and IKTS as well as the TU Dresden and the HTW Dresden, which contribute their materials science competence. The High-Performance Center develops new technologies on an interdisciplinary basis on the subject of digitization of production, is a central hub for strategic research and transfer projects with the active involvement of SMEs and provides sustainable support for the transfer of innovation and knowledge to the economy. The goal of the High-Performance Center is transferring developments for digital industrial production from basic and advanced research to companies as quickly as possible. Moreover, strengthening of innovation and knowledge transfer, international recognition and sustainable positioning of the region, cooperation network for regional businesses and serving as an incubator for start-ups as well as attracting new talents and top researchers are overall in the focus of the work.

www.leistungszentrum-smart-production.de

In the second phase, which is now underway, the focus is on additive generative manufacturing using a wide variety of materials on the one hand and on the expansion of intelligent production technology on the other hand. Both focus on increased data acquisition and its use through the integration of sensors and actuators, and on the digitization and networking of production processes.

High-Performance Center »Functional Integration of Micro and Nanoelectronics«
The High-Performance Center »Functional Integration of Micro and Nanoelectronics« combines the expertise of the four Fraunhofer Institutes IPMS, ENAS, IIS-EAS and IZM-ASSID as well as the competences of the universities TU Dresden, Chemnitz University of Technology and the University of Applied Sciences Dresden (HTW) along the value chain for products in microelectronics and microsystems technology.

www.leistungszentrum-mikronano.de

The High-Performance Center is designed as an inter-institutional platform for the core competences system design, device and manufacturing technologies, system integration and reliability assessments. These core competences are particularly utilized in R&D projects of industry-related topics:

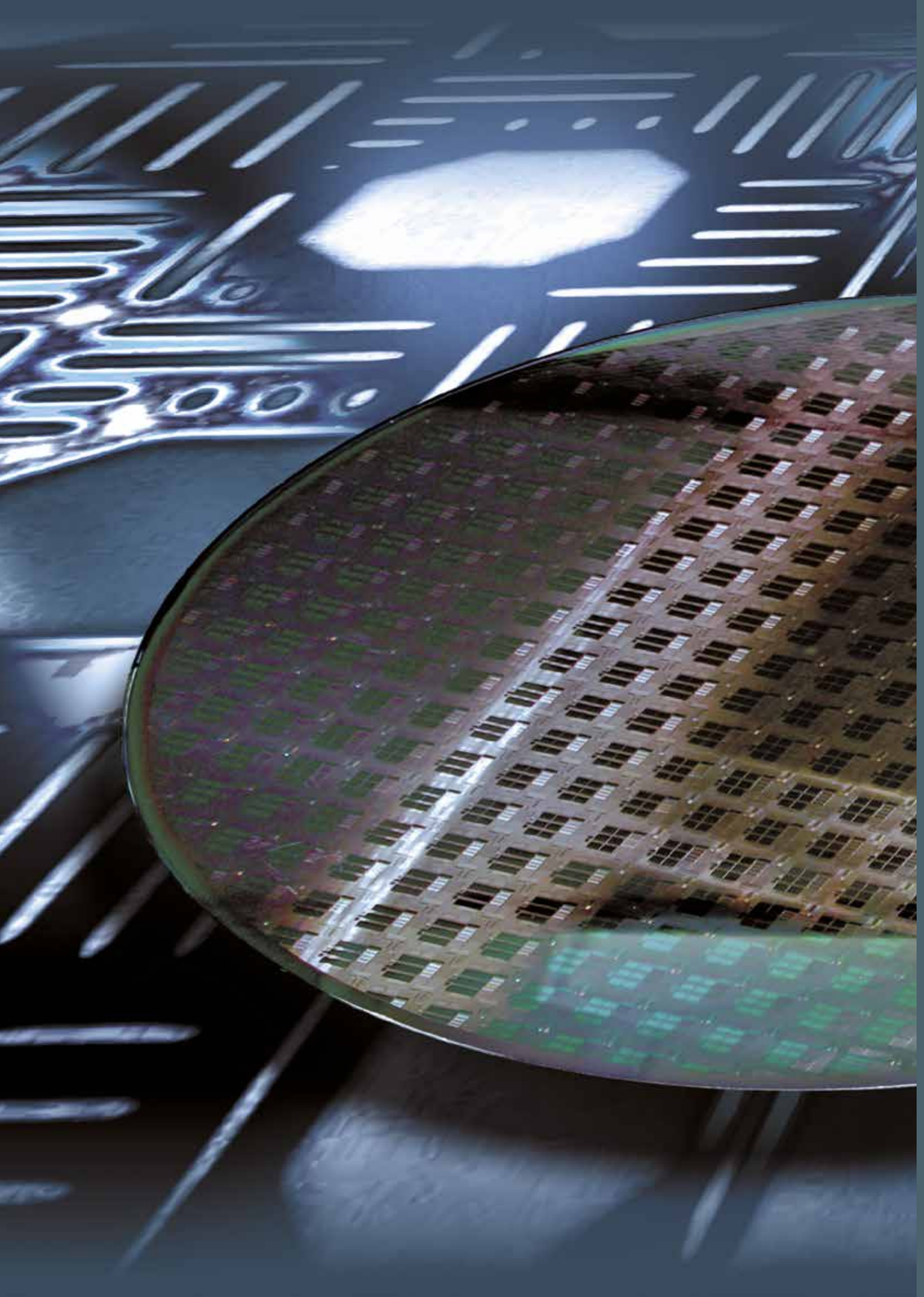
- Novel materials for new functionalities
- Modular, heterogeneous wafer systems
- Platform for ultrasonic sensors
- Integrated spectrometers with nano structures / optical systems
- Sensors / actuators in tools and machines

In October 2019, the funding phase 2019/2020 officially started with a kick-off event. During the second funding phase, the High-Performance Center will be further developed and expanded into a center with a transfer obligation. This is done with the help of the following platform projects:

- Structure integrated wireless sensor systems in tools and machines
- Platform for micromechanical ultrasonic transducers (MUT)
- Modular integration for thin heterogeneous sensor systems
- Testwafer hub – provision of 300 mm test wafers for wafer-based technologies and products

Photo © iStock (Radachynskyi)

BUSINESS UNITS



MICRO AND NANOELECTRONICS

Micro and nanoelectronics is one of the key enabling technologies of the 21st century. The ongoing downscaling (More Moore), the integration of different functionalities (More than Moore) as well as the development of possible future technologies beyond the CMOS scaling limits (Beyond CMOS) are the ongoing development trends. The business unit micro and nanoelectronics is focusing especially on:

Processes and technologies for micro and nanoelectronics with the focus on back-end of line and interconnects

The development of individual processes (metal ALD, CVD, PVD, ULK processes, dry etching), novel concepts for diffusion barriers, alternative interconnect architectures for the reduction of parasitic effects and process and technology development for memristor crossbar arrays are the main focus of this topic.

Modeling and simulation of technological processes, equipment and devices

Experimental developments are supported by the simulation of processes and equipment (PVD, CVD, ALD, ECD). Furthermore, device simulation and modeling of CMOS and nano devices (i.e. CNT FETs) as well as blackbox modeling and event-driven modeling and simulation are realized.

Beyond CMOS and RF devices, integrated circuits and technologies

This topic comprises developments of memristive devices and circuits for neuromorphic computing and hardware security applications, RF MEMS switches as well as CNT FETs for analog high-frequency applications.

Packaging and (heterogeneous) integration (2D, 2.5D, 3D) for electronic devices

This research and development area focuses on the development of processes for the integration of electronic devices for wafer-level packaging, especially joining and contacting processes, thin film encapsulation and screen printing for metallization and solder.

Electromagnetic and thermomechanic characterization and reliability evaluation

This topic addresses back-end of line components, chip-package interaction and reliability assessment of board and system level. Both, the thermomechanical reliability analysis and optimal layout for electronic components, devices and systems and simulative thermoelectrical reliability on a system (PCB) and package level, are addressed.

BUSINESS UNIT MANAGER

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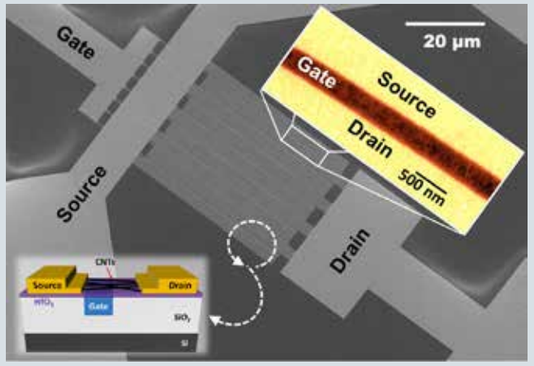
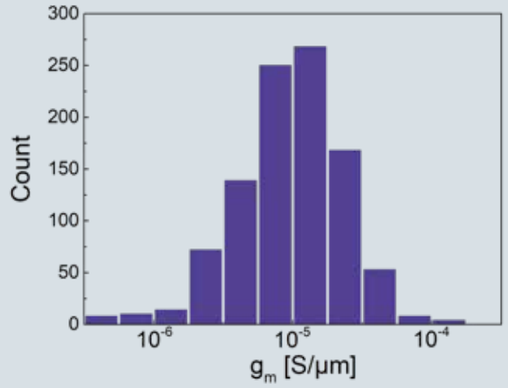
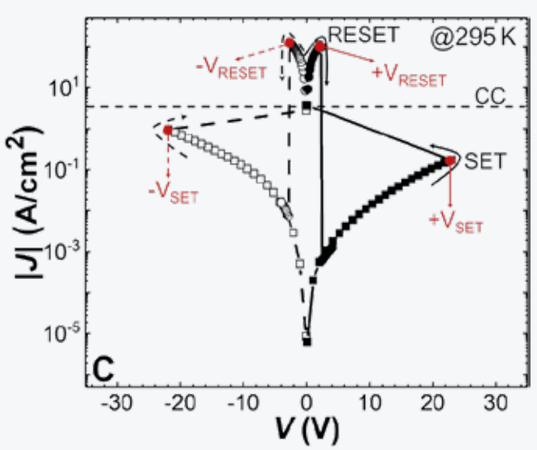


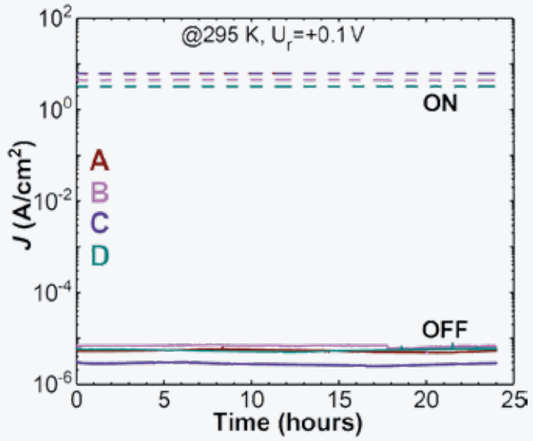
SEM image of a multifinger CNT-FET with buried gate and 280 nm channel length. Inset AFM image of the FET channel with the CNTs and the schematic device architecture in a cross-sectional view.



Typical statistical distribution of the peak transconductance implementing over 1000 CNT-FETs.



Current density–voltage (J-V) characteristics of a unipolar resistive switching device with an Al/$Y_{0.94}Mn_{1.05}Ti_{0.01}O_3$/Pt MIM with a current compliance (CC) limit of 5 mA at room temperature. Current density and voltage are plotted on a logarithmic and linear scale, respectively.



Constant read-out current density of the digital memristors A ($Y_1Mn_1O_3$), B ($Y_{0.95}Mn_{1.05}O_3$), C ($Y_1Mn_{0.99}Ti_{0.01}O_3$), and D ($Y_{0.94}Mn_{1.05}Ti_{0.01}O_3$) measured with read-out voltage of U_r = +0.1 V at room temperature on Al top electrode of 300 µm diameter.

RESEARCH AND DEVELOPMENT

· BEYOND CMOS AND RF DEVICES

MICRO AND NANOELECTRONICS

TECHNOLOGY PLATFORM FOR CARBON NANOTUBE DEVICES

Carbon Nanotubes (CNTs) are considered as an emerging functional element in advanced electronics and sensors seeking for new functionalities, further miniaturization and alternative device technologies. In a close cooperation between Fraunhofer ENAS and the Center for Microtechnologies at Chemnitz University of Technology, a nanotechnology platform was established enabling manufacturing of CNT-based nanodevices compatible with wafer-level silicon technologies.

A flexible prototyping technology was developed for CNT-based field effect transistor (FET) arrays on wafers up to 200 mm diameter. Based on this, various applications can directly be build on optical, chemical, biological or mechanical strain sensors. So far the fabrication yield is above 90 % with respect to FET on/off ratio of larger than 1000. A flexible design and reliable fabrication process allows to provide specific FET geometries with channel length down to 300 nm, high device density and low device variability.

High-performance FETs were realized by addressing applications in analog high-frequency (RF) front-end transceiver electronics. Therefore, a new class of FETs are under development perusing for higher energy efficiency and transmission bandwidth. Using a multi-layered nanostructuring approach on wafer-level, complex device structures were developed by implementing asymmetric FET geometries with 280 nm channel length. Thereby, realizing an extrinsic operation frequency of up to 14 GHz.

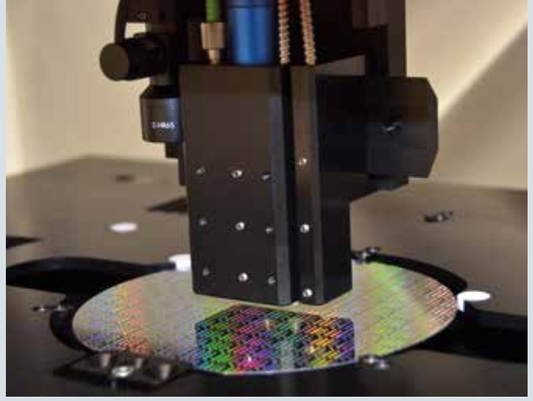
On a system level, we developed heterogeneous wafer-level technologies for the integration of CNT devices in MEMS, MOEMS or ASICs.

RESISTIVE SWITCHING IN FERROELECTRIC, POLYCRYSTALLINE $YMNO_3$ THIN FILMS

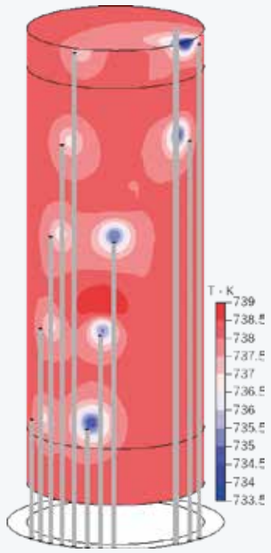
Memristors are passive circuit elements for data processing and non-volatile data processing. The resistance of these passive components is small in the ON state and high in the OFF state. The resistance values can be continuously changed in analog memristors and can be digitally changed in digital memristors. The digital memristors are comparable to other bistable systems, for example to transistors which can be switched between high-resistance (HRS) and low-resistance states (LRS). At Fraunhofer ENAS, we are investigating analog memristors ($BiFeO_3$, BFO) and digital memristors ($YMnO_3$, YMO), since both classes of memristors are required for different purposes, both individually and in combination.

The differences in the resistance values of the digital YMO memristor in the HRS and LRS differ by 4–5 orders of magnitude. This makes YMO particularly suitable as a so-called selector material in crossbar structures. Typically, transistors are used as selector materials in cross-bar structures to suppress leakage currents in not directly addressed cells of crossbar structures. The perfectly stoichiometric digital YMO memristor already has very good properties in terms of electroforming-free, endurance, and retention. We examined and optimized the data storage and reading capability of the digital YMO memristor in dependence on the chemical composition of the YMO.

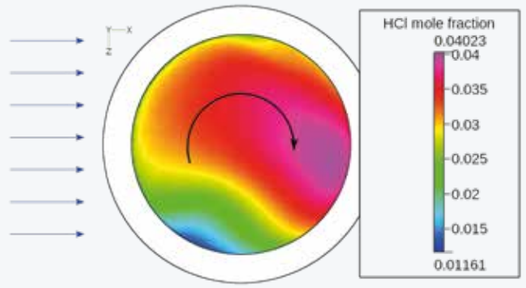
Multi-sensor measurement systems »FRT MicroProf300TTV«.



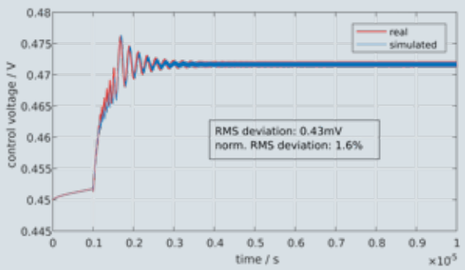
Sensor stage with chromatic distance sensor, withe light reflectometer (250 µm und 50 µm), and infrared interferometer.



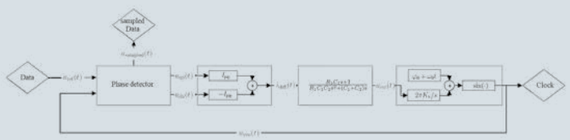
Simulated temperature distribution on the wafer stack in the model of a batch reactor.



Amount-of-substance fraction of HCl on the wafer surface in a single wafer reactor with lateral flow over the wafer (velocity direction of incoming reaction gases: blue arrows) and with wafer rotation (rotation direction: black arrow).



Comparison between the real behavior of the control voltage of a CDR-PLL with Hogge phase detector in CMOS and the simulated result.



Simplified block diagram of a typical phase locked loop for clock and data recovery.

RESEARCH AND DEVELOPMENT

- **PROCESSES AND TECHNOLOGIES FOR MICRO AND NANOELECTRONICS**
- **SIMULATION**

MICRO AND NANOELECTRONICS

NEW CHARACTERIZATION OPPORTUNITIES FOR SURFACE PROCESSING

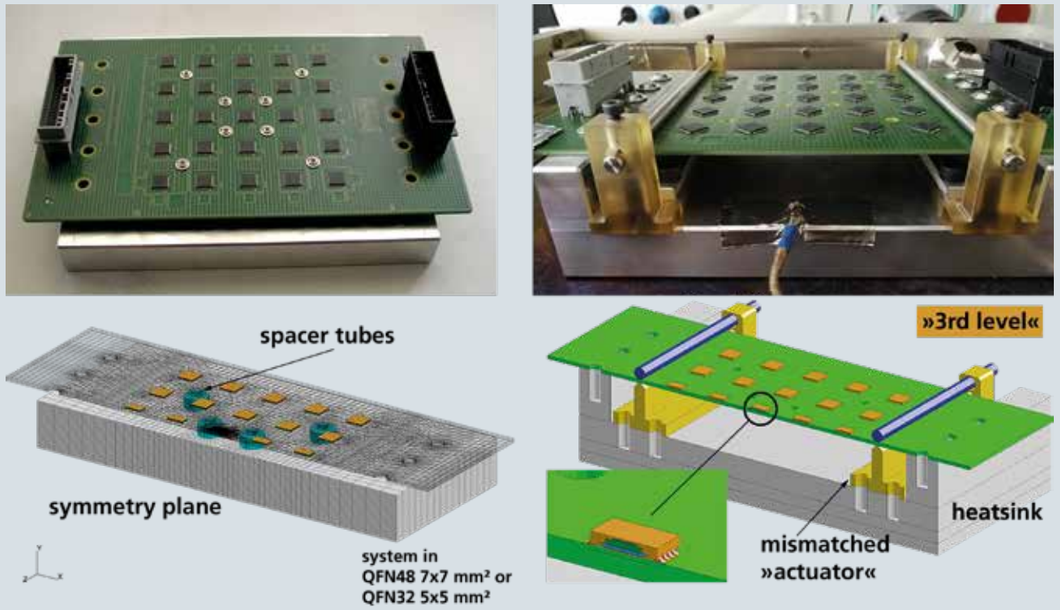
Surface processing, such as grinding or Chemical Mechanical Polishing, has become a basic technology in all areas of semiconductor processing. Both, More Moore and More than Moore applications, generate continuously increasing demands to the quality of these processes. In order to meet these requirements, a precise and reliable surface and substrate inspection is mandatory. The »UnitSC4see« inspection system allows a particle and defect detection even below 100 nm (app. 60 nm lower detection limit) by an innovative scattering light module. The additional 2D/3D brightfield module detects pattern defects, i.e. after CMP, based on microscopical image recognition. An additional »FRT MicroProf300TTV« multi-sensor measurement systems allows a comprehensive substrate characterization (TTV, bow, warp, …) using chromatic withe light sensors. The thickness of transparent films can be measured using a white light reflectometer. At least, an infrared interference sensor is able to measure membranes, cavities, and even stacked assemblies.

SIMULATION OF SILICON EPITAXY FOR 22 NM FD-SOI TECHNOLOGY WITHIN THE PROJECT MOMENTUM

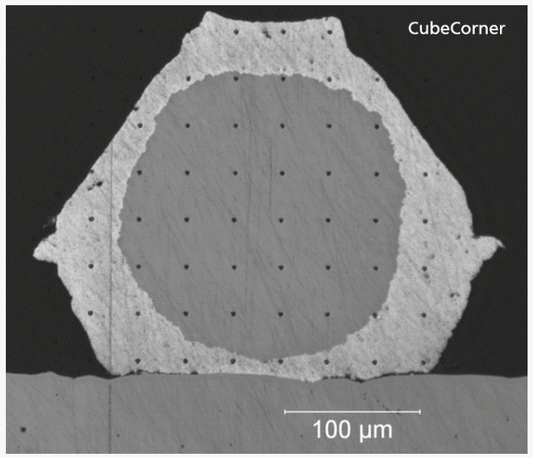
The 22 nm FD-SOI technology enables the production of microchips with high energy efficiency and low production costs. The reduction of variations during the production process poses a big challenge. In the project MOMENTUM, Fraunhofer ENAS investigates the reduction of process variabilities for epitaxial growth of silicon in the channel region as well as silicon and silicon-germanium in raised source drain (RSD) regions. For this purpose, different equipment for the silicon epitaxy is investigated using simulation methods. In the first case, the optimization of a multi wafer reactor for the channel epitaxy is realized. Causes for the thickness fluctuations between wafers were identified, experimentally verified and first optimizations delivered. Further optimizations are currently validated. In the second case, a single wafer reactor for the RSD epitaxy is simulated, at which the thickness variation over the wafer is investigated. To examine effects across length scales in more detail, we collaborate with the Center for Microtechnologies, which provides chemistry, growth, and diffusion models for epitaxy. In the project, which is funded by the Sächsische Aufbaubank (SAB), Fraunhofer ENAS cooperates with the chip manufacturer GLOBALFOUNDRIES.

PRECISE SIMULATION OF PHASE-LOCKED LOOPS FOR CLOCK AND DATA RECOVERY

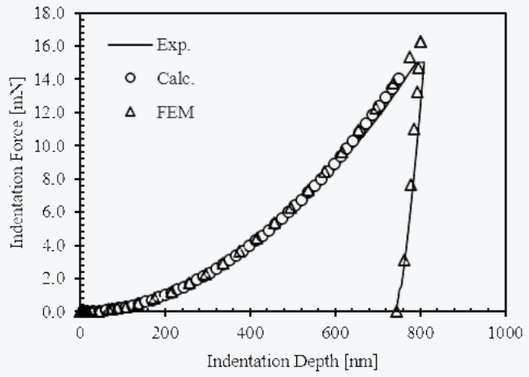
The demand for ever-faster technologies for data transmission is still growing rapidly. The communication systems used for clock and data recovery, such as phase-locked loops (PLL), are required in those asynchronous communication processes. However, the modeling and optimization of these mixed-signal systems is a challenge due to their complex behavior.
Based on the method of fully event-driven modelling, a behavioral simulation software has been developed which only calculates its successive switching points by combining analytical and numerical methods. This leads to a higher precision of the simulation with a significantly shorter simulation time. In comparison with common simulators, a speed-up factor of about 10-100 is achieved.
The modular implementation allows to characterize parasitic and nonlinear effects on system level by Monte-Carlo methods and to optimize the architectures accordingly.
In current projects, the software is also used for developing novel receiver systems for 5G applications.



Test setups to study the reliability of sensor systems. Boards mounted on loading stages for solder fatigue analyses by optical deformation measurements and FE simulations.



Nanoindentation into aluminum cladded copper wires with a cube corner tip.



Measurements to extract the elastic-plastic behavior as well as to investigate gradients of the mechanical properties within in the bonding zone.

RESEARCH AND DEVELOPMENT

- **RELIABILITY**

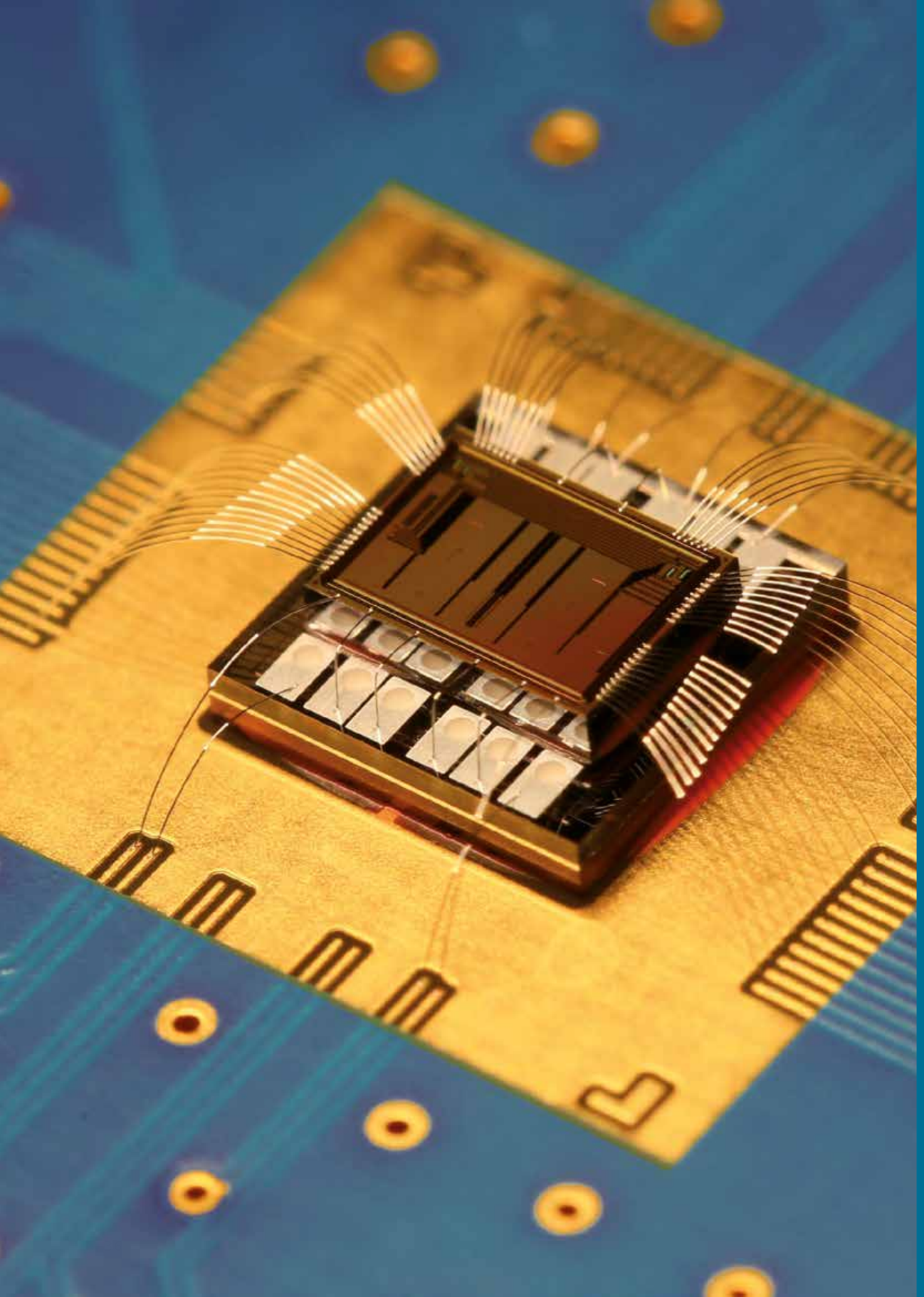
MICRO AND NANOELECTRONICS

COMBINED EXPERIMENTAL-NUMERICAL METHODS FOR THERMO-MECHANICAL SYSTEM RELIABILITY

The use of electronics in harsh environmental conditions is still increasing. One major reliability issue is solder fatigue, in particular in applications where consumer components enter automotive sector. Solder fatigue issues were frequently studied, however, differences in the fatigue behavior for standard free-standing board testing and effects of board mounting have been rarely investigated.
A methodology has been developed which combines measuring and simulation techniques for improved reliability evaluation on system level. An optical multi-sensor measurement method is applied which is capable of precise deformation measurements of boards that are mounted in automotive electronic control units from a global level to a local level. The methodology was demonstrated with test setups, where the local warpage and in-plane straining effects are analyzed down to component level (sensor systems in packages). The »3rd level« component loadings originate either from screwing on aluminum plates or from four-point bending loading stages. Finite element simulation was used to analyze the deformations with regard to their effects on the stress in soldered joints. Due to the mounting, a dramatic drop in solder fatigue life of up to several hundred percent was observed.

MATERIAL PARAMETER IDENTIFICATION BY MEANS OF NANOINDENTATION

For the reliability analysis of electronic systems based on finite element simulations, the exact knowledge of the thermal and mechanical properties of the materials is of great importance. Due to the increasing complexity and structural fineness of electronic components, the determination of these properties becomes a major challenge. Nanoindentation offers a possibility to locally investigate the mechanical properties of materials. In order to extract not only elastic but also plastic parameters, coupled evaluation routines based on numerical models are used. Due to the high deformations below the indenter tip, simulations with geometrical non-linear approaches in combination with meshing optimizations are used. By means of suitable optimization methods, the corresponding material parameters can be determined by means of measured force-displacement data.
The elastic-plastic material data was examined, for example, on a wire bond connection. A matrix of approx. 6x6 indentations with an indentation depth of up to 800 nm was used on the cross-sections of the wires. In the area of the bonding zone, the determined yield strength increased compared to the initial states of the wires. Another example is the indentation in TSV structures. Such measurements, which take the manufacturing process or real geometries into account, are not possible with classical tests (e.g. tensile tests).



SENSOR AND ACTUATOR SYSTEMS

The business unit comprises manifold sensor and actuator systems, which are based on different technologies and working principles as well as procedures, methods and sensor technologies for material and structural analysis. The prospective focus lies on an increasing integration of nanostructures. The following topics are addressed:

Inertial sensors || This topic focuses on the development of high-precision silicon-based sensors for measuring acceleration, vibration, inclination and angular rate. The value chain, starting with the design of the MEMS or system, the development of technologies as well as the manufacturing of prototypes, followed by the characterization and testing of the system, is fully covered.

Optical systems/MOEMS || Optical systems/MOEMS are well-established silicon-based systems, i.e. variable frequency optical filters and shutters based on optical Bragg reflectors which are complemented by light sources and detectors. Furthermore, quantum dot-based LED and photo detectors enable customer specific spectral sensors, material integrated light sources as well as design and display devices.

Electromagnetic sensors || Multi-dimensional magnetic field sensors based on the GMR and TMR effect, respectively, while using ferromagnetic thin films, are in the focus of this topic. In any case, they can be applied for both, the direct measurements of magnetic fields from the mT down to the nT range, and the resulting determination of, for instance, distance, position, rotation or movement. Due to the very large sensitivity of those kind of sensors, new applications become possible.

Pressure and power transducer || Silicon-based ultrasonic transducer and ambient pressure-sensitive resonators as well as MEMS loudspeaker are developed. Speakers are based on novel materials and technologies, i.e. sputtered metallic glass and printed permanent magnetic layers.

Material and structure sensors || This topic includes methods, techniques and arrangements for material and structure sensors. The sensors for mechanical strain, stress and overload (detection of cracks) are based on silicon technologies. Nano composite-based overload sensors as well as humidity sensors are using thin layers of organic materials with embedded nano particles enabling the integration into fiber-reinforced composites. Another approach are sensors based on carbon nanotubes.

BUSINESS UNIT MANAGER

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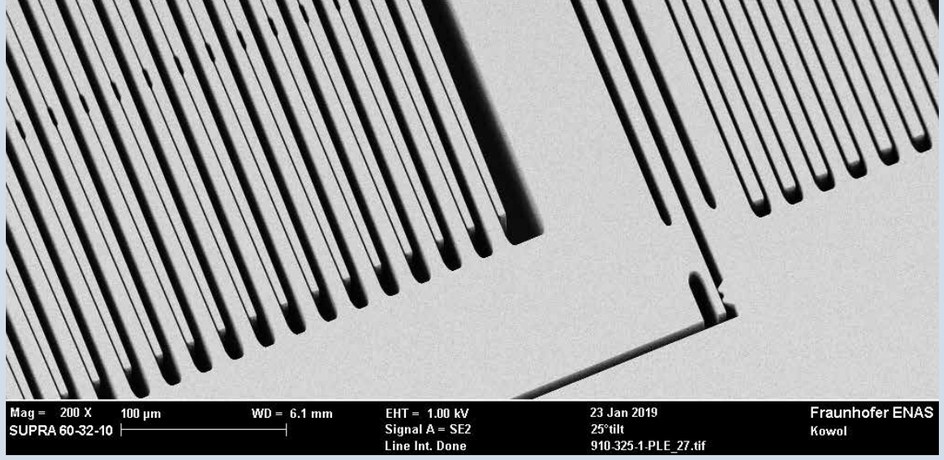


SEM photographs of the 20 g acceleration sensor, electrodes (bottom left) and damping elements (right part of the structure).

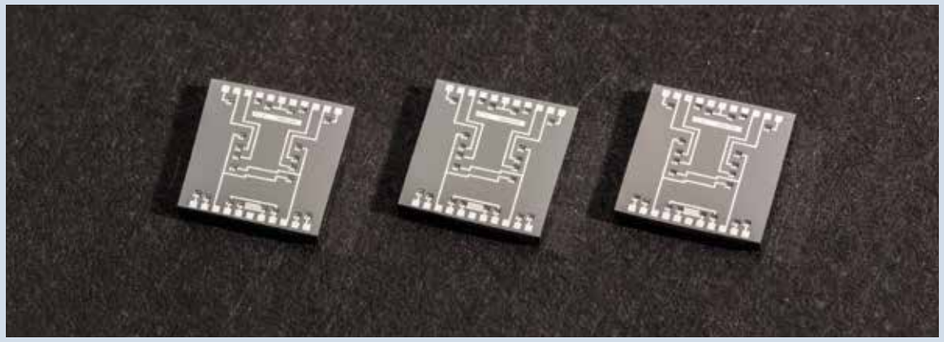
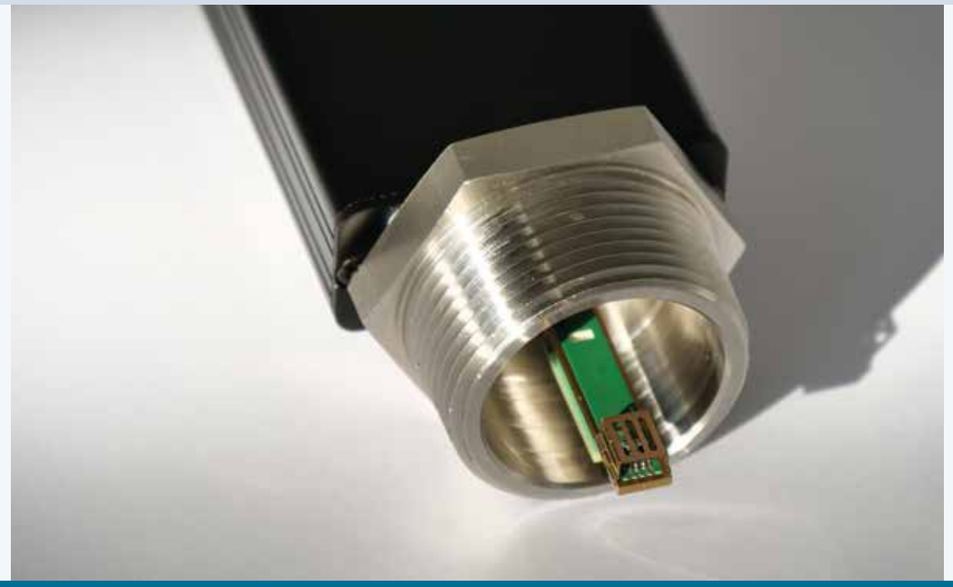


Photo of MEMS gyroscope dies.



Detailed view onto the immersed part of the viscosity and density sensor.

RESEARCH AND DEVELOPMENT

- INERTIAL SENSORS
- OPTICAL COMPONENTS / MOEMS

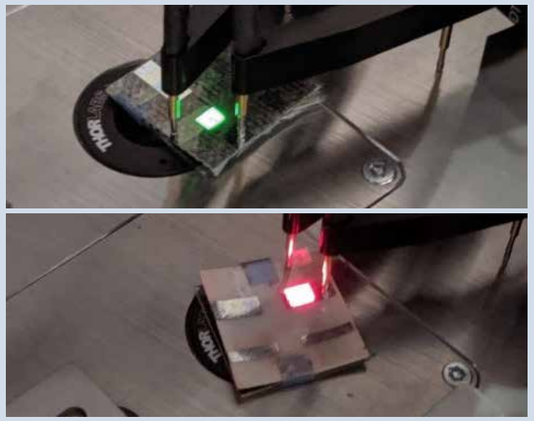
SENSOR AND ACTUATOR SYSTEMS

KOLIBRIS – MODULAR TECHNOLOGY PLATFORM FOR HIGHLY COMPACT INERTIAL SENSORS WITH INTEGRATED CIRCUIT ELECTRONICS

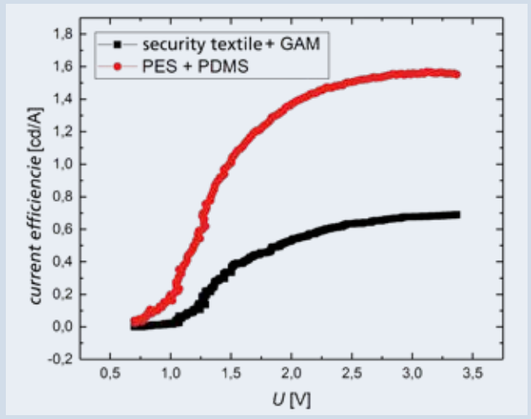
KoliBriS stands for compact low-power broadband sensors with integrated circuit electronics and is a research and development project that was initiated by EDC Electronic Design Chemnitz GmbH and carried out with the cooperative participation of X-FAB MEMS Foundry GmbH and Fraunhofer ENAS in the period from August 1, 2016 to October 31, 2019. Various inertial sensors with increased capacitive sensitivity were developed within the three-year period. This includes an acceleration sensor up to 1.5 g with a bandwidth of 100 Hz to 8500 Hz. Using a »post process gap reduction« technology, the 3 µm wide initial gaps etched by X-FAB are reduced to 500 nm and are firmly bonded and fixed in this position by micro-welding. For another application, a 2-axis sensor for a measuring range of ± 20 g and the frequency range 4 Hz to 8800 Hz was developed. The MEMS was designed and manufactured at Fraunhofer ENAS. A new technology idea, which was developed in parallel to the project and has now been patented (DE102018210810B3), was implemented and tested for the first time. Necessary large masses and at the same time electrode gaps in the sub-µm range can now be realized (enabled by the implementation of a new wafer stepper).
For the further development of a MEMS gyroscope, the main focus was set on increasing the sensitivity and improving the thermal stability. The former target was achieved by increasing the structure height from 50 µm up to 70 µm. Hereby, the typical width of 1.8 µm of the capacitive etching gaps is kept constant. The latter aim was realized due to the further development of the BDRIE technology in a full silicon variant. For this purpose, the 5th generation sensors were re-designed and the 6th generation (MEMS Gyroscope FG6) with modifications was created and successfully implemented.

SENSOR FOR THE VISCOSITY AND DENSITY OF FLUIDS

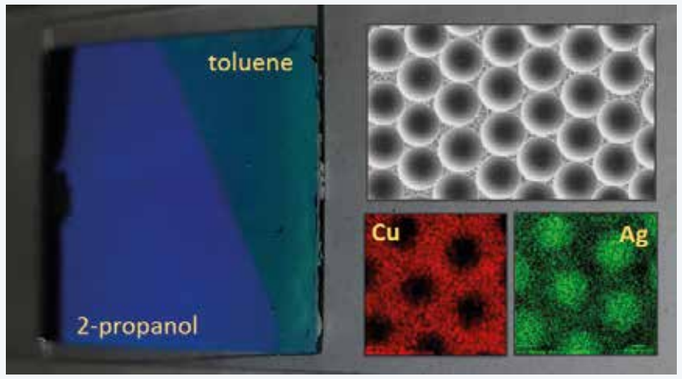
The fluidity and specific weight of organic liquids such as lubricating oils and fuels are decisive parameters for many applications. Information about this is desirable in many applications, i. e. for quality assessment, for the detection of aging and admixtures as well as changes caused by high or low temperatures, and is absolutely necessary in critical applications. At Fraunhofer ENAS, a viscosity and density sensor has been developed, which is based on MEMS resonators that are influenced by the fluid to be tested. Silicon cantilevers are mechanically excited by piezoelectric aluminum nitride transducers, and the resulting vibration is detected. The frequency dependence of the vibration properties are measured. The resonance frequency of the cantilevers is significantly changed by the density of the fluid to be tested, while the damping of the resonators is influenced by the viscosity. However, both vibration parameters are influenced by the respective other fluid property. A suitable mathematical algorithm has been developed that interprets the physical relationships from the vibration parameters viscosity and density. For practical tests in a wide temperature range from −40 °C to 150 °C, sensors are available that are screwed into a fluid-filled equipment by means of NPT threaded nipples. An integrated controller generates the excitation signal and processes the signals from the vibration detection. It provides information about the viscosity of the liquid in a measuring range of 0.5 cP ... 100 cP and about the density in a range of 0.6 kg/l ... 1.5 kg/l to a USB interface.



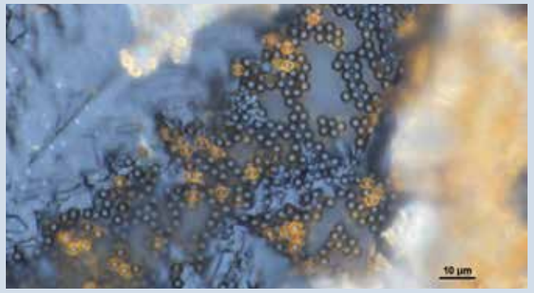
Green Quantum Dot LED on a security textile and red Quantum Dot LED on a PES fabric.



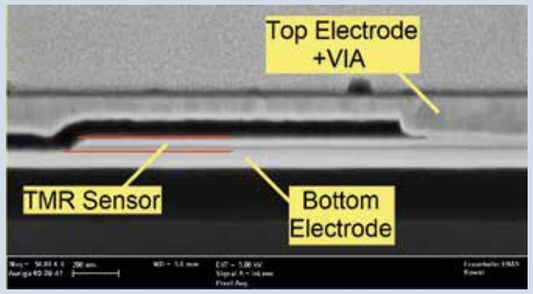
Current efficiencies of QD LEDs on textiles.



Colorimetric distinction of solvents by interaction with two-dimensional regularly arranged, metallic concave mirrors at nanometer scale.



Biologically functionalized microbeads for diagnostics via magnetic field sensor.



FIB cross section electron microscopy of a ready-to-use micropatterned TMR sensor element.

RESEARCH AND DEVELOPMENT

- MATERIAL AND STRUCTURE SENSORS
- OPTICAL COMPONENTS / MOEMS
- ELECTROMAGNETIC SENSORS

SENSOR AND ACTUATOR SYSTEMS

QUANTUM DOT-BASED LIGHT EMITTING DIODES ON TEXTILES

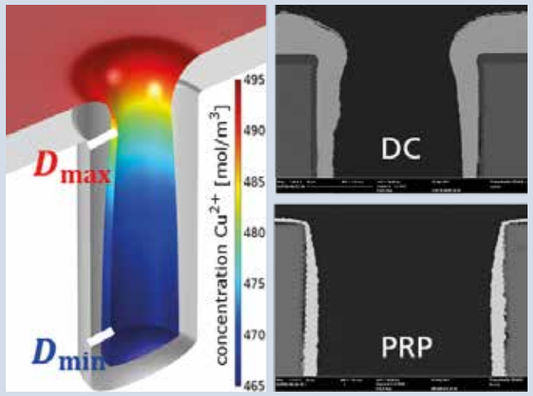
For many years, Fraunhofer ENAS has been investigating light-emitting diodes based on semiconductor nanocrystals, so-called quantum dots (QDs), for special applications. This includes the use of their distinctive light for sensors (e.g. spectroscopy or distance detection) and the preparation on special substrates. A large number of technologies are available for this preparation at Fraunhofer ENAS. By combining both, solvent and gas phase-based application methods under an inert gas atmosphere, rigid substrates such as glass or flexible substrates such as PET foils can be coated with QD LEDs. Applying these technologies, it was possible to produce the first laboratory samples of QD LEDs on textile substrates. Planarization using Parylene C has succeeded in reducing the roughness of the surface of the textile from 140 nm to 20 nm by filling in the unevenness as well as preventing the solvent from being absorbed into the textile. The QD LEDs were applied with an inverse »top-emitting« structure to make the light clearly visible from the outside. This could find numerous new application in the future, e.g. for better visibility of safety clothing or ambient lighting in the car interior.

REGULARLY ARRANGED METAL STRUCTURES FOR SENSOR APPLICATIONS

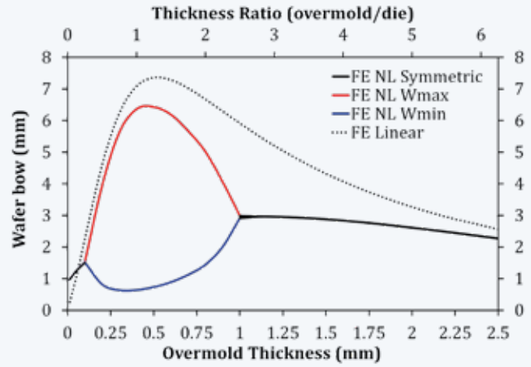
Driven by the demand for miniaturized and highly integrated functionalities in the photonics sector, metal or plasma optics have developed into a promising tool for the manipulation of light. Especially the fabrication of periodic, nanostructured, ultra-thin metal films shows promising approaches for the realization of filter arrays with smallest spatial resolution. Such nanostructured films can be produced easily and cost-efficient using an electrochemical template method. Therefore, at first monodisperse polystyrene microspheres with diameters in the range of the wavelength of visible light were synthesized by dispersion polymerization and afterward deposited as monolayers on electrical conductive surfaces using a modified Langmuir-Blodgett approach. These regularly arranged layers were used as templates for the electrochemical deposition of Ag and Cu. Sphere diameter and layer thickness can be varied to adjust pore size, distance and shape. Structured Ag layers were used exemplarily to distinguish liquids and their mixtures by the color, caused from the interaction of their different refractive indexes with the porous metal surface.

SPINTRONIC SENSORS FOR MAGNETIC MICROBEADS DETECTION

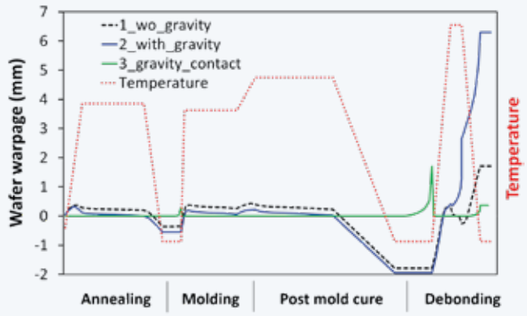
Magnetic field sensors utilizing spintronics, most notably such based on the giant and tunneling magnetoresistance (GMR and TMR) effect, offer great advantages over the Hall technology: they can be much smaller, have a lower power consumption, and a sensitivity being some orders of magnitude higher. Common applications are the determination of rotational movements, distances, amperage, or the electronic compass. Because of the large sensitivity that, for instance, guarantees a reliable magnetic stray field detection from just a few nanometer large bits in modern hard disk drives, even completely new applications become possible. In an internal Fraunhofer project, together with Fraunhofer IIS/EAS, a platform to demonstrate a defined movement of superparamagnetic microbeads by a coil arrangement was developed. Furthermore, the magnetoresistive magnetic field sensors are suitable for the microbeads detection. This work is a prerequisite, for instance, for medical lab-on-a-chip applications or point-of-care diagnostics, in order to detect pathogens or any contamination in a fluid sample.



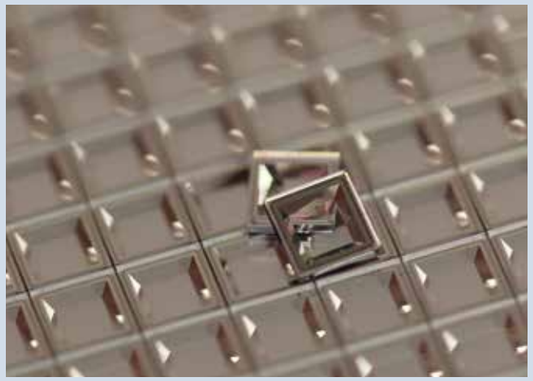
Exemplaric results of experiment (left) and simulation (right) for the Cu-ECD in very deep TSVs.



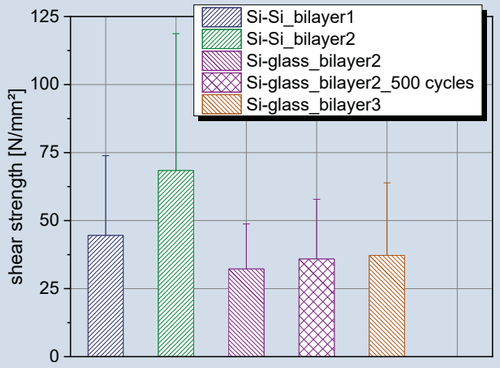
Reconstituted wafer bow as a function of overmold thickness showing bifurcation region.



Evolution of Fan-out process induced reconstituted wafer warpage.



CuO/Al bonded Si-quartz glass demonstrator for optical components.



Shear strength of CuO/Al bonded wafer substrates.

RESEARCH AND DEVELOPMENT

- 3D INTEGRATION
- RELIABILITY
- PACKAGING

SENSOR AND ACTUATOR SYSTEMS

METALLIZATION OF HIGH ASPECT RATIO TSVS IN 3D INTEGRATION OF MEMS AND SENSORS

3D integration via Through Silicon Vias (TSVs) is a promising technology for miniaturized electronic systems. For MEMS that cannot be thinned below a critical value, a large TSV depth (>300 µm) with a high aspect ratio (HAR) (>5:1) is characteristic. One challenge in the fabrication process is the conformal metallization of such TSVs. In the BMBF project VEProSi, Fraunhofer ENAS and its project partners X-FAB MEMS Foundry GmbH, KETEK GmbH, NB Technologies GmbH and Fraunhofer IPMS-CNT developed different approaches for a TSV technology to be used in sensors with large substrate thicknesses. In particular, Fraunhofer ENAS investigated a PRP method for the conformal metallization of very deep TSVs without using any organic additives. The aim was to reduce the very high consumption of organic additives as well as the complexity of additive control. In experiments, the use of a Cu-MOCVD-based seed layer in combination with the PRP method was successfully demonstrated for a conformal metallization of TSVs with 400 µm depth. Moreover, simulations could verify the results of the experiments and the beneficial effect of PRP compared to pure DC plating.

AUTOMATED VIRTUAL PROTOTYPING OF RECONFIGURED FOWLP WAFERS

Fan-out wafer-level packaging (FOWLP) technologies are getting significant attention for the heterogeneous system integration. One of the challenges is excessive wafer warpage, while going through fabrication process steps such as molding, debonding, RDL processes and grinding. For FOWLP packaging, wafer warpage study is crucial to keep the warpage within defined ranges to complete all processes successfully. In the EuroPAT-MASiP project, analytically calculated wafer deformations for mold/Si structure are validated by simulation which is used to study the reconstituted wafer warpage having mold and dies. Simulating the dependence of the wafer warpage on overmold thickness, bifurcation is found where the shape of warpage changes from spherical to cylindrical at wafer cooling from 150 °C to 25 °C. This bifurcation region can further guide to design optimum wafer maps and process flows that avoid excessive wafer warpage. Finally, FOWLP process induced warpage is analyzed by FE analysis considering geometrical nonlinearity, gravity and ground support modelled by contact elements.

LOW-TEMPERATURE BONDING OF HETEROGENEOUS SUBSTRATES BASED ON REACTIVE CUO/AL MULTILAYER SYSTEMS

Over the last ten years, Fraunhofer ENAS developed integrated reactive material systems (iRMS) for bonding applications. Based on a self-propagating exothermic reaction, thermal energy is generated directly at the bond interface itself. While medium energetic systems such as Zr/Si require a large number of individual single layers, high energetic systems such Pd/Al are quite expensive. To compensate these disadvantages, the high energetic CuO/Al multilayer system has been developed over the last three years as cost efficient alternative. Within the public funded project RNFSys (16ES0539), Fraunhofer ENAS implemented the complete process chain for design, manufacturing and bonding with CuO/Al multilayer systems on 200 mm wafers. The new material systems enables the heterogeneous integration of silicon, glass, ceramics and stainless steel in one package. The mechanical stability of the bond interface has been verified by a combined test regime of shear tests and thermal cycling. Together with MSG Lithoglas GmbH, the bonding on 200 wafer scale for optical silicon-glass devices has been demonstrated.

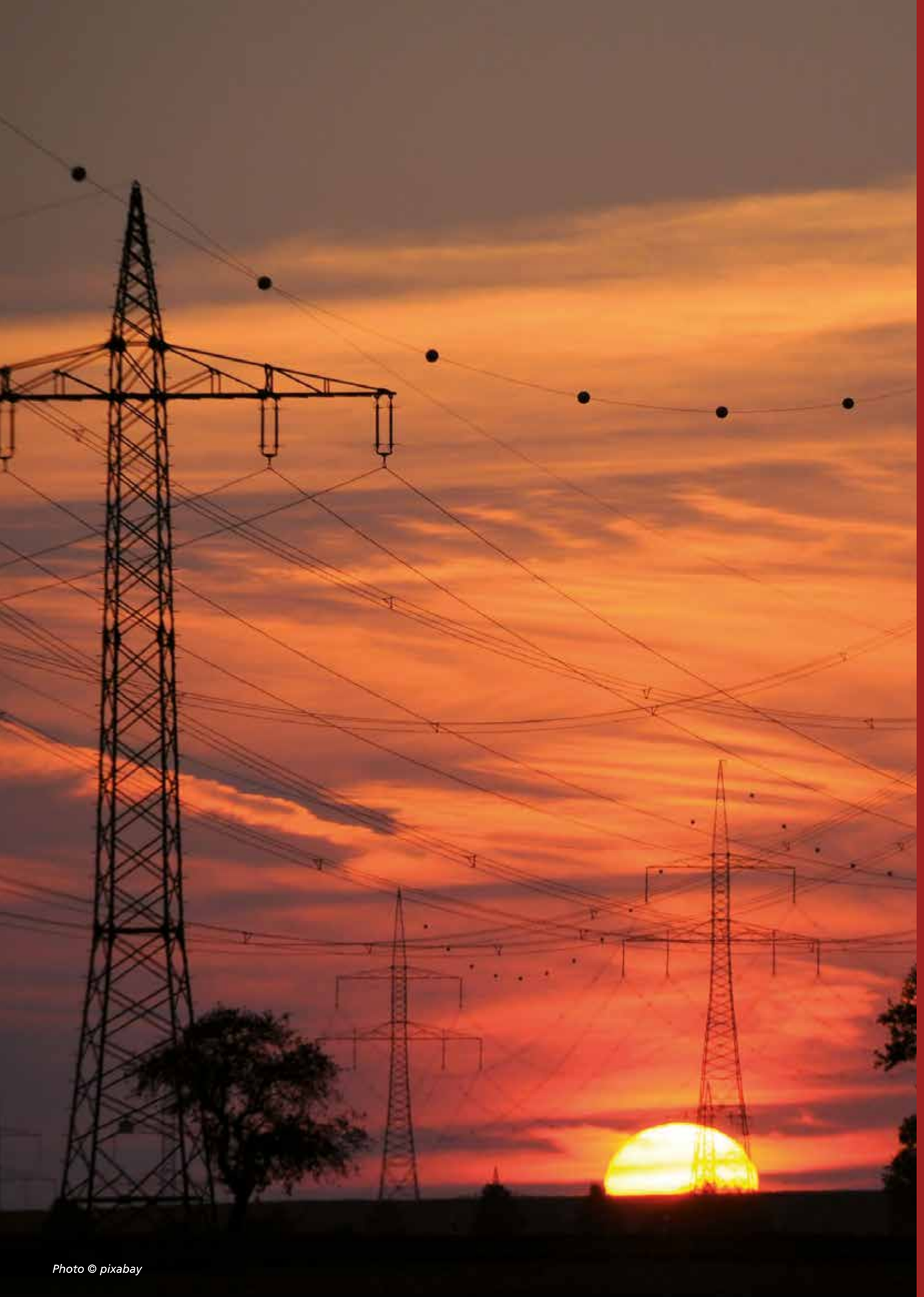


Photo © pixabay

TECHNOLOGIES AND SYSTEMS FOR SMART POWER AND MOBILITY

In the business area »Technologies and Systems for Smart Power and Mobility«, Fraunhofer ENAS develops know-how and conducts technology transfer, including the development of research samples and prototypes in the field of generation and transmission of electrical energy and in the field of transport.

The generation, distribution and control of energy flows, especially electrical energy, are becoming increasingly important due to various aspects of the paradigm shift in the energy sector, electric mobility and autonomous driving. Fraunhofer ENAS continued to develop monitoring systems for high- and medium-voltage systems during the reporting year.

However, the focus of the following page is on methods for reliability improvement that have been developed and made available. On the one hand, increasing integration density reduces resistance losses, but on the other hand, increases the problems of heat dissipation of the components and modules used.

Furthermore, attention is drawn to a novel approach to flow control on rotor blades of wind turbines. This project is intended to show to what extent the efficiency of wind turbines can be increased by active flow control if the airflows around the wings are optimized by such a technology.

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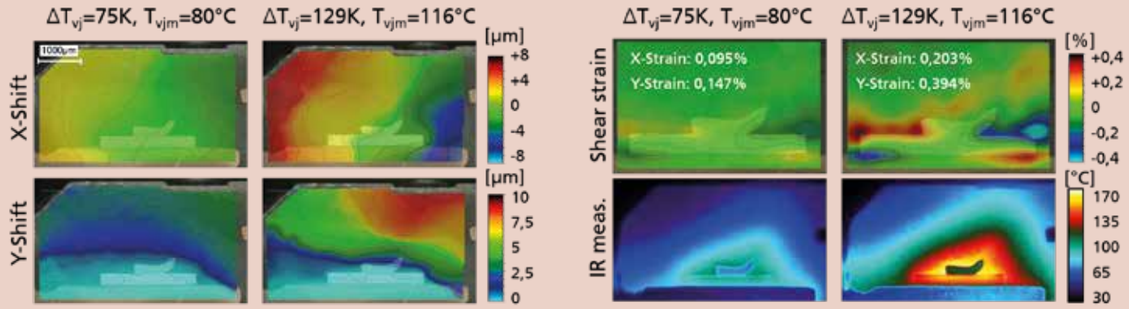
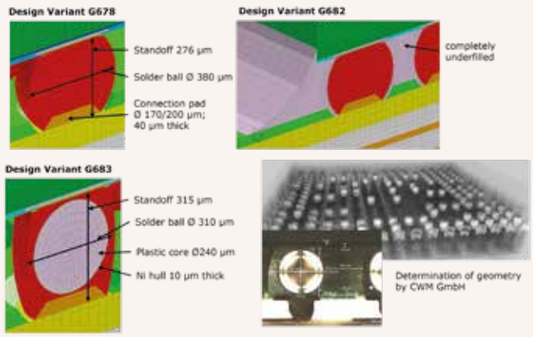
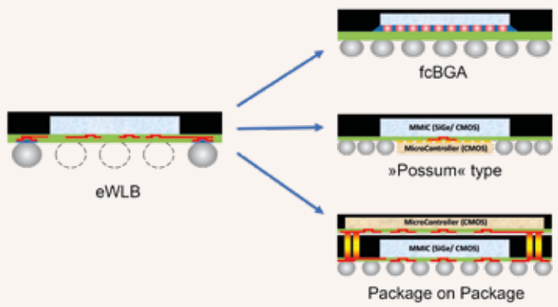


Exemplary illustration of displacement fields, the derived shear strains and of the temperature distributions recorded by an IR camera of a discrete power component under power cycling conditions.



Comparison of different solder ball variants for package contacting.



Investigation of potential package setups not yet used for radar.

The goal of TOpWind: optimaziation of wind harvesting capability of wind turbines by means of innovative flow control concepts.
Photo © Nicholas Doherty on Unsplash.

RESEARCH AND DEVELOPMENT

- RELIABILITY
- ACTIVE FLOW CONTROL

TECHNOLOGIES AND SYSTEMS FOR
SMART POWER AND MOBILITY

OPTICAL IN SITU ANALYSIS OF POWER ELECTRONIC DEVICES UNDER POWER CYCLING CONDITIONS

For the visualization and analysis of thermo-mechanical (damage) processes in power electronic devices under active power cycling conditions, an in situ investigation methodology was realized. It is based on an in-plane deformation measurement, for which the structures to be examined are prepared up to the desired grinding level by ensuring at the same time their electrical functionality. In the next step, (microscopic) images are captured under different power cycling loading conditions, both in the loaded and unloaded (initial) state. Based on these images, displacement fields and mechanical strains can be derived by means of digital image correlation. This allows, for example, the analysis of the interaction between chip connections and mold compound for different load scenarios. Furthermore, the approach enables the investigation of thermal transient processes in the cross sectioned device by using an IR camera. However, challenge is the translation of the investigation results back to the unprepared conditions. For this purpose, it is necessary to combine these investigations with FE methods in the future.

»DESIGN FOR RELIABILITY« IN RADIO FREQUENCY ELECTRONICS

High-frequency electronics in the form of radar sensors are a central component of future mobility strategies. Within the BMBF-project radar4FAD concepts for universal radar modules for fully automated driving were developed. Fraunhofer ENAS dealt with the heterogeneous module integration for the realization of small, light and large series production-suited designs. Questions concerning the thermo-mechanical robustness of radar components in the to be developed radar module construction kit were solved. Potential package structures and their contacting, which are not yet used for radar applications, were investigated. The failure modes were analyzed and the reliable functionality was examined and optimized by means of experimental and theoretical methods. For this purpose »Physics of Failure«-based models for reliability prediction and optimization were developed. The predictions were made by means of numerical simulation. These models were calibrated on the basis of existing packages and applied to potentially usable packages. By means of this strategy of »virtual prototyping«, the goal of »first time right« should be secured during the project planning and design phase of the radar components.

TOPWIND

The collaborative project TOpWind addresses the development of new concepts for active flow control around the rotor blade based on novel structure-integrated fluidic actuators to optimize the aerodynamic behavior. In order to develop such actuators and to validate their application on rotor blades of wind turbines, Fraunhofer participates with four institutes in the joint project. Fraunhofer covers all areas of research, which includes numerical investigation, the development of actuators and systems and finally the test of all those components. Fraunhofer ENAS develops flow control actuators for wind tunnel and robustness tests. For the application on wind turbines, important design aspects are already considered during development. For instance, besides focusing on the improvement of the performance and service life, reducing the energy consumption and noise emissions are also important aspects. The latter points have already been verified. The latest generation of actuators is 20 dB quieter and, in conjunction with the electronics developed by partners, much more energy efficient than previous systems.

Photo © fotolia

TECHNOLOGIES AND SYSTEMS FOR SMART HEALTH

The business unit »Technologies and Systems for Smart Health« combines R&D activities with applications in the field of health and life sciences. Our research is focused on the technical and technological aspects, especially in using micro and nanotechnologies for applications in the service of medical science, biology, and healthy living. Medical expertise is achieved via cooperation with partners, consultants and external experts in- and outside of Fraunhofer-Gesellschaft.

Our research activities can be divided in three main areas: technologies for implants, technologies for medical devices as well as measurement technology and analytics.

Technologies for implants include all developments of miniaturized sensor and actuator systems including system integration and biocompatible encapsulation for medical implants. The main motivation for implantable sensors and actuators is the replacement, restoration and improvement of human senses and organs.

The developments in the area of medical devices are dedicated to technologies, including integrated sensors and actuators that can be utilized in surgical tools and smart medical devices for the monitoring of patients and equipment. Main research activities are biocompatible materials, especially for the interface between biological tissue and technical devices as well as the utilization of MRI-compatible materials and wireless data and energy transfer.

The area of measurement technologies and analytics combines all developments for diagnostic test systems using microfluidic and/or spectroscopic components. Goal of the development is the miniaturization and automation of established analytical procedures into fast and portable systems as well as the development of novel systems and components based on micro and nano technologies.

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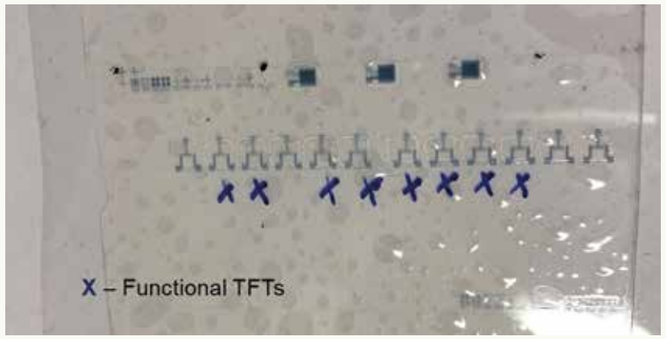
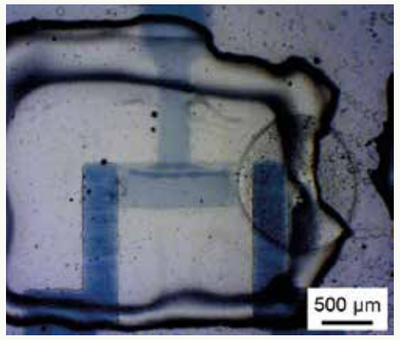
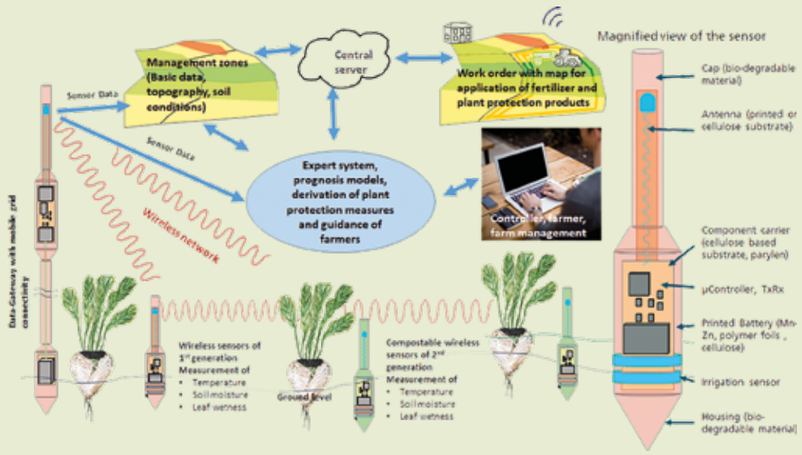
3D model of the microfluidic cartridge for the MOLOKO project.



Fully inkjet-printed Bottom Gate Bottom contact architectured biodegradable TFTs manufactured on biodegradable ORMOCER® substrate.



Microscopic image (with magnification).



Sensor network for sub-area management.

RESEARCH AND DEVELOPMENT

- **MEASUREMTENT AND ANALYTIC SYSTEMS**
- **IMPLANTS**

TECHNOLOGIES AND SYSTEMS FOR SMART HEALTH

MOLOKO – RAPID MILK ANALYSIS ENABLED BY NOVEL SENSOR

Milk is seen as staple food and part of most people's daily diet. Nevertheless, the prices for traditionally produced cow milk are constantly decreasing, resulting in increasing economic pressure for milk farms. Thus, especially smaller milk producers try to produce high-value products either by ecological production, special properties (e.g. protein content) or other milk producing animals (e.g. buffalo, goat,…). Naturally, the achievable higher prices of these high-quality products also increase the chance of food fraud. For example, expensive buffalo milk may be mixed with cheap cow milk or products might be intentionally mislabelled. Although analysis procedures for many food quality and safety parameters exist in the lab, they are not suited to efficiently prevent food fraud because of the long and complicated analysis. In the H2020 Project MOLOKO (GA Nr.780839), a test system based on a novel plasmonic sensor is developed in order to enable rapid and onsite analysis of food quality and safety parameters of milk. In the consortium, Fraunhofer ENAS is developing a reusable microfluidic chip in order to enable a fast analysis.

ADDITIVE MANUFACTURING OF BIODEGRADABLE ELECTRONIC COMPONENTS

Properties like biocompatibility and -degradability represent a promising class of raw material for electronics manufacturing. Fraunhofer ENAS has actively contributed within a Fraunhofer-internal Research Project »Bioelektron« to the development of active implants for human body based on biodegradable electronics. To this, electronic components like conductor, semiconductor and isolator have been implemented into a Multi-layer system manufactured by biodegradable materials. With inkjet and aerosol-j Jet Fraunhofer ENAS has utilized direct writing technologies for additive manufacturing. This has resulted in a workflow for manufacturing of biodegradable conductive tracks and organic fieldeffect transistors (OFET). In detail the OFETs consist of conductive electrodes (PEDOT:PSS), dielectrical layer (Shellac) and Semiconductor (β-Carotene, Indigo). Moreover Fraunhofer ENAS has developed printing and functionalization of zinc-based, conductive tracks by principle. All used ink formulations have been self-made due to lack of commercial availability.

IRRIGATION SENSOR

In recent years, Fraunhofer ENAS has developed technologies for cost-effectively manufactured and environmentally friendly sensor systems that can be used both, for environmental monitoring and to support smart monitoring of agricultural areas. The development of novel sensors using printing technologies and environmentally friendly and inert materials is the base of this work. The sensors consist of an electronic module with a single-chip radio system and sensors for air and soil temperature as well as a printed antenna and a printed battery enclosed in a plastic-coated cellulose substrate. In addition, a novel sensor is used to measure the state of irrigation and control fertilization and irrigation, which determines the suction potential. The suction potential is a measure of the pressure that plant roots have to overcome in order to absorb water from the soil structure. The conductivity of a special matrix material, which changes with the suction potential of the soil, is used as the measuring principle. In the application, the sensors are anchored underground, the irrigation sensor is connected hydraulically to the soil matrix. A part of the sensors reaches above the ground surface, and houses the electronic module and the antenna. The currently used radio system ensures direct communication of the data to a gateway installed in the field.

Photo © RF123 (Oliver Sved)

TECHNOLOGIES AND SYSTEMS FOR SMART PRODUCTION

The business unit »Technologies and Systems for Smart Production« addresses topics regarding the automation and digitalization of manufacturing. The focus is on providing technologies for the individualization of products and on sensors for production monitoring.

The digitally controlled manufacturing process of inkjet printing is used to expand existing manufacturing systems (industrial robots and roll-to-roll production lines). This enables individual product adaptations in mass production, e.g. for the automated manufacture of cable harnesses directly onto components or the material-efficient manufacture of fuel cell components such as MEA (membrane electrode assembly).

We use in-house sensor technologies for production monitoring, such as the combined use of spatially resolved vibration generation and vibration detection at micro-welding points in MEMS using laser pulses and laser Doppler vibrometers. This offers a new quality in structural health monitoring of microelectronic devices. Furthermore, we use technologies that allow the detection of sensors that move freely in industrial fluids during the manufacturing process. For this, a magnetic field-based location method is used, which is supported by artificial intelligence.

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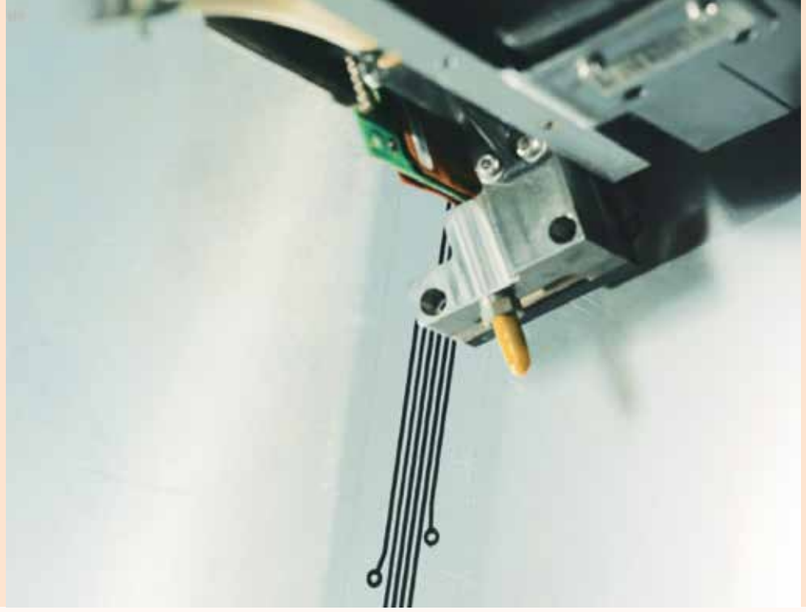
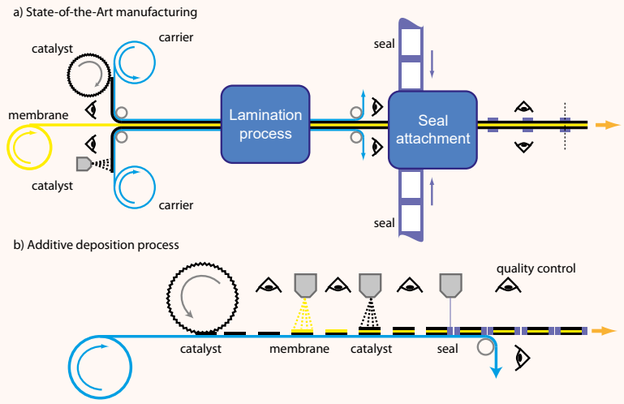
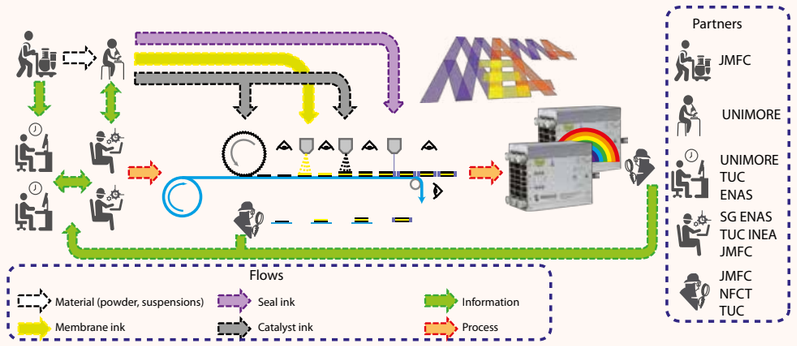


Manufacture of printed wiring harness segment on the inside of a vehicle door via 6-axis robotic-controlled inkjet printing technology.



Substitution of established processes by additive manufacturing steps.



Process flow of the cooperation between the partners within the project MAMA-MEA.

RESEARCH AND DEVELOPMENT

- **SMART DIGITAL PRODUCTION**

TECHNOLOGIES AND SYSTEMS FOR SMART PRODUCTION

PRODUCT CUSTOMIZATION IN MASS PRODUCTION – PRINTING OF WIRING HARNESS SEGMENTS ON INTERIOR AND EXTERIOR COMPONENTS

Today, wiring harnesses are individually assembled in a manual process and later on manually integrated into each vehicle. Thus, it is handcrafted instead of digitally controlled mass production. In order to increase the efficiency of production, new technologies are required. One solution approach is the combination of robotic-supported and digitally controlled printing technologies, which allow an individualized production of wiring harness segments directly on a vehicle component. Fraunhofer ENAS developed the technology within the framework of the Fraunhofer lighthouse project »Go Beyond 4.0«. We are now able to print functional layers (dielectric layers as wiring insulators and electrically conductive layers as signal conductors) by using this robotic-controlled inkjet printing technology to apply and manufacture wiring harness segments directly onto vehicle components (i.e. sheet metal and plastic parts). This technology can be introduced and applied into the vehicle production directly in the factory. Furthermore, product customization can be performed in a matter of seconds without the need to depend on suppliers. In the electrification of vehicles and thus, subsequent increase of electronic components and accompanied demand for wiring, the technology to manufacture printed wiring harness segments offers the potential to increase the production efficiency of vehicle manufacturing.

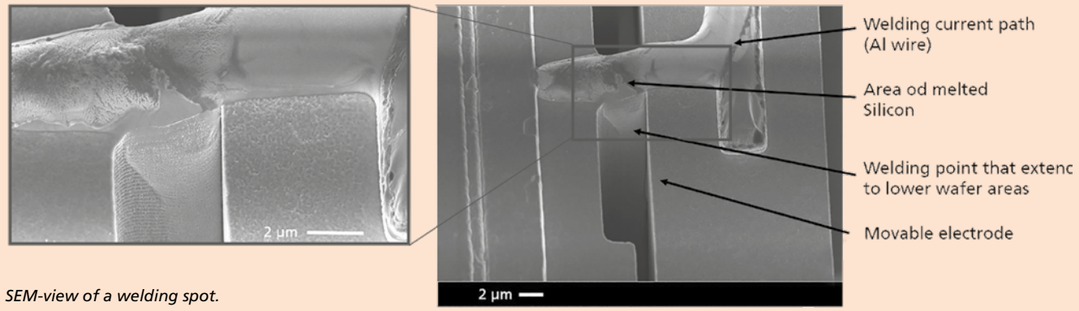
MAMA-MEA – MASS MANUFACTURE OF MEAS USING HIGH-SPEED DEPOSITION PROCESSES

A MEA (Membrane Electrode Assembly) is the core component for the chemical reaction within low-temperature polymer electrolyte membrane (PEM) fuel cells (FC). The MEA contains catalytic ingredients that split hydrogen molecules into protons and electrons. The protons recombine with oxygen to water, while the electrons drive an electric circuit. The PEM FC is e.g. used to drive vehicles or to enable off-the-grid electricity.

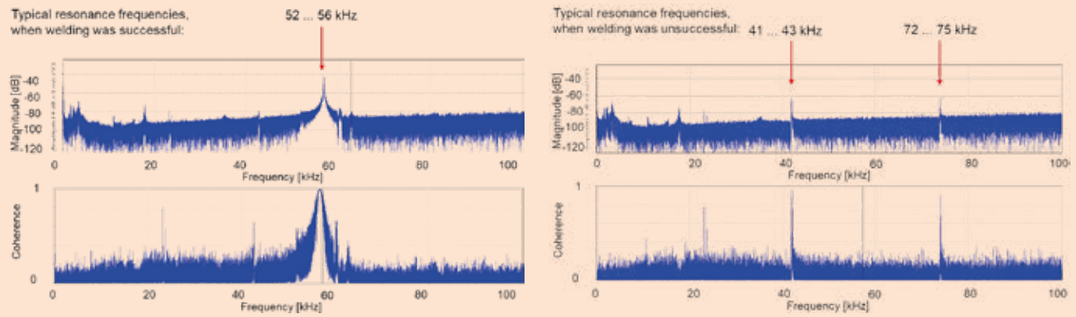
For powering a passenger car, a stack of about 400 PEM FCs generating about 110 kW is employed. The active PEM area of one stack to operate one car is in the order of 30 m². Targeting to manufacture just 1000 cars will require 30,000 m² of MEA – a size equivalent to five soccer fields. To produce such large areas of functional MEAs an effective manufacturing approach is mandatory.

MAMA-MEA is funded from the FCH JU and the European Union's Research and Innovation programme Horizon2020 research and innovation programme under Grant Agreement no. 779591. The partners INEA, JMFC, Nedstack, System Group, Chemnitz University of Technology, UNIMORE and Fraunhofer ENAS began to evaluate existing printing and coating technologies for their potential to enable the mass manufacturing of MEAs in 2018. By employing printing and coating technologies, the manufacturing workflow will be changed to generate a larger output volume compared to state-of-the-art workflows.

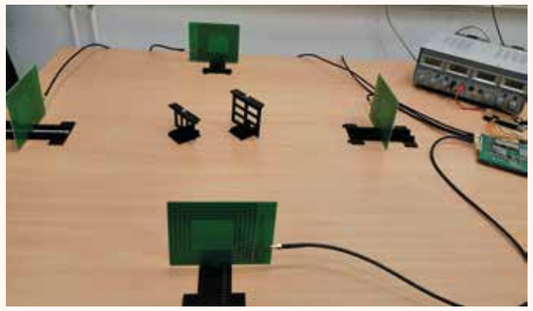
For quickly generating large areas of homogenous functional layers, slot-die coating is employed. Another technology under investigation is inkjet printing which has the advantages of being digitally driven and contact-free. Fraunhofer ENAS is supporting the project with inkjet printing experience and machinery.



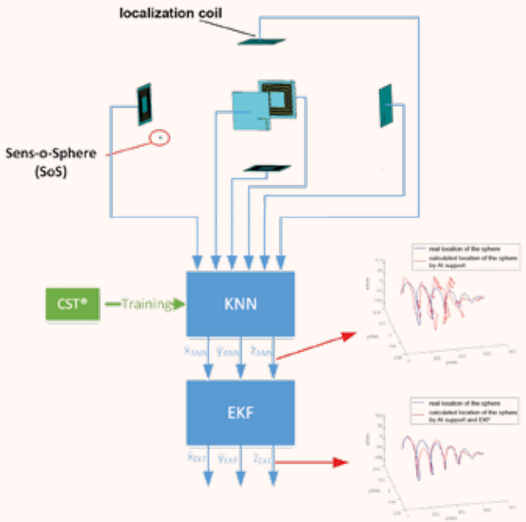
SEM-view of a welding spot.



Frequency response of a typical mechanical structure with successful weld (left) and with faulty weld (right).



Measurement set-up for a 2D locating procedure of the Sens-o-Spheres using a sending coil, three locating coils, a microcontroller unit and a WiFi interface.



Scheme of an inductive locating procedure of the Sens-o-Spheres.

RESEARCH AND DEVELOPMENT

- **SENSOR SYSTEMS AND TECHNOLOGIES FOR PROCESS AND CONDITION MONITORING**

TECHNOLOGIES AND SYSTEMS FOR SMART PRODUCTION

ON-LINE MONITORING OF THE MICRO WELDING PROCESS OF SI PARTS IN MEMS

Micro-welding processes are applied in special MEMS components in order to permanently fix the position of initially moving parts in a new position and thus, achieve structures and dimensions that cannot solely be produced by etching processes. For this purpose, electric current impulses are fed through the welding points in order to melt them for a short time. This results in a material-locked connection of the parts to be joined. Due to the small dimensions of the weld spots, which are often only 2 µm x 1 µm, a visual or microscopic inspection is not possible or too imprecise. Therefore, a method has been developed which tests the strength of the welding points immediately after welding or at a later fabrication stage. For this purpose, the resonance frequency of the structure with the weld spot is measured, which gives information about the rigidity. While thermally stimulating the mechanical structure to oscillations by means of laser pulses at a suitable location, these oscillations are detected by means of a laser doppler vibrometer. Due to the applied broadband excitation, the frequency response of the mechanical structure and its resonant frequencies are determined by evaluating the excitation and vibration signals. In a learning process, typical frequency values of structures with intact welds are determined, so that defective welds can be easily identified on the basis of lower resonance frequencies. The use of the laser excitation together with an infrared laser doppler vibrometer is particularly advantageous for subsequent testing of sealed chips, since the strength of the welding site can also be assessed in a fabrication stage in which the systems are not freely accessible but hidden under a silicon lid wafer. This can only be achieved by using the IR wavelength for excitation and detection.

IMPLEMENTATION OF A NEW MAGNETIC FIELD-BASED LOCATING PROCEDURE USING AI

The precise localization of sensing objects inside inhomogeneous substances still remains a major issue in the industry. Varying material parameters aggravate the localization by electromagnetic waves due to their complex influence on signal power and propagation velocity in unknown material density distributions. These complex density distributions also rule out the use of ultrasonic-based localization. Furthermore, optical methods are restrained to transparent media. As part of the Sens-o-Spheres project, a novel magnetic field-based method was developed remedying these disadvantages and achieving a local resolution of about a few centimeters. The induced magnetic field generates a current inside the Sens-o-Spheres coil which, in turn, produces a counter magnetic field. This counter magnetic field is then detected and analyzed by localization-coils placed outside the medium. This method brings the advantages of being quite insensitive to medium influences by operating in the near field area and allowing a very energy efficient localization of the object.
Since the distribution of magnetic fields differs strongly from the one of electric fields and from the propagation waves, complex calculations are needed for the precise localization. For these computations, a neural network has been developed. By means of additional mathematical operations (like the Kalman-Filter), this AI-based localization procedure can be optimized to allow a correction of the measured data and even a prediction of the objects future position.

Photo © pixabay

HIGHLIGHTS

DISSERTATIONS

October 1, 2019

PhD:	Saeed Motaragheb Jafarpour
Topic:	Investigation of multicomponent catalyst systems for type-selective growth of SWCNTs by CVD
Institution:	Chemnitz University of Technology

November 11, 2019

PhD:	Petra Streit
Topic:	Entwicklung von Entwurfs- und Analysemethoden für integrierte Heizfunktionalitäten in bioanalytischen Systemen
Institution:	Chemnitz University of Technology

AWARDS AND ACHIEVEMENTS

Thomas Gessner Award

The »Thomas Gessner Award« has been granted for the first time at the Smart Systems Integration Conference and Exhibition 2019,. The winner is Dr. Christian Huber from Robert Bosch GmbH Renningen. He obtained the prize for his PhD thesis »Micromechanical Tunable Fabry-Pérot Interferometers with Membrane Bragg Mirrors Based on Silicon/Silicon Carbonitride«. Particular mention should be made of the new MEMS FPI design with two released membrane mirrors and the demonstration of the feasibility of his concept.

The »Thomas Gessner Award« is a contribution of Fraunhofer ENAS to promote applied research by awarding a prize for excellent scientific work at the annual Smart Systems Integration Conference. The award is aimed at national and international master and PhD students in the field of Smart Systems Integration, whose thesis is at least assessed as »very good« and does not date back more than two years. The evaluation process considers in particular the novelty of the scientific and methodical approach, advance of knowledge, implementation of the scientific results into the application, proof of economic success and internationality.

Thomas Gessner Award Ceremony from left: Committee member Dr. Stefan Finkbeiner (President of EPoSS), Awardee Dr. Christian Huber (Robert Bosch GmbH), Committee chairman Prof. Dr. Thomas Otto (Fraunhofer ENAS), CEO Petra Haarburger (Mesago Messe Frankfurt). Photo © Mesago Stuttgart

AWARDS AND ACHIEVEMENTS

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Best Paper Awards at Conferences

Dr. Rainer Dudek received the Best Paper Award at the »IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)« (May 28-31, 2019) in Las Vegas/USA for his paper »Comparison of Solder Joint Fatigue Life Prediction and several long-term Testing Results« within the »Mechanics and Reliability« track. He focused on the results of the ultimate validation of the lifetime models, comparing the field load vs. accelerated tests based on the ultra-long-term reliability tests at the mine »Sankt Anna«, the European test lab for ultra-long-term reliability testing.

The team of Katja Meinel, Dr. Chris Stöckel, Marcel Melzer, Dr. Sven Zimmermann, Dr. Roman Forke, Prof. Dr. Karla Hiller, and Prof. Dr. Thomas Otto were honored with the Outstanding Paper Award at the »Transducers 2019 – EUROSENSORS XXXIII« in Berlin (June 27, 2019) for their publication »Piezoelectric Scanning Micromirror with Large Scan Angle based on Thin Film Aluminum Nitride«. Katja Meinel accepted the award on behalf of the team.

On September 18, 2019, Toni Großmann received the Best Paper Award at »IMTC – 4th International MERGE Technologies Conference Lightweight Structures« in Chemnitz for his publication titled »Reflection based Strain Sensing using Metamaterials«.

1 Handing over of the Best Paper Awards at the Transducers – Eurosensors XXXIII 2019 in Berlin.

Fraunhofer ENAS Research Award

Fraunhofer ENAS awarded its ninth Research Award to the Chemnitz' scientist Dr. Christian Helke. His development of technologies for nanostructuring enabled the manufacturing of two novel reflector systems for micro-optical devices. The acting director of Fraunhofer ENAS, Prof. Dr. Thomas Otto, awarded the prize on December 17, 2019.

2 The acting director of Fraunhofer ENAS Prof. Dr. Thomas Otto (2nd f.l.) hands the 9th Fraunhofer ENAS Research Award to Dr. Christian Helke (2nd f.r.) together with the chairwomen of the committee, Prof. Dr. Karla Hiller (l.) and Dr. Danny Reuter (r.), head of the department Lithography and Pattern Transfer of the Center for Microtechnologies at Chemnitz University of Technology.

The Rotary Club of Chemnitz honors Prof. Dr. Thomas Gessner and welcomes him into the circle »Great Chemnitzer«

At the Chemnitz Red Tower, a memorial plate embedded into the ground reminds of Prof. Dr. Thomas Gessner (1954–2016) as »Great Chemnitzer«. With this award, the Rotary Club of Chemnitz honors the former director of the Fraunhofer Institute for Electronic Nano Systems ENAS and the founder and long-standing director of the Center for Microtechnologies at Chemnitz University of Technology, who died in 2016.

Awards from our industry partners

The »FMD-Space« offers start-ups with an innovative product idea and a resulting microelectronic question access to the infrastructure of the Research Fab Microelectronics Germany (FMD). The access is announced as a competition. The aim of the cooperation is the joint development of demonstrators and prototypes. Quantune Technologies GmbH received funding via FMD Space for the implementation of its project »Transportable Laser Spectrometer based on a Fabry-Pérot filter for Glucose Detection« together with Leibniz FBH, Fraunhofer IAF and Fraunhofer ENAS. The analysis is to be carried out by a fingerprint sensor via smartphone.

The Innovation Prize for Craftsmanship of the State of North Rhine-Westphalia was awarded to Ulrich Rotte Anlagenbau und Fördertechnik GmbH for the project »Active force-sensitive workpiece carrier« (short: »AWT«). Research partners in the project are the Department of Sensor Technology at Paderborn University in cooperation with the department Advanced System Engineering of Fraunhofer ENAS, the Fraunhofer Institute for Mechatronics Design Technology IEM, MSF-Vathauer Antriebstechnik and Miele.

CONFERENCES AND WORKSHOPS

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International conferences, seminars and workshops

On January 23, 2019, the second transfer event of Silicon Saxony e.V. under the title »Science meets Industry« took place in Chemnitz. Saxony's most important high-tech network invited representatives from research, science, industry and commerce to the Fraunhofer Institute for Machine Tools and Forming Technology IWU. During a guided tour at Fraunhofer ENAS, interested partners from industry and research were given an insight into the topics of Fraunhofer ENAS. One of two workshops of the day was organized by Fraunhofer ENAS together with Chemnitz University of Technology on the topic »Customized adapted piezoelectric microsystems for industrial sensor systems«.

On March 13, 2019, experts from the field of lithography met for the 31st Chemnitz Seminar on »Electron Beam Lithography: Materials – Processes – Applications«. Since 2015, Fraunhofer ENAS has been equipped with an electron beam exposure system and therefore invited colleagues and interested parties as well as potential users and operators of electron beam lithography to the institute in order to get into conversation with each other and to exchange information on current topics concerning electron beam-based nanostructuring in a relaxed atmosphere. In addition to the scientific issues, practical aspects and background information were discussed, e.g. on electron beam coatings, new material developments, data preparation and applications. Another event of the series »Chemnitz Seminars« took place at Fraunhofer ENAS on May 21 and 22, 2019. Organized by the System Packaging department, the seminar addressed the latest research results with the topic »MEMS Technologies and Applications«. The focus was on advanced MEMS and MEMS packaging technologies, current integration trends and national/international funding opportunities.

The 13th Smart Systems Integration 2019 took place in Barcelona, Spain, from 10 – 11 April 2019. 242 experts from 19 countries discussed the latest components and new technologies in both manufacturing and system integration. In addition, the presentations focused on results from cooperations in current EU projects, but also in the application areas Industry 4.0 and Healthcare. The keynote sessions addressed the future topics artificial intelligence, printing technologies and quantum computing. Furthermore, the first Thomas Gessner Award was awarded on April 10, 2019 (see: Awards). Due to the change of the organizer, the next Smart Systems Integration Conference will take place in 2021. The conference will also be reorganized. However, Prof. Thomas Otto from Fraunhofer ENAS will continue the SSI as Chairman together with EPoSS and a new organizer. The next Smart Systems Integration Conference will be held in Grenoble, France, in 2021.

After a one year break, Fraunhofer ENAS together with the staff of the Fraunhofer Project Center »MEMS / NEMS Devices and Manufacturing Technologies at Tohoku University« and the WPI-AIMR of Tohoku University organized the 13th Fraunhofer Symposium on April 15, 2019 in Sendai, Japan. 50 Japanese experts from industry and science informed themselves about the topics Society 5.0 and Industry 4.0, especially about current research results in these areas. Society 5.0 is especially shaped in Japan and addresses all topics of society that deal with digitization. These include healthcare, mobility, living conditions in urban and rural areas, energy production and distribution as well as industrial and agricultural production.

During the »long night of sciences« on May 4, 2019, Fraunhofer ENAS opened its doors and invited interested residents from Chemnitz and surrounding areas to join in lab tours, hands-on demonstrators from the fields of medical technology, aviation, energy and mechanical engineering and some extras to join in and enjoy.

40 years of microelectronics in Chemnitz

Within the framework of C-Town 360°, two jubilees were addressed with the symposium »40 years of microelectronic technology as an enabler for the industry of the future«. The success story of the microelectronics location Chemnitz began in the 1970s with the foundation of the Technikum Mikroelektronik at today's Chemnitz University of Technology. For decades, scientists at the Faculty of Electrical Engineering and Information Technology researched and developed in the field of microelectronics and microsystems technology. Today, on the Smart Systems Campus Chemnitz, which has now been in existence for 10 years, in addition to the Center for Microtechnologies at Chemnitz University of Technology as the successor to the Technikum Mikroelektronik and the Fraunhofer ENAS, other research units at Chemnitz University of Technology and local companies are working on the latest sensors and intelligent electronic systems.

1 Lab tours at Fraunhofer ENAS during the long night of sciences 2019.

2 Dr. Martina Vogel guided through the symposium »40 years of microelectronic technology as an enabler for the industry of the future«.

CONFERENCES AND WORKSHOPS

On October 21, 2019, the first Chemnitz Industry Meeting, organized by the German Physical Society (DPG), took place at Fraunhofer ENAS. Dr. Volker Linß, leading researcher and developer of VON ARDENNE GmbH from Dresden, reported on how his company developed from a research institute to a globally active high-tech company and which fields of activity are interesting for physicists in plant engineering and technology development. The aim of the industry talks is to create regional forums for the exchange of experience on topics of physical research, at the interface of the transfer of scientific knowledge into application as well as on current industrial topics and to promote networking.

The first public event of the High-Performance Center »Smart Production and Materials« took place on October 29, 2019 with the symposium »Smart Production« at Fraunhofer IWU in Chemnitz. In addition to a variety of technical presentations on the project results of the first funding phase of all High-Performance Center partners and an outlook on the main topics of current projects, the 45 participants were also presented with best practice examples of successful innovation transfer from the High-Performance Center to industry.

3 The German Physical Society (DPG) invited Dr. Volker Linß from VON ARDENNE GmbH for a talk to the first Chemnitz Industry Meeting at Fraunhofer ENAS.

Science meets arts

Following our RETROSPECTIVE of all artists invited so far in our exhibition series »Science Meets Art«, which has been running since 2010, we presented two regional artists at the institute again in 2019.
In spring we showed the exhibition »DESASTER« by the Chemnitz artist Frank Maibier. Within the framework of the now 19th exhibition of our series, we invited the artist to present graphics and objects made of acrylic and metal in our institute rooms. With his graphic works and lithographs on paper as well as three-dimensional, almost floating objects, he brought new perspectives into our house. For the first time the atrium of the institute was also included. At this central point, Frank Maibier created a »module chaos« by installing a metal sculpture made of numerous uniform aluminum modules. About his exhibition »DESASTER«, he says himself: »The examination of geometric modules, overlays, distortions and a playful handling of forms and materials create constructive states. Images and objects in fabric-like entanglements, order in chaos, chaos in order – a kind of positive disaster.«
In November, the exhibition »QUO VADIS« by the Chemnitz artist Dagmar Ranft-Schinke moved into our institute. Ranft-Schinke is mainly concerned with the influence and impact of scientific work on humans and nature. Thus, she created the scientist Professor Smith, who in her pictures as struggles as »sorcerer's apprentice« with his called spirits. Known as a critical and visionary artist, she already made her pictures accessible through digitalization in the 1990s together with scientists from Darmstadt. She herself describes her style as visionary realism and calls curiosity and imagination the two common starting points in science and art.

Chemnitz company run

For the eighth time, Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology participated in the 14th Chemnitz company run with a team of 28 employees. 9215 runners took part at the company run, our best male runner Patrick Schwarz finished at position 66 and our best female starter Doreen Jäger at position 210. The four best male runners finished in 13th place, the best female team finished the run in place 64. The mixed team also finished 20th.
Congratulations!
We are looking forward to the Chemnitz company run 2020.

EXHIBITIONS AND TRADE FAIRS

Fraunhofer ENAS has presented its research results and prototypes at the following international trade shows and exhibitions in 2019:

www.fraunhofer.de

3D & Systems Summit 2019	Dresden, Germany	January 28–30, 2019
INTEC 2019	Leipzig, Germany	February 5–8, 2019
LOPEC 2019	Munich, Germany	March 20–21, 2019
Smart Systems Integration 2019	Barcelona, Spain	April 10–11, 2019
BioCHIP 2019	Berlin, Germany	May 7–8, 2019
SEMIEXPO Russia 2019	Moscow, Russia	May 14–15, 2019
techtextil 2019	Frankfurt/Main, Germany	May 14–17, 2019
International Transport Forum 2019	Leipzig, Germany	May 22–24, 2019
SIAE – Paris Air Show 2019	Paris/Le Bourget, France	June 17–23, 2019
SENSOR + TEST 2019	Nuremberg, Germany	June 25–27, 2019
SEMICON West 2019	San Francisco, USA	July 9–11, 2019
IMTC 2019	Chemnitz, Germany	September 18–19, 2019
MST-Kongress 2019	Berlin, Germany	October 28–30, 2019
Agritechnica 2019	Hannover, Germany	November 10–16, 2019
SEMICON Europa 2019	Munich, Germany	November 12–15, 2019
COMPAMED 2019	Düsseldorf, Germany	November 18–21, 2019

MEMBERSHIPS

Memberships of Fraunhofer ENAS	
AGENT-3D e.V.	Dresden, Germany
ALD Lab Saxony	Dresden, Germany
biosaxony e.V	Dresden, Germany
Cool Silicon e.V.	Dresden, Germany
DECHEMA	Frankfurt/Main, Germany
Dresden Fraunhofer Cluster Nanoanalysis	Dresden, Germany
Dresdner Gesprächskreis der Wirtschaft und Wissenschaft e.V.	Dresden, Germany
Eureka Cluster Metallurgy Europe	Ulm, Germany
European Center for Micro and Nanoreliability EUCEMAN	Berlin, Germany
European Platform on Smart Systems Integration EPoSS	Berlin, Germany
FED Fachverband für Design, Leiterplatten- & Elektronikfertigung	Berlin, Germany
Fraunhofer Alliance AutoMOBIL Production	Germany
Fraunhofer Alliance Nanotechnology	Germany
Fraunhofer Alliance Textile	Germany
Fraunhofer Group Microelectronics	Germany
Fraunhofer Cluster 3D Integration	Dresden and Chemnitz, Germany
futureSAX – innovation platform of the Free State of Saxony	Dresden, Germany
Hzwo e.V.	Chemnitz, Germany
Industrieverein Sachsen 1828 e.V.	Chemnitz, Germany
InnoZent OWL e.V.	Paderborn, Germany
it's OWL – Intelligente Technische Systeme OstWestfalenLippe e.V.	Bielefeld, Germany
IVAM Microtechnology Network	Dortmund, Germany
MEMS Industry Group®	Pittsburgh, USA
Micromachine Center	Tokyo, Japan
EFDS Europäische Forschungsgesellschaft Dünne Schichten e.V.	Dresden, Germany
Organic Electronics Association OE-A	Frankfurt/Main, Germany
Organic Electronics Saxony e.V. OES	Dresden, Germany
Semiconductor Equipment and Materials International (SEMI)	San José, USA
Silicon Saxony e.V.	Dresden, Germany
VEMAS innovativ	Chemnitz, Germany
Partner in ZIM networks	
ZIM Cooperation Network »3D electronics«	Darmstadt, Germany
ZIM Cooperation Network »Scaling of bond technologies for micro- and macroscopic production processes« (SCALE)	Chemnitz, Germany
ZIM Cooperation Network »Environmental Technology and Soil Reclamation« (UtBr)	Berlin, Germany

PUBLICATIONS AND PATENTS

Publications

In 2019, the scientists of Fraunhofer ENAS published their results in 147 book articles and conference proceedings as well as 10 book chapters.

You can find our published content within the database Fraunhofer Publica which contains all publications and patents published by Fraunhofer Institutes:
http://publica.fraunhofer.de/starweb/pub09/newPub.htm

Moreover, they are listed on the website of our partner Center for Microtechnologies of Chemnitz University of Technology:
http://www.zfm.tu-chemnitz.de/publications/index.php.en

Electronically available documents can be downloaded via Fraunhofer Publica.

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Patents

In 2019, 13 patents from scientists of Fraunhofer ENAS have been published and/or granted. In summary, staff of Fraunhofer ENAS holds 193 patents in 64 patent families.

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