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FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS

Annual Report 2017

CONTENT

Cover page:
Sensor system for hemodynamic controlling developed within the lighthouse project »Theranostic Implants« of Fraunhofer-Gesellschaft (please see page 24).
The system consists of the acceleration sensor developed by Fraunhofer ENAS (visible in the middle of the systems, fabricated in BDRIE technology as glass/Si/glass stack) and the pressure sensor with protected wirebonds by glob-top technology as well as the ASIC, both developed by Fraunhofer IMS.
photo: Frank Roscher, Fraunhofer ENAS

PREFACE

photo: Ines Escherich

»*If there is any one secret of success, it lies in the ability to get the other person´s point of view and see things from that person´s angle as well as from your own.*« *(Henry Ford)*

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

In 2018, we celebrate the 10th anniversary of the Fraunhofer Institute for Electronic Nano Systems ENAS and we can look back at a continuous positive development of the institute. A large portion of our research volume is generated by contract-based research, i.e. in the framework of direct orders from industry and publicly funded projects. At this point, we would like to thank our partners and customers for their trust and support.

In 2017, we started new things and continued traditional ones. We decided to obtain a DIN EN ISO 9001:2015 certification for the institute. We strengthened our cooperation within the Fraunhofer-Gesellschaft, especially in the Research Fab Microelectronics Germany. Moreover, we intensified our research activities in topics related to digitization, especially reconfigurable switches for hardware security and artificial intelligence applications, sensors for harsh environment, sensor systems for industrial internet and application in agriculture as well individualized production of serial components under mass production conditions.

Our central focus toward the market still lies in sensor and actuator systems as well as semiconductor technology / microelectronics / nanoelectronics. In addition, smart systems for a variety of applications were the focus of our research and development activities.

The year 2017 was also characterized by two changes in the management. Dr. Tina Kiessling started her position as head of administration in December 2017. Since October 2017, Dr. Ralf Zichner is managing the department Printed Functionalities.

In the annual report, you find a selection of topics we have been working on during the past year. Let yourself be inspired.

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

photo: pixabay

STRATEGY: THE KEY TO SUCCESS

STRATEGY: THE KEY TO SUCCESS

Strategy process / follow-up process

Fraunhofer ENAS can look back at a positive development with high industrial revenues and a continuous increase in budget and number of employees since its formation in 2008. In order to ensure and to expand the position in the market, to open new areas of application, to develop our R&D portfolio further and to anticipate new markets, a permanent monitoring of trends, developments and shifts in the markets is essential. All this is subject of the continuous strategic process at Fraunhofer ENAS.

During the strategic process we analyzed the project portfolio, goals, customers and markets intensely. The results have been audited in September 2016 by an external brain trust consisting of representatives from industry, science and politics. They are the base for our goals and action plans within a period of up to five years.

In 2017, we started a follow-up process by defining and prioritizing action plans to secure the institute's future success. The newly formed project teams prepare discussion papers and decision proposals supported by the institute's management. The period for completion of the various projects is between one and four years.

One of the results of the strategic process is the adjustment of the business units as well as the sharpening and the further development of core competences.

Another project addresses the certification of the whole institute in accordance with DIN EN ISO 9001:2015. This certification will be completed within the next three years.

Strategic partnerships are an essential base for successfully operating on the market in the digital age with increasing requirements concerning interdisciplinarity and competences. In 2017, Fraunhofer ENAS entered a number of strategic partnerships. Three of them will be briefly introduced on the following pages.

Strategic alliances

Research Fab Microelectronics Germany (FMD)

The Research Fab Microelectronics Germany (FMD) is a union of eleven institutes of the Fraunhofer Group for Microelectronics (VµE) and two research institutes (FBH, IHP) of the Leibniz Association with an industry-relevant background. The jointly developed concept aims at uniting the technological capabilities in a common technology pool, concertedly closing gaps in equipment availability and updating the most important lab equipment for microelectronics to an industrial standard. The goal of FMD is to offer customers from large-scale industry, small and medium-sized enterprises, startups and universities the entire value chain for micro and nanoelectronics from a single provider in a straightforward way. Thus, resulting in a unique offering for German and European semiconductor and electronics industries. In addition, this new form of collaboration contributes significantly to strengthening the international competitiveness for European industry.

www.forschungsfabrik-mikroelektronik.de/en

With the launch of the ICT 2020 research program »Microelectronics from Germany – Driver of innovation for the digital economy« and its support of the Research Fab Microelectronics Germany, the Federal Ministry of Education and Research (BMBF) invests approximately 800 million euros until 2020. For modernizing and extending their equipment, all 13 participating research institutes receive 350 million euros. The Fraunhofer Institutes located in Saxony receive 100.8 million euros from that budget.

Four technology parks comprise the inner structure of the FMD to push future-relevant areas of technology in a fast and efficient manner.

- Technology Park 1: The latest »Silicon-based Technologies« for sensor technology, actuation systems, and information processing technology
- Technology Park 2: »Compound Semiconductors« with modern materials for power-saving and communications
- Technology Park 3: »Heterointegration« – the latest combinations of silicon and other semiconductors, i.e. the Internet of Things
- Technology Park 4: »Design, Test and Reliability« for design and design methods, quality, and security

Fraunhofer ENAS is represented with its expertise in the technology parks one, three and four. The existing locations of all involved institutes will be retained, while expansion and operation will be coordinated and organized in a shared business office in Berlin.

photo: Kick-off meeting of »Research Fab Microelectronics Germany« in August 2017 in Saxony photo: Jürgen Lösel for Fraunhofer IPMS

STRATEGY: THE KEY TO SUCCESS

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

The research project USeP (Universal Sensor Technology Platform) focusses on the development of a new type of sensor technology platform, which enables in a modular concept the automatic generation of a wide range of innovative components and their integration into a complete system. 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 shall cover hundreds of application scenarios.

www.eas.iis.fraunhofer.de/en/media_press/newsletter/2017/03_2017/usep

The sensor technology platform is expected to be developed by 2019 to suit the growing development efforts and manufacturing requirements for next generation electronics allowing small system providers in particular to benefit the most. The newly developed platform is based on the 22FDX technology (Fully Depleted SOI) by GLOBALFOUNDRIES. Fabricated in Dresden, it 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. The project is funded by the Free State of Saxony and the European Union as part of the European Regional Development Fund (ERDF). The project partners include the Fraunhofer Institutes IPMS, ENAS, IZM and IIS/EAS as well as GLOBALFOUNDRIES Dresden.

Smart Systems Hub – Enabling IoT

The Federal Ministry for Economic Affairs and Energy (BMWi) supports the formation of digital hubs in Germany with its »Digital Hub Initiative for the Strategic Promotion of Companies, Entrepreneurs and Science«. In April 2017, locations were selected including the Smart Systems and Smart Infrastructure Hub with its headquarters in Dresden and Leipzig. In addition, Chemnitz includes its expertise particularly in the Smart Systems Hub. Exploiting digital design and being successful in innovative developments and value creation despite relentless competition, the Smart Systems Hub – enabling IoT puts emphasis on the tightly networked cooperation of all stakeholders involved: As a central link, the hub combines the expertise in the key areas hardware – software – connectivity at the location and brings economy, innovative start-ups, science and investors together.

www.smart-systems-hub.de/en

The innovation area with access to expert knowledge, companies, start-ups and ambitious makers starting from software developer to hardware and connectivity expert will lead to a national and international visible high tech community, which will reach a new quality level in the subject of technology transfer. Easy access to means of production, necessary knowledge and technical expertise generate offers in a creative atmosphere for the crucial leap into the digital future.

The Smart Systems Hub currently offers various trails (trail = a specific field of competence) to visitors where innovative applications, technologies and business models for the digitization in numerous fields of applications are demonstrated. The aim is to start an exchange of knowledge, cooperation and collaboration between stakeholders within and outside the hub.

Fraunhofer ENAS engages in both, the establishment of the Smart Systems Hub and in the trails »Smart Maintenance« and »Smart Sensor and Production Systems for Industrial IoT«. The latter trail aims at presenting innovative solutions for a full digitization of production along the entire value chain. In particular, various aspects of IoT are a focal point, for instance sensor-based provision of device data, their analysis and interpretation as well as feedback of supporting and production relevant information. Additionally, with visualizing and displaying the devices in Augmented Reality, this trail displays scenes of a full digitization process.

photo: Susann Hering, Silicon Saxony e. V.


photo: Fraunhofer

FRAUNHOFER ENAS: PROFILE

FRAUNHOFER-GESELLSCHAFT

www.fraunhofer.de

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 25,000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

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.

FRAUNHOFER ENAS

www.enas.fraunhofer.de

The strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the development of smart systems for various applications. These systems combine electronic components with nano and micro sensors as well as actuators, communication units and self-sufficient power supply. Furthermore, smart systems are equipped with the ability to respond to each other, to identify one another and work in consortia. Hence, they form the base for the internet of things.

The research and product portfolio covers single components, manufacturing technologies and system concepts, system integration technologies and transfers them into production. Fraunhofer ENAS offers research and development services 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 and helps to transfer them into production.

Application areas 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.

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, Back-End of Line, Micro Materials Center, Multi Device Integration, Printed Functionalities, System Packaging, and Administration. The headquarters of Fraunhofer ENAS are located in Chemnitz. The department Advanced System Engineering is seated in Paderborn. In addition, a project group of the department Micro Materials Center is working in Berlin-Adlershof.

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: Dr. S. Kurth / Dr. A. Weiß

Department
Micro Materials Center
Prof. Dr. Sven Rzepka

Department
Printed Functionalities
Dr. Ralf Zichner

Department
Back-End of Line
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

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. Thomas Otto
Prof. Masayoshi Esashi
Prof. Shuji Tanaka

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

Faculty of Mechanical Engineering

Professorship of Digital Printing and Imaging Technology
Prof. Dr. Reinhard R. Baumann

Clusters of Excellence

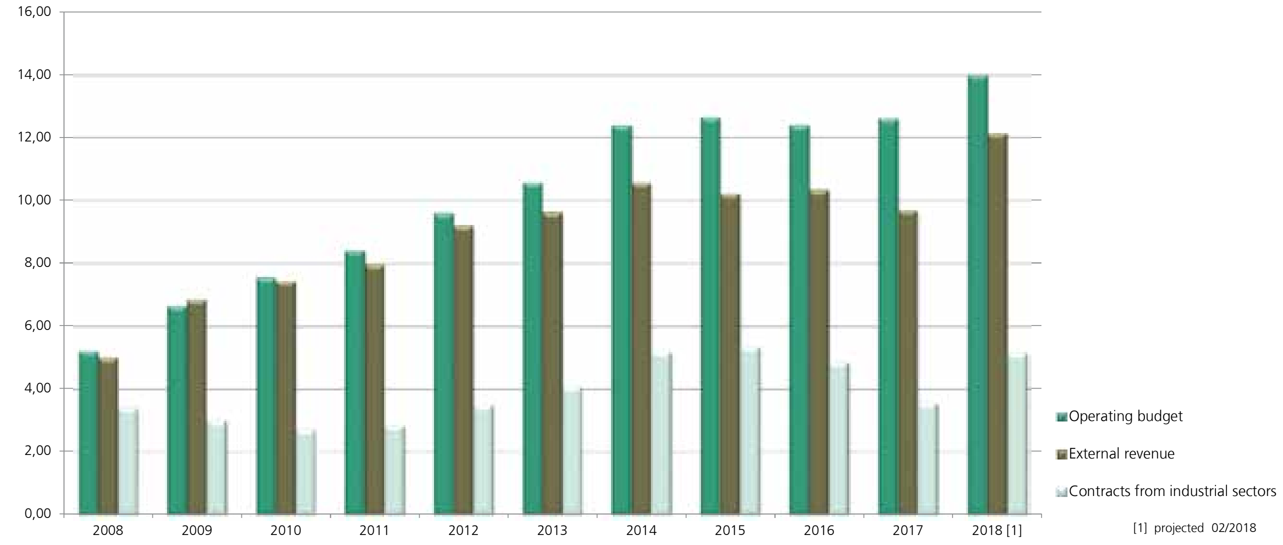
MERGE
Prof. Dr. Thomas Otto
Martin Schüller

cfaed
Prof. Dr. Stefan E. Schulz
Dr. Sascha Hermann

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
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
Increase of the budget (in relation to 2008)	–	29 %	46 %	62 %	85 %	104 %	138 %	143 %	139 %	143 %
Industrial revenues (in million euros)	3.4	3	2.8	2.8	3.49	4.1	5.2	5.24	4.85	3.54
Investment (in million euros)	0.65	5.45	6.8	1.5	1.81	1.44	7.23	2.02	1.89	2,72
Staff	63	73	91	102	104	125	129	127	132	139
Apprentices	0	2	3	5	6	7	7	6	7	6
Students and student assistants	10	10	20	40	43	51	51	43	43	35
Publications and oral presentations	61	75	114	119	112	215	198	173	176	144
Patents	7	5	13	20	8	17	9	9	12	6
Dissertations	6	0	4	2	3	3	3	5	3	5
Academic lectures (TU Chemnitz)	17	17	23	27	24	24	24	24	17	17
Academic lectures (Paderborn University)	8	9	9	8	9	10	7	10	10	11
Academic lectures (TU Dresden)	0	0	2	2	2	1	0	0	0	1

Financial situation and investment

In 2017, the Fraunhofer ENAS budget was shaped by a strong growth in public project funding, which is in accordance with the Fraunhofer ENAS development strategy. The institute generated external revenues of 9.7 million euros. The revenue quota is 77.1 percent. Both numbers reflect the main focus of Fraunhofer ENAS on further technological development of the institute within Fraunhofer internal programs. The participation in Fraunhofer internal programs have more than doubled compared to the previous year. Orders from German and international industrial companies amount to 3.54 million euros. The operational budget of Fraunhofer ENAS was 12.62 million euros in 2017.

The investments of the year 2017 were 2.72 million euros. Altogether, the total budget amounted 15.34 million euros, which represents an increase of 1.04 million euros.

Head of administration:
Dr. Tina Kießling
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E-Mail: tina.kiessling@enas.fraunhofer.de

Personnel development

At the end of the year 2017, Fraunhofer ENAS employed 145 people in Chemnitz, Paderborn and Berlin. Fourteen people were hired, whereas six employees moved from Fraunhofer ENAS either to the industrial sector or retired.

Two apprentices successfully completed their training at our institute and Fraunhofer ENAS has since employed one of them. In cooperation with Chemnitz University of Technology and Paderborn University, students and young scientists have successfully defended their graduate theses.

At the end of 2017, Fraunhofer ENAS employed 35 interns, graduate students/master's students and student aids. This employee base continues to prove itself as an excellent source for young scientists and technicians.

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.

In 2017, the members of the Fraunhofer ENAS board of trustees were:

At the nd of the year 2017, Helmut Warnecke left our board of trustees. We are grateful for his support during the last seven years. We welcome Dr. Stefan Finkbeiner und MinR Hermann Riehl as new members of the board in 2017.

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, 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

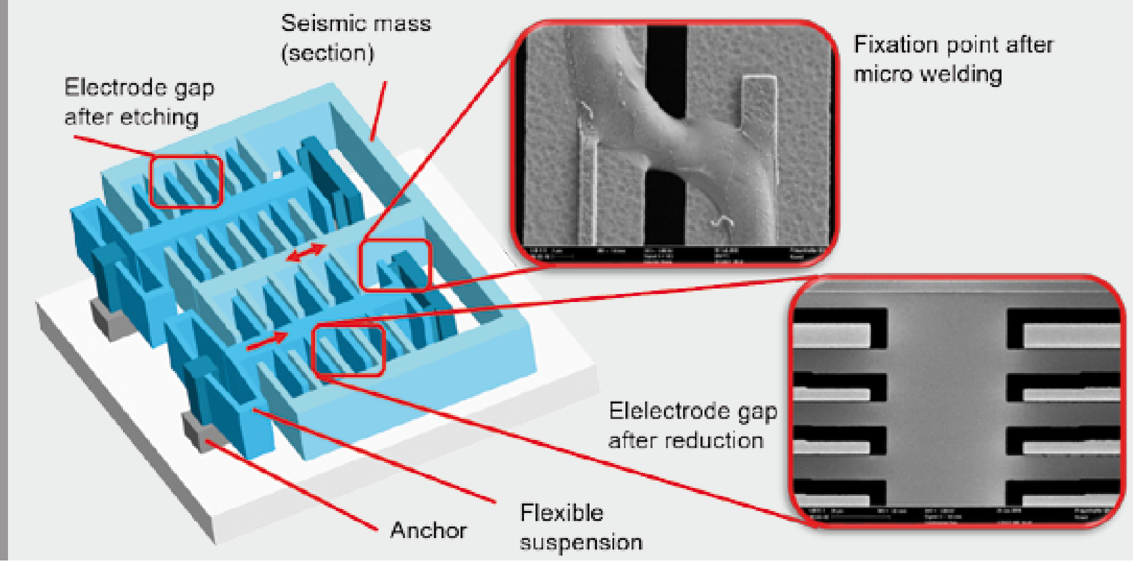
Fraunhofer ENAS is located on the Technology Campus Reichenhainer Straße, more specifically on the Smart Systems Campus Chemnitz. The Smart Systems Campus is an innovative network with expertise in micro and nano technologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with entrepreneurial spirit and business acumen and an economic boost at a location where all is in one place. A close cooperation between science (Chemnitz University of Technology in particular), applied research and industry is an everyday reality and reflects a strategy that is being fulfilled.

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 for microelectronics and smart integrated systems
- Analytics for materials, processes, components and systems
- High-performance / high-precision sensors and actuators
- Printed functionalities
- 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

Markets and fields of application

- Semiconductor and semiconductor equipment and materials industries
- Communication sector
- Medical engineering and life sciences
- Agriculture and farming
- Mechanical engineering and manufacturing
- Process measurement and control equipment
- Security sector
- Automotive industry
- Logistics
- Aeronautics
- Internet of Things



Scheme and SEM picture of a capacitive detection structure with gap reduction capability.

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.
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 support, is more effective than operating alone.
In 2017, Fraunhofer ENAS has cooperated and collaborated with more than 150 partners from companies worldwide. Fraunhofer ENAS carries out direct orders as well as joint R&D projects and pre-competitive research.

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 transferred technological expertise to partners in Germany, Europe and Asia in order to enable them to build their own fabrication capabilities. Furthermore, there is a strong cooperation with MEMS foundries to transfer MEMS designs developed at Fraunhofer ENAS into a commercial fabrication technology. Hereby, we especially support SMEs in getting access to innovative sensor solutions.
One example for a successful technology transfer is the development of a wide-band acceleration sensor with very small noise, which requires a very high sensitivity for the capacitive detection of narrow deflections. These requirements can only be fulfilled by a large structure height (75 µm) for large seismic mass and a permanent post-process reduction of the electrode gap (compared to the gap size achievable by etching). In the past years, prototypes of these type of sensors designed by Fraunhofer ENAS and fabricated by using its own technology approach have successfully been proven. At present, the design is adapted to the PDK of the MFB MEMS foundry process of X-FAB, which is improving this technology with regard to an increase of the structure height from 30 µm to 75 µm.
Fraunhofer ENAS has developed a process for the gap reduction and permanent fixation of the detection electrodes, which is based on a silicon micro-welding process (figure above). Hereby, it is possible to reduce the electrode gaps from approx. 3 µm to approx. 500 nm, which results in an increase of the sensitivity by factor 36. A special electrode configuration for a wafer prober and the defined initiation of current pulses for welding enable an effective processing of this sophisticated method on wafer-level. This micro welding technology has been transferred from the Fraunhofer ENAS lab to our research partner EDC Electronic Design Chemnitz GmbH, which develops the sensor electronics (ASIC). Furthermore, EDC will be the commercial provider for this sensor system.

Cooperation with universities and research institutes

www.enas.fraunhofer.de/en/about_us/cooperations/fraunhofer-project-center.html

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. To further establish and intensify their cooperation, they started the Fraunhofer Project Center »NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University« in 2012. Nowadays, 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.

www.zfm.tu-chemnitz.de

Furthermore, 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. Printed functionalities and lightweight structures are topics of the cooperation with the Faculty of Mechanical Engineering. The department Advanced System Engineering, located in Paderborn, continues the close cooperation with the Paderborn University especially in the field of electromagnetic reliability and compatibility, wireless energy and data transmission technology and wireless sensors nodes for mechanical engineering.

Multiple Excellency – cooperation within clusters of excellence

Germany funded »Excellence Initiatives for Cutting-Edge Research at Institutions of Higher Education« until October 2017. The program is followed by a new initiative by the federal states and government, which also funds cutting-edge research at universities. However, tran-

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

sitional funding for current projects are provided until the new initiative is coming into effect. Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology work in two clusters of excellence.

Merge Technologies for Multifunctional Lightweight Structures – MERGE

www.tu-chemnitz.de/MERGE

The Cluster of Excellence »Merge Technologies for Multifunctional Lightweight Structures - MERGE« based at Chemnitz University of Technology is coordinated by Prof. Kroll, Director of the Institute of Lightweight Structures at the Faculty of Mechanical Engineering. The main object of the cluster is the fusion of basic technologies suitable for mass-production, comprising plastic, metal, textile and smart systems for the development of resource-efficient products and production processes. At present, more than 100 researchers and technicians are working in the six domains of the cluster. Fraunhofer ENAS plays a significant role in research area D, called Micro and Nano Systems Integration.

Center for Advancing Electronics Dresden cfaed

www.tu-dresden.de/cfaed

»The Center for Advancing Electronics Dresden cfaed« focusses on the development of promising technologies for micro and nanoelectronics. The cluster of excellence aims at complementing and expanding todays leading CMOS technology by adding novel technologies, thus developing future electronic information processing systems. Prof. Fettweis is the head of the cluster, which is based at TU Dresden. Research teams from 11 institutions are cooperating interdisciplinary in nine different research paths. Scientists of Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology jointly work on the carbon path and the biomolecular assembled circuit (BAC) path. Within the carbon path, CNT FETs have been developed and prototyped using a wafer-level technology. Their application is focused on analog high-frequency circuits. Within the BAC path, Chemnitz' scientists work on structuring on wafer-level, which is necessary for the self-assembly of deoxyribonucleic acid (DNA).

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. Based on the topic, Fraunhofer ENAS also participates in the Fraunhofer clusters 3D Integration and Nanoanalytics.

Kick-off meeting of the lighthouse project »Go Beyond 4.0« . photo: Ines Escherich for Fraunhofer-Gesellschaft

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. Within the lighthouse project »Theranostic Implants«, Fraunhofer ENAS is working together with 11 other Fraunhofer Institutes on smart implants. The third lighthouse project Fraunhofer ENAS is involved, »eHarsh« focusses on developing and providing a technology platform for sensor systems that can be applied in extremely harsh environments.
High-Performance Center 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« started in September 2017. The High-Performance Center »Functional Integration of Micro and Nanoelectronics« started its work in 2016 and was positively evaluated in 2017.

Lighthouse projects

Go Beyond 4.0

www.fraunhofer.de/en/research/lighthouse-projects-fraunhofer-initiatives/fraunhofer-lighthouse-projects/fraunhofer-go-beyond-40.html

The demand for innovative and individualized devices for the future markets automotive, aerospace, photonics and manufacturing is growing in general. 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, Fraunhofer Institutes ENAS, IWU, IFAM, ILT, IOF and ISC interdisciplinary combine their expertise in the fields of mechanical engineering, electrical engineering, photonics and material science. Following the concept, a reliable zero error production will systematically be integrated into the process chain to manufacture product demonstrators.
The demonstrators address the major markets automotive, aerospace and lighting: smart door, smart wing and smart luminaire. To realize the demonstrators, the digital production technologies (digital printing and laser processing) will be adapted to the geometries of the individual demonstrators and the material properties.

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

Opening of the High-Performance Center »Smart Production« in the E³ Research Factory Resource-Efficient Production at Fraunhofer IWU.
photo: Fraunhofer IWU

Theranostic Implants

www.fraunhofer.de/en/research/lighthouse-projects-fraunhofer-initiatives/fraunhofer-lighthouse-projects/theranostic-implants.html

Theranostic implants are complex implantable medical products, which combine both diagnostic and therapeutical features in one system. The requirements for implants of the next generation are enormous: highly complex with small dimensions and low weight, stable functionality within the body (a warm and moist environment) and surrounded by constant cell growth. Crucial factors are the power supply and biocompatibility with the body. The project consortium focuses on a technology platform for power and signal solutions as well as longevity and compatibility of the implants in particular. The permanent monitoring of vital parameters helps in purposefully deploying therapeutic measures. Within the Fraunhofer lighthouse project 12 Fraunhofer Institutes (management: Fraunhofer IBMT) are working cooperatively on three subprojects, which focus on skeletal, cardiovascular and neuromuscular demonstrators. Fraunhofer ENAS is researching within two subprojects on miniaturized sensors, energy transmission and storage, communication, and last but not least on packaging and integration aspects as well as biocompatible encapsulation technologies.

eHarsh

www.fraunhofer.de/de/forschung/fraunhofer-initiativen/fraunhofer-leitprojekte/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«. Within the lighthouse project, 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 analyses 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«

www.leistungszentrum-smart-production.de

The High-Performance Center »Smart Production«, with the participating Fraunhofer Institutes IWU and ENAS as well as Chemnitz University of Technology, develops new technologies for the digitization of production processes. In future, the High-Performance Center will be a central hub for strategic research and technology transfer projects while actively involving SMEs and supporter for a sustainable transfer of innovation and knowledge to the industry. The goal of the High-Performance Center is transferring developments for digital industrial production processes from basic and advanced research to companies as quickly as possible.
Main topics and research objectives of the High-Performance Center are interdisciplinary and profile-forming research, digitization of production, smart factory, smart materials and Industry 4.0.
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.

High-Performance Center »Functional Integration of Micro and Nanoelectronics«

www.leistungszentrum-mikronano.de

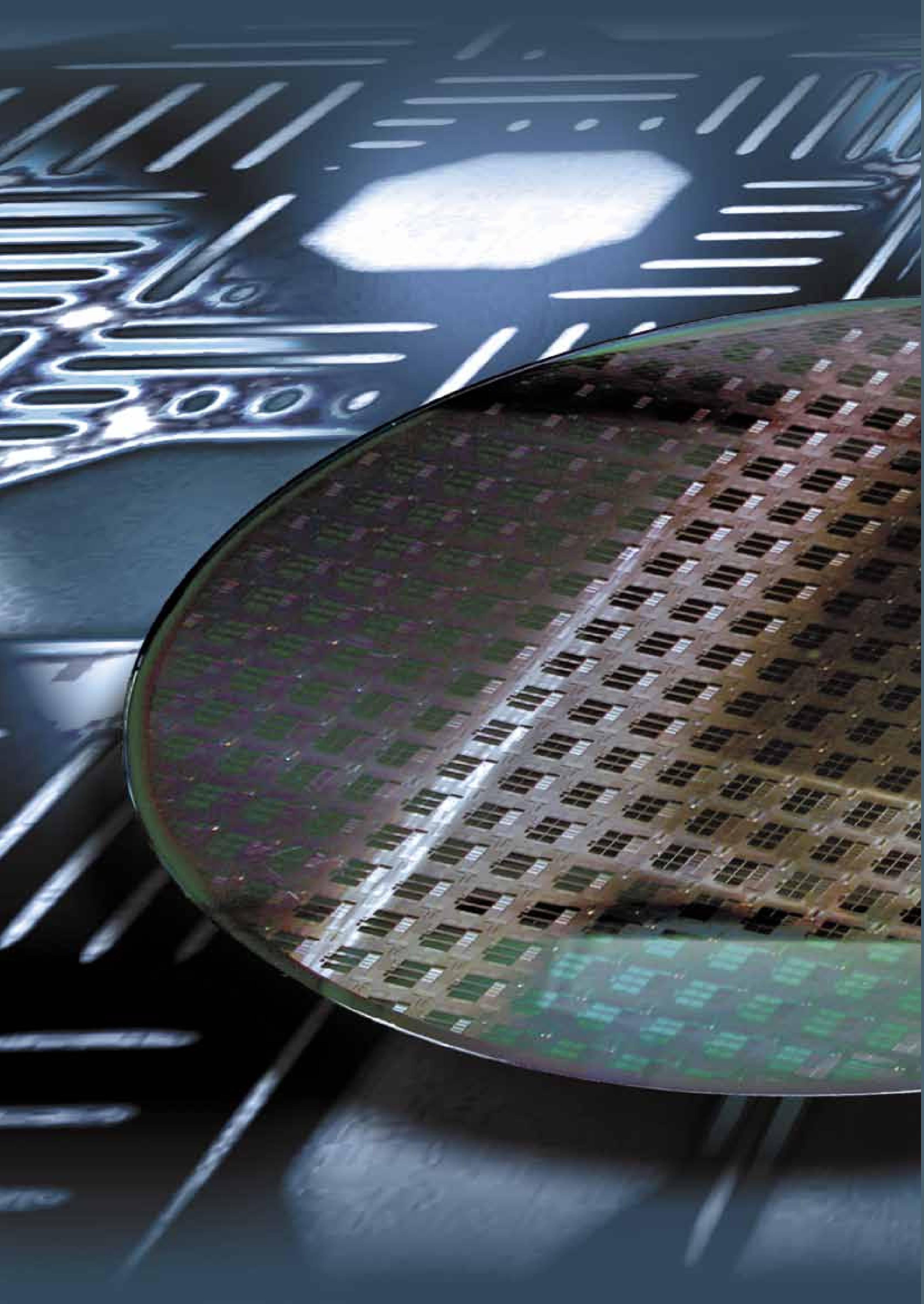
The High-Performance Center »Functional Integration of Micro and Nanoelectronics« started as a pilot project for the period from February 12, 2016 to December 31, 2017. It was successfully evaluated by Fraunhofer-Gesellschaft, which was supported by an external brain trust consisting of representatives from industry, science and politics on November 30, 2017.
The aim of the performance center was to establish an eco-system for a rapid transfer of innovations from research up to novel applications and products, thus, further developing and strengthen the region. In the pilot phase is was necessary to establish not only a central office for the marketing of R&D results and technology transfer but also to prove and verify the effectiveness of the center by intensive contributions of industrial partners. The Saxon Fraunhofer institutes IPMS, ENAS, IZM/ASSID and IIS/EAS joined forces with TU Dresden, Chemnitz University of Technology and the University of Applied Sciences Dresden to form the High-Performance Center »Functional Integration of Micro and Nanoelectronics«.
The expertise of the High-Performance Center focused on technologies for the development of integrated micro and nanoelectronic systems:

- From system design via development of components, system integration up to reliability assessments and evaluation
- Demonstrators are available for the development of technologies and systems, e.g. for industry 4.0 applications as well as IoT innovations

The project was financed from funds of the Free State of Saxony, the Fraunhofer-Gesellschaft and the industrial partners during the biennial pilot phase. Based on the pre-industrial research results, the research partners acquired industrial projects with an overall budget of 6 million euro. The High-Performance Center will be further developed into a transfer center and funded by new projects from 2018 until 2020.

photo: iStock (Radachynskyi)

BUSINESS UNITS



MICRO AND NANOELECTRONICS

Micro and nanoelectronics are one of the key technologies of the 21st century. The ongoing downscaling (More Moore), the integration of different functionalities (More than Moore) as well as the development of novel non-silicon based materials (Beyond CMOS) are hot topics. 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, ULK processes, dry etching), novel concepts for diffusion barriers and alternative interconnect architectures for the reduction of parasitic effects (air gaps, alternative ULK integration) 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 (PVD, CVD, ALD, ECD), equipment and devices. 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 RF MEMS switches, CNT FETs as well as memristive devices and circuits.

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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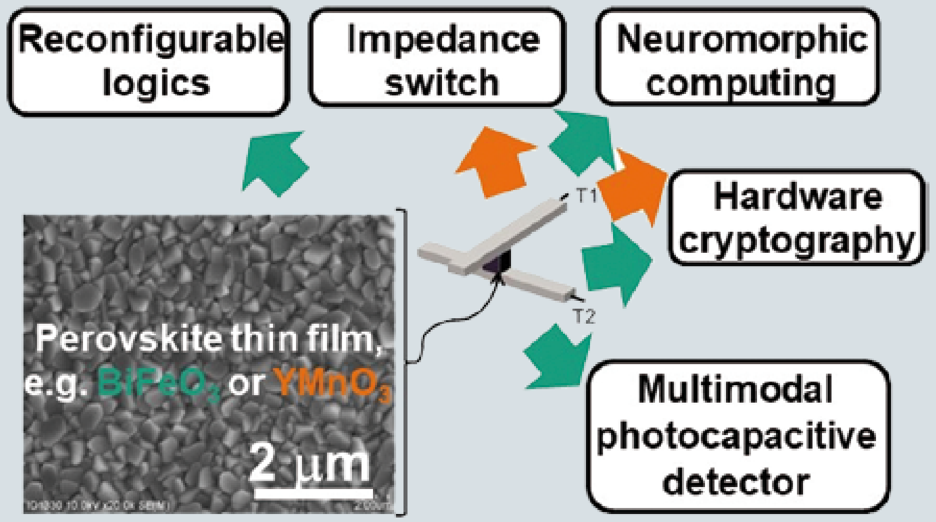
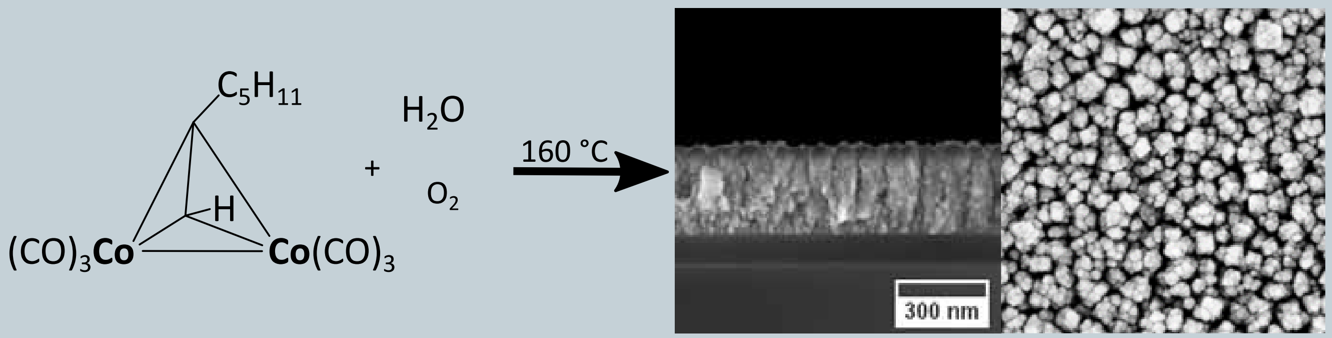
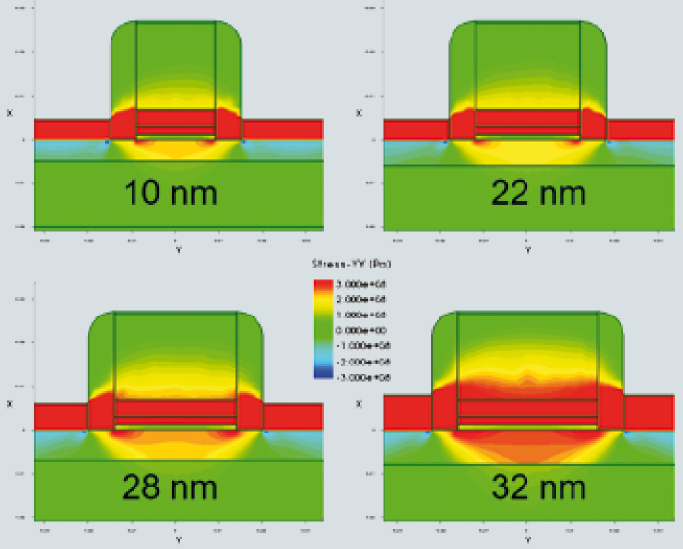


Scanning electron microscopy image of the surface of a $BiFeO_3$ film in a $BiFeO_3$-resistance switch with Bit line (T1) and Word line (T2) and schematic respresentation of possible applications of non-volatile, reconfigurable resistance switches.



Cobalt oxide CVD scheme with precursor, co-reactant and SEM images of the resulting layer.



Strain in FDSOI transistors of different technology nodes. With shrinking dimensions, the strain transfer from the raised source drain to the channel becomes less efficient.

RESEARCH AND DEVELOPMENT

- INTERCONNECTS AND BEOL INTEGRATED FUNCTIONALITIES
- SIMULATION OF DEVICES

MICRO AND NANOELECTRONICS

NON-VOLATILE, RECONFIGURABLE RESISTANCE SWITCHES

The thriving of memristive oxide switches is arousing interest in the field-enhanced hopping transport of oxygen vacancies because memristive oxide switches exhibit ultra-nonlinear switching dynamics. Optimized performance requires resistive switching (SET and RESET) within tens of nanoseconds upon the application of a writing bias, and the ON and OFF resistance states should remain stable for up to ten years. Field-accelerated ion mobility constitutes one such source of ultra-nonlinearity. The Mott-Gurney has been employed nonlinear ionic drift model to interpret the effect of an electric field on the nonlinear rate of ion transport in a memristive Au/$BiFeO_3$/Pt/Ti metal-oxide-metal switch using a quasistatic state-test protocol. Memristive bismuth iron oxide (BFO) switches possess excellent bipolar switching performance, including long retention time and stable endurance even at elevated temperatures. Furthermore, due to the interface-mediated resistive switching, memristive BFO switches reveal zero Joule heating and electroforming-free resistive switching. Thus, the measured increase in mobility of oxygen vacancies can be attributed unambiguously to the field enhancement rather than to temperature enhancement.

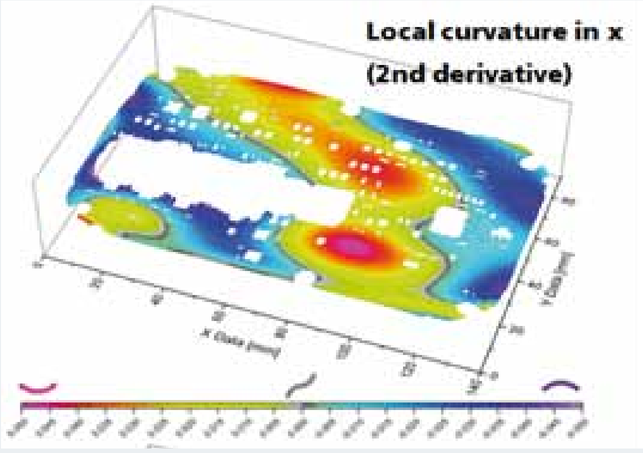
CHEMICAL VAPOR DEPOSITION OF COBALT OXIDES AT LOW TEMPERATURES

Cobalt oxides are promising materials for a wide range of applications. They can be used as catalysts for the combustion of hydrocarbons, as sensitive materials in gas sensors or as anode material for lightweight rechargeable lithium ion batteries. Thus, developing a low temperature deposition process of cobalt oxide is a key technology for the production of flexible energy storage systems enabling novel application opportunities such as wearables. To satisfy the emerging process requirements the dicobaltatetrahedrane precursor $[Co_2(CO)_6(\eta^2\text{-H-C}\equiv\text{C-}^nC_5H_{11})]$ was investigated for the low-temperature chemical vapor deposition of cobalt oxides. Oxygen, water vapor and a combination of both were examined as possible co-reactants. In particular, wet oxygen proves to be an appropriate oxidizing agent providing dense and high purity cobalt oxide films within the examined temperature range from 130 °C to 250 °C. Film growth occurred at temperatures as low as 100 °C, making this process suitable for the coating of temperature-sensitive and flexible substrates.

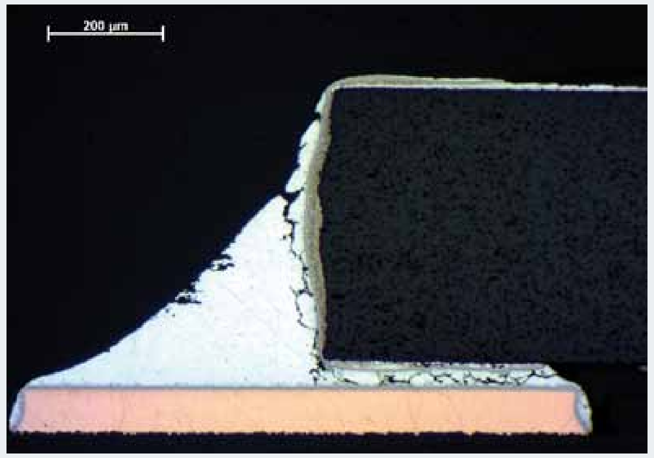
SIMULATION OF MECHANICAL STRAIN IN 22 NM FDSOI DEVICES

Fully Depleted Silicon On Insulator (FDSOI) is the European approach for ultra-scaled energy efficient microelectronic circuits. Within the WAYTOGOFAST project, which is a part of the European initiative ECSEL, a big industry driven research consortium explores FDSOI devices at the 22 nm technology node and beyond.

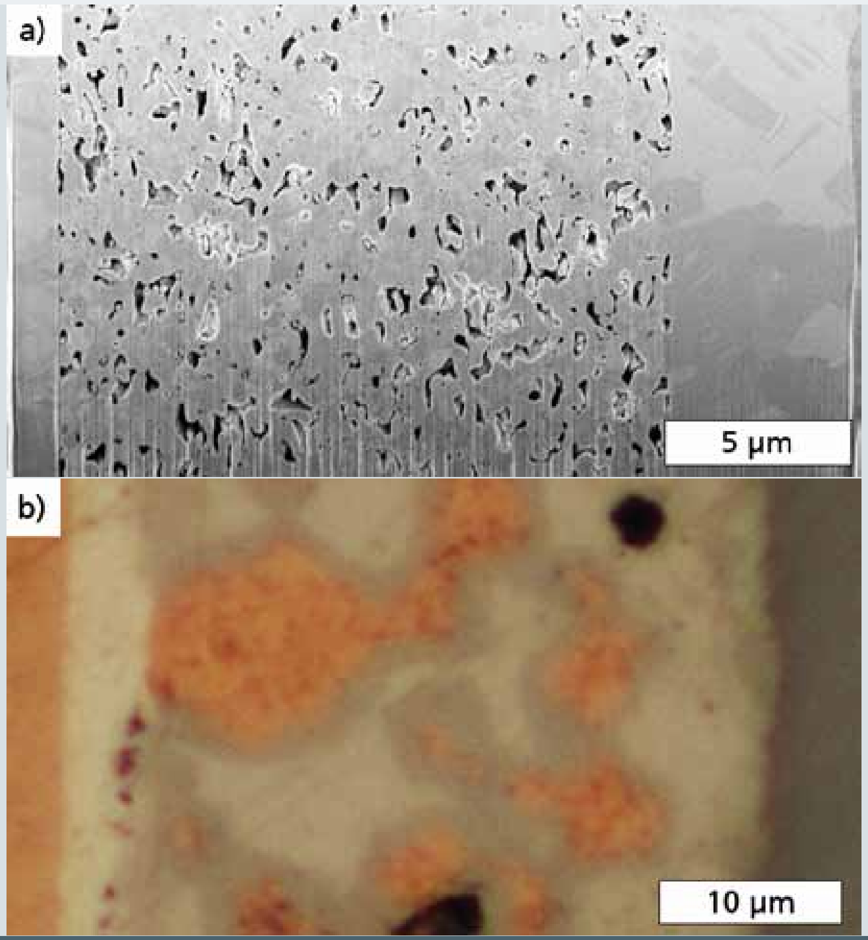
Strained transistor channels are used to increase the charge carrier mobility. Engineered channel strain is one of the key factors to obtain high performance energy efficient FDSOI devices. Many factors such as device geometry, details of the process flow as well as pre-strain of the ultra-thin silicon layer on the wafer influence the actual strain level in the transistor channel. Researchers from Fraunhofer ENAS worked on the modeling and simulation of strains in 22 nm FDSOI devices. The strain simulations provide unique insights into the interplay of mechanics and electronics inside the nanoscale devices. Several key parameters could be identified, which have a drastic influence on the strain level and thus on the device performance. By using the opportunity to explore huge parameter spaces, it could be shown that process-induced variations occurring during the device fabrication can give rise to severe strain induced performance loss.



Distribution pattern of local curvature of an automotive control unit board in mounted situation for a heating step.



Characteristic damaged SAC solder joints after 8 years of cycles.



In cooperation with

SHINKO

Die attach interfaces.
a) Sintered silver bonded at 250 °C.
b) CuSn bonded at 225 °C.

RESEARCH AND DEVELOPMENT

▪ PACKAGING AND RELIABILITY

MICRO AND NANOELECTRONICS

SYSTEMIC AND LONG-TERM EFFECTS ON THE RELIABILITY OF SOLDERED JOINTS FOR FUTURE MOBILITY

In light of the very high reliability and safety requirements, which are of particular importance for developing electronic systems in applications toward autonomous driving, a renewed interest in the reliability analysis and prediction for electronic interconnections can be stated. One focus is the endurance of lead-free solder joints.

Theoretical modeling has been widely used to evaluate risks of thermo-mechanical induced failure in electronic systems. However, there are still limitations in complexity of the models both in regard of system geometry, e.g. complete mounted units, and evaluation criteria, which frequently do not consider system effects. Therefore, a methodology has been set up which combines measuring and simulation techniques for improved reliability evaluation on board and system level. An optical multi-sensor measurement system has been developed, which is capable of precise deformation measurements of boards mounted in automotive electronic control units (ECUs) from global level to local level. The high precision, which is above the currently applied solutions, allows in particular the measurement of component deformation down to nanometer range under system loading conditions. Additionally, software tools allow the determination of derived quantities like strains, local curvatures and local warpage radius. The latter can be taken as input for Finite Elements simulations.

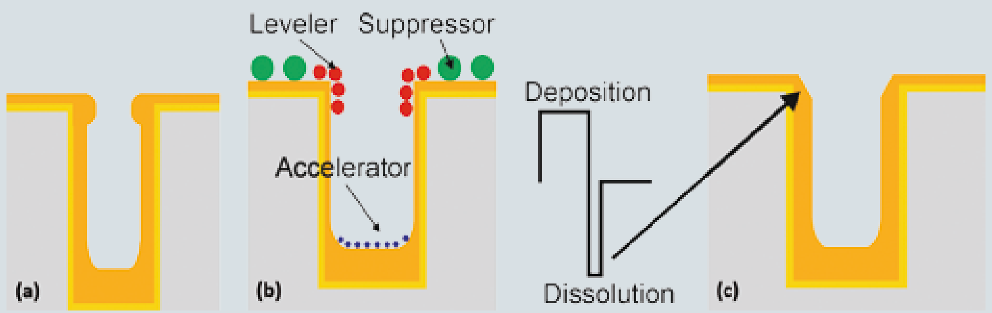
Another challenge of general interest is a mission profile transformation process down to relevant mechanical, thermal and electrical interface levels of affected components. The quality and precision of the acceleration models need to be re-investigated also for solder joints. To calibrate the theoretical models, a typical thermal field cycling test with automotive like slow temperature swings (20/90 °C) and a relatively long dwell time (6 hours) has been run for more than eight years. The right figure on page 32 (top) shows SAC solder joints cracking after eight years of cycles.

POWER PACKAGING – SILVER AND COPPER/TIN SINTERING FOR POWER ELECTRONICS

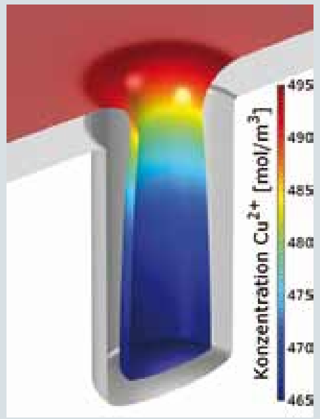
The market for power packaging grows about 8 percent per year. Higher power densities, needs for lower costs, reliability and a higher grade of integration demand for new packaging concepts and materials. One critical point is the die attachment, which can lead to premature failing of a power module. Fraunhofer ENAS investigated silver sintering materials but also transient liquid phase (TLP)-based pastes for die attach within a research and development project together with SHINKO (Japan).

To get optimum process parameters, a parameter screening is done for the die attach material. Printing parameters, drying conditions and the bond process have to be considered. In general, the bonding parameters have the highest influence. It is necessary to keep the bonding temperature low to not crack the samples due to CTE mismatch. Examples of the resulting interface are shown in the bottom figures (a and b) on page 32.

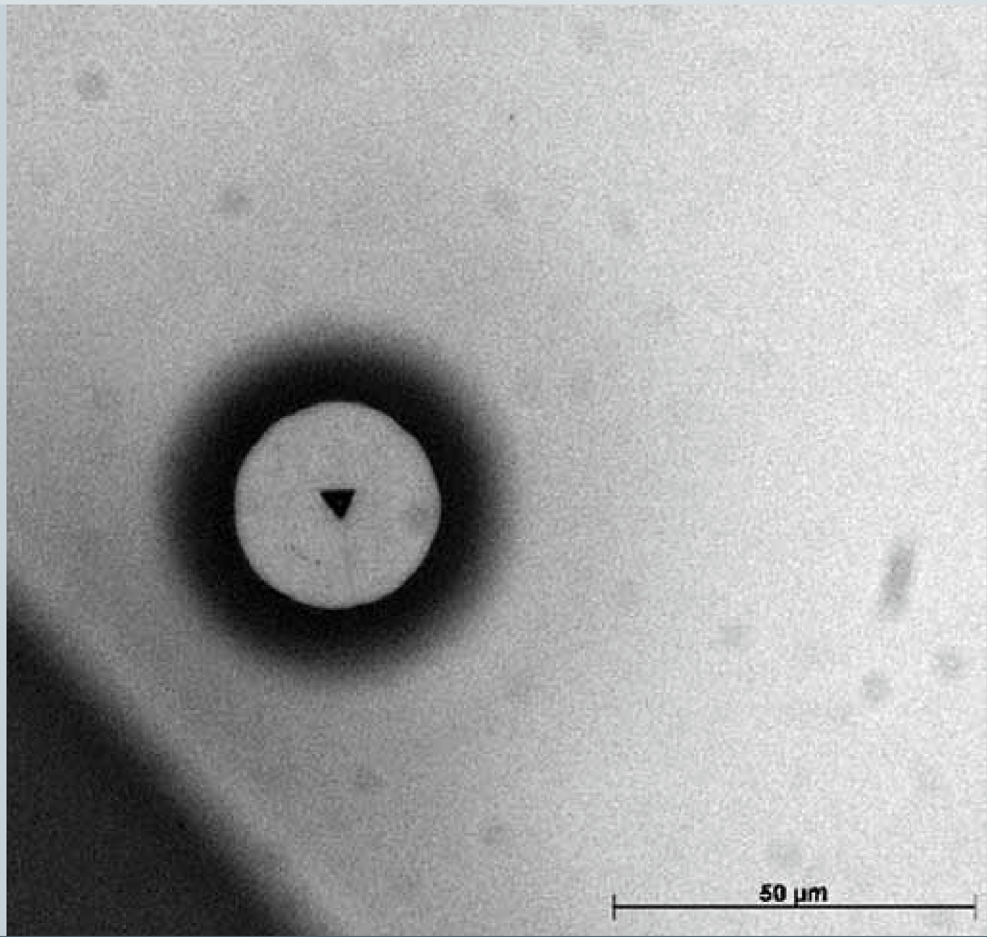
The samples were tested in a power cycling test afterward. Usually, failures could be classified into two main physical failures: Die attach or wire bond failure. So far, the results show that wire bond failures dominate the die attach failures for both die attach materials, pointing to high reliability of the module.



Comparison of conventional unpulsed copper ECD without additives (a), with additives (b) and PRP ECD without additives (c).



TSV model (gray, Ø 50 µm, depth 100 µm) with simulated copper surface (colored surface) after 3 hours of unpulsed deposition with a current density of 0.4 A/dm².



Berkovich imprint on a TSV section.

RESEARCH AND DEVELOPMENT

- 3D TSV
- SIMULATION OF TECHNOLOGICAL PROCESSES
- RELIABILITY

MICRO AND NANOELECTRONICS

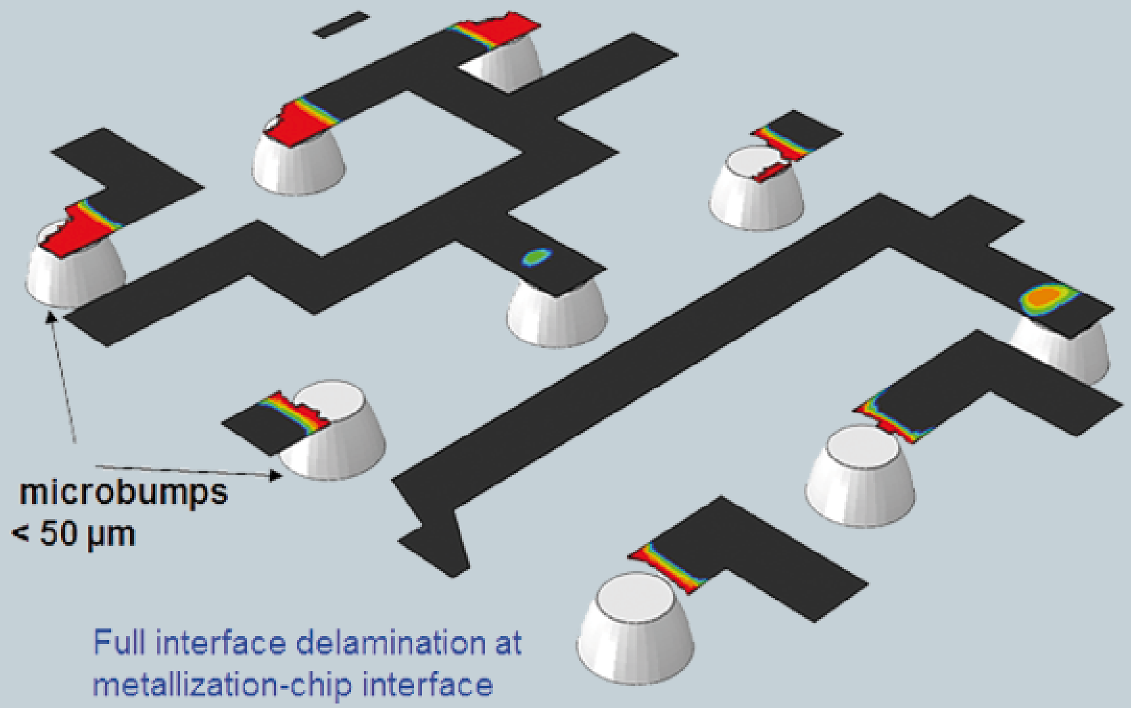
SIMULATION OF PULSED ELECTROCHEMICAL COPPER DEPOSITION IN THROUGH SILICON VIAS WITH HIGH ASPECT RATIO

Through silicon vias (TSVs) are of key interest for 3D integration, enabling higher device densities and performances. The research goal of project VEProSi is a simplified process for the electrochemical deposition (ECD) of metals within TSVs. Plating of TSVs with high aspect ratios is still challenging. Expensive and polluting chemicals (additives) are currently used to improve the uniformity of deposited metal layers. An alternative approach is periodic pulse reverse plating. This process was modeled at Fraunhofer ENAS, based on the Nernst-Planck equation, solved with the finite element method for a large number of combinations of pulse parameters.

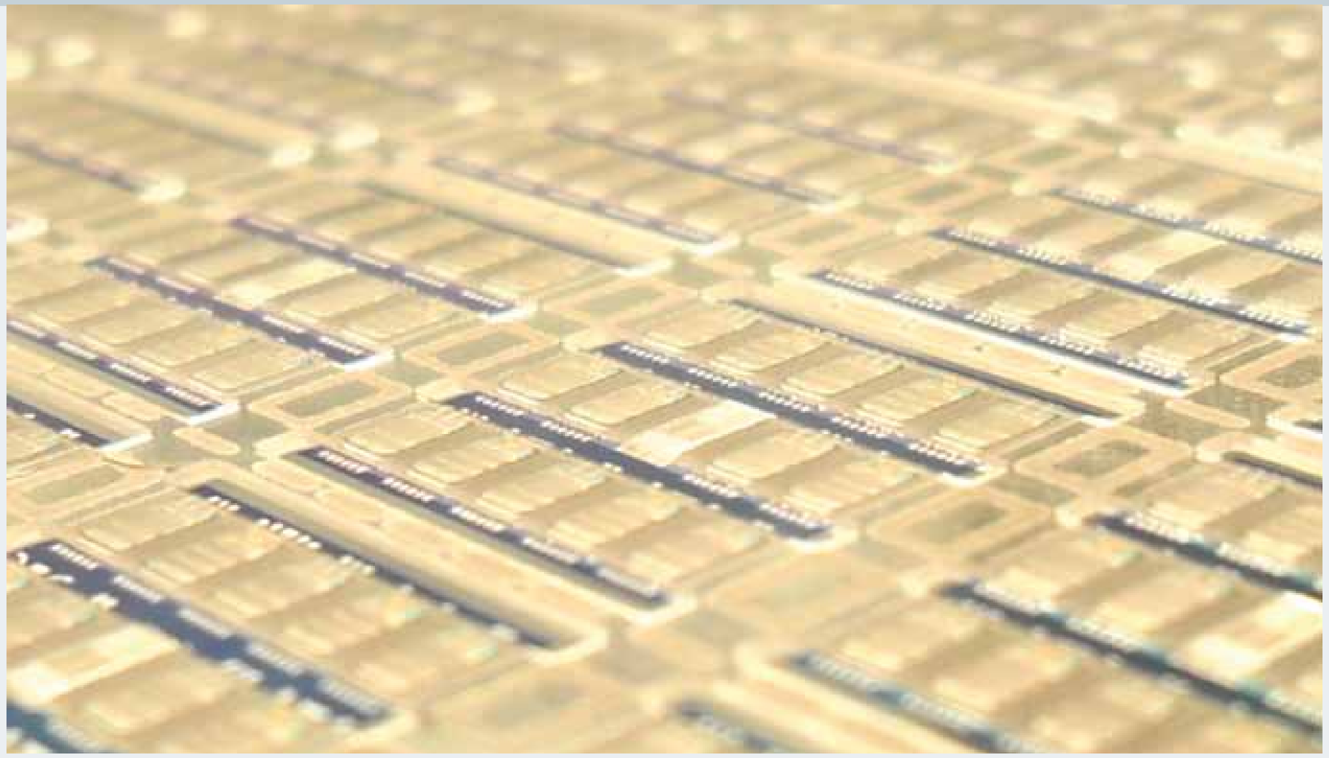
It could be shown that the uniformity of deposited layers can be improved even without the use of additives. However, there is a tradeoff between process time and uniformity. From the simulation results, clear guidelines for optimal pulse plating processes are derived.

PARAMETER IDENTIFICATION BY NANOINDENTER

Continual downsizing and the integration of multiple features into microelectronic circuits continuously increase their structural complexity. This is also the case for through silicon vias (TSV), in which the mechanical characterization of copper in the TSV is not feasible with classical methods of material characterization due to the small size. However, the instrumented nanoindentation is a promising approach when using several indenter tips. Unique solutions for elastic-plastic material behavior were achieved using Berkovich and Cube Corner Indenter tips. The force displacement curves were modeled by the finite elements method and simulated under the assumption of isotropic hardening (Ramberg-Osgood). After comparing the results, it was possible to specify the hardening exponent and yield strength. The presented method enables a fast prediction of the material behavior in a first approach. With the help of finite element simulations it was possible to estimate the risk of delamination in the BEoL stack around copper TSVs where materials with large thermal expansion differences interact.



Metallization delamination analysis of a 3D stacked wafer-level package subjected to shear testing.



Photographic image of a part of a silicon wafer containing hermetically sealed RF MEMS switches.

RESEARCH AND DEVELOPMENT

- **RELIABILTIY OF 3D PACKAGES**
- **RF COMPONENTS**

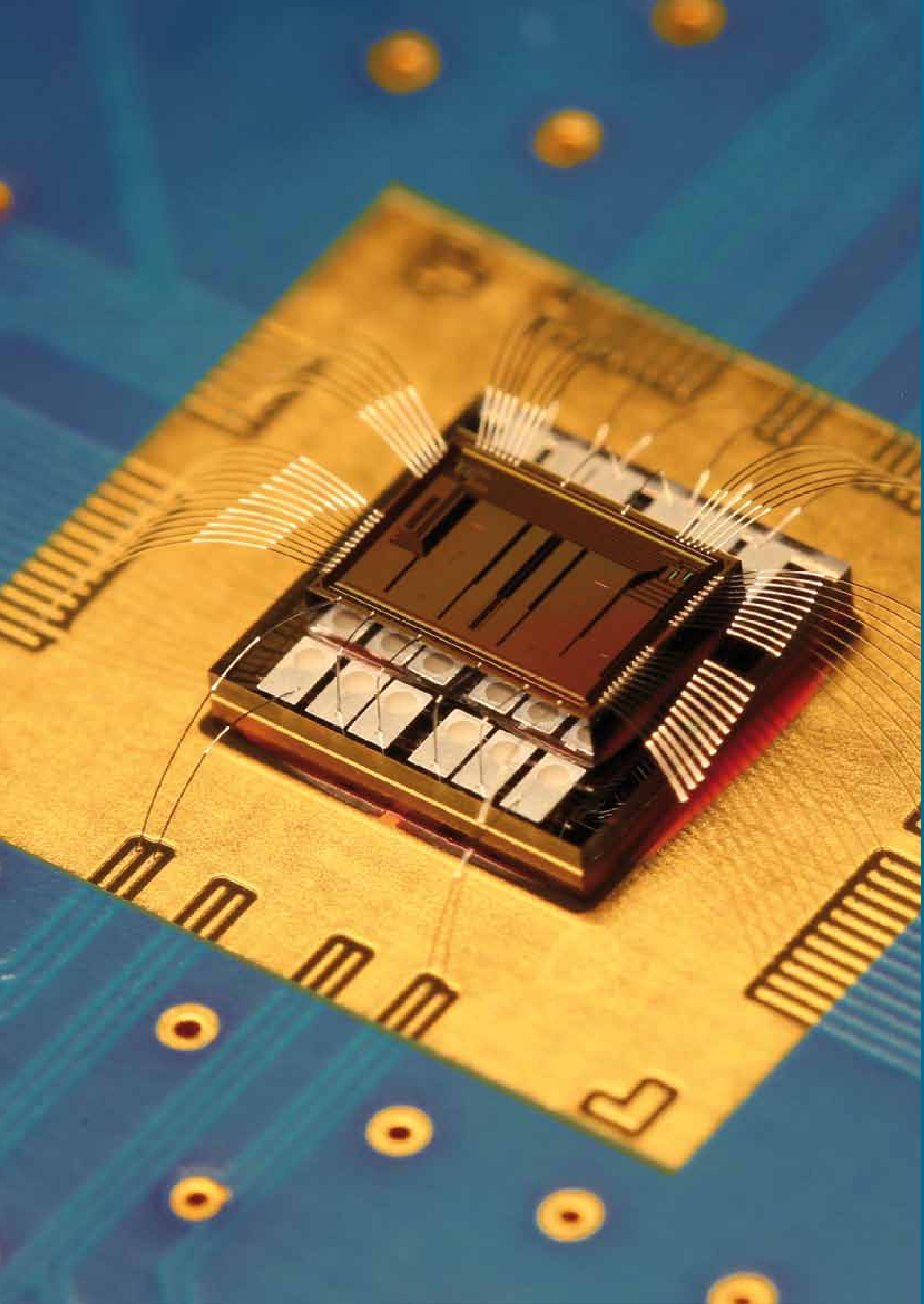
MICRO AND NANOELECTRONICS

NEW SIMULATION APPROACH: RELIABILITY ANALYSIS APPLYING CZM FOR 3D PACKAGES

Thermo-mechanically driven interface delamination is one major concern that may cause reliability problems in multi-material structures, generally occurring in 3D microsystems packaging. Finite element simulations, traditionally based on the strength of materials theory, are frequently used to reach a better understanding of the reasons for failure and of critical parameters. However, the correct evaluation of finite elements results at interfacial discontinuities is a general problem for the numerical analysis of interface delamination, as the stress field at sharp interface edges and interface cracks obeys a singularity. Fracture or damage-mechanical treatment is needed to avoid misleading simulation results. In recent years the damage methodology »cohesive zone modeling (CZM)« has been developed, which can additionally track the delamination progress, and has been applied to a variety of packaging and interconnect solutions. By adjustment to experimental findings, e.g. collected by shear tests as exemplified for a »metallization to stacked chip interface« according to the upper figure on page 36, parameters were collected for different electronic material interfaces. Thus, predictive capabilities are available for several interface strength evaluations.

RF MEMS SWITCH

The RF MEMS switch is a miniaturized RF relay with electrostatic actuation. It is a silicon chip with a hermetically sealed cavern containing the movable parts of the actuator and the contacts. The signal path contains two metal-metal contacts in a series configuration that makes it possible to transfer signals in the frequency range of DC to mm-wave frequencies. A high aspect ratio MEMS technology is used for the fabrication and leads to large actuation electrodes and to high contact force for making and breaking the contacts even by low actuation voltage (5 Volt). Hence, the switch can be directly controlled by the digital electronics without power consuming step-up voltage converters. The actuation electrodes and the RF signal path are separate from each other, which introduces lower noise from the digital control electronics in comparison to many other RF MEMS switches. Due to the novel RF wiring concept of the switch, it supports coplanar waveguides at the RF terminals. Therefore, a low insertion loss of approximately 1 dB is achieved up to 75 GHz signal frequency. This is unique in the field of RF switches. The application fields range from automated test equipment (switch matrix with very high frequency bandwidth, controllable attenuators), antenna beam steering and agile antennas (controlling of the antenna pattern by phase shift of the feed line signals) to the reconfiguration of the front-end circuits of radio systems (antenna switches, filter reconfiguration with very highly linear behavior with an $IIP_3 > 65$ dBm).



SENSOR AND ACTUATOR SYSTEMS

The business unit comprises manifold sensor and actuator systems, which are based on different technologies and transducer 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 sensors based on the GMR and TMR effect, respectively, while using ferromagnetic thin films, are in the focus of this topic. However, they can be applied both in the direct measurements of magnetic fields and in the measurement of distance, position and rotation. Furthermore, sensors for near field measurements of electromagnetic fields and determination of radiation characteristics were developed.

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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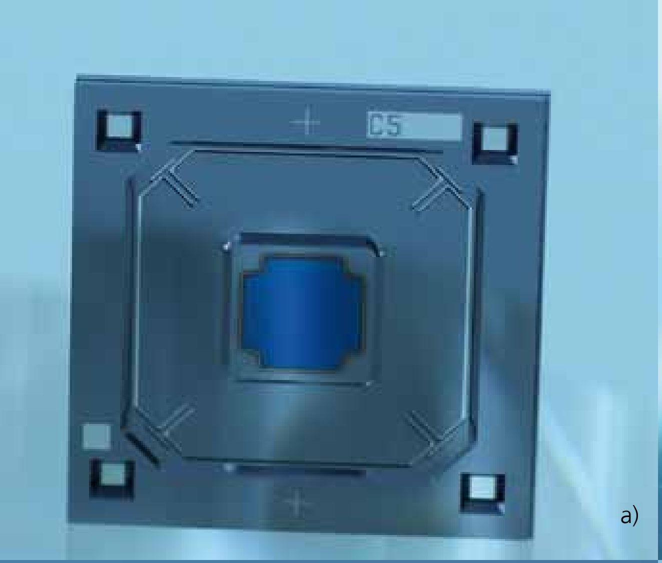
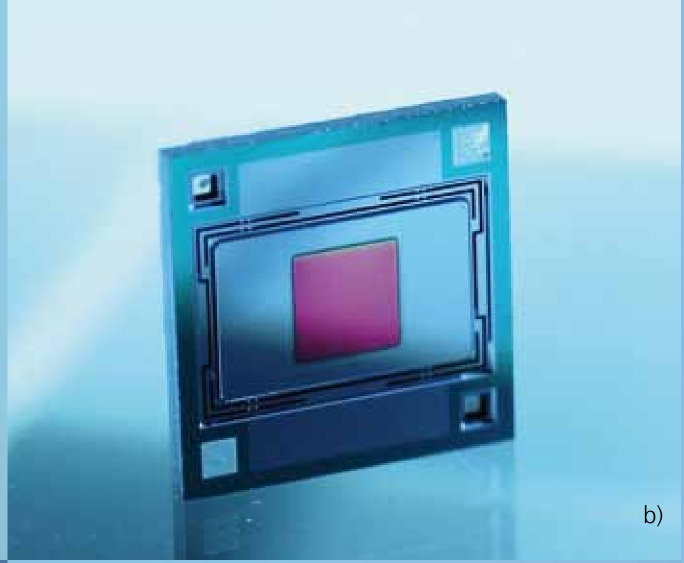
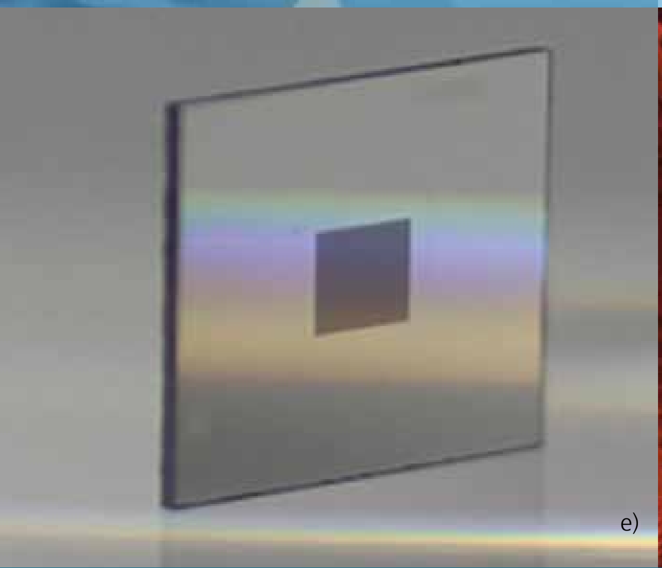
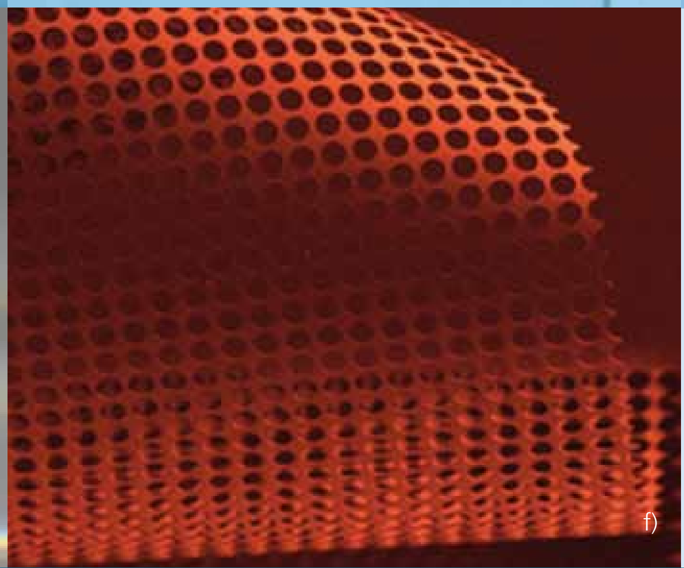
SENSOR AND ACTUATOR SYSTEMS





a) to c) Photographic images of FPIs for the infrared spectrum and
d) FPIs for the visible spectrum.





e) Photographic image of a MEMS chopper for infrared radiation and
f) SEM view of a part of the used membrane with subwavelength structures that is used as top layer of this component.

RESEARCH AND DEVELOPMENT

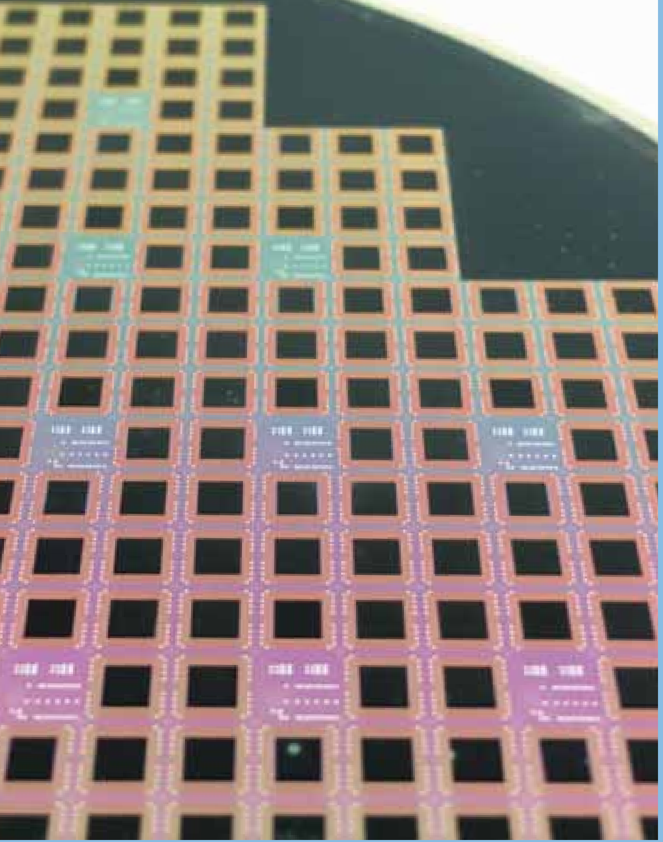
- **OPTICAL SYSTEMS / MOEMS**
- **SUBWAVE LENGTH STRUCTURES AS ALTERNATIVE WAY TO FUNCTIONALIZE OPTICAL SURFACES**

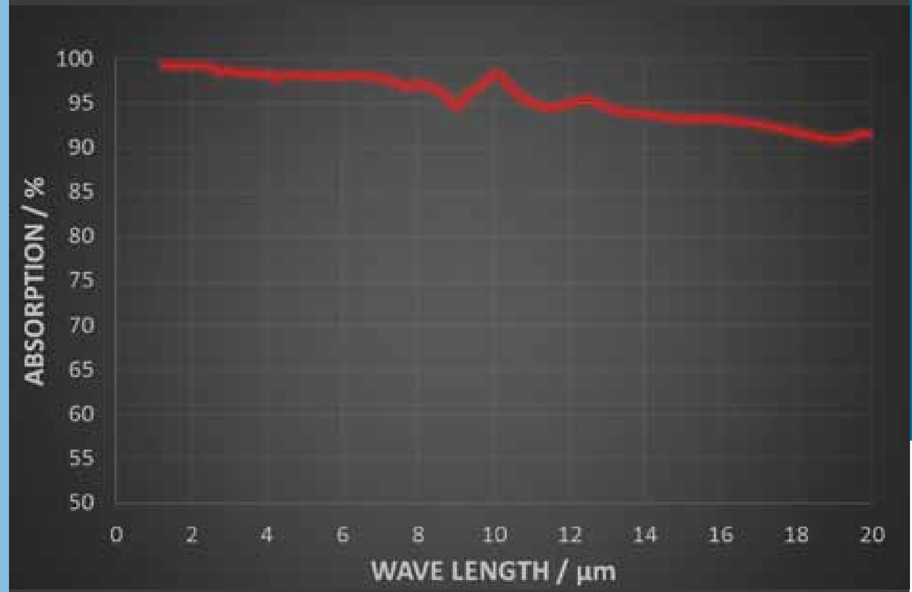
FABRY-PÉROT INTERFEROMETER FROM CHEMNITZ: A FLEXIBLE MOEMS PLATFORM FOR SENSOR APPLICATIONS FROM THE VISIBLE SPECTRUM TO THE THERMAL INFRARED

Spectral optical sensors detect the intensity of electromagnetic radiation as a function of wavelength. The applications are diverse, ranging from simple color sensors to complex laboratory spectrometers, from color image sensors for photography, to hyperspectral cameras for earth observation with satellites. All of these applications are based on the interaction of electromagnetic radiation with matter in the visible or infrared spectral range and the resulting, different and wavelength-dependent transmission, reflection and absorption behavior of materials. The Fabry-Pérot Interferometers (FPI) developed in Chemnitz are used to narrow-band filter electromagnetic radiation in the visible or infrared wavelength range. The spectral transmission range can be electrically and continuously adjusted with respect to the wavelength. By combining FPI and single-point detector or a detector array, low-cost, robust and very small spectral sensors or image sensors can be produced. In various projects their application in medical devices (anesthesia monitoring), in safety devices (gas detectors), in ATR probes for process control, in stationary gas analyzers, in hand-held spectrometers and in spectral cameras has been successfully demonstrated. The developments are carried out in cooperation between the Fraunhofer ENAS (design, characterization and applications) and the Center for Microtechnologies of Chemnitz University of Technology (technology development and fabrication). For FPI development in the infrared spectral range, there is a long-standing and close cooperation with the company InfraTec GmbH.

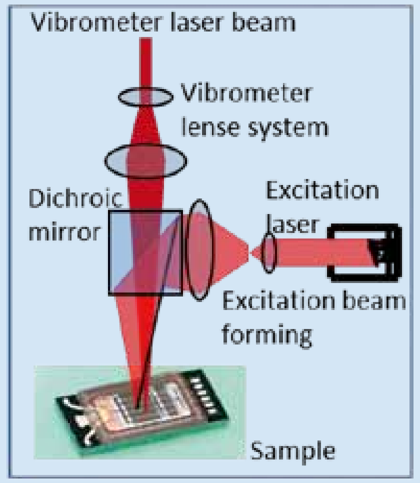
MEMS COMPONENTS WITH SUB-WAVELENGTH STRUCTURES FOR INFRARED APPLICATIONS

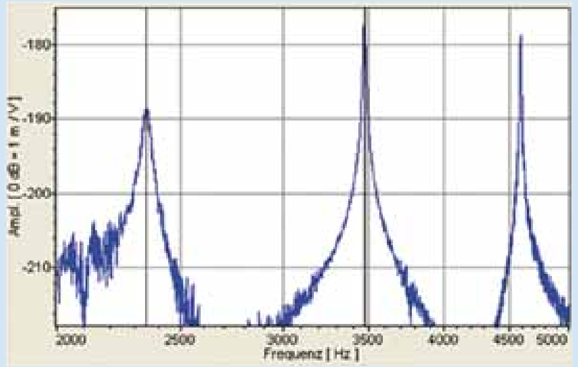
The use of sub-wavelength structures is an alternative way for functionalizing optical surfaces in contrast to the application of optical layers or layer stacks. Highly reflecting surfaces, wavelength filtering surfaces, surfaces with extremely low reflectance and highly absorptive surfaces can be achieved. In many cases, only one single layer of a metal or of a dielectric material is applied to form the sub-wavelength structures. Nano structuring by nano imprint lithography recently opened the way for the commercial application of principles using subwavelength structures and plasmon related optical effects for volume fabrication of these components. Nano imprint lithography is also compatible to other processes, which are needed to fabricate complex MOEMS components, such as MEMS and MOEMS fabrication technology sequences. Tunable spectrum filters and shutters are key components of such hyperspectral imaging systems next to the detector arrays. These novel components can turn infrared imaging into spectral and hyperspectral imaging, which enables the gathering of substantially more information in comparison to single spot spectrum recording and regular wideband infrared imaging.

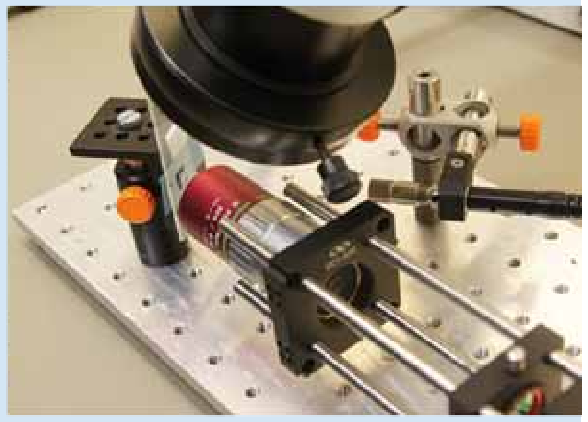




CNT absorption layers integrated in an IR emitter structure (left) and the absorption behavior of such CNT layers (right).







Set-up for the measurement of the resonance behavior of MEMS using thermo-mechanic excitation (left), example of a measurement result (middle) and photographic image of the test set up (right).

RESEARCH AND DEVELOPMENT

- INERTIAL SENSORS
- OPTICAL SYSTEMS / MOEMS

SENSOR AND ACTUATOR SYSTEMS

CARBON NANOTUBE (CNT) FILMS AS BLACK BODY ABSORBER OR EMITTER FOR IR APPLICATIONS

Next generation of micro optical infrared (IR) sensors require advanced absorbers, which fulfil tough technological and material requirements. Current solutions, considering materials such as black metals, filled polymers or λ/4 type layers, are afflicted with compromises in absorption level, spectral range, heat capacity, mechanical instability and technology compatibility. A promising alternative represent directly integrated carbon nanotubes (CNTs) as absorption layers. Carbon nanotubes have the potential to overcome the above mentioned limitations by offering a high wavelength independent absorption capability and good thermal and mechanical properties at the same time.

Their scalable integration was addressed in the High-Performance Center »Functional Integration of Micro and Nanoelectronics« with the goal of developing an optical absorber for an IR sensor or emitter. Therefore, a Chemical Vapour Deposition (CVD) process for patterned CNT growth at temperatures below 500 °C and implemented the process into a MOEMS technology was developed. Key features of the obtained CNT-based MOEMS are:

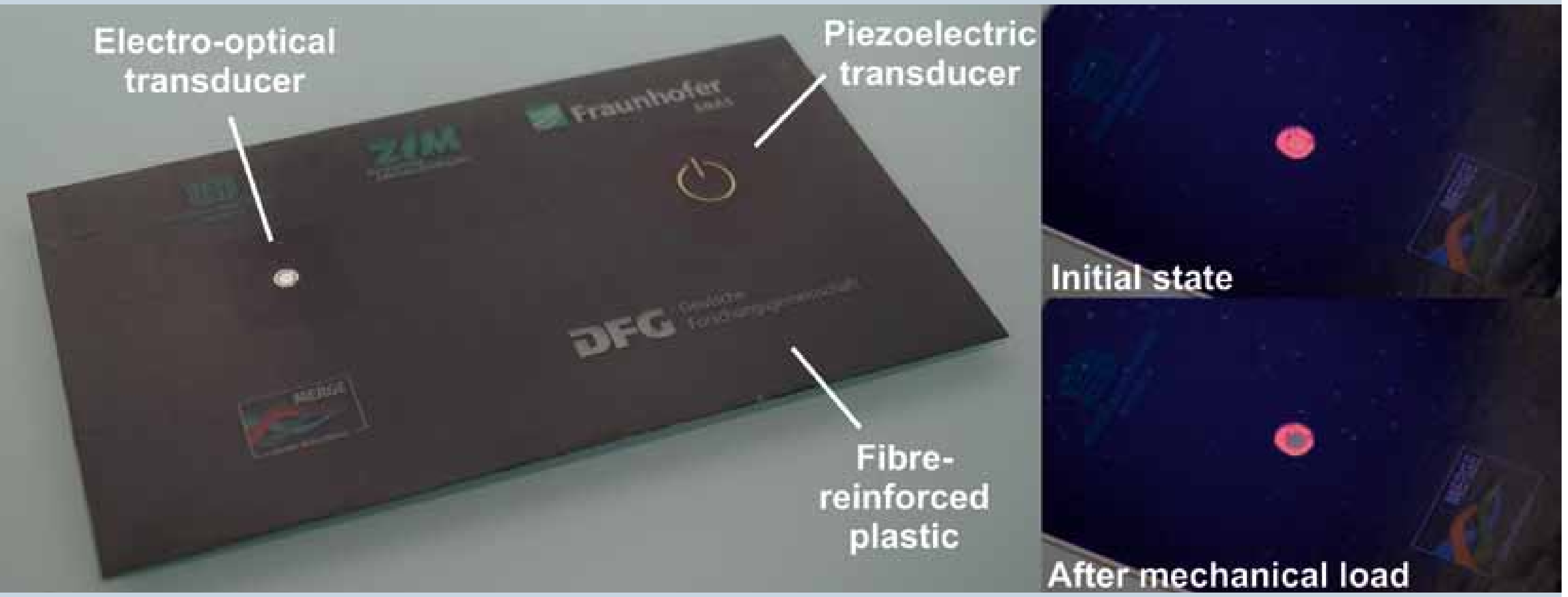
- High broadband absorption values above 95 % for λ = 2 … 12 µm and above 90 % for λ = 2 … 20 µm
- Temperature stability up to 500 °C in N_2 atmosphere
- High compatibility of MEMS, MOEMS and CMOS technologies with IR absorbers and emitters

Possible applications are anti-reflective coatings, absorption layers for thermal IR sensors (thermopiles, pyro detectors, e.g. for gas detection and thermography) and black layers for IR emitter (gas detection, e.g. for area monitoring, medicine and safety equipment). CNT absorption layers may also be suitable for high-speed IR sensors due to their good thermal conductivity and low thermal mass.

THERMO-MECHANIC EXCITATION OF ENCAPSULATED MEMS COMPONENTS

When testing the mechanical properties of MEMS, typically the motion of the movable parts of the MEMS components is observed while the structure is mechanically stimulated to vibrate. The resonant frequencies and Q values are determined, which indicate fabrication tolerances. Beside the commonly used excitation techniques for MEMS components by integrated transducers, by vibration chucks or external electric fields provided by electrostatic probes, thermomechanical excitation comes into view when using an intensity modulated laser source. Light or infrared radiation can be applied for the contactless excitation. In the case of encapsulated MEMS with a silicon cap, an infrared laser radiating in near infrared wavelength range is the best choice. Fraunhofer ENAS developed together with project partners from the industry and academia a laser based thermo-mechanic excitation principle that is used in combination with a laser Doppler interferometer. The beam of a directly modulated laser diode is collimated and directed to the microscope objective of the laser doppler interferometer by a beam steering optics and a dichroic beam splitter. The beam steering enables adjusting of the excitation laser spot to a dedicated location of the inner structure of the MEMS. Testing of the measurement set-up with different MEMS devices showed a good signal/noise ratio at the resonant frequencies of the MEMS structure. The resonance frequencies and the Q values can be determined easily.

Sensor film with initial light intensity (left) and reduced intensity of sensor due to mechanical load (right).



Sensor film (electro-optical transducer) and piezoelectric transducer integrated in fibre-reinforced plastic.

RESEARCH AND DEVELOPMENT

- ELECTROMAGNETIC SENSORS
- MATERIAL AND STRUCTURE SENSORS

SENSOR AND ACTUATOR SYSTEMS

XMR SENSOR OPERATING AT MHZ SAMPLING RATES

Actual technical revolutions covering the IT sector, industry and our daily lives, pooled as internet of things, are accompanied with the development toward automatization and the capability for autonomous behavior. This trend is linked with the strong need for accurate, self-calibrating and reliable sensors, where magnetic field and current sensors are important classes supporting the advancements. Especially the latter is of importance for global efforts toward green energy and electromobility, too.

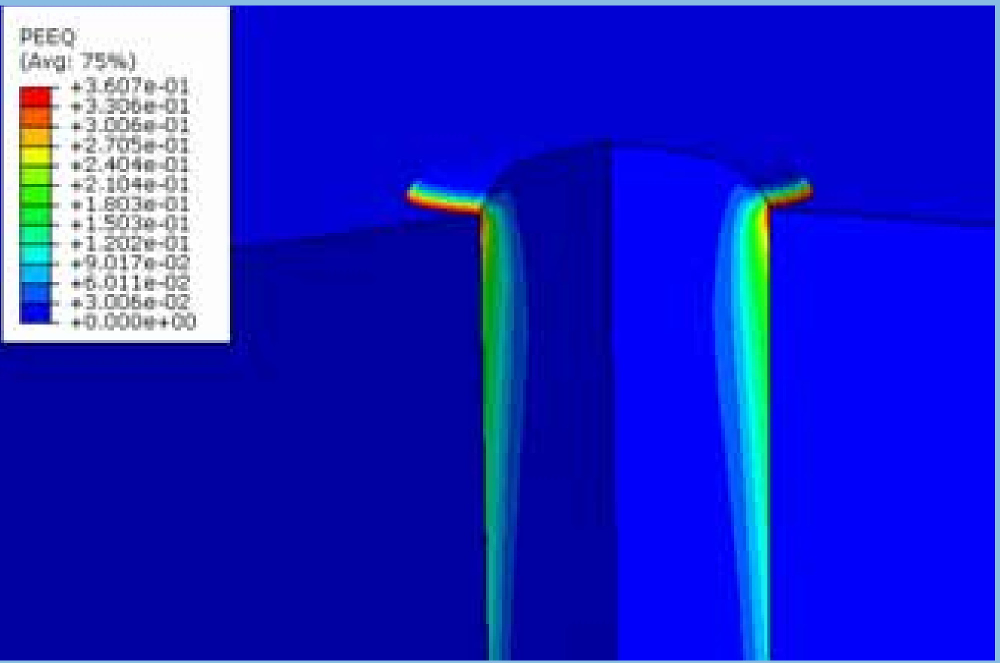
Fraunhofer ENAS, which has a long-term experiences with a variety of sensors and actuators together with their integration into smart systems, recently developed a technology demonstrator with an SPI interface, revealing a measurement data acquisition at MHz sampling rates shown by an example of a current sensor. As sensor, a high sensitive giant magnetoresistance (GMR) effect based Wheatstone bridge is used, enabling for sub-µT magnetic field resolution as well as ultra-high dynamic measurements of the magnetic stray field, which makes the measurement of, for instance, the amperage accessible. XMR sensors, which are always subject to saturation effects due to the ferromagnetic materials involved in the sensor layer stack, still can be used for broad range electric current sensors due to, e.g. a dedicated design of the XMR sensors, conductive paths or electromagnetic coils, to finally utilize the high sensitivity of this sensor class for current sensing. Another application example for XMR based magnetic field sensors, allowing for high frequency data acquisition, is the precise position determination and angular detection of rotational movements in, for instance, turbochargers.

MECHANICAL LOAD DETECTION FOR LIGHTWEIGHT MATERIALS

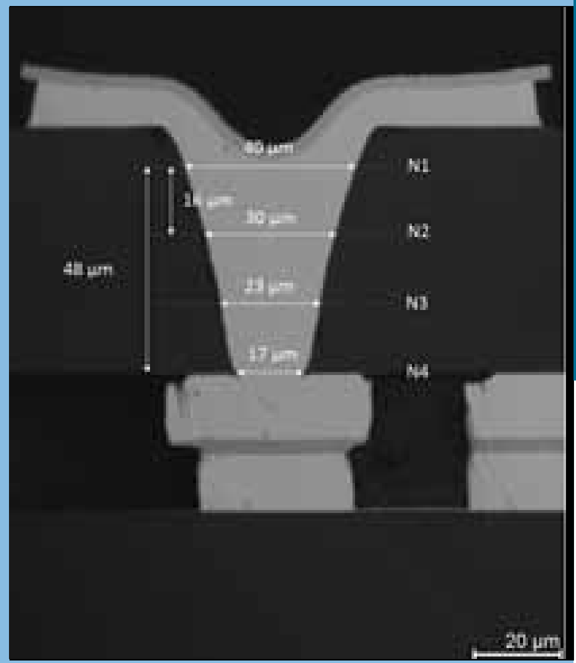
Optical information are an integral part for our actions in daily life. Electro-optical transducers based on quantum dots detect electrical information and store them without further energy consumption. Thus, the information can be optically read out at a later time, whereby the electro-optical transducers based on quantum dots offer a large variety of applications for event and condition monitoring. In combination with a force sensitive element, the stored information can be used as an indicator of the condition or mechanical load of lightweight materials.

A sensor film based on quantum dots, developed by Fraunhofer ENAS in cooperation with the Center for Microtechnologies of Chemnitz University of Technology, offers the basis for such transducers. Their flexible shape makes them easy to integrate into lightweight materials. In the initial state, UV light is transformed into visible light with a certain initial light intensity. Due to mechanical load, electrical charge carriers (< 50 nC/mm^2) are injected into quantum dots within 1 ms via the system of electrodes and the process of photoluminescence (PL) is prevented. As a result, the intensity of the visible light is reduced, which can be used as an indicator of the applied mechanical load on the lightweight material even after more than 60 hours. Due to this development the state of the lightweight component can be determined more quickly and allows taking action in a timely manner. Thus, leading to a gain in security that is also a possible solution for many other applications.

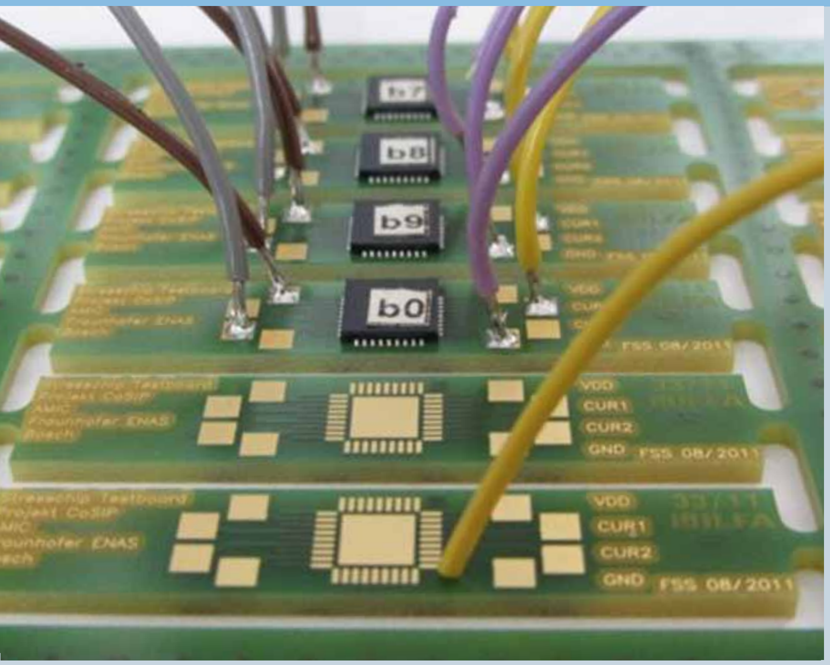
The work was performed within the Federal Cluster of Excellence EXC 1075 »MERGE Technologies for Multifunctional Lightweight Structures« and supported by the German Research Foundation (DFG). Financial support is gratefully acknowledged.



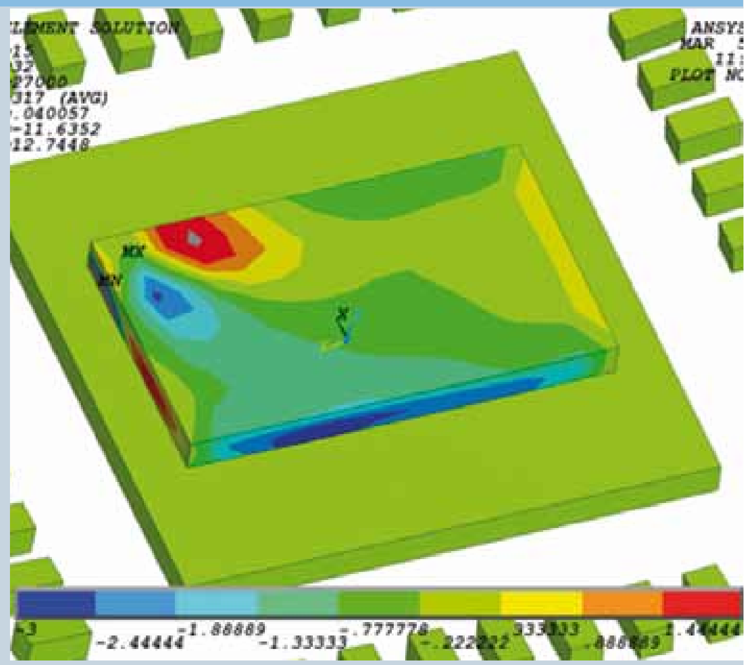
Accumulated plastic strains.



Cross section of a TSV.



Stresschip testboard.



Evolution of the stresses and propagation of delamination.

RESEARCH AND DEVELOPMENT

- RELIABILITY ASSESSMENT
- THROUGH SILICON VIAS

SENSOR AND ACTUATOR SYSTEMS

TSV RELIABILITY

Copper Through silicon vias (TSVs) are an effective contacting solution for 3D integration but they also pose new challenges for thermo-mechanical reliability. The large mismatch of thermal expansion between copper and the surrounding silicon presents a significant risk of delamination between copper and the adjacent seed layer as well as of damage to Redistribution Layer (RDL) and back-end of line (BEoL) stacks on both sides of the silicon substrate. The resulting pumping and protrusion effects are evident both in the manufacturing of BEoL structures and during thermal cyclic testing (TCT). This is also due to changes in the copper morphology – grain size, grain orientation – as an annealing effect. For this purpose, extraction of mechanical properties from nanoindentation experiments were performed. Finite elements simulations to investigate the thermo-mechanical behavior of damage processes affect possible delaminations between the copper TSV and the barrier and also within the BEoL stack under TCT and CPI (chip package interaction) conditions. A CSM procedure (Cohesive Surface Contact Method), in combination with a traction separation law to describe the damage progress, was used to take the crack formation of bimaterial interfaces into account. Simulation results show interface delamination risks at the copper-seed interface close to at the upper end of the TSV. The evaluation of the interaction of TSVs and BEoL stacks using damage mechanics provides a good basis for damage initiation studies within the RDL and BEoL stacks on the top and bottom of the silicon substrate. Based on simulations of the dependence of the damage risk on the distance between the TSVs as well as the crystal orientation of silicon versus pairs of TSVs, proposals for a reliable via design were submitted.

IN SITU STRESS MONITORING USING A STRESS CHIP

The direct detection of thermo-mechanical weak points in microelectronic components and sensor components still poses a major challenge. State of the art in product qualification is still based on the detection of the interconnect failure by monitoring the resistance of daisy chains. Those failures are complete interruption or the increase of the electrical resistance above a given threshold. They may be caused by various geometric, material or process related reasons and may even interact with each other. However, the daisy chains can only signal the failure occurrence. They cannot provide information on the current state of health of the interconnects such as solder joints. For further improvement of the reliability, the ability to gain more information about the root cause of the failure is necessary. The stress sensing system allows measuring the magnitudes and the distribution of mechanical stresses induced in silicon dies during fabrication and testing of electronic packages. The stress sensing system has been successfully used for exploring the curing of adhesives and underfills, soldering processes, active and passive temperature cycling tests, moisture swelling, encapsulation tests and other in situ measurements. In the future, it is planned to use the chip for evaluating the remaining lifetime. Therefore, the whole stress history will be stored on the chip and the time until the failure will be mathematically estimated based on the knowledge of the physics of failure.

photo: pixabay

TECHNOLOGIES AND SYSTEMS FOR

SMART POWER AND MOBILITY

Know-how and technology transfer and development of research samples and prototypes are the main services of the business unit »Technology and System for Smart Power and Mobility«. The focus is currently put on systems for monitoring of electric power lines, on the integration of actuators for active flow control, on the optimization of the reliability of high power electronics, on powering of mobile devices and on integrated sensors for lightweight structures.

PLM || Fraunhofer ENAS, together with partners, develops smart sensor systems for monitoring of high voltage and medium voltage power lines including the transmission of data into the grid control center. Such sensor systems are used for increasing the ampacity of existing power lines, for the detection of ice load on the power lines, and for the localization of ground faults.

SJA || In case of high speed cruise, the largest amount of driving power of aircrafts and vehicles is dissipated by the surrounding air flow and vortexes. The influence of the air flow bears a high potential of power saving. Different approaches are pursued by using Synthetic Jet Actuators to optimize the air flow.

WiPo || Fraunhofer ENAS proposes and develops a series of customized wireless electric power transmission modules for low power (< 100 Watt for handheld devices and IoT) and for higher power applications. Moreover, the design of flexible, low-cost batteries and the development of dedicated fabrication technologies are offered as a service of Fraunhofer ENAS.

SHM || A further aspect is the development of passive sensors for Structural Health Monitoring (SHM) into lightweight structures. Passive sensor function and remote read-out is realized by the use of electromagnetic resonators that are seamlessly integrated in lightweight structures. It offers a novel approach to detect cracks, delamination and penetration of moisture.

BUSINESS UNIT MANAGER

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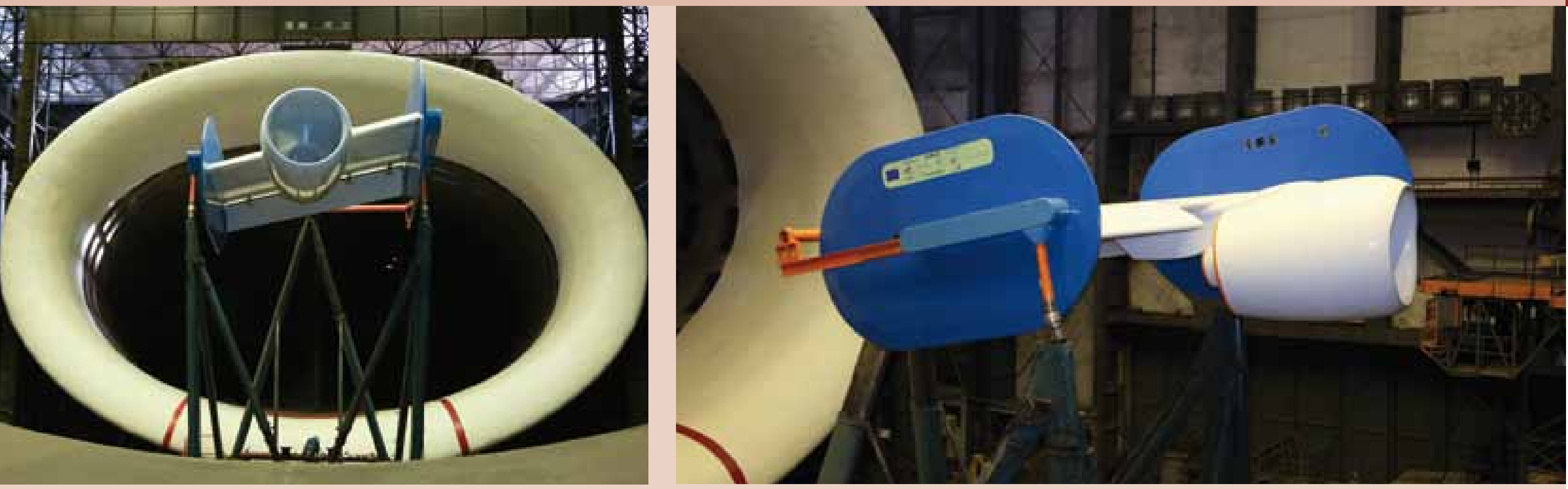
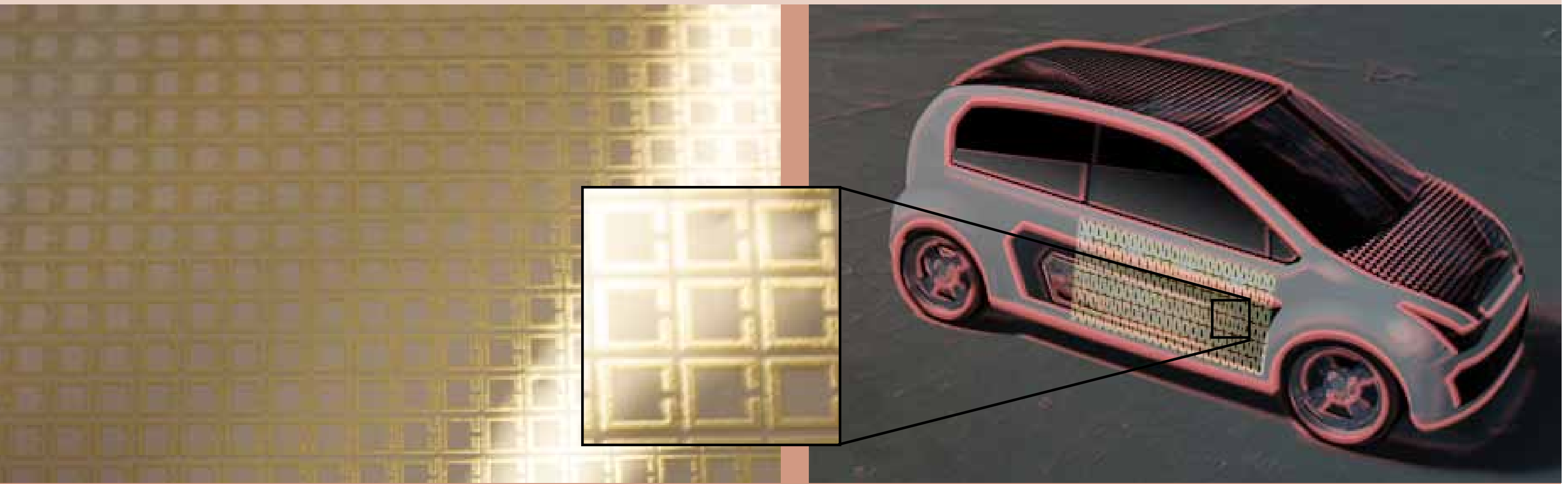
Overhead high voltage power line with PLM system for ground fault detection and localization.



AFLoNext wind tunnel model with integrated Synthetic Jet Actuator array.



Gravure printed metamaterial structures consisting of SSR resonator array on flexible substrate for structural health monitoring of lightweight structures.

RESEARCH AND DEVELOPMENT

- POWER GRID MONITORING
- REDUCTION OF POWER CONSUMPTION
- SYNTHETIC JET ACTUATORS FOR AIRCRAFTS
- MONITORING LIGHTWEIGHT STRUCTURES FOR AUTOMOTIVE APPLICATIONS

ISOSTROSE – LOCALIZATION OF GROUND FAULTS ON 110 KV OVERHEAD POWERLINES WITH A WIRELESS SENSOR SYSTEM MOUNTED AT THE CONDUCTOR

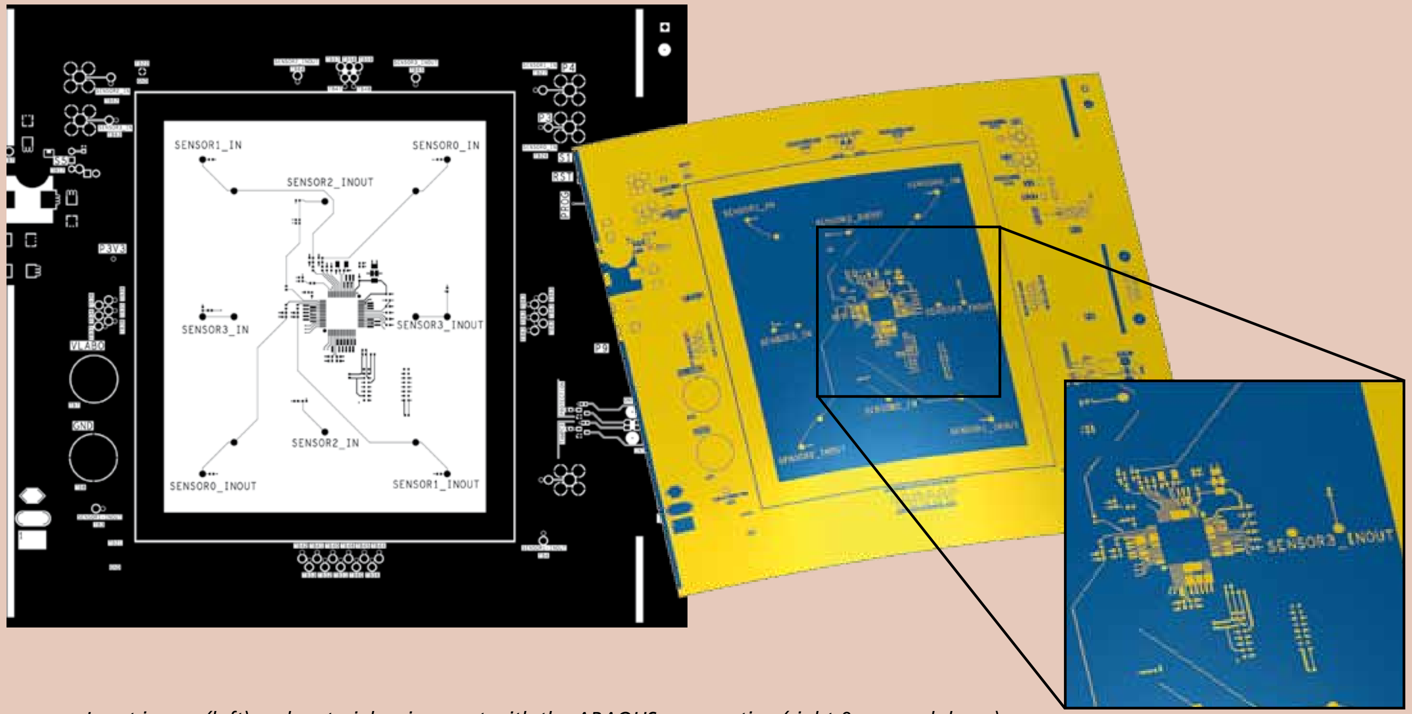
Despite all precautions, such as regular pruning of trees or regular inspections of the overhead transmission lines, ground faults cannot completely be avoided in the power distribution network of the 110 kV high voltage level. Ground faults are usually caused by trees pressed in the direction of the overhead line by strong wind. But even bird nesting or damaged and polluted insulators can trigger short-term ground faults. An occurring ground fault always affects the entire galvanically connected subnetwork.
At best, with the help of electronic protective devices mounted in substation the error can be limited to a single overhead line. However, these can be up to 70 kilometers long in Germany. The logistical and financial effort as well as the time necessary for troubleshooting is enormous.
In the ISOSTROSE project (funded by BMWi / BMBF), a rope-based wireless monitoring system for the localization of ground faults was developed in cooperation with the partners MITNETZ Strom, LTB, First Sensor and Fraunhofer IZM. The centerpiece of the self-sufficient system is a ground fault sensor developed by Fraunhofer ENAS. The ground fault detection is implemented via various independent principles. On the one hand the voltage drop and the maximum current flowing at the moment of the ground fault is used. On the other hand the error is detected by the high-frequency electromagnetic wave caused by the briefly flowing ground fault current. The localization is done via the distributed wireless sensor system. Since mid-November 2017, a field test is running at an 110 kV power line in the Harz mountains. Several ground faults have already been detected.

AFLONEXT / CLEANSKY 2

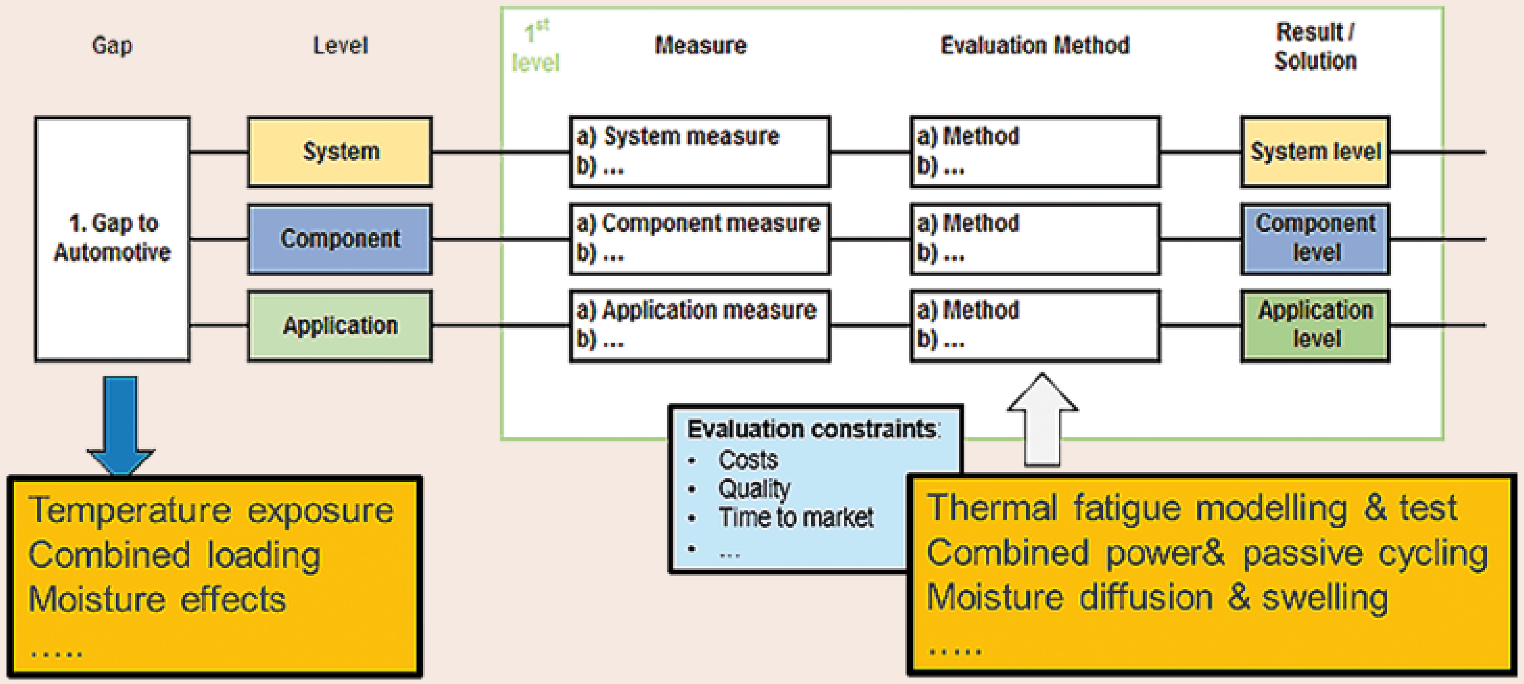
Fraunhofer ENAS participated in the European research project AFLoNext and expedited the development of actuators for active flow control. This technology is used in different fields of applications and constitutes the prospective aerodynamic optimization of aircrafts, vehicles and windpower plants.
Prototypes of so-called Synthetic Jet Actuators (SJA) for improving the flow conditions over an airfoil on aircrafts were analyzed within AFloNext. The project was finished with large-scale wind tunnel tests for evaluating the actuator prototype efficiency.
85 actuators arranged as an actuator array were therefore tested in a wind tunnel in the Central Aerohydrodynamic Institute (TsAGI) in Zhukovsky (Moscow / Russia). The actuators were successfully integrated and evaluated on a six meter span wing section model with an engine dummy. The results will be used as starting point for further research in the field of synthetic jet actuators within CleanSky2, a European research program with the long-term goal of reducing emissions and noise levels produced by aircrafts.
Synthetic Jet Actuators are compact devices that generate short, well directed air pulses with velocities larger than 100 m/s and are not requiring a bulky compressed air supply. Therefore, they may also be used in industrial sorting applications or for (long-term) testing of tiny membranes of MEMS.

METAMATERIALS – POSSIBILITIES FOR THE REALIZATION OF PASSIVE ACTING SMART STRUCTURES

Monitoring the condition of lightweight structures or rubbery-elastic composite materials is still a challenge due to the interface problem. It can lead to complex failure modes, such as delamination, when different material boundaries come into contact due to the intrinsic material properties of the involved materials, thus leading to a loss of stability and reliability of the composite material. For this reason, within the framework of the Federal Cluster of Excellence MERGE, the application and integration of metamaterials in composite materials is investigated in order to produce materials with sensory properties that allow condition monitoring to be determined contactless and in a passive fashion. The approach of realizing sensor-based metamaterials is based on the integration of electromagnetic sub-wavelength resonators into composite materials. The resonators are applied as a two-dimensional array on substrate using printing or embroidery technologies. The size, alignment and arrangement of the individual resonators allow a specific reflection, transmission and



Input image (left) and material assignment with the ABAQUS user routine (right & zoomed down).



Some selected gaps for evaluation by »physics of failure« methods.

RESEARCH AND DEVELOPMENT

- ELECTROMOBILITY
- POWER SUPPLY
- RELIABILITY OF CONSUMER PRODUCTS AND HARSH ENVIRONMENTS

adsorption behavior of electromagnetic waves in the microwave regime, which subsequently change by material changes, such as moisture penetration, or by the interaction between further integrated resonator arrays due to deformation or delamination processes. This is used to realize the sensor function to detect material changes or changes in the structural integrity of the composite material. The remote read out is performed by reflection measurement using a high-frequency microwave signal and the evaluation of the obtained reflection response.

PROFILE OPTIMIZATION OF MULTILAYER PCBS IN SIMULATION AND DEFORMATION MEASUREMENT

Today's electronics developments are driven by an increase of functional density but also by increasing the reliability of all components on chip, package and board-level. Thereby, the interconnection to the board is one key issue for the system reliability and the mechanical behavior of mounted or embedded components, and the board behavior has to be well understood and represented in terms of thermo-mechanically induced stresses and strains. Therefore, a detailed representation of printed circuit board (PCB) by means of finite element method (FEM) was established. The modeling approach for considering multilayer PCBs based on the commercial software ABAQUS has been verified by experimental warpage measurements, performed by using the MicroProf 300 test equipment.
A Python V2.7.3 based user routine is now able to adequately represent multilayer PCBs within ABAQUS. The procedure uses images of each layer layout and its thickness as input for discretization into a user defined rectangular mesh (source grid). After buildup of a CAE-model (ABAQUS GUI), considering drills and cut-outs and meshing of the model with user defined in- and out-of-plane mesh density, elements of the finite elements model are mapped onto the corresponding segments of the image discretization to assign the material information to the finite elements model. The advantage is simple meshing of the complex base geometry and high accuracy in detail with appropriate finite elements discretization, keeping the ability of using a wide range of material properties for the model such as linear elastic, elastic-plastic or visco-elastic behavior. Simulation is now and in the future able to describe the thermo-mechanical behavior of loaded PCBs, based on a more precise multilayer PCB representation, regarding the interaction with surface mounted as well as embedded devices.

PROJECT TRACE – TECHNOLOGY READINESS FOR CONSUMER ELECTRONICS USE IN AUTOMOTIVE APPLICATIONS

The TRACE project involves more than 30 European partners whose aim is to develop a methodology that will enable the use of electronic semiconductor devices and technologies in automotive applications under transparent rules and restrictions. The development of technologies for autonomous driving causes numerous challenges in regard to the reliability of the automotive electronics. In some cases, there is a lack of special components that are suitable for use in automobiles and there is a need to use consumer components that hardly meet automotive standards. Many of the reliability challenges are of a thermo-mechanical nature, since use in the automotive industry means use in a much harsher environment. The main effort has been spent on identifying differences or gaps at component, system and application level. Fraunhofer ENAS, together with several project partners, are developing »physics of failure« based evaluation strategies to cover most critical failure mechanisms for avoiding product malfunctions due to typical automotive loads. Characteristic reliability challenges such as SAC solder fatigue or system induced in-plane and warpage loading effects on components were figured out and a new dedicated test setup has been virtually designed to study the effects of mounting. The development and application of combined experimental numerical techniques to evaluate and avoid thermomechanical failure resulted in test and simulation strategies as illustrated. The »physics of failure« analysis methodologies linked to systems foreseen for CE/AE transfer have shown their potential to be generally applicable for reliability analyses and evaluation of 3D structures used in harsh environments.

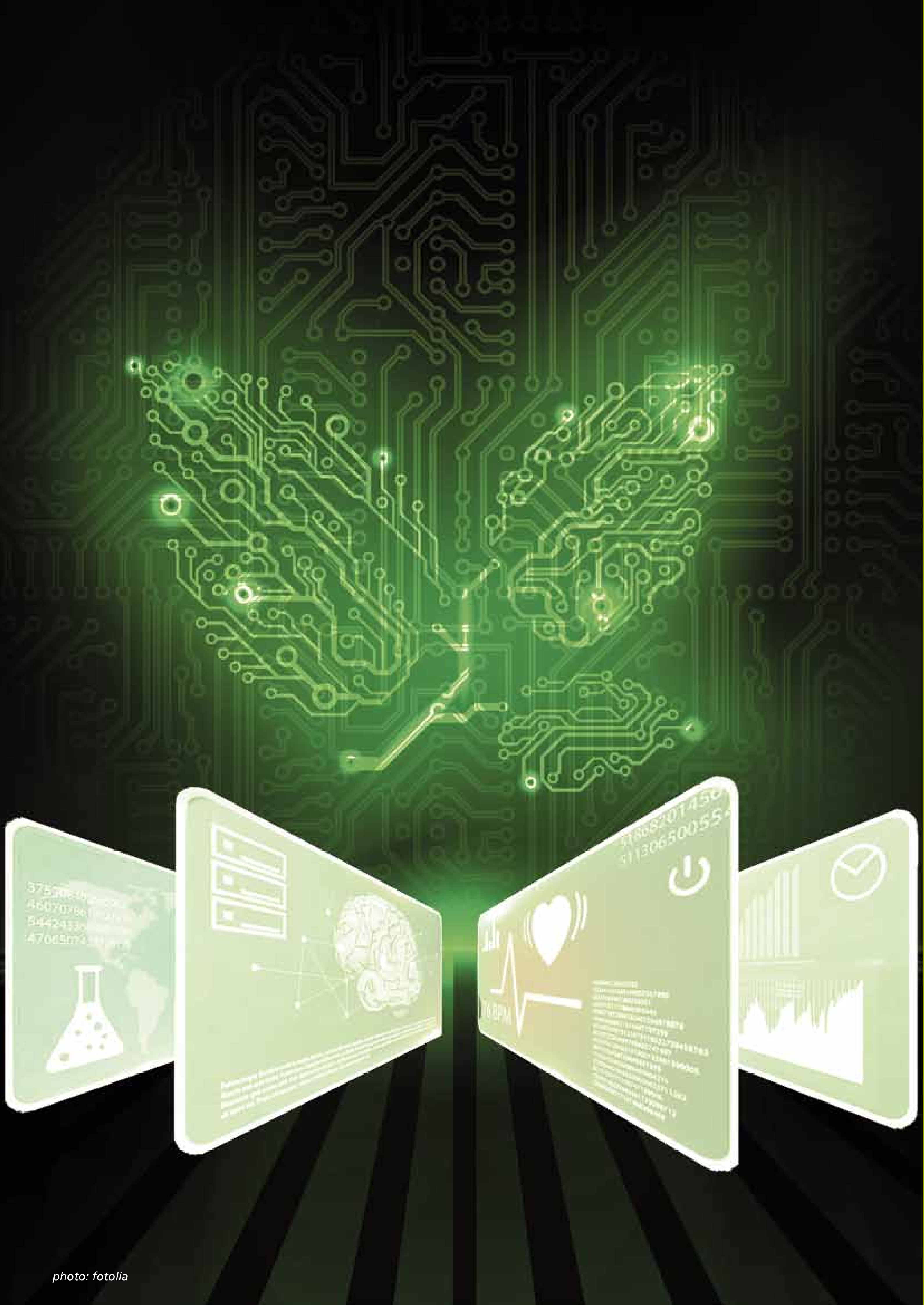


photo: fotolia

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 field of medical science, biology, and healthy living.

Our research projects include, among others, developments for 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.

In addition, integrated sensors and actuators can also be utilized in surgical tools and smart medical devices for the monitoring of patients. 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 field of measurement and analytical technologies 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 portable systems as well as the development of novel systems and components based on micro and nano technologies.

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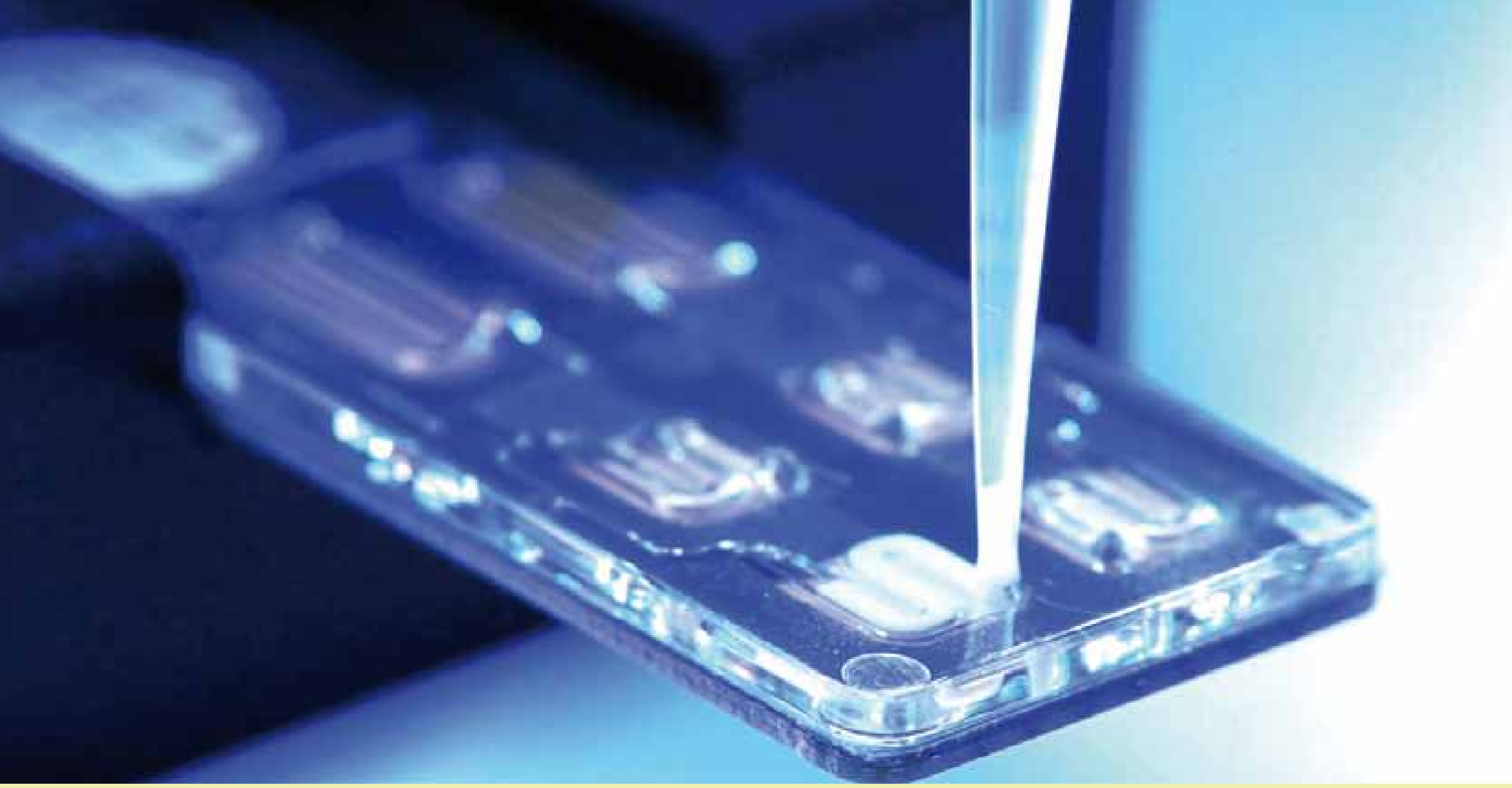
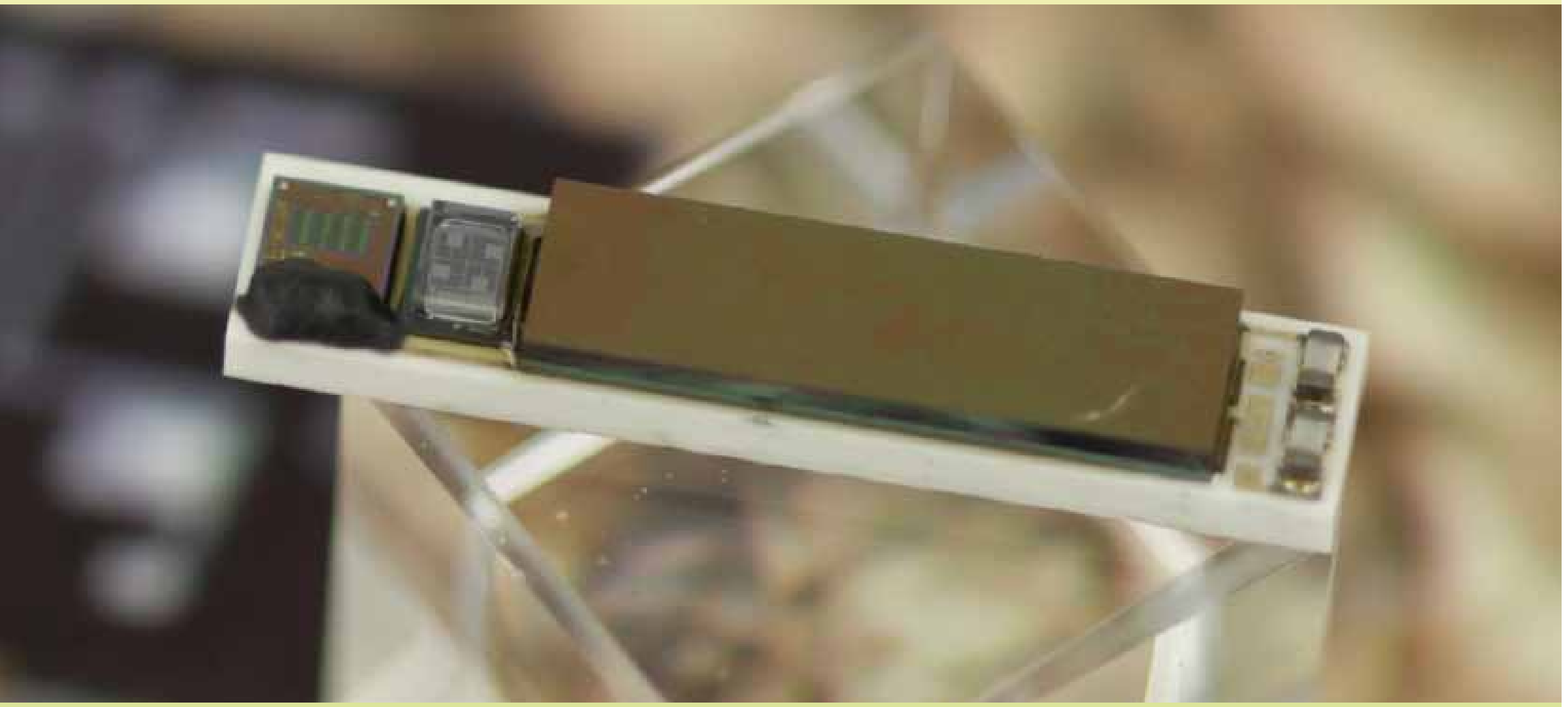


A milk sample is introduced into a microfluidic cartridge for analysis.



Sensor system for hemodynamic controlling developed within the lighthouse project »Theranostic Implants« of Fraunhofer-Gesellschaft.

RESEARCH AND DEVELOPMENT

- POINT-OF-CARE DIAGNOSTICS FOR VETERINARY CARE
- MINIATURIZED IMPLANTS AND THERANOSTIC DEVICES
- THIN FILM PACKAGING AND ENCAPSULATION

TECHNOLOGIES AND SYSTEMS FOR SMART HEALTH

MOBILE PATHOGEN ANALYSIS FOR THE REDUCTION OF BROADBAND ANTIBIOTICS

In the year 2011, nearly 2/3 (approx. 1700 t) of the annual antibiotics consumption in Germany was used in the field of veterinary medicine. Resulting from the increasing number of pathogens with antibiotic resistances in veterinary and human medicine and the developing awareness of the negative results of the drug input into ecosystems, a rational usage of antibiotics became an important target. Mastitis, i.e. the infection of an udder segment, is among the most common indications for antibiotics use in milk production. Untreated mastitis may result in the loss of the infected udder section or even the death of the cow. In the project MANTRA, which is funded by the Sächsische Aufbau Bank, Fraunhofer ENAS is cooperating with veterinarians, biotechnologists and device manufacturer in the development of a novel quick test for mastitis. The test will reduce the time until a pathogen-specific treatment can be started by identifying relevant pathogens and, eventually, antibiotic resistances in milk samples. Thus, additionally the use of non-pathogen specific broadband antibiotics will be reduced.
For the rapid detection of pathogens, a milk sample is transferred into a microfluidic system, which automatically executes all necessary process steps for sample preparation, DNA amplification and detection of the pathogen DNA with a DNA microarray. The same applies for the detection of DNA point mutations, which are specific for antibiotic resistances.

THERANOSTIC IMPLANTS

Within the Fraunhofer Lighthouse Project »Theranostic Implants«, technologies for future implants were developed. Theranostic, an artificial word, means the combining diagnostic and therapeutic features in a device, which measures and acts autonomously.
The overall system consists of a pressure sensor, an ASIC for data and energy management, an accelerometer for measuring the position of the patient and an interposer as a base, whereby the ASIC and the pressure sensor were developed by Fraunhofer IMS.
As a the base of the system, an LTCC interposer with 75 µm line/space and 13 layers in a stack, provided by NIKKO (Japan), contains a coil for inductive energy supply and data transmission. The ASIC and the MEMS accelerometer are mounted onto the interposer either by flip-chip bonding with gold stud bumps or by die attach and wire bonding. The buildup was investigated in regard to bond quality and voids with microcomputer tomography (Micro-CT) equipment and scanning acoustic microscopy (SAM).
Last but not least, an Al_2O_3/Parylene thin film multilayer approach has been used for biocompatible and hermetic encapsulation. Finally, the highly miniaturized system (length: 15 mm, diameter: 3 mm) will be tested for functional operation after silicone encapsulation together with Fraunhofer IMS.

ENDOSTIM

Medical ultrasound is a powerful diagnostic modality that is utilized for imaging a wide variety of internal body structures, particularly soft tissue. The majority of medical ultrasound procedures are non-invasive; however, the minimally invasive form of ultrasound or endoscopic ultrasonography, allows high resolution imaging of target tissues. These endoscopic ultrasound probes are usually piezo based transducers.
In the framework of Endostim, a BMBF funded project, Fraunhofer ENAS is working toward the development of highly miniaturized silicon based ultrasound transducers for diagnostic and therapeutic applications. These Capacitive Micromachined Ultrasonic Transducers (CMUTs) offer many advantages including wide bandwidth, small size and high thermal efficiency compared to piezo based transducers.
The developed CMUT devices will, in collaboration with two companies participating in the project, be integrated with CMOS based optics and associated control electronics into a »microscope« system for ultrasound assisted procedures.

TECHNOLOGIES AND SYSTEMS FOR
SMART HEALTH

A printed battery manufactured on a technical textile driving one LED.

The Sens-o-Spheres demonstration system for wireless monitoring in different types of biotechnical mediums.

RESEARCH AND DEVELOPMENT

- BIOCOMPATIBLE MATERIALS
- FLEXIBLE ENERGY SUPPLY
- AUTONOMOUS SENSOR SYSTEMS
- WIRELESS COMMUNICATION

PROJECT LEITEX: PRINTED ENERGY STORAGE FOR WIRELESS EVALUABLE SENSOR LABEL

Today sensor labels are already used in many different ways. In particular, for applications in the field of medical technology. However, there are still challenges that do not allow applicability or only to a limited extent. This includes, e.g. the high integrability into medical textiles, the wireless evaluation by means of WLAN or Bluetooth and a comparatively cost-effective production. The goal is to develop printed energy storage devices that meet the high requirements of medical technology and sensor properties.
The implementation project leiTEX (Print Production of Conductive Structures and Energy Sources on Textile Fabrics) within the project futureTEX is funded by the BMBF within the framework of Zwanzig20. This project addresses the question of the development of printable, thin and highly integrable energy sources for applications in wirelessly evaluable sensor systems, i.a. applications in medical technology. In addition to the development of printed energy sources (i.e. batteries), the project also develops further parts of the sensor system, such as printed conductors and antennas. As printing processes, inkjet and screen printing are used. Thus, sensor systems for e.g. temperature measurements on technical textiles, e.g. artificial leather and hygiene textiles, are possible.
Within the project, 3 V batteries with 20 mAh were initially set up on the technical textiles (the functionality is shown by driving of a LED). In addition, the circuit and Bluetooth antenna were designed. In the next step, the circuit will be finalized and realized on the available substrates.

SENS-O-SPHERES

In the area of bioprocess engineering, electronic monitoring techniques are used to improve process effectiveness. To achieve high efficiency but also resource friendly products, the exact knowledge of the process data is one of the key issues. To address the problems of process monitoring, a new concept for a location-independent, fully autarkical and minimally disrupting micro measuring device, the so called Sens-o-Spheres, has been introduced. Each sphere has its own rechargeable battery and floats freely within the medium without any disruption. In order to explicitly identify each of the spheres working in parallel, every sphere has its own ID.
Fraunhofer ENAS developed a special smart charging pipe, combining several coils that allow the recharge of the battery inside the spheres in random positions.
Another challenging aspect of this monitoring system is the reliable radio link that transmits data through the bioprocess liquid toward the reader. For that purpose, the Fraunhofer ENAS engineers designed and integrated a miniaturized communication antenna inside the sphere with the highest possible efficiency. Furthermore, the exact electrical characterization of the nutrient medium was an important issue for the design of an optimized communication system, allowing the transmission of data to a reader placed several meters away from the reactor.

photo: RF123 (Oliver Sved)

TECHNOLOGIES AND SYSTEMS FOR
SMART PRODUCTION

The business unit Technologies and Systems for Smart Production addresses topics of the automation and digitization of production. The focus is on the provision of technologies for the individualization of products and sensor-based monitoring of production.

Digital production processes such as inkjet and aerosol jet printing processes enable resource-efficient mass production of intelligent and individualized products down to batch size 1. The necessary smart production environments are supported by our own sensor solutions. These include, in particular, sensor solutions, which monitor machine conditions and processes during production. Thus, e.g. in addition to the implementation of the plug and play functionality for the exchange of sensors in production environments, new sensor systems for harsh environments or for monitoring production resources such as greases and oils or for monitoring air quality will be developed.

BUSINESS UNIT MANAGER

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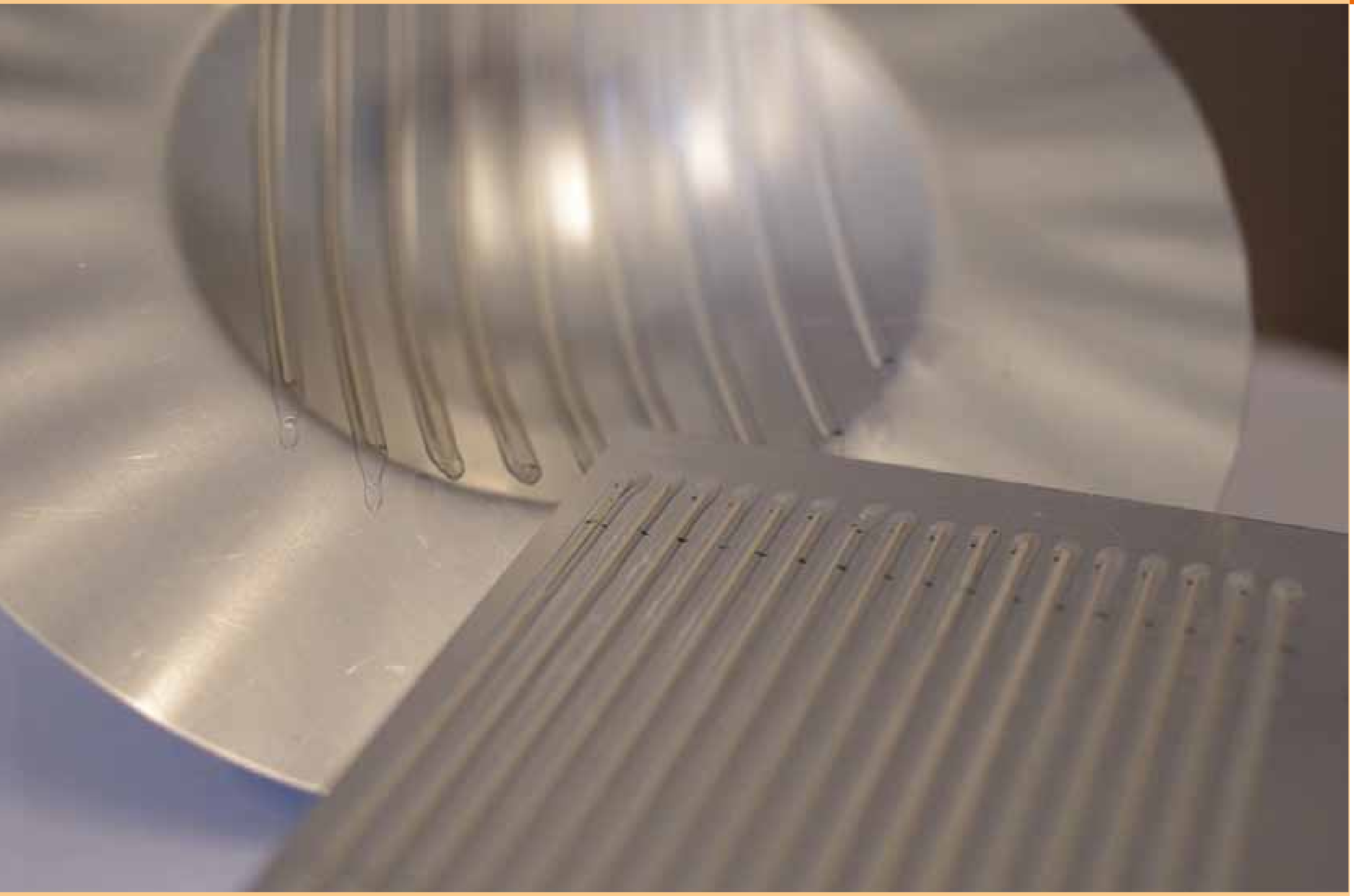
TECHNOLOGIES AND SYSTEMS FOR
SMART PRODUCTION



Printed conductive paths on a planar and on a three-dimensionally formed aluminum sheet.

RESEARCH AND DEVELOPMENT

- SMART DIGITAL PRODUCTION
- INDIVIDUALIZED PRODUCTION OF SERIAL COMPONENTS

DIGITAL PRODUCTION IN MASS PRODUCTION – INNOVATION OF SERIES PRODUCTION WITH DIGITAL PRINTING AND LASER PROCESSES

Due to the market demand of individualized production of serial components under mass production conditions, the use of digital printing and laser technology in production is currently being worked on. In this context, Fraunhofer ENAS is researching the applicability of the inkjet and dispensing printing process. The scientific investigations will be carried out on printed wire harnesses / conductive paths for automotive applications. More concretely, the scientific challenge was to provide fully automated printed conductive paths on top of an aluminum sheet, which will be used for vehicle constructions. Thus, the laying of a standard wiring harness would be obsolete in some areas of a vehicle. The savings potential is correspondingly high. In the production of a vehicle, an aluminum sheet is transformed to be used as a vehicle part. In order not to disturb the cycle time of this production step, either (a) the printed conductive paths must be digitally applied to the planar aluminum sheet or (b) to the three-dimensionally formed aluminum sheet. In 2017, both concepts were examined. On the one hand, printed conductive paths could be produced on planar aluminum sheets, which survived the three-dimensional forming process and, on the other hand, printed conductive paths printed on already formed aluminum sheets could be realized. The targeted adaptation of printing process parameters and ink parameters is the key to success.

PRINTING TECHNOLOGIES FOR THE INTEGRATION OF ELECTRONIC FUNCTIONALITIES

Printing processes are a hot topic in today's industry all over the world. Offering direct integration of additional functionalities into or onto the structural material during production, it creates a completely new »Hardware for Industry 4.0«. The advantages are savings in components and assembly steps, which reduces cost, material consumption and weight. As part of the collaborative project AGENT-3D funded by the BMBF in the initiative »Zwanzig20«, AGENT-elF was approved as a subproject in 2016. The goal of the project is the production of three-dimensional components with integrated electrical functionalities as multi-material systems in one production plant. The whole process is based on dispense printing and all process steps are performed in a closed process chain. As a result, material compositions are produced, which have so far been difficult or impossible to manufacture and in which sensory elements can be integrated as required. The AGENT-elF consortium consists of ten industrial partners, four Fraunhofer Institutes and two universities. It represents all elements of the value chain, from material development to simulation and modeling, process monitoring and plant engineering up to the end user. Fraunhofer ENAS is developing models, measuring methods and evaluation strategies for additively manufactured electrical structures in two subprojects. The results are transferred into technology demonstrators for two selected industrial applications in the field of circuit engineering and thermoelectrics.

Model of a ball screw drive with sensor ring developed in the project SdSeMa. (image: Fraunhofer IWU)

RESEARCH AND DEVELOPMENT

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

STRUCTURE-INTEGRATED WIRELESS SENSOR/ACTUATOR TECHNOLOGY FOR MANUFACTURING SYSTEMS (SDSEMA)

Digitization of industrial working environment has the demand of more comprehensive intelligence of the underlying technical systems to reach the goal of a self-organizing, user-oriented and demand-driven automated production (Industry 4.0). During the SdSeMa project, approaches for structure-integration of sensors into manufacturing systems were developed, using a ball screw drive as an example.
New challenges had to be faced in order to achieve a process-controlled in situ condition monitoring at hardly accessible positions inside machines and constructions. Hence, miniaturized, cross-linked, and energy-efficient information and communication technologies had to be integrated into drive mechanisms and tool components. Key developments cover, for instance, miniaturization of the sensor system by implementation of micro and nanoelectronic technologies, access to this structure integration concept for further system components, and a wireless energy transmission.
Here, the High Performance Center »Functional Integration in Micro- and Nanoelectronics« – in particular the Fraunhofer Institutes ENAS, IIS/EAS, IPMS, and IZM/ASSID with assistance of Fraunhofer IKTS and Fraunhofer IWU – demonstrates its competences to develop, fabricate and implement sensors and actuator technologies in machines to achieve an all-integrated solution. Those methods and technologies apply to a lot of applications for functional integration in machine construction where an insignificant retroactive effect on machine and components, a minimal form factor, a robust installation in machines, an intelligent data logging, pre-processing and wireless data transmission is relevant.

FUNCTIONAL SAFETY

Industry 4.0 means highly connected production with communication across the full value chain. It requires smart systems to provide the capabilities of sensing, data processing, data interpretation and communication. Even under harsh industry environments, these smart systems must be very reliable. Unexpected failures could lead to a loss of essential information or even a sudden stop in the highly connected automated production line. In order to prevent the substantial economic damage this could create, a new concept of prognostics health management (PHM) is introduced for adding a minimum of PHM features at all levels of the industrial electronics. It starts with adding nanoscale sensors to the individual components, which can detect delamination or interconnect damages. The information are collected and processed at board, module, and machine levels in order to trigger maintenance on demand, well before the failure occurs. At top level, schemes of artificial intelligence are employed for self-learning with continued improvement of the accuracy. Thus, the new generation of reliability methods is able to guarantee functional safety and system availability at the high level needed for Industry 4.0 applications.

In cooperation with SHINKO

TECHNOLOGIES AND SYSTEMS FOR
SMART PRODUCTION

Optical sensor system for monitoring of electroplating processes.

RESEARCH AND DEVELOPMENT

- SENSOR SYSTEMS FOR PROCESS AND CONDITION MONITORING
- WIRELESS SENSOR SYSTEMS

WIRELESS SENSOR SYSTEMS FOR THE FLEXIBLE DESIGN OF PRODUCTION PROCESSES

In the framework of Industry 4.0, the level of automation, the flexibility of production processes and the efficiency are improved by using the newest ICT technologies. Within the BMBF funded research project named »DiSSproSiP«, Fraunhofer ENAS develops, together with its partners, a new procedure, in which the productions process is indirectly controlled by the workpiece. Therefore, it is equipped with an RFID tag that carries all necessary production information transmitted step by step to each machine along the production line.

Supported by the implementation of the needed sensors, the product is able to control its own production process and to monitor the correct execution of specific production steps. Some of the RFID tags are equipped with a microcontroller and need an additional energy storage, which needs to be charged periodically.

In this project the main task of the Fraunhofer ENAS is to create a suitable wireless power transmission system to supply the RFID sensor system and to develop an appropriate protocol allowing the RFID reader to communicate via the RFID tag with the implemented microcontroller.

OPTICAL MONITORING SYSTEM FOR QUALITY CONTROL OF ELECTROPLATING SOLUTIONS

Complex offline methods, such as high-performance liquid chromatography, are state-of-the-art for monitoring quality and consistence of electroplating solutions during the deposition process. In a joint project, Fraunhofer ENAS and Japanese enterprise SHINKO ELECTRIC INDUSTRIES CO., LTD. have developed an optical sensor system in order to have a cost efficient online quantification of essential ingredients of electroplating solutions. The system is based on the acquisition of spectral properties of measured liquids using solid-state sensors. In combination with multivariate algorithm, the concentration of the ingredients to be acquired will be determined. By recognizing a deviation of the predetermined parameters, the consistence of the solution can be regulated directly if necessary.

Compact dimensions, wireless communication and optional battery operation enables an efficient integration of the sensor in existing systems as well as an adaption to further applications. These include process and quality monitoring systems for food technology, environmental analysis or semiconductor industry.

photo: pixabay

HIGHLIGHTS

DISSERTATIONS

January 10, 2017

PhD:	Robert Schulze
Topic:	Sensors Based on Piezoelectric Polymers for Structure Integration
Institution:	Chemnitz University of Technology

May 12, 2017

PhD:	Christian Friedemann Wagner
Topic:	Mechanical, Electronic and Optical Properties of Strained Carbon Nanotubes
Institution:	Chemnitz University of Technology

June 13, 2017

PhD:	Christian Hangmann
Topic:	Hocheffiziente Modellierung, Charakterisierung und Analyse von Mixed-Signal Phasenregelkreisen unter Berücksichtigung von nichtlinearen und nicht-idealen Effekten
Institution:	Paderborn University

November 2, 2017

PhD:	Xiao Hu
Topic:	Multiskalensimulation der Atomlagenabscheidung von metallischem Kupfer und Kupferoxid aus Cu-Beta-Diketonaten
Institution:	Chemnitz University of Technology

November 29, 2017

PhD:	Lutz Hofmann
Topic:	3D-Wafer Level Packaging approaches for MEMS by using Cu-based High Aspect Ratio Through Silicon Vias
Institution:	Chemnitz University of Technology

AWARDS AND ACHIEVEMENTS

EuroSimE Achievement Award

In April 2017, the 18th EurosimE conference was held in Dresden. To honor extraordinary research accomplishments and long-standing achievements for their distribution and implementation in industry practice, the EuroSimE achievement award was granted for the first time. The six-membered award committee honored Dr. Rainer Dudek from Fraunhofer ENAS, notably for his longstanding experiences in analyzing the reliability of microsystems and microelectronic circuits via simulation (FEM) and experimental thermo-mechanical characterization methods.

www.enas.fraunhofer.de/en/about_us/data_and_facts/awards

Best Poster Award at MAM2017

In March 2017, the MAM2017 – Advanced Metallization Conference was held in Dresden. Dr. Ramona Ecke was presented with the best poster award for her contribution titled »Resistive switching behavior of $BiFeO_3$ and $BiFeO_3$:Ti-based films on different bottom electrode materials«.

Fraunhofer ENAS Research Award

For the seventh time, Fraunhofer ENAS awarded the Fraunhofer ENAS Research Award to a scientist for his excellent scientific research results in microelectronics and/or micro system technologies. On December 20, 2017, Dr. Christian Hangmann from Paderborn has been awarded. Dr. Hangmann developed more efficient and robust stability conditions and hence, optimized the design process for highly complex systems. Due to these new and robust design criteria, engineers gain a faster and more accurate insight in the highly complex and chaotic system behavior. They can simplify the layout for non-linear and non-ideal control circuits and accelerate the design process significantly as well.

Fellows of Fraunhofer ENAS

At irregular intervals, Fraunhofer ENAS honors longstanding and commendable employees with the title of »Fellow of the Fraunhofer Institute for Electronic Nano Systems ENAS«. In December 2017, three scientists received the honor.

AWARDS AND ACHIEVEMENTS

Prof. Dr. Reinhard R. Baumann established the department Printed Functionalities at Fraunhofer ENAS. Within the managing of the department at Fraunhofer ENAS and his Professorship of Digital Printing and Imaging Technology at Chemnitz University of Technology, he received outstanding scientific results in the field of printed functionalities. Due to his commitment, the first lighthouse project (Go Beyond 4.0) of Fraunhofer-Gesellschaft coordinated by Fraunhofer ENAS started in 2017.

Furthermore, Dr. Jürgen Auersperg was honored with the fellow degree for his excellent research activities. Dr. Auersperg is an internationally acknowledged scientific expert in the field of fracture and damage mechanics and a longstanding project manager in the department Micro Materials Center at Fraunhofer ENAS.

The third fellow of Fraunhofer ENAS is the longstanding project group leader Dr. Dietmar Vogel. He is a scientist in the department Micro Materials Center as well and also is an internationally known expert in the field of experimental analysis.

Fraunhofer research manager

Since 2015, Fraunhofer-Gesellschaft has been training highly promising young researchers in the prestige program »Fraunhofer research manager«, thus enabling them to support their respective institutes with novel ideas regarding the exploitation of research results. Dr. Mario Baum, member of the 2nd class of trainees, received his award from the Executive Vice President Technology Marketing and Business Models Prof. Georg Rosenfeld on March 8, 2017. Dr. Baum is the deputy head of the department System Packaging and manager of the business unit »Technologies and Systems for Smart Health«.

Best apprentice

Every year, Fraunhofer-Gesellschaft awards the best apprentices. In 2017, Mr. Carol Schmidt finished his vocational training and has been honored as one of the best apprentices in the Fraunhofer-Gesellschaft.

Prof. Dr. Georg Rosenfeld (l.), Executive Vice President Technology Marketing and Business Models of Fraunhofer-Gesellschaft, congratulated Dr. Mario Baum, Manager of the business unit »Technologies and Systems for Smart Health« of Fraunhofer ENAS, on his successful completion of the Fraunhofer Research Manager program.

Prof. Dr. Thomas Otto (2nd on the left side), acting director of Fraunhofer ENAS honored three Fraunhofer scientists – Dr. Dietmar Vogel (l.), Prof. Dr. Reinhard R. Baumann and Dr. Jürgen Auersperg (r.) – with the title Fellow of Fraunhofer ENAS.

The awardee of the Fraunhofer ENAS Research Award 2017, Dr. Christian Hangmann (3rd from l.) with the acting director of Fraunhofer ENAS, Prof. Dr. Thomas Otto (2nd from l.), the chairwomen of the research award committee, Prof. Dr. Karla Hiller (l.) as well as the laudator Prof. Dr. Yves Leduc (r.) from the University Nice-Sophia Antipolis, Polytech'Nice Sophia, Dr. Christan Hedayat (3rd from r.), head of the department ASE and Prof. Dr. Hilleringmann, Paderborn University.

CONFERENCES

The workshop »micro and nanotechnologies for applied spectroscopy« organized by Fraunhofer ENAS took place in Dresden in October 2017.

International conferences, seminars and workshops

The 11th Smart Systems Integration Conference and Exhibition was held on March 8–9, 2017, in Cork, Ireland. More than 280 experts from 22 countries were discussing the latest developments in the fields of system integration and packaging, design of smart integrated systems and smart systems applications putting a special focus on »Emerging Trends and Technologies in IoT and Industry 4.0«. Prior to the conference, a field trip to the Tyndall National Institute in Cork took place as well as EPoSS working group meetings.

The MAM2017 – Advanced Metallization Conference was held on March 26–29, 2017, in Dresden. More than 80 scientists from around the world participated in the international workshop. The conference focused on practice-oriented aspects of the semiconductor industry: materials, processes and integration, layer deposition, characterization and modeling as well as applications (micro- and nanoscale).

On May 19, 2017, the first innovation forum of Fraunhofer ENAS was held in Chemnitz together with representatives from industry, politics and science. The purpose of the innovation forum is to encourage and pursue discussions between industry and research on specific topics. The key topic of the first innovation forum was »optical sensors«.

The Chemnitz workshop series on nanotechnology, nanomaterials and nanoreliability successfully continued in 2017.

The department System Packaging invited researchers to the workshop on June 13–14, 2017. The topic of the workshop was »System Integration Technologies«, focusing especially on bonding technologies and applications in medical engineering.

On October 17, 2017, Fraunhofer ENAS hosted a workshop with the focus on »micro and nanotechnologies for applied spectroscopy« in Dresden. The department Multi Device Integration organized the workshop, aiming at encouraging the exchange between the end user, manufacturer, systems integrator, and research institutions and driving the development of the next generation of miniaturized spectrometers organized the workshop.

In 2017, the scientist of Fraunhofer ENAS presented their research results at more than 80 conferences. Moreover, the scientists of Fraunhofer ENAS work in scientific boards of numerous international conferences.

Fraunhofer ENAS is organizer/co-organizer of the following conferences and workshops:

Smart Systems Integration Conference (co-organizer)	Cork, Ireland	Mar 8–9, 2017
Materials for Advanced Metallization MAM 2017 (organizer)	Dresden, Germany	Mar 26–29, 2017
Microclean 2017 (organized by the head of the department Micro Materials Center)	Meerane, Germany	May 11–12, 2017
5th European Expert Workshop on Smart Systems Reliability – EuWoRel 2017 (co-organizator)	Berlin, Germany	Sep 26-27, 2017
Printing Future Days (organized by the head of the department Printed Functionalities)	Chemnitz, Germany	Oct 4-6, 2017

EXHIBITIONS AND TRADE FAIRS

Science meets arts

For seven years, an art exhibition is held at Fraunhofer ENAS twice a year. The institute invites cooperation partners, guests from politics and public life and interested citizens from Chemnitz and surrounding areas to the exhibiton series »science meets arts«.

In 2016/17, we have shown the exhibition »Zeitmomente« of our curator George Felsmann on the occasion of his 75th birthday. The exhibition ended with a gallery talk between him and the art historian Beate Düber in April.

During the summer, the painter and graphic artist Siegfried Otto Hüttengrund from Bernsdorf was guest at Fraunhofer ENAS with his exhibition »Aus der Tiefe«. He presented color woodcut and oil glaze paintings with mainly mythological themes. Georg Felsmann and Siegfried Otto Hüttengrund took the guests of the gallery talk on a journey through the evolution process of his works. They talked about the techniques of color woodcut, explained the world of mythology as well as the picture themes of Otto Hüttengrund.

Since fall 2017, the painter Ralf Dunkel from Oberlausitz nearby Dresden has been exhibiting his works under the topic »CARS«. He presented paintings in mixing technique with acrylic, oil, gold and silver foil. His predominated theme has been speed and shapeliness of classic cars and current special editions of high-performance road cars.

Chemnitz company run

Four women and 21 men, a joint team of employees of Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology, participated in the 12th Chemnitz company run which took place on September 6, 2017.

7640 runners took part at the company run, our best male runner finished at position 10 and our best female starter at position 374. The four best male runners finished in 2nd place, the best female team finished the run in place 124 and the mixed team finished 13th.

Congratulations! We are looking forward to the Chemnitz company run 2018.

Fraunhofer ENAS has presented its research results and prototypes at the following international trade shows and exhibitions in 2017:

European 3D Summit 2017	Grenoble, France	January 23–25, 2017
Smart Systems Integration 2017	Cork, Ireland	March 8–9, 2017
SEMICON China 2017	Shanghai, China	March 14–16, 2017
LOPEC 2017	Munich, Germany	March 29–30, 2017
MEMS Engineer Forum	Tokyo, Japan	April 26–27, 2017
HANNOVER MESSE 2017	Hannover, Germany	April 24–28, 2017
Techtextil 2017	Frankfurt, Germany	May 9–12, 2017
SENSOR + TEST 2017	Nürnberg, Germany	May 30–June 1, 2017
SEMIEXPO Russia 2017	Moscow, Russia	June 7–8, 2017
Paris Air Show 2017	Paris, France	June 19–25, 2017
12th Silicon Saxony Day 2017	Dresden, Germany	June 20, 2017
MEMS Sensing & Network System 2017	Chiba, Japan	October 4–6, 2017
MST Kongress 2017	Munich, Germany	October 23–25, 2017
COMPAMED 2017	Düsseldorf, Germany	November 13–16, 2017
SEMICON Europa 2017	Munich, Germany	November 14–17, 2017
productronica 2017	Munich, Germany	November 14–17, 2017

MEMBERSHIPS

Memberships of Fraunhofer ENAS

AGENT-3D e.V.	Dresden, Germany
ALD Lab Dresden	Dresden, Germany
biosaxony e.V	Dresden, Germany
Cool Silicon e.V.	Dresden, Germany
Dresdner Fraunhofer-Cluster Nanoanalytik	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
Fraunhofer AutoMOBILE Production Alliance	Germany
Fraunhofer Alliance Nanotechnology	Germany
Fraunhofer Alliance Textile	Germany
Fraunhofer Group Microelectronics	Germany
Fraunhofer Cluster 3D Integration	Dresden and 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
Micromachine Center	Tokyo, Japan
Nano Technology Center of Competence »Ultrathin Functional Films«	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 Jose, USA
Silicon Saxony e.V.	Dresden, Germany
Mechanical Engineering Network Saxony VEMAS*innovativ*	Chemnitz, Germany

PUBLICATIONS AND PATENTS

Publications

In 2017, the scientists of Fraunhofer ENAS published their results in 176 book articles and conference proceedings. Starting with the annual report 2016, we stopped listing them in the report.

You can find our published content:
1) Within the database Fraunhofer Publica which contains all publications and patents published by Fraunhofer Institutes: publica.fraunhofer.de/starweb/pub09/newPub.htm
2) Moreover, they are listed on the website of our partner Center for Microtechnologies of Chemnitz University of Technology: www.zfm.tu-chemnitz.de/publications/index.php.en

Electronically available documents can be downloaded via Fraunhofer Publica.

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Patents

In 2017, 6 patents from scientists of Fraunhofer ENAS have been published and/or granted. In summary, staff of Fraunhofer ENAS is involved in 155 published or granted patent applications, which belong to 42 patent families.

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