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FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS

Annual Report 2020

Front page:
In order to integrate electronic components directly into components in a cost-saving manner, three-dimensional surfaces are printed with electronic structures (electrodes, antennas, heating structures, sensors). A robotic arm equipped with a print head applies conductive or insulating inks to a wide variety of surface materials and shapes. These processes were investigated, among others, in the Fraunhofer lighthouse project „Go Beyond 4.0“ about which you can read more on page 55.
Photo © Ines Escherich

CONTENT

PREFACE

Photo © Ines Escherich

Don't try to be someone who is successful. Be someone who creates value!
Harald Kuhn, quote loosely based on Albert Einstein

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

As of September 1, 2020, I have taken over the management of the Fraunhofer-Institute for Electronic Nano Systems ENAS in Chemnitz from the previous acting director Prof. Dr. Thomas Otto who has since joined my team as one of the two deputy directors of the institute.

Overall, the institute continued to develop positively in 2020. A large part of our research volume is generated from contract research, i.e. within the framework of direct orders from industry and via publicly funded projects. Together with the management team and our employees, we stand for trusting and solution-oriented cooperation, innovation, quality, but also continuity and stability.

The current global situation highlights the importance of digitization. Consequently, we are systematically expanding our core competencies in smart systems integration and providing new impetus via innovative approaches in areas such as data analysis with artificial intelligence and system security. Through a deeper understanding of the different customer requirements, we continue to develop existing solutions in a targeted manner and focus on future-relevant technologies. In cooperation with our customers, we focus on the practical application of our research and development results in business and industry as a central role in the innovation process.

We would like to thank you, our partners and customers, for your trust and support. We invite you to inform yourself about the latest topics from our business units and we will be pleased to be personally available for in-depth, continuing discussions.

Yours,

Prof. Dr. Harald Kuhn
Executive Director
Fraunhofer Institute for Electronic Nano Systems

Prof. Dr. Thomas Otto
Acting Director (until 08/2020) and Deputy Director
Fraunhofer Institute for Electronic Nano Systems

STRATEGY PROCESS / FOLLOW-UP PROCESS

Management of the institute: (from left) Prof. Dr. Karla Hiller, Prof. Dr. Harald Kuhn, Dr. Tina Kießling, Prof. Dr. Thomas Otto, Prof. Dr. Stefan E. Schulz
Photo © Ines Escherich

STRATEGY PROCESS / FOLLOW-UP PROCESS

Interview with the new director of the institute Professor Harald Kuhn and the former acting director Professor Thomas Otto

Prof. Harald Kuhn took over the management of Fraunhofer ENAS in September 2020. At the same time, the acting director of the institute Prof. Thomas Otto, who had been in office until then, resumes the role of deputy director of the institute. The change in leadership comes at a socially challenging time.

Mr. Kuhn, you joined Fraunhofer ENAS as the director of the institute in September 2020. How did you arrive in Chemnitz and at the institute and how were you received?

Both, the management level and the employees of Fraunhofer ENAS gave me a very warm welcome. From the very beginning, there was an open atmosphere. At the same time, however, the discussions clearly reflected the expectations placed on me to keep the institute on the road to success and to continue to build on the level we have already achieved.

Mr. Otto, for more than four years, you and your team have ensured that the institute has continued to develop positively. Where does the institute stand and where do you see challenges that now need to be solved as a team in the future?

From my point of view, Fraunhofer ENAS is well positioned in cooperation with the Center for Microtechnologies of Chemnitz University of Technology. At this point, I reflect in particular on the motivated employees of both facilities, the technological equipment of Fraunhofer ENAS as part of the Research Fab Microelectronics Germany and its infrastructure. We have to maintain this level and expand it further.

Mr. Otto, what contribution is made in connection with the Corona pandemic at the institute?

Fraunhofer ENAS has continued to develop positively even under these more difficult conditions. We processed our industrial orders punctually and successfully. Delays that resulted from limited on-site activity were resolved constructively and by mutual agreement with the involved project partners.

At this point, I would like to point out that we are of course also part of the initiative Fraunhofer versus Corona and have pushed several anti-corona projects with local companies. You will find articles within the business unit "Technologies and Systems for Smart Health".

Mr. Otto, what has changed in the cooperation with customers during this time?

We have reorganized our internal workflows to ensure that Fraunhofer ENAS, in cooperation with the Center for Microtechnologies, will continue to be reliable partners during this crisis.

Mr. Kuhn, you worked in a management position in industry for many years and have now moved on to a research institute. Where do you see similarities or differences?

There are topics that are very similar, such as management tasks, the structuring of topics, decision-making processes and similar things. As in industry, we at the institute are also part of a constantly changing working world with new challenges. Thus, for me the most important task is leadership – such as communicating with the team, providing impetus for innovation, motivating and, above all, empowering and strengthening others. However, I see differences in the range and diversity of topics, starting with the fact that as director of the institute, I am also a professor at the local university, via committee work to lobbying, including in politics.
As the head of an institute of applied research, I see myself, and my task in particular, as being a link between science and industry with the clear aim of generating added value.

To be economically successful, you need satisfied customers and satisfied employees. Mr. Kuhn, what do you expect from your management team and from your employees?

In my team and at the entire institute, I expect an open and honest exchange on a wide variety of topics. Reliability in decision-making and trust in the chosen path are essential. I expect the management team and each employee to be committed both to the cause itself and to working together as a team, i.e. team spirit with a clear task structure. Only by working together and pulling together in the same direction will we continue to be successful in this dynamic environment.

STRATEGY PROCESS / FOLLOW-UP PROCESS

In addition, what is important to you with regard to the institute’s customers?

For me, applied research means research in the service of the customer, enabling the industry to compete successfully in tomorrow’s international markets with innovative, future-oriented solutions. My point is that it is about understanding the customer and his needs, offering him a viable/practical/best solution and implementing it together with him or for him. However, this requires an open exchange of ideas on both sides, including a trustful involvement in future strategic topics.

The first one hundred days in a new position are often formative for the next few years. What forward-looking topics have you tackled? How would you like to develop the institute further? Which topics are important to you?

First, I have built up a good understanding of the issues and processes, which form the basis for decisions. I will continue to develop the organization of the institute in order to prepare us for future tasks. My aim is to sharpen the system view, i.e. the view of the intelligent system, and to build up this topic as a step in the value chain. This includes data analysis in particular. We will thus establish AI as a “tool”.

Mr. Kuhn, with the start of 2021, you have filled the new position of Technical Lead in the organization with an experienced scientist. What do you expect from this?

I would like to secure the technical leadership of Fraunhofer ENAS with its focus on smart systems integration in the long term. The necessary focus is on innovation and bundling synergies. This includes the development of a technological roadmap and strategy in collaboration with the departments, which benefits the entire institute. In Dr. Kurth, we have been able to recruit an excellent employee for this task.

Mr. Kuhn, you are not only head of Fraunhofer ENAS and Professor for Smart Systems Integration at Chemnitz University of Technology, you also work as director of the Center for Microtechnologies of the Faculty of Electrical Engineering and Information Technology. How would you like to develop the cooperation on site and across sites further?

Yes, this close connection to the local university is a good and sustainable tradition within Fraunhofer-Gesellschaft. We will further reinforce and expand the existing close cooperation.
At the university, my aim is to strengthen scientific excellence in the core topics of micro- and nanotechnologies and thus expand preliminary research. This will ensure the future and sustainable attractiveness of both institutions.
Of course, we also look beyond Chemnitz and we are committed as a team to the entire microelectronics innovation chain from basic research to applied research (i.a. including the special capabilities of the Research Fab Microelectronics Germany) to the economy including applications for the benefit of all people.

Thank you very much for the interview! Would you like to conclude with a statement?

With pleasure. I stand as head of Fraunhofer ENAS and the Center for Microtechnologies for teamwork, stability, and innovation. As a reliable partner, we dependably continue our research topics and reasonably complement them with new topics such as AI as a tool for smart systems as well as intelligent process control and process environment.

FRAUNHOFER ENAS: PROFILE

FRAUNHOFER-GESELLSCHAFT

www.fraunhofer.de/en

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

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

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 75 institutes and research institutions. The majority of our 29,000 staff are qualified scientists and engineers who work with an annual research budget of 2.8 billion euros. Of this sum, 2.4 billion euros are generated through contract research. Around two thirds of Fraunhofer's contract research revenue is derived from contracts with industry and publicly funded research projects. The remaining third comes from the German federal and state governments in the form of base funding. This enables the institutes to work on solutions to problems that are likely to become crucial for industry and society within the not-too-distant future.

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

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

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

Last updated: January 2021

FRAUNHOFER ENAS

www.enas.fraunhofer.de

The Fraunhofer Institute for Electronic Nano Systems ENAS is the expert and development partner in the field of smart systems and their integration for various applications. Smart systems combine electronic components, micro and nano sensors as well as actuator components with interfaces for communication and a self-sufficient energy supply. Systems are increasingly equipped with the ability, on the one hand, to pre-evaluate data, detect errors and thus prepare decisions, and, on the other hand, to address and identify each other and work in consortia.

They are the key to digitization and the Internet of Things. Smart systems are applied in a variety of fields. The design, integration and technology to realize such systems require novel approaches and pose new tasks for interdisciplinary research.

Whether start-up, SME or large enterprise, Fraunhofer ENAS supports customer projects along the whole value-added chain of smart systems starting from the idea, via design and technology development or realization based on established technologies up to tested prototypes as well as technology transfer. If standard components do not meet the requirements, Fraunhofer ENAS provides expert assistance in the realization of innovative and marketable products.

The services of Fraunhofer ENAS are focused on design, micro and nano technologies, printed functionalities, specific components as well as smart systems integration and reliability. As a reliable innovation partner we develop high performance sensors, new sensor and actuator systems based on integrated nano structures, beyond CMOS components, innovative integration technologies and extended reliability approaches. Moreover, we complement these topics by innovative developments in the fields of simulation, data analyses by means of artificial intelligence and security of systems.

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 as well as Technologies and Systems for Smart Production. The business units address different markets, different customers and different stages of the value chain depending on the required research and development services.

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

ORGANIZATIONAL STRUCTURE

Fraunhofer Institute for Electronic Nano Systems ENAS

Director: Prof. Dr. Harald Kuhn
Deputy directors: Prof. Dr. Stefan E. Schulz, Prof. Dr. Thomas Otto

Department
Multi Device Integration
Dr. Alexander Weiß

Department
Micro Materials Center
Prof. Dr. Sven Rzepka

Department
Printed Functionalities
Dr. Ralf Zichner

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

Department
System Packaging
Dr. Maik Wiemer

Department
Advanced System Engineering
Dr. Christian Hedayat

Administration
Dr. Tina Kießling

Infrastructure
Uwe Breng

Quality Management
Dr. Martina Vogel

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

Technical Lead
Dr. Steffen Kurth

Program Coordinator
Dr. Christian Wagner

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

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

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

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

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

International Offices

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

Office Shanghai, China
SHI Min

Office Manaus, Brazil
Hernan Valenzuela

Chemnitz University of Technology

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

Director: Prof. Dr. Harald Kuhn

Deputy director: Prof. Dr. Karla Hiller

Department
Lithography and Pattern Transfer
Dr. Danny Reuter

Department
Layer Deposition
Dr. Sven Zimmermann

Professorship of
Smart Systems Integration
Prof. Dr. Harald Kuhn

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

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

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

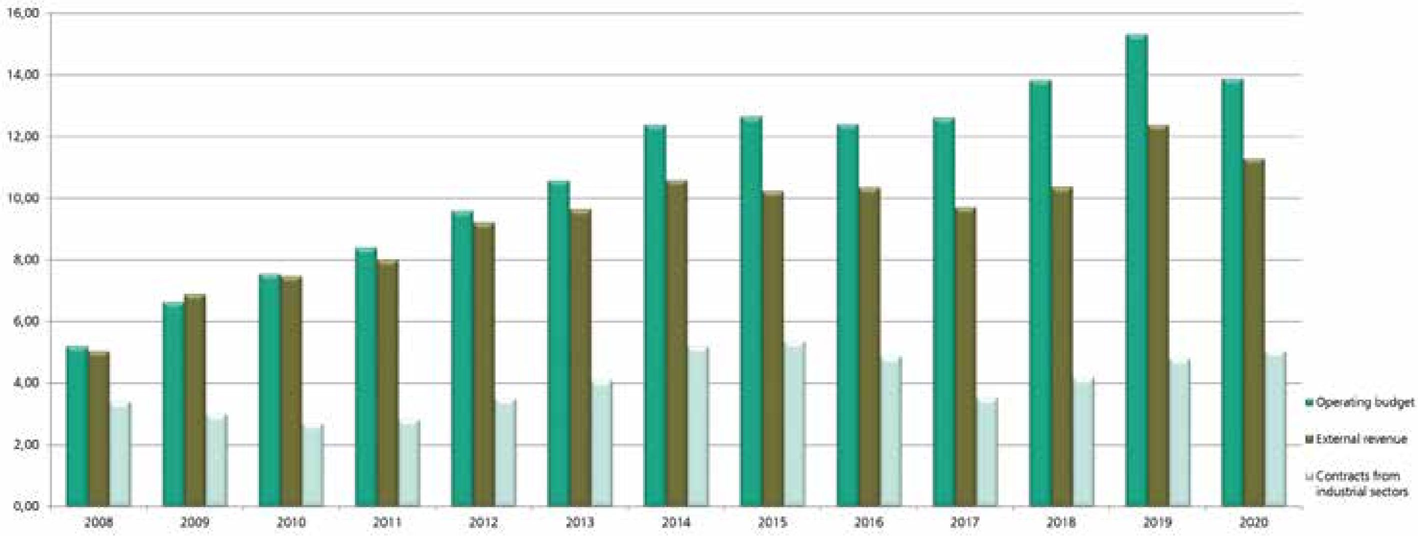
Paderborn University

Professorship of Sensor Technology
Prof. Dr. Ulrich Hilleringmann

FACTS AND FIGURES

Development of the Fraunhofer ENAS

	Year												
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total budget (in million euros)	5.2	6.7	7.6	8.4	9.6	10.6	12.4	12.65	12.41	12.62	13.83	15.32	16.2
Increase of the total budget (in relation to 2008)	–	29 %	46 %	62 %	85 %	104 %	138 %	143 %	139 %	143 %	166 %	195 %	212 %
Industrial revenues (in million euros)	3.4	3	2.8	2.8	3.49	4.1	5.2	5.24	4.85	3.54	4.18	4.8	5.0
Investment (in million euros)	0.65	5.45	6.8	1.5	1.81	1.44	7.23	2.02	1.89	2.72	1.7	1.23	2.28
Staff	63	73	91	102	104	125	129	127	132	139	157	174	169
Apprentices	0	2	3	5	6	7	7	6	7	6	8	8	8
Students and student assistants	10	10	20	40	43	51	51	43	43	35	50	50	45
Publications and oral presentations	61	75	114	119	112	215	198	173	176	144	141	147	76
Patents	7	5	13	20	8	17	9	9	12	6	9	13	16
Doctoral Theses	6	0	4	2	3	3	3	5	3	5	2	2	4



Financial situation and investment

After a strong growth in 2019, the overall budget of 2020 could be kept at almost the same level as the previous year despite the influence of the Corona pandemic and increased investments. Due to increased industrial revenues and consolidated expenses, the revenue quota increased slightly to 81.3 %. Orders from German and international industrial companies amounted to 5.0 million euros. Increased slumps due to the crisis were recorded in the application-oriented business areas, whereas the order situation in the technology-oriented business areas improved significantly in the second half of the year. The operational budget decreased by 1.4 million euros to 13.9 million euros.

Current investments for the fiscal year amounted to 2.28 million euros. Altogether, the total budget amounted to 16.2 million euros.

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

Personnel development

At the end of the year 2020, Fraunhofer ENAS employed 169 people in Chemnitz, Paderborn and Berlin. 11 new employees were hired, whereas 15 employees left the institute.

On December 31, eight apprentices in total worked and learned at Fraunhofer ENAS. Furthermore, one apprentice successfully completed her training in summer 2020. In cooperation with Chemnitz University of Technology and Paderborn University, students and young scientists have successfully defended their graduate theses.

By the end of 2020, Fraunhofer ENAS employed 45 interns, graduate students/master students and student aids, while during the year, more than 50 were employed. This employee base continues to prove itself as an excellent source for young scientists and technicians.

BOARD OF TRUSTEES

The board of trustees is an external advisory body attached to the institute. It consists of representatives fom science, industry, business, and public life. The members of the board of trustees are appointed by the Executive Board of Fraunhofer-Gesellschaft with the approval of the director of the institute. Their annual meetings are attended by at least one member of the Executive Board of the Fraunhofer-Gesellschaft. In 2020, Prof. Dr. Ralf B. Wehrspohn attended our hybrid meeting in his function as Executive Vice President for Technology Marketing and Business Models of the Fraunhofer-Gesellschaft.

In 2020, the members of the Fraunhofer ENAS board of trustees were:

We thank Dr. Wolfgang Buchholtz from GLOBALFOUNDRIES Dresden and Dr. Arbogast M. Grunau from Schaeffler Technologies, for supporting our institute as members of the advisory board until 2020. We also 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

The research and development portfolio of Fraunhofer ENAS is oriented along the whole value-added chain of smart systems starting from the idea, via design and technology development or realization based on established technologies up to tested prototypes as well as technology transfer. If standard components do not meet the requirements, Fraunhofer ENAS provides expert assistance in the realization of innovative and marketable solutions.

Interdisciplinary cooperation – key to success

Fraunhofer ENAS is an active member of different worldwide, European and regional industry-driven networks, starting from Semi and the Micromachine Center, via EPoSS – the European Technology Platform on Smart Systems Integration, Silicon Saxony and IVAM up to the Smart Systems Campus Chemnitz. Fraunhofer ENAS supports the establishment of the Smart Systems Hub in Saxony, which links the Saxon players in the key technologies – Hardware, Software, Connectivity. The full list is included in the attachment.

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 different branches and markets.

The most common way of cooperating with industrial partners is contract research. However, if the tasks and challenges are too complex, we offer pre-competitive research. In those cases, teaming up with companies and research institutes, while using public funding, is more effective than operating alone.

Fraunhofer ENAS has established a strategic network with research institutes and universities in Germany and worldwide. Long-term international partnerships exist with the Tohoku University in Sendai (Japan), the Fudan University in Shanghai (China) and the Shanghai Jiao Tong University (China).

RESEARCH AND DEVELOPMENT SERVICE PORTFOLIO

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

Smart Systems Campus Chemnitz.
Photo © Biermann und Jung

Fraunhofer ENAS and the Tohoku University have been cooperating in the field of new materials for microelectronic systems for many years and continued the Fraunhofer Project Center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University" which was established in 2012.The project center is not only a platform for joint research and development activities but also a joint platform for offering R&D services to industry.

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

Moreover, Fraunhofer ENAS works closely with the local universities, in particular with Chemnitz University of Technology and Paderborn University. The cooperation ensures synergies between the basic research conducted at the universities and the more application-oriented research at Fraunhofer ENAS.

The main cooperation partner at Chemnitz University of Technology is the Center for Microtechnologies at the Faculty of Electrical Engineering and Information Technology. The cooperation includes not only shared research projects but also a joint use of equipment, facilities and infrastructure.

www.zfm.tu-chemnitz.de

The department Advanced System Engineering, located in Paderborn, continues its close cooperation with Paderborn University particularly in the field of electromagnetic reliability and compatibility, wireless energy and data transmission technology, wireless sensors nodes for mechanical engineering and application-specific integration of AI methods.

www.uni-paderborn.de

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 Automobile Production Alliance, Fraunhofer Nanotechnology FNT and Fraunhofer Technical Textiles. Depending on the topic, Fraunhofer ENAS also participates in the Fraunhofer Clusters 3D Integration and Nanoanalytics.

www.forschungsfabrik-mikroelektronik.de

Together with the other institutes of the Fraunhofer Group for Microelectronics, Fraunhofer ENAS is part of the Research Fab Microelectronics Germany (FMD). This research network with 13 members and with more than 2000 scientists is the largest R&D association for micro- and nanoelectronics in Europe. The cross-institutional technology portfolio of FMD covers the areas of sensor systems, extended CMOS, microwave & terahertz, power electronics, MEMS actuators and optoelectronic systems. Due to its broad R&D portfolio, Fraunhofer ENAS is represented

in all six technology platforms as well as in the cross-technology and cross-sectional topic Advanced System Design. Furthermore, Fraunhofer ENAS contributes its expertise especially in the implementation of the cross-site Manufacturing Execution System MES.

Fraunhofer-Gesellschaft is tackling the current challenges facing German industry by putting a strategic focus on its lighthouse projects. These projects aim at exploiting the potential for synergies within Fraunhofer-Gesellschaft by bringing different Fraunhofer Institutes and their respective expertise together. Fraunhofer ENAS manages and coordinates the lighthouse project "Go Beyond 4.0", which was launched in December 2016, and also works in the lighthouse project "eHarsh". Both projects have been successfully finished in 2020.

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

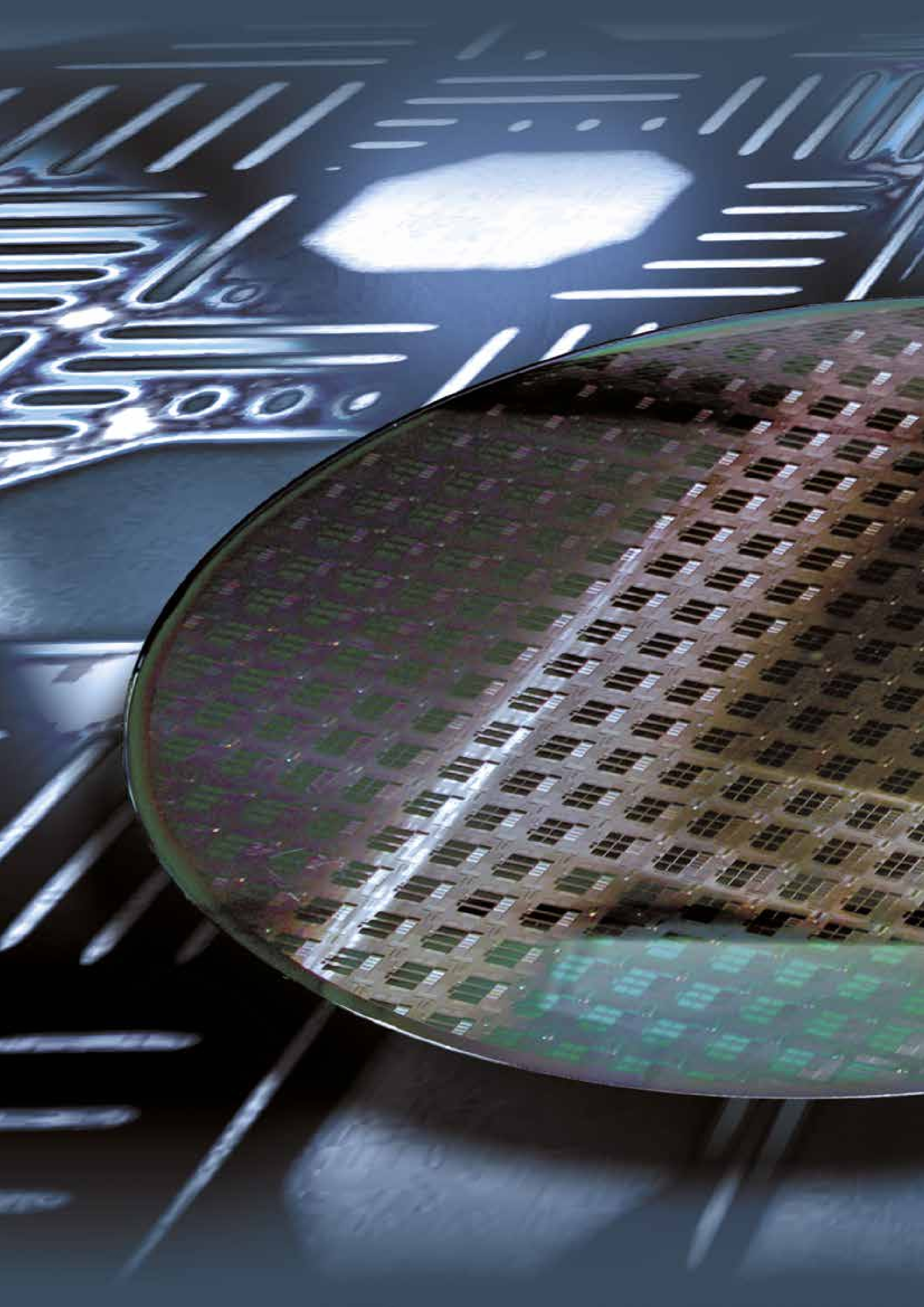
www.enas.fraunhofer.de/e-harsh

High-Performance Centers combine and link the competences of research institutes and universities within a certain region. Fraunhofer ENAS is working in two High-Performance Centers. The High-Performance Center "Smart Production and Materials" and "Functional Integration of Micro and Nanoelectronics". Within the High-Performance Center "Smart Production and Materials", Fraunhofer ENAS also actively participates at the Fraunhofer Academy program Smart Production Professional.

www.leistungszentrum-smart-production.de

www.leistungszentrum-mikronano.de

RESEARCH



MICRO AND NANOELECTRONICS

Micro and nanoelectronics is one of the key enabling technologies of the 21st century and is an enabler for digitization and all application sectors. The ongoing downscaling (More Moore), the integration of different functionalities (More than Moore) as well as the development of possible future technologies beyond the CMOS scaling limits (Beyond CMOS) are the ongoing development trends. The business unit micro and nanoelectronics is focusing on research and development services, wafer taxidermy services and technology transfer for the following topics:

Processes and technologies for micro and nanoelectronics with the focus on back-end of line and interconnects || The development of individual processes (deposition and structuring processes for metals and dielectrics including low-k dielectrics), full metallization modules (Al, Cu damascene, alternative materials including necessary diffusion barriers) and process and technology development for memristor crossbar arrays are the main focus of this topic.

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

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

Packaging and (heterogeneous) integration (2D, 2.5D, 3D) for electronic devices || This research and development area focuses on the development of processes for the integration of electronic devices for wafer thinning, TSV processes, wafer-level joining and contacting processes including surface preparation and printing processes for metallization and solder deposition. Another focus of development is the heterogeneous integration of both different substrate materials and wafer diameters on wafer level using TSV and wafer bonding technologies.

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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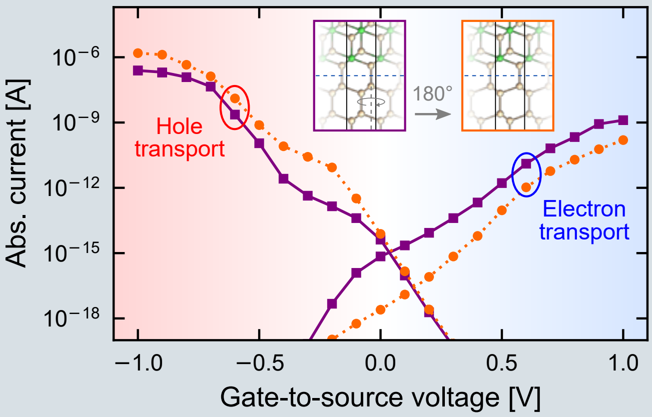
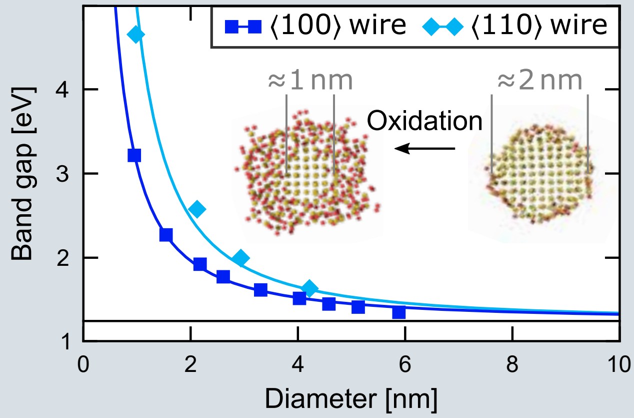
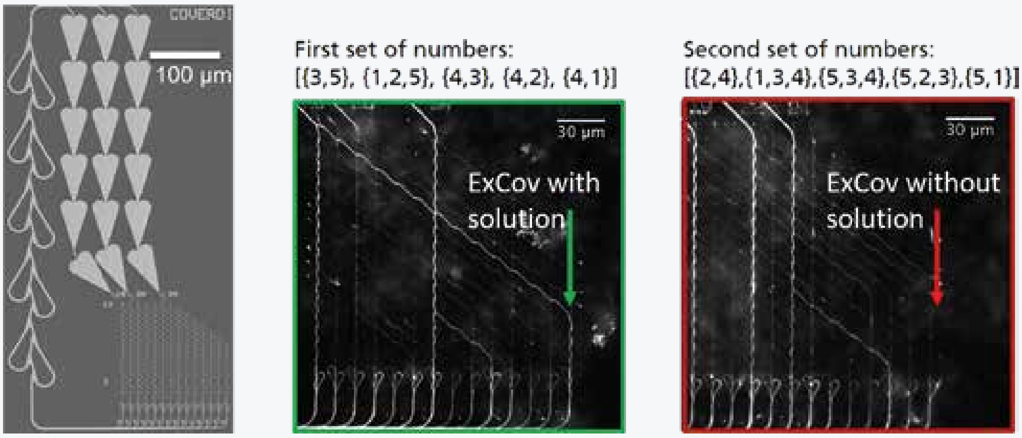


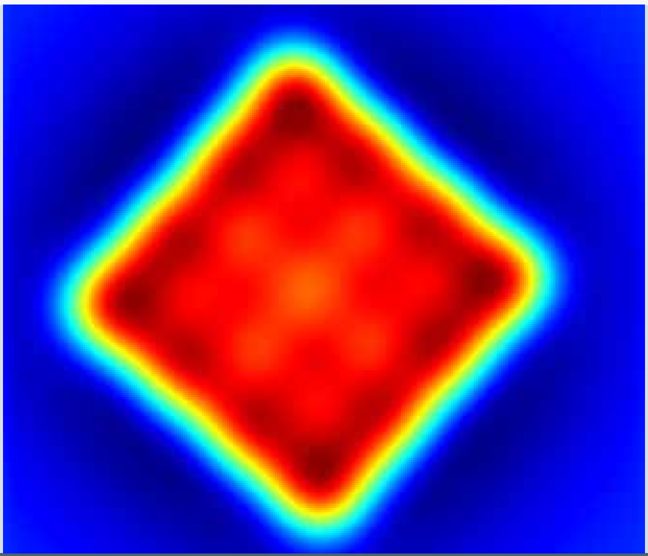
Transfer characteristics of silicon-based reconfigurable field-effect transistors with $NiSi_2$ contacts. Changes of the atomistic structure significantly change the symmetry between electron and hole currents.



Oxidation of nanowires leads to a reduction of the diameter, which leads to quantum confinement, which in turn increases the band gap.



ExCov network to find a combination of sets covering the integers {1,2,3,4,5}.



Measurement of a micromagnet array.

RESEARCH AND DEVELOPMENT

- **BEYOND CMOS AND RF DEVICES**
- **MODELING AND SIMULATION**

MICRO AND NANOELECTRONICS

SIMULATION MODELS FOR SILICON NANOWIRE FIELD-EFFECT TRANSISTORS

Silicon nanowires offer a promising and reliable way to build transistors with improved device performances. Using suitable contact materials, the fabrication of reconfigurable transistors becomes feasible. Such transistors can be reprogrammed to support either electron or hole currents, allowing more flexible circuit designs. The atomic structure of the contact interface and of the nanowire itself is becoming increasingly important to enable highly optimized devices.

To understand the relation between the atomic interface structure and the resulting transistor characteristics, a first-principles model based on density functional theory was developed. It was shown how different orientations and types of the $NiSi_2$-silicon interface result in a different symmetry between the on-currents in the electron or hole program. In case of {111} interfaces, for example, a rotation of the silicon part by 180° can change the on-currents by about one order of magnitude. The transport was related to fundamental material properties, for which one example is the Schottky barrier height at the contacts.

To engineer the properties of silicon nanowires and their contacts, the lattice can be mechanically strained by oxidizing the nanowire. Using molecular dynamics, we studied the resulting strain profiles as well as the reduction of the nanowire diameter. Quantum and surface effects become increasingly important for smaller diameters. These effects were studied using density functional theory. It was shown how the electronic transport properties differ between nanowire center and surface. Additionally, the increase of the band gap due to the decreasing diameter was calculated.

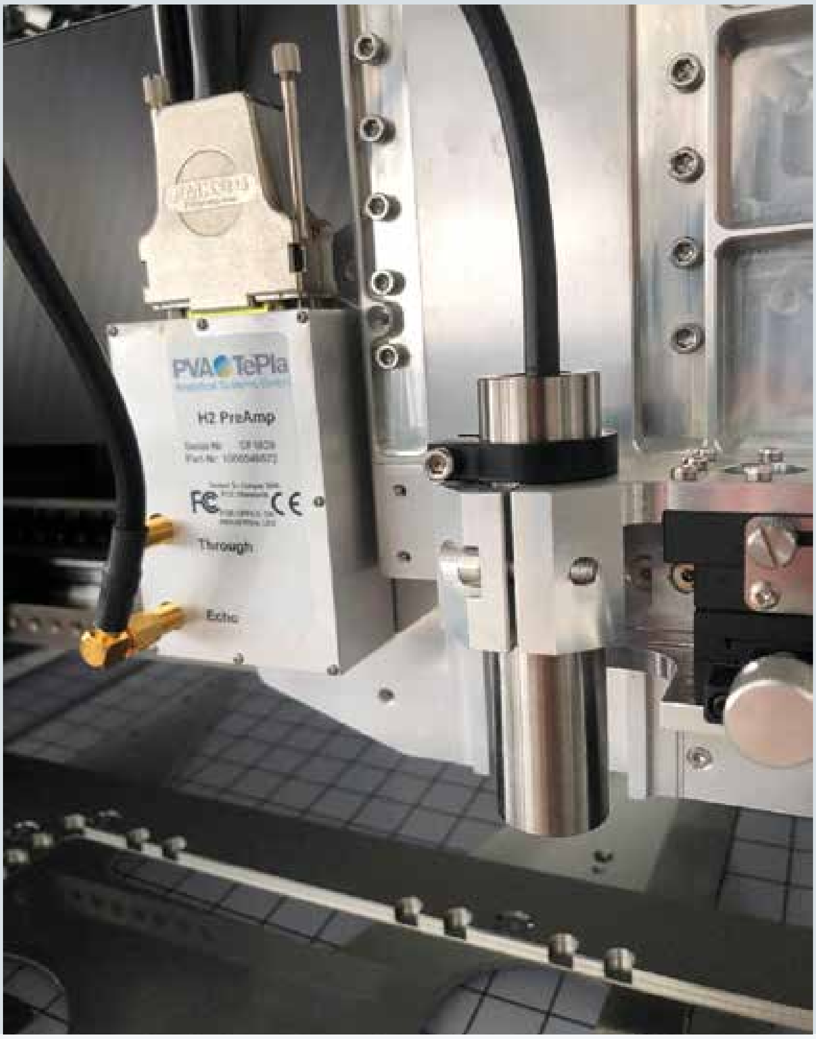
DEMONSTRATION ON THE FABRICATION OF BIOCOMPUTATIONAL DEVICES

The established nanofabrication technology for network-based biocomputation (NBC) was put forward to fabricate demonstrators for large-scale exact-cover (ExCov) networks and for devices that can solve satisfiability (SAT) problems. The nano patterning processes were improved and evaluated to achieve the requirements regarding reproducibility and biological functionality. The images shows ExCov devices for a power set of five numbers.

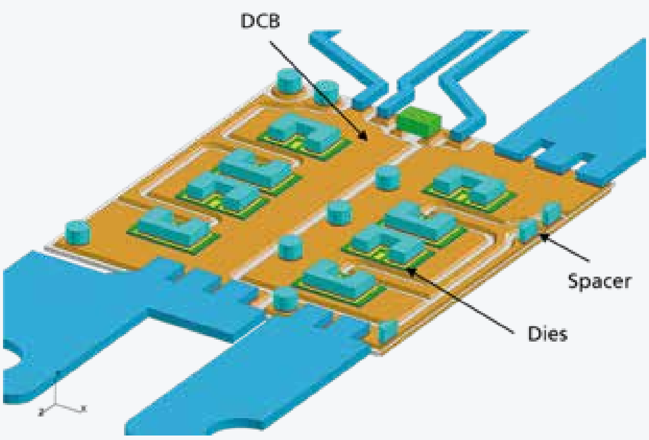
For the fabrication of SAT devices, two different network designs were used: a) "agent-encoded" for the kinesin-1-microtubule system in cooperation with TU Dresden and b) "space-encoded" for the actin-myosin system in cooperation with the University of Lund and the Linnaeus University Kalmar, both in Sweden. The "agent-encoded" network is compact and scalable. The required tagging was realized via laser bleaching of a barcode into the microtubules. The main achievement was to enable tagging of the microtubules on transparent substrates (e.g. glass, silica). The "space-encoded" network does not require agent tagging. Here, a novel encoding method was utilized by converting the decision problem into a unitary summation problem. For both biological systems, the operation of these devices was demonstrated.

AUTOMATIZED MEASUREMENT OF MICROMAGNETS ON WAFER-LEVEL IN CLOSE DISTANCE

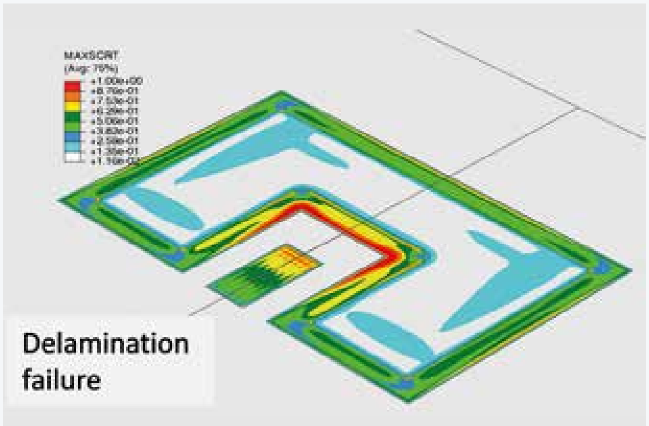
Nowadays miniaturization concerns various technological fields of applications. Recent developments on a novel powder-based MEMS manufacturing process enable the realization of micromagnets with a structural size of tenths of a micrometer. As characterization tools for such small magnetic structures are rare, Fraunhofer ENAS started to develop a high-precision measuring device for this purpose in collaboration with their colleagues of



Scanning Acoustic Microscope (SAM) Transducer.



FE-Model of molded SiC modules (mold compound not shown).



Critical regions at die-spacer interface derived by cohesive zone model.

RESEARCH AND DEVELOPMENT

- **PROCESSES AND TECHNOLOGIES FOR MICRO AND NANOELECTRONICS**
- **ELECTROMAGNETIC AND THERMOMECHANICAL CHARACTERIZATION AND RELIABILITY ASSESSMENT**

MICRO AND NANOELECTRONICS

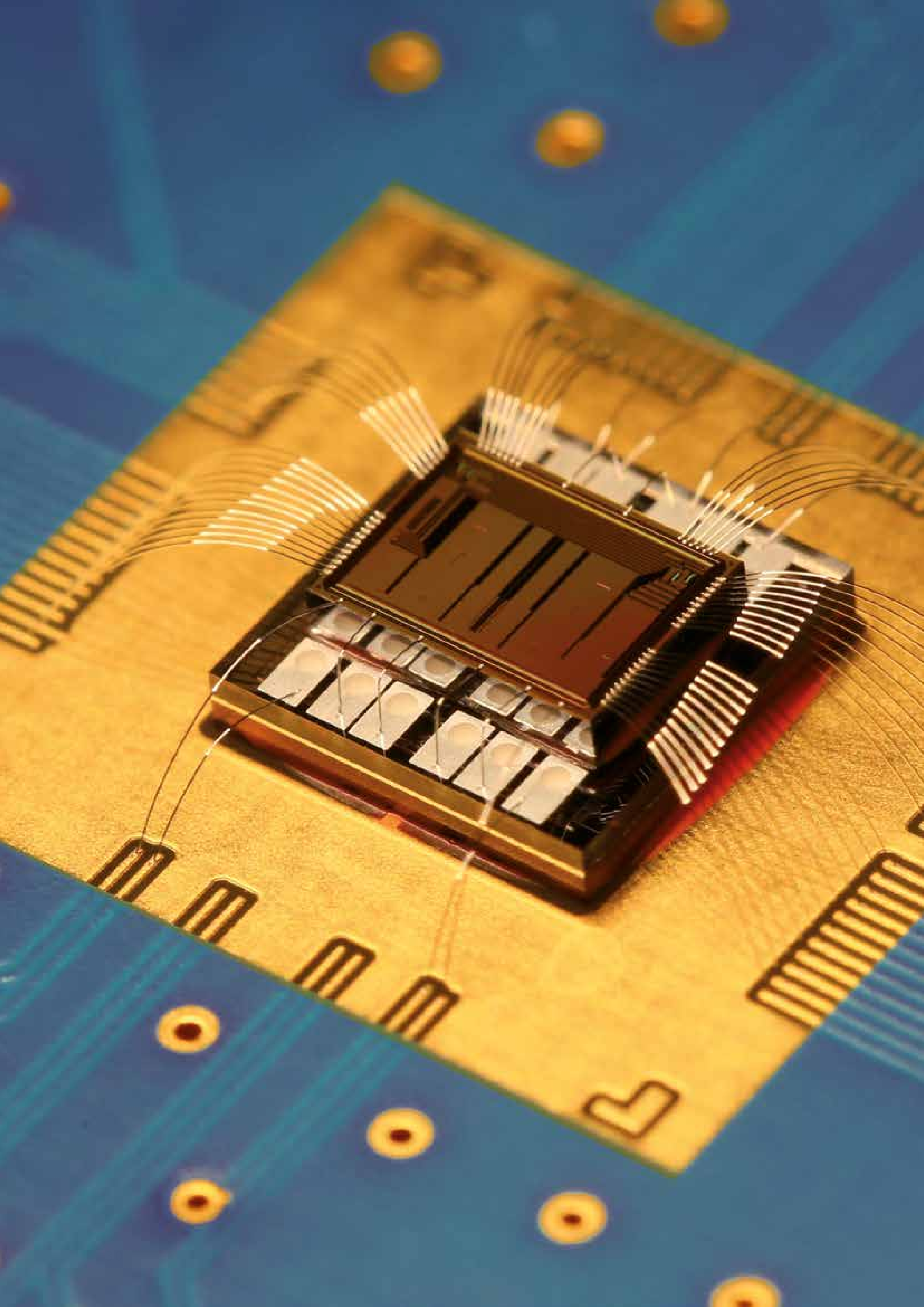
Fraunhofer ISIT. The basis of the development is a three-axis portal robot with a positioning accuracy of 1 µm in every direction, allowing to precisely navigate across the device-under-test (DUT). Using a 3D hall sensor with minimized package, the achievable vertical distance from the hall element to the DUT is approx. 110 µm. Moreover, a 3D scanning unit creates a heightmap of the DUT that enables a fully automated contour measurement of a whole wafer guaranteeing a constant distance to the surface at every measuring point. To further enhance the measurement results, appropriate postprocessing by deconvolution is used to filter the disturbing effect of the magnetic field spatial integration related to the hall sensor. The result is a detailed, clear view of the magnetic field strengths of micromagnets.

NEW POSSIBILITIES FOR LIFETIME TESTING

In order to address today's reliability challenges, a few invests were necessary at the Micro Material Center department. Thanks to the massive invest of the FMD (Research Fab Microelectronics Germany) in new production and characterization tools for the 13 partner institutes, we can now offer new very exciting lifetime evaluation methodologies to our customers. One of our latest developments was centered on a self-made active power-cycling test set-up (2 x 8 samples, max. 500 A), which is now back-up with a brand new test-bench from Siemens / Mentor Graphics (12 samples, max. 1800 A) that features thermal transient measurement with structure function analysis. This set-up allows for fast testing of larger batches of samples with the combined application of temperature while actively powering the components. Due to these machines new more accurate lifetime models were already established for GaN power modules and presented in the PhD work of Dr. Alexander Otto. While testing components is the essence of building a lifetime model, investigating the failure mechanism is also of the highest importance. This is why we invested, next to the already existing computed tomography, cross-section and optical microscopy, in a new Scanning Acoustic Microscope (SAM) which can accommodate samples from 200 µm up to 320 mm with an accuracy of 0,5 µm. The whole set is completed with a state of the art shear tester to test material properties like adhesion or wire bond lift off.

RELIABILITY OPTIMIZATION OF INNOVATIVE DESIGN TECHNIQUES OF POWER ELECTRONIC SYSTEMS

In power electronics the replacement of the traditional interconnecting technologies becomes in particular a necessity when new wide bandgap semiconductors are introduced to manage the challenges of increasing power density, reliabilty and cost.
A new interconnection technology based on wireless top side interconnects has been developed for compact inverter modules. Electrical connection is made by these structures, which provide additional heat spreading from top of the dies.
For the new interconnection technology, top side interconnects to the SiC semiconductors are made by metallic structured spacers to a leadframe. Parametric finite-element studies on the stress in dependence on spacer geometry and materials were made for temperature cycling. Different molding compounds were analyzed. Additionally, effects of different spacer attach solders with standard lead-free solder properties, highly creep resistant Innolot properties, and high-temperature solder HT1 with creep compliant behavior have been compared.
Chip pad fatigue failure was observed to be one dominant failure mode. The evaluataion of this failure mode by standard FE methods is limited due to high pads aspect ratios and strongly non-linear materials behavior, in particular the aluminum pads and solder layers. Cohesive zone modeling (CZM) has been introduced to have a comparable damage metric. The methodology allows for modeling of the interface strength as well as the damage progress. By combined electro-thermal-mechanical modeling the overall transient temperature and stress fields are finally linked to the effects studied on local level.



SENSOR AND ACTUATOR SYSTEMS

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

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

Optical systems/MOEMS || Optical systems/MOEMS are well-established silicon-based systems, i.e. variable frequency optical filters and shutters based on optical Bragg reflectors which are complemented by light sources and detectors. A new technology platform combines a multitude of optical components on a silicon chip for spectroscopic analyses. Furthermore, quantum dot-based LED and photo detectors enable customer specific spectral sensors, material integrated light sources as well as design and display devices.

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

Pressure and power transducer || The focus of research and development is put on silicon-based ultrasonic transducers, which utilize both electrostatic and capacitive as well as piezoelectric working principles and respective technologies. Furthermore, ambient pressure-sensitive resonators were developed. Novel power transducers based on integrated carbon nano tubes elicit a very sensitive piezo resistive detection.

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.

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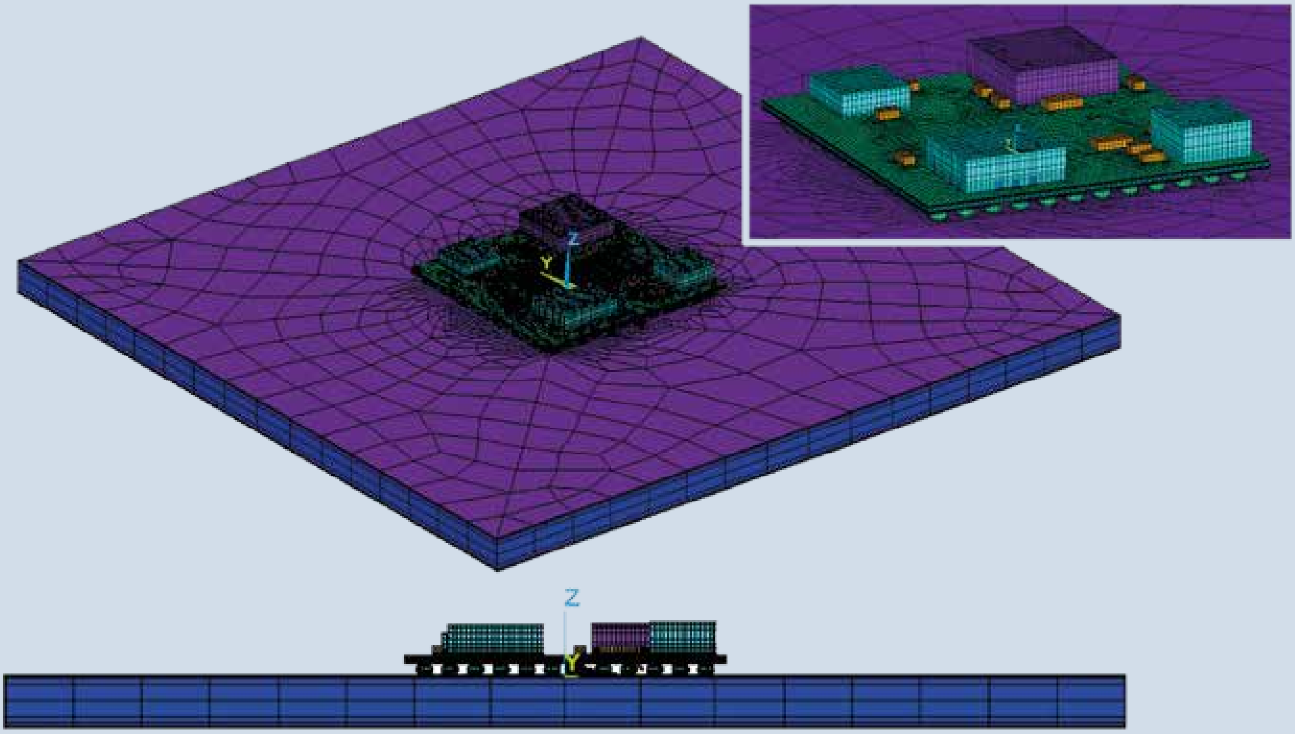
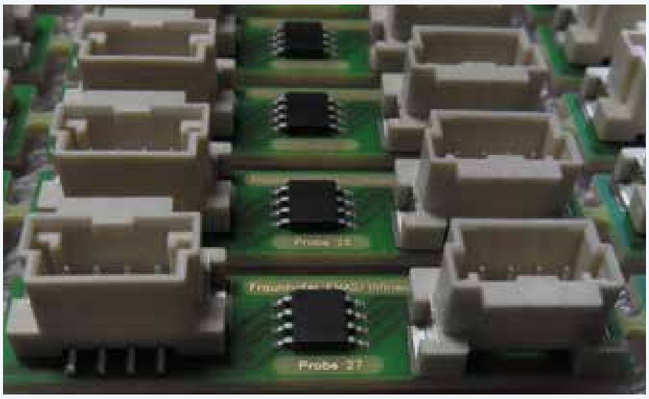
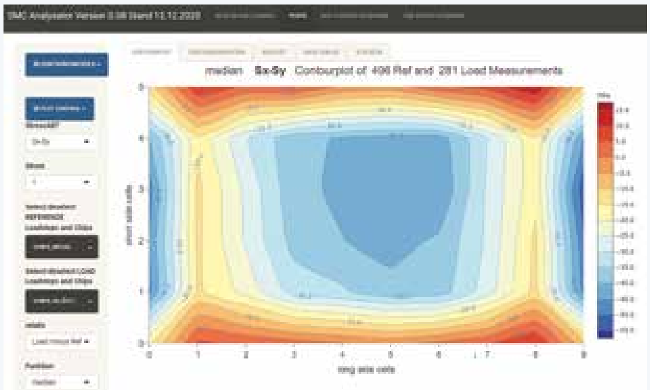


Finite element model of the USeP module with sensor assembly.



Stress chip package solders on the test PCBs.



Stress chip evaluation application (median difference stress of 50 chips).

RESEARCH AND DEVELOPMENT

- **SENSOR MODULES**
- **RELIABILITY**

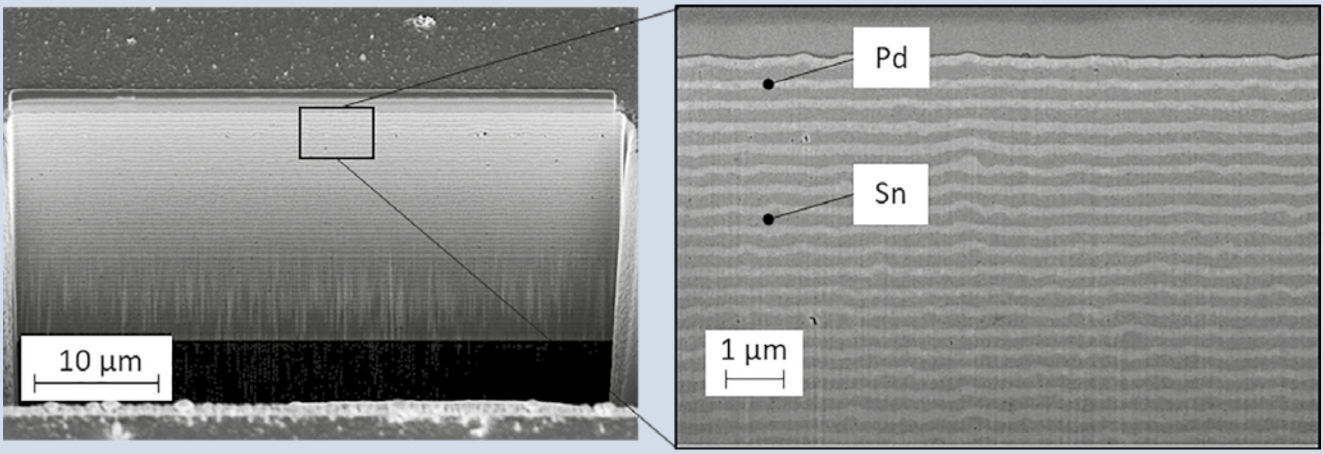
SENSOR AND ACTUATOR SYSTEMS

VIRTUAL PROTOTYPING FOR FAST DESIGN OF UNIVERSAL SENSOR PLATFORMS

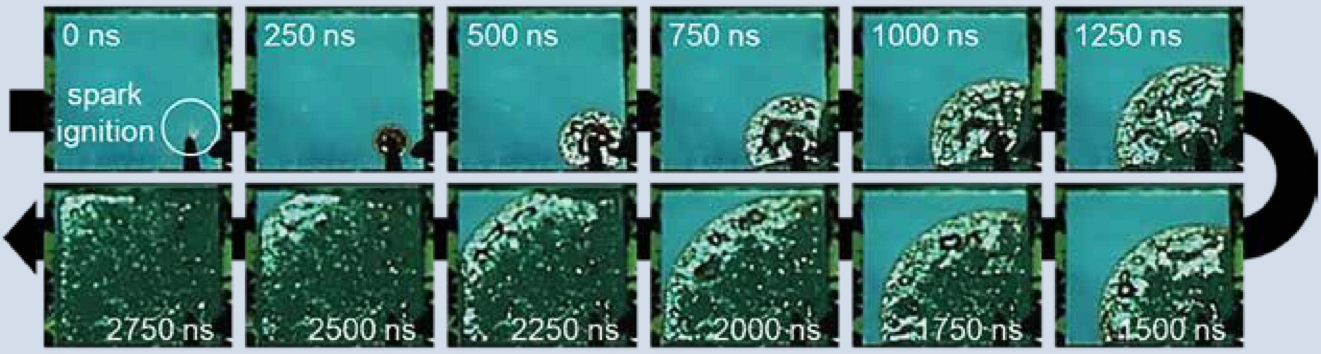
The advantages of virtual prototyping ensure that the process has a significant place in product development. For example, digital prototypes usually cost less than physical prototypes. The costs for 3D CAD systems and simulation programs have decreased in recent years, but they are still considerable for small and medium-sized enterprises. Through the SAB-funded USeP project, SMEs are given access to electronic solutions through innovative system architectures and manufacturing methods that allow them to remain competitive in the IoT market. The reliability of the assembly and connection technology is of central importance in the implementation of the desired design variations of the overall system configured by means of a modular system. The application of a "bottom-up" method enables reliability assessments to be made sequentially with increasing system complexity. The virtual prototyping method was used to ensure the thermal and thermomechanical reliability of the universal sensor platform. Based on parametric finite element models, the desired variations could be ensured through the modular approach. All levels of packaging components are integrated in a combined set of models which enable the system to react quickly to model changes, towards further current and future SiP products based on FOWLP. The simulation schemes developed in the USeP project will enable SMEs to take advantage of virtual prototyping.

ON-LINE STRESS MEASUREMENT DURING MANUFACTURING AND IN FIELD-TESTING WITH THE STRESS CHIP

A FEM simulation is a well-established method to investigate the reliability of an IC package. The results can predict warpage, residual stresses or remaining lifetime of packages. Nevertheless, these FEM models are always an ideal form without any production tolerances, misalignments or other failures. Many time-consuming tests have to be done to identify, investigate and minimize these statistical realities. The biggest challenge for health monitoring is to find a monitor structure with a strong physics of failure connection. Measuring the current or the temperature inside an electrical package is the simplest way. However, the changes of these values are very weak and late in the behavior of a physical failure. The stress chip can measure little setups and material variations directly without destroying the package. All package components and their production technologies have an impact on the residual stress state of the package. The residual stress is measured at important production steps (naked, die-attach, molding, soldering on a PCB). Finally, a temperature-cycling test with in situ stress measurement is prepared. With newly programmed software it is possible to compare all packages at any stress state. The different cycling behavior of the different packages combined with modern AI evaluation technics will be investigated. Since the residual stresses can be measured directly, new package materials or processes can be qualified more quickly. The gained thermomechanical behavior of packages can also be used for health monitoring.



Cross section of an electroplated Pd/Sn multilayer stack on a silicon substrate.



Self-propagating exothermic reaction in a Pd/Sn multilayer stack.

Gyrocompass.

RESEARCH AND DEVELOPMENT

- INERTIAL SENSORS
- PACKAGING

SENSOR AND ACTUATOR SYSTEMS

ELECTROCHEMICAL DEPOSITION OF INTEGRATED REACTIVE PD/SN MULTILAYER SYSTEMS

The reduction of process temperatures is essential for the integration of heterogeneous materials. For more than 10 years, Fraunhofer ENAS develops integrated reactive material systems (iRMS) as internal heat source for bonding applications on wafer, chip and component level. The energy stored in the reactive multilayer stacks is released upon ignition. The resulting self-propagating exothermic reaction generates the heat directly at the bonding interface. Within the public funded project ElisA, electroplated Pd/Sn multilayer system are being developed as an alternative to sputtered reactive systems. The electroplated multilayer system are deposited in a dual bath technology, enabling the stacking of reactive multilayers directly on standard substrates such as silicon and glass as well as printed circuit boards and ceramic substrates. The reactive layers grow directly on the printed base metallization of the printed circuit boards or ceramics. The thickness of the reactive multilayers varies between 20 µm and 50 µm depending on the substrate and premetallization. Applying a local ignition impulse (short electric spark), the exothermic reaction in the Pd/Sn multilayer stack propagates with a maximum velocity of 5.7 m/s and the metallization of the bond partners melt. The bonding technology enables the encapsulation of temperature-sensitive components without external heat input within fractions of a second. It can be applied for printed circuit boards as well as ceramics. Even pre-assembled components on the printed circuit boards are not affected by any subsequent thermal load.

GYROCOMPASS: THE USE OF A FULLY INTEGRATED PRECISION MEMS GYROSCOPE IN A STANDALONE NORTH-FINDER

North-finders based on gyroscopes are commonly used because of their robustness against local Earth magnetic field distortion and independence of electromagnetic transmission. The high resolution and precision needed for this task is currently only achieved by optical gyroscopes or hemispherical resonator gyroscopes. To show that much less expensive and smaller state-of-the-art MEMS gyroscopes are capable of being used in such a device, Fraunhofer ENAS designed an easy-to-use, compact, transportable, standalone north-finder based on one MEMS gyroscope. The in-house developed, fully integrated tuning fork MEMS gyroscope offers low enough noise and drift to determine north heading down to 1 degree of deviation in less than 10 minutes at a latitude of 50.8 degrees (Chemnitz, Germany) without additional signal conversion electronics. This is possible because of the constantly improved full-silicon BDRIE-technology and specific MEMS-ASIC-co-design as further developed in the KoliBriS-project. Moreover, the implemented Maytagging algorithm allows the use of inexpensive consumer electronics, for example a standard stepper motor and STM microcontrollers. The measurement routine is fully controlled by the microcontroller, which also collects the angular rate data and determines the north direction by phase fitting. The power consumption stays below 4 W for the complete measurement cycle. After finishing the routine, the Gyrocompass points in the determined north direction. This can be used for example to align equipment in buildings that requires a specific orientation to the Earth's rotational axis.

Spectrometer components on SOI wafer (infrared sources, waveguides, filters and couplers).

Measurement setup for optical characterization of wafer-level spectrometer components.

Laser defined magnetic contrast from a 5 nm thick CoFeB film on the basis of the exchange bias effect. The logo is visible in a limited magnetic field range only, here H=15 mT was applied.

RESEARCH AND DEVELOPMENT

- **OPTICAL COMPONENTS / MOEMS**
- **ELECTROMAGNETIC SENSORS**

SENSOR AND ACTUATOR SYSTEMS

PLATFORM FOR CHIP-INTEGRATED OPTICAL IR COMPONENTS

A miniaturized, modular spectrometer system that combines a large number of individual optical and micromechanical components on a silicon chip and thus opens up spectroscopic technologies for mass applications is being developed in the two projects ESAIRQ and PHiPMEMs. The projects are each looking at different individual components, which can be combined at chip level to form diverse spectrometer systems. This has the advantage that the complexity of the system only affects the design, but not the technology sequence. Fabrication in a near-surface microtechnology allows guidance and modulation of infrared radiation at the chip level. Thus, a high degree of miniaturization and complexity of the overall system is achievable.

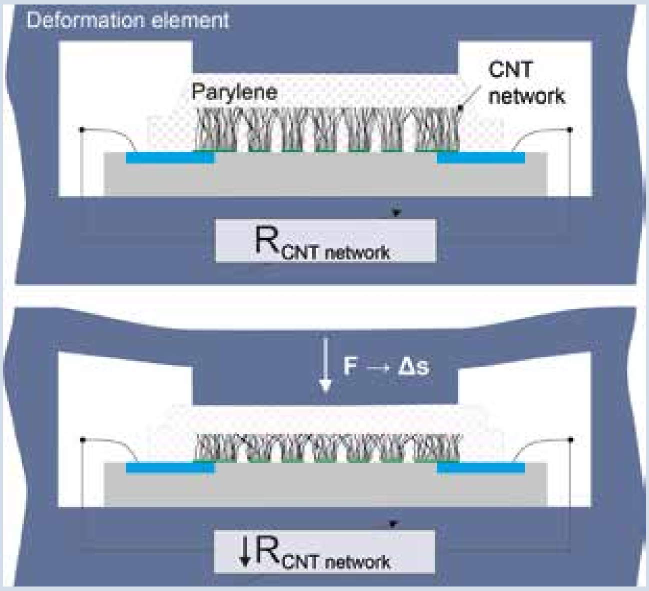
In the ESAIRQ project, infrared radiation sources, Fabry-Pérot filters and optical grating couplers are being developed. The PHiPMEMs project focuses on digital MEMS actuators for the variation of optical properties, such as filter wavelengths, and on integrated cavity resonators.

To characterize the spectrometer components on the chip, a new measurement setup was built, consisting of a wafer probe station with controllable fiber holders to couple the optical structures on the wafer.

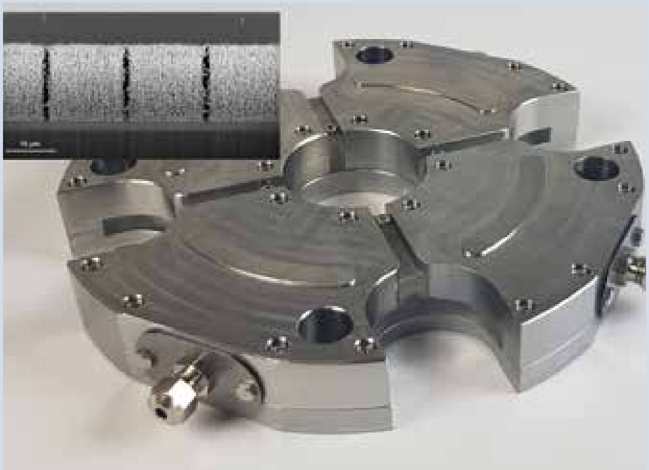
The development of a miniaturized, low-cost spectrometer enables the use of spectroscopic technology in many areas of daily life, such as analyzing food with a smartphone or monitoring air quality in buildings or in road traffic.

SPINTRONICS: LASER ANNEALING FOR LOCAL CRYSTALLIZATION OF TMR SENSORS

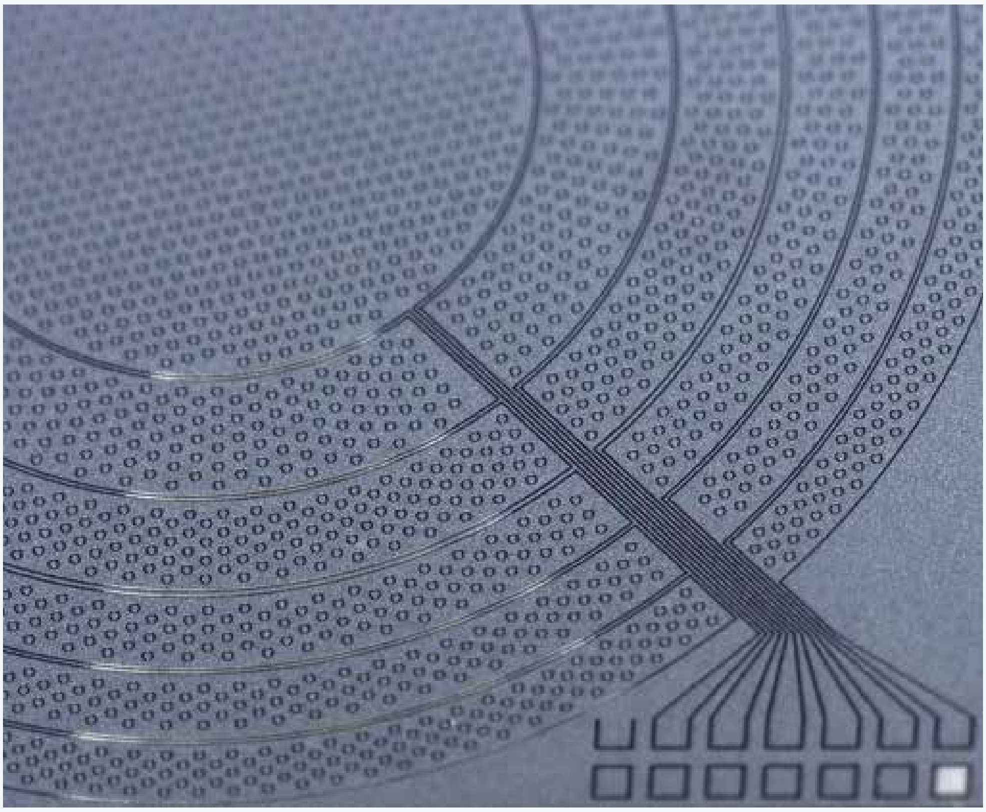
The performance of magnetic field sensors based on spintronic effects, particularly the "giant magnetoresistance" (GMR) and "tunneling magnetoresistance" (TMR) effects, causes a continuous growth of their market volume. TMR-based systems, which have been in the focus at Fraunhofer ENAS for the past few years, provide a significantly higher sensitivity, smaller dimensions and better energy efficiency, representing a promising technology for the next generation of sensors also in the automotive and industrial sector. In the case of CoFeB/MgO-based sensor elements, a maximum TMR signal is dependent on an annealing step, which is necessary for particular crystallization, as well as setting a reference magnetization in the thin-film system. Especially the temperature requirements for the crystallization of CoFeB are often challenging for their integration in smart systems or on flexible substrates, since this step typically takes place by vacuum oven annealing in the presence of an external magnetic field. Alternatively, this annealing process can be performed by laser irradiation, which allows a locally resolved magnetic patterning of the sensors and thereby a monolithic integration of multidimensional sensors, too. Recently, the successful crystallization of CoFeB thin-film systems by local laser annealing at dwell times in the µs-range has been demonstrated, which further develops potential for the implementation of highly sensitive TMR elements in architectures with special temperature requirements. This allows to considerably expand the scope of application by a more versatile integration of the spintronic technology into smart systems.



Sensor principle of the CNT-based force sensor.



Load cell with four sensor cells for process monitoring as well as a SEM cross section image of the CNT network embedded in parylene developed in cooperation with Fraunhofer IWU.



Fabricated and diced silicon-based piezoelectric micromachined ultrasonic transducer with radial symmetric array.

RESEARCH AND DEVELOPMENT

▪ PRESSURE AND POWER TRANSDUCERS

SENSOR AND ACTUATOR SYSTEMS

CNT-BASED FORCE SENSORS: PROCESS MONITORING IN FORMING TOOLS

For the precise process monitoring of cutting and forming processes, a vicinity of the sensor system to the working point is necessary to determine the real forces in machine tools. This vicinity to the working point requires a high sensitivity of the sensors to obtain a high stiffness of the sensor environment. A too large stiffness loss due to the integrated sensors would lead to an accuracy decrease of the components and to a degradation of dynamic properties of tools and machines.

To satisfy these requirements a novel force sensor was developed. The sensor principle is based on a network of vertically aligned carbon nanotubes (CNTs) whose electrical resistance can be altered by compression.

For realizing a load cell, CVD-grown CNT structures were arranged as resistors in a Wheatstone bridge configuration and integrated in a deformation element. For process monitoring, a sensor cell with four testing points in a circular arrangement was developed. Following results could be obtained from testing the load cell in a press test stand:

- For normalized load until nominal load, a sensitivity up to 75 mV/V could be achieved. This is 35 times higher as it is the case for standard metallic strain gauges with 2 mV/V sensitivity.
- The deformation element has a stiffness of 8 kN/µm. Comparable commercial available force sensors with nominal load between 1 and 5 kN have a stiffness from 0.05 to 0.2 kN/µm. Therefore, the stiffness of the CNT sensors is one to two orders of magnitude higher.

ALUMINUM NITRIDE PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCERS

Ultrasonic devices with a high working frequency can achieve a high resolution. These devices allow precise imaging applications such as fingerprint sensors or medical imaging of tissues. A radial sensor array enables future beam steering applications. Focusable ultrasonic devices allow high acoustic energy on a small area with high resolution. Consequently, a very good signal-to-noise ratio and a high resolution can be achieved. Furthermore, acoustic manipulation can be realized, e.g. heating of tissue for medical treatment or single micro and nano particle transport and activation. Additionally, the miniaturization of the micro technologies allows new applications, such as endoscopic medical treatments and low-cost integration in consumer, automotive and industrial devices. Piezoelectric micromachined ultrasonic transducers (PMUTs) can be designed to be very small with very high working frequencies. Therefore, PMUTs have advantages compared to bulk technology ultrasonic transducers. Additionally, the arrangement of the single ultrasonic elements by micro technology has a large degree of freedom. For example, the array design is not limited by linear dicing lines, which are commonly used for bulk ultrasonic transducers. Fraunhofer ENAS in cooperation with the Center for Microtechnologies of Chemnitz University of Technology developed a new design for radial focusable PMUTs with high frequencies in the MHz range. The aluminum nitride (AlN) based technology allows the more than 4000 membranes to perform with high deflections. Due to the very homogeneous manufacturing processes, the technology tolerances could be minimized, which means that the more than 4000 individual structures can be reliably controlled in parallel.

Photo © pixabay

TECHNOLOGIES AND SYSTEMS FOR

SMART POWER AND MOBILITY

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

As before, the reliability of the equipment and assemblies in both areas plays an immense role for the security of supply and availability with regard to the average failure frequency and duration. We consider predictive maintenance and design for reliability as two essential methods of effectively counteracting possible failures in advance.

Fraunhofer ENAS continuously develops sensor technology for monitoring equipment and is active in testing of such sensor systems in application scenarios together with energy suppliers. In the last two years, the focus was put on the monitoring of medium-voltage systems. Radio-based multi-sensor systems for cable connectors and connection points in switchgears and transformers with maintenance-free and battery-free sensors have been developed. The data is transmitted via a LoRa data network so that developing degradations can be detected in advance of failures and appropriate maintenance can be carried out. In the following, this system is reported, which was developed and tested in cooperation with the South Korean energy supplier KEPCO and the research facility Korea Electric Power Corporation Research Institute (KEPRI).

A solid knowledge of the physical relationships between degradation and failure mechanisms is necessary for the Design for Reliability. The use of new materials such as SiC for power semiconductors and the use of new assembly and connection technologies require continuous research into the relationships and development of methods for analysis and design with regard to thermo-mechanical reliability and electromagnetic compatibility. Modeling and simulations as well as extensive experimental validation are in the focus. Articles on the following pages report on aspects of this work with regard to semiconductor power modules for motor control and the integration of special test structures for establishing prognostics and health management.

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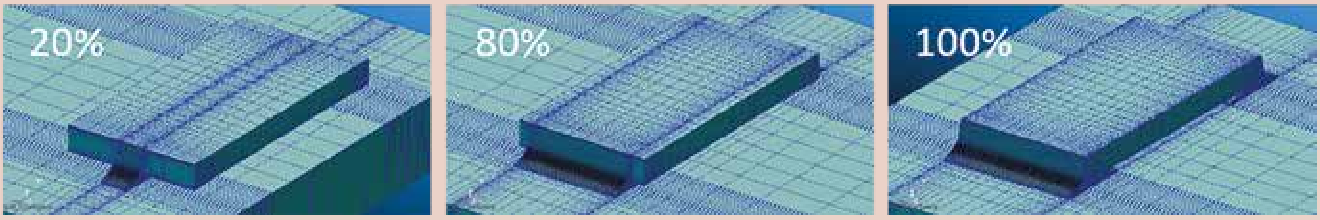
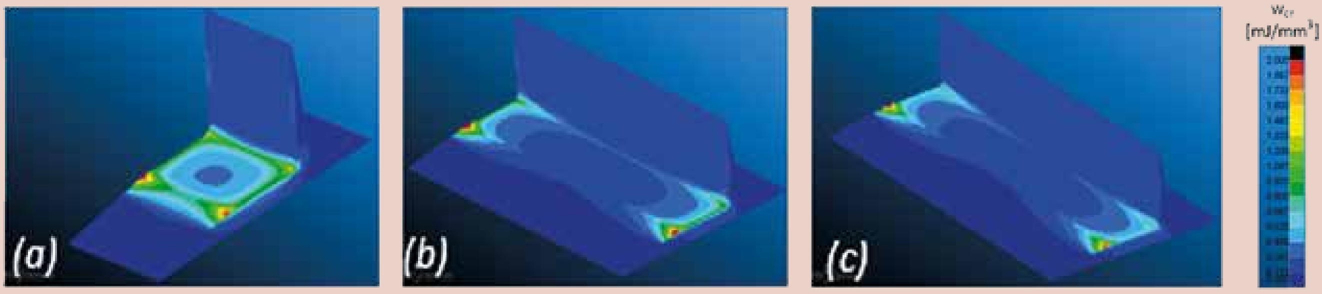
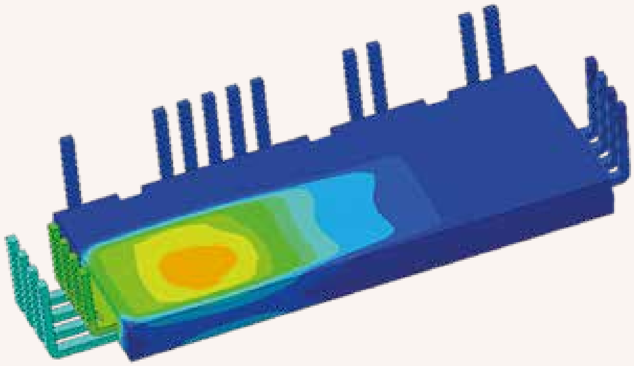


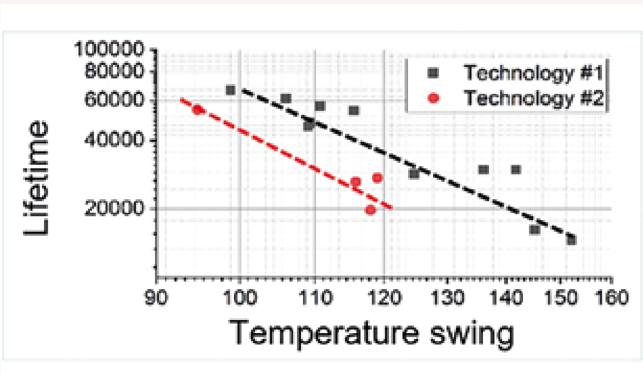
Geometry models of SMD resistors with reduced solder width.



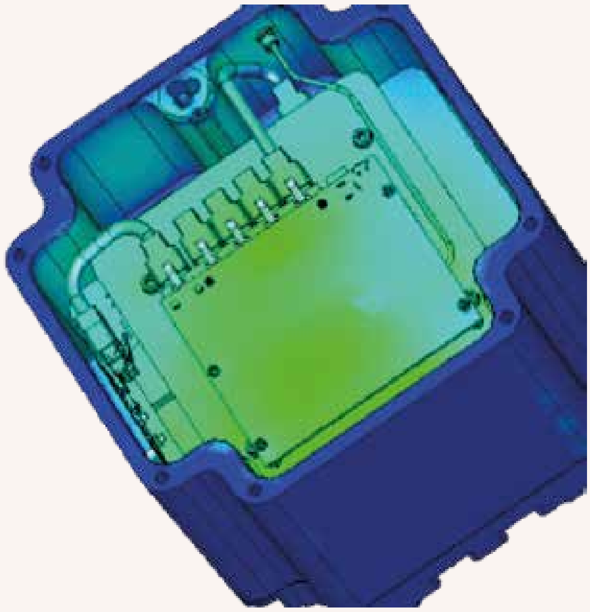
Distribution of accumulated creep energy density during passive thermal cycling.



Simulated temperature distribution in a SiC-based power module during active cycling.



Lifetime curves for different power module designs investigated within the project CosmoDU.



Simulation of a field distribution using nearfield data as a source.

RESEARCH AND DEVELOPMENT

- **RELIABILITY**
- **PROGNOSTIC HEALTH MONITORING**

TECHNOLOGIES AND SYSTEMS FOR
SMART POWER AND MOBILITY

CANARY STRUCTURES BASED ON SMD DEVICES WITH REDUCED SOLDER WIDTHS FOR PHM

Canary structures being used as early warning indicators represent an important tool for condition and health monitoring of electronic components and systems in the context of Prognostics and Health Management (PHM). For this purpose, printed circuit boards with canary structures based on SMD 2512 ceramic chip resistors with reduced solder pad sizes (20 % and 80 %) were studied within the European project EVC1000. Focus of these investigations was set on thermo-mechanical and mechanical stresses caused by thermal cycling as well as by vibrational loads. They included temperature-dependent out-of-plane and in-plane deformation measurements, end-of-life stress tests as well as finite element simulations. Based on these studies, a fundamental understanding of the lifetime in dependency of the solder pad geometry is now available. In the next step, this can be employed in order to further develop the methodology for implementing such canary structures into different applications. As example case, health monitoring of a dual inverter electronic control unit (ECU) boards for electrical powertrain applications is currently being investigated.

HIGHLY INTEGRATED INDUSTRIAL MOTOR DRIVE WITH SELF-LEARNING CAPABILITIES AND EMC-COMPLIANT DESIGN

Within the recently completed PENTA project CosmoDU, a modular hardware architecture for industrial motor drives was successfully developed together with several European partners. The architecture enables full integration of the inverter and the sensors for health monitoring and drive performance optimization based on self-learning. All information are shared throughout the motor and with the higher system layers using a standard for data exchange (OPC UA), which provides a scalable and manufacturer independent way to disclose information toward the higher layers of the control and monitoring system. Fraunhofer ENAS was responsible for assessing and improving the reliability within the motor drive integrated SiC-based power modules that were developed within the project and based on novel cooling and interconnection technologies. For this purpose, experimental investigations, incl. active power cycling tests and temperature-dependent deformation measurements, were conducted in conjunction with finite element studies in order to assess their thermo-mechanical reliability under passive and active thermal loads. The gained results are now available for the reliability evaluation of SiC-based power assemblies in future projects and cooperation.
One novelty is that all electronic components needed for the smartification of the motor are integrated into a single housing. This situation leads to a dense electromagnetic field concentration and a wide disturbing spectrum. To face occurring EMC challenges, the technique of nearfield (NF) scanning can be used. The results of a NF scan are used in two ways. First, the EMC sources can be revealed by a NF scan to fix any issue. Second, NF scanning can be combined with subsequent simulations using the NF results as a source. Merged with CAD models of further components and housings, the field radiation into other areas caused by high-frequency components can be investigated and characterized before physically integrating all components together. With this yet emerging combination of NF measurement and simulation, EMC issues can be avoided before they cause trouble after the assembly of electronic components.

Wind tunnel model equipped with actuators at DNW Braunschweig. (photo © 2021 Niko Bier, DLR)

Outlets of the integrated fluidic actuators in a 2.5D model of a wind turbine rotor blade. (photo © 2021 Fraunhofer ENAS)

Prototype mounted at cable joint in lab.

Installation of sensors at elbow connectors in ground switchgear.

RESEARCH AND DEVELOPMENT

- **IMPROVEMENT OF AERODYNAMIC CONDITIONS**
- **NETWORK MONITORING IN THE TRANSPORT OF ELECTRICAL ENERGY**

TECHNOLOGIES AND SYSTEMS FOR
SMART POWER AND MOBILITY

IMPROVED WIND HARVESTING CAPABILITY BY USING ACTIVE FLOW CONTROL

The joint project TOpWind dealt with the "Technological and economical consideration of the application of active flow control to optimize the wind harvesting capability of wind turbines". Five industrial partners and two research institutes as well as four Fraunhofer institutes participated in the development of concepts for actively controlling the airflow on rotor blades of wind turbines. The consortium covered all necessary research areas: aerodynamic simulations, development of the actuator system including electronics and its integration, aerodynamic and aero acoustic tests as well as the ecological and economical evaluation of the overall system.
Fraunhofer ENAS focused on the development of the fluidic actuators, so-called synthetic jet actuators, which generate a pulsed and directed airflow to influence the airflow over the rotor blade. The challenges were the optimization of the actuator system in terms of performance, reduction of noise emission and robustness for a large number of load cycles. Final tests of the overall system have been performed in December 2020. Compared to the basic configuration, a significant improvement in the lift coefficient of up to 10 % was achieved. Beside this, the acoustic noise emission was reduced by 20 dB and the reliability of the actuators was significantly improved. In perspective, the yields of wind turbines can be improved in various scenarios. This will not only increase the amount of produced energy and reduce their costs during operation, but also reduce the environmental impact and optimize the carbon footprint.

CABLE JOINT MONITORING SYSTEM

Most error-prone parts of a cable-based power grids are the cable joints and connectors. Partial discharge (PD) currents lead to degradation, heat generation and ground faults as a consequence. These errors usually result in extremely high short circuit currents, and finally destroy the cable connection. With a thermal imaging camera, the joints can be checked very reliably. However, this is very time consuming and expensive. With the help of a real-time monitoring system, faults in the cable connections can be detected at an early stage, appropriate maintenance work can be carried out and blackouts avoided.
Therefore, Fraunhofer ENAS developed together with an international grid operator a flexible, easily mountable, small-sized, self-sufficient multi sensor wireless monitoring system for medium voltage cable joints. The sensor nodes themselves consist of a wireless communication module, a power conversion module, and various sensors for detecting e.g. PD, over-temperature and external impacts like vibrations or shocks. The developed system is featured by an impressive flexibility, small size and small weight. It can be fitted easily around all common power cables with shielding and cable joints. Even the current induction energy harvester has a flexible design. From a current flow of around 15 amperes, the radio electronics and sensor technology is supplied with sufficient energy. The whole sensor node including radio, sensors and energy harvester is designed for and practically tested in a wide operating temperature range from -40 °C to +110 °C. The system is currently undergoing extensive field testing in a switchgear in a 22.9 kV distribution grid.

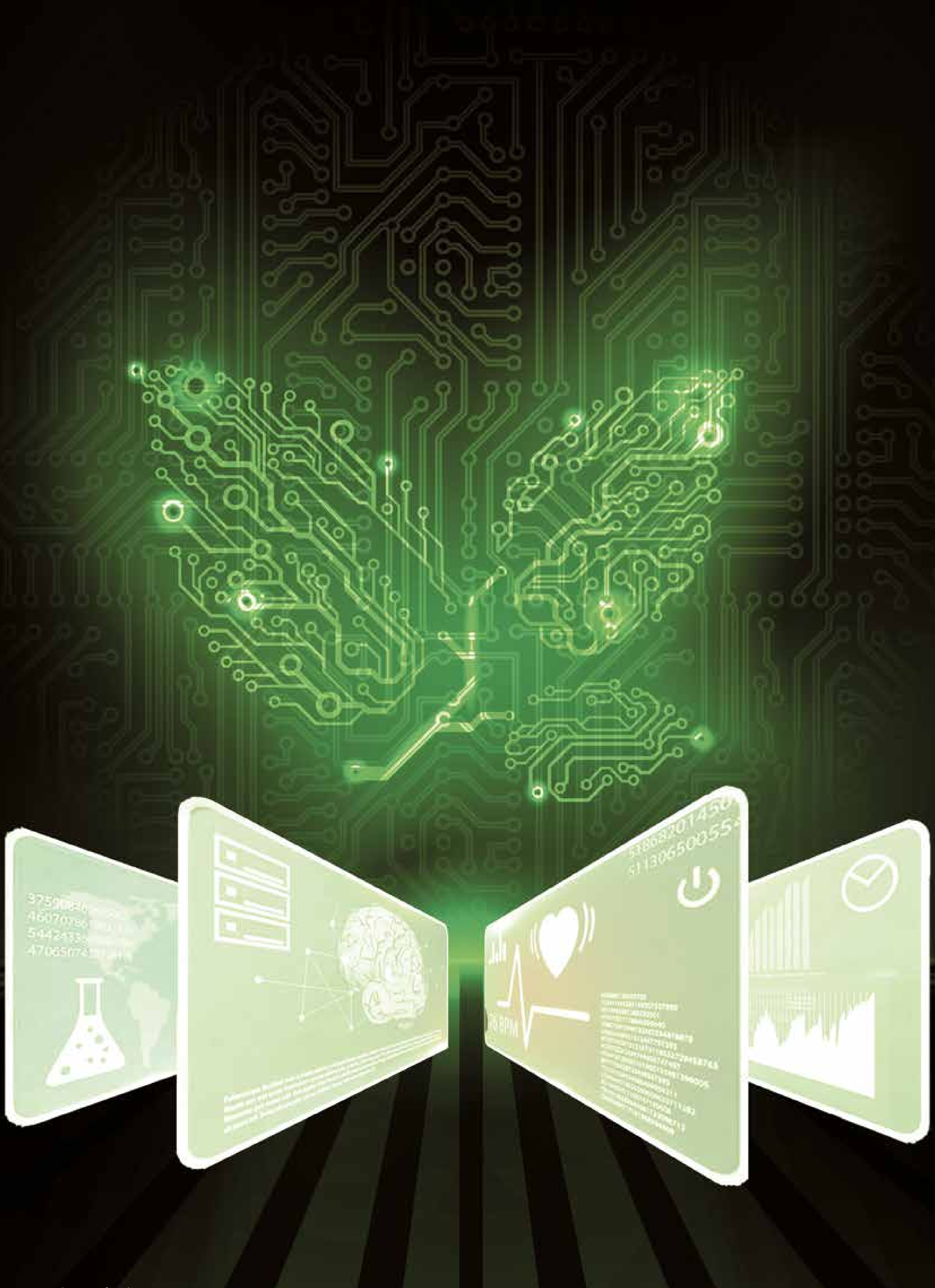


Photo © fotolia

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. In addition to human health aspects, we also consider animal health, plant health and agricultural and forestry issues. Our research is focused on the technical and technological aspects, especially in using micro and nanotechnologies for applications in the service of medical science, biology and healthy living. Medical expertise is achieved via cooperation with partners, consultants and external experts in- and outside of Fraunhofer-Gesellschaft.

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

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

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

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

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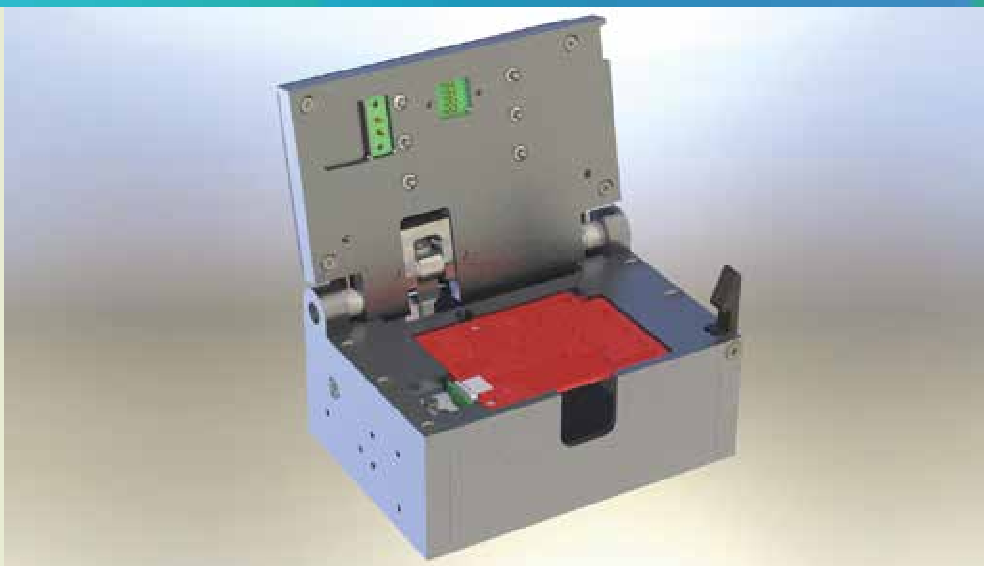
#WeKnowHow

FRAUNHOFER VS. CORONA



3D model of the measurement setup for the microfluidic cartridge (red) for the project CovMoTe.

Hyperspectral camera system with Vision-System-on-Chip (VSoC) image sensor and a tunable Fabry-Pérot filter developed by Fraunhofer ENAS. (Photo © Fraunhofer IIS/EAS)

RESEARCH AND DEVELOPMENT

- MEASUREMENT AND ANALYTIC SYSTEMS
- MEDICAL DEVICE

TECHNOLOGIES AND SYSTEMS FOR

SMART HEALTH

FRAUNHOFER VERSUS CORONA

The year 2020 was characterized by many exceptional situations created by the Covid-19 pandemic. In addition to the everyday and personal influences on all our lives, certain patient groups were at high to life-threatening risk. In order to be able to help quickly and effectively, the Fraunhofer-Gesellschaft set up a short-term and rapid funding program "Fraunhofer vs. Corona", in which the best ideas for combating the effects of the pandemic could be implemented in the form of research projects in all sectors at the institutes. The Fraunhofer-Gesellschaft provided a total of more than 40 million euros for this purpose. Currently, the program is in its second phase, which focuses on strategic projects to fight the pandemic and to position the Fraunhofer-Gesellschaft in terms of research policy.
The scientists of Fraunhofer ENAS are involved in a total of three projects and cooperation projects based on essential core competencies of the institute:

CovMoTe

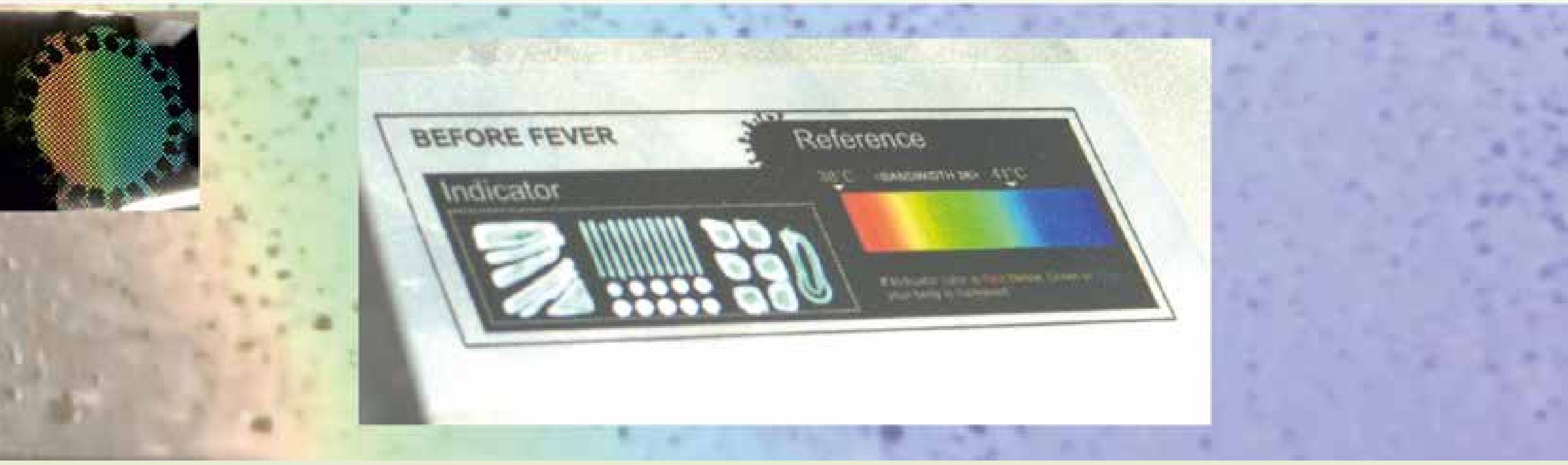
In 2020, the outbreak of Covid-19 made an unforeseen economic and social impact. Rapid testing was quickly identified as a major tool for the monitoring and control of the spread of the virus. Nevertheless, the partially poor performance of first antibody tests also showed the necessity for not only fast but also high-quality rapid tests. Besides fast antibody tests, for the detection of the immune response of the patient, also fast DNA tests for confirmation of acute infections are necessary.
Fraunhofer responded to this demand with the establishment of strategic internal cooperation projects. In the project CovMoTe, five Fraunhofer institutes joined forces in order to establish rapid testing based on a novel isothermal amplification method. The new method is rolled out as a laboratory test, in mobile labs as well as in a point of care system. Although PCR is still the gold standard for DNA testing, isothermal amplification of pathogen DNA has been chosen due to its much easier and robust process which is favorable for point of care testing. Fraunhofer ENAS is developing the microfluidic platform in order to establish the new method in a small analytical cartridge. The microfluidic cartridge includes integrated micro pumps based on a patented technology as well as reagent storage, valves and heating elements for the isothermal amplification. The amplified pathogen DNA is detected by an electrochemical biosensor developed by Fraunhofer ISIT. In the final configuration, the test system will not only be able to detect pathogen DNA but also perform antibody testing. For the seamless uptake of the development results, two potential distributors are already involved in the development of the system.

M³Infekt

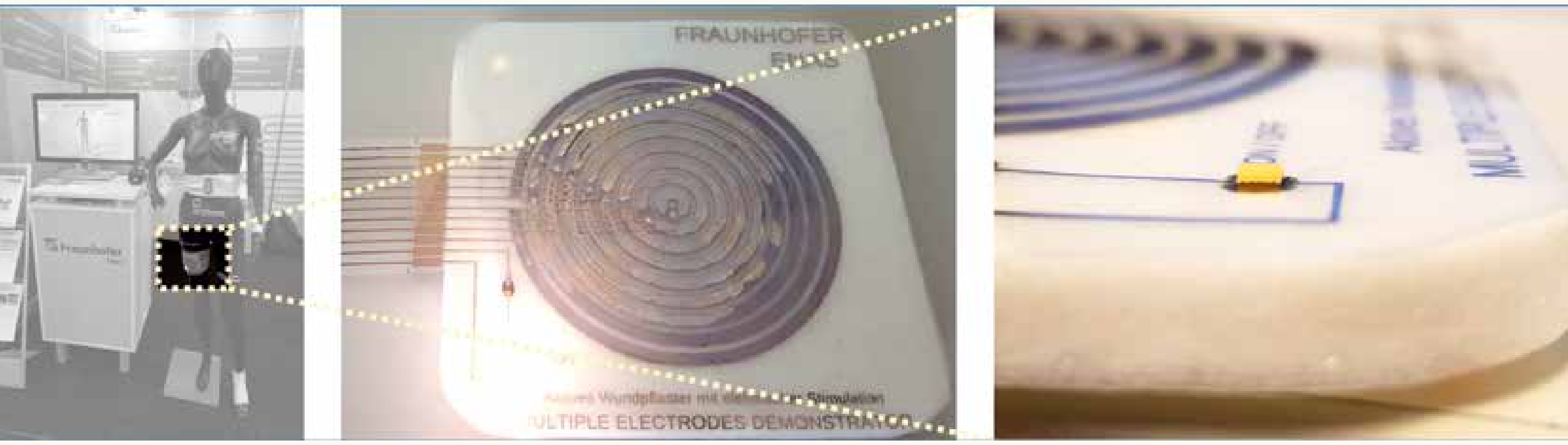
The cooperative project M³Infekt – Modular, Multimodal, Mobile Sensor System for Early Detection of Condition Deterioration in Infectious Diseases Using the Example of Covid-19 Patients – combines competencies and preliminary work of ten Fraunhofer facilities as well as clinical partners and addresses medical solutions in prevention, diagnostics and therapy of infectious diseases as well as the management of the associated care processes.
So far, there are no solutions for monitoring infected patients outside intensive care units (ICU). Thus, frequently occurring acute changes in condition with initially mild courses are detected with a significant time delay and the affected Covid-19 patients are consequently hospitalized too late. This has a direct negative impact on the prognosis of the disease and usually prolongs the required therapy. The task of M³Infekt is to close this gap in the care of sick people by developing a solution for the early detection of deterioration in the condition of infectious diseases, even outside the ICU, using Covid-19 patients as an example. The solution of M³Infekt consists in the acquisition and analysis of the bio signals relevant for the detection of acute condition deteriorations with an overall system.

#WeKnowHow

FRAUNHOFER VS. CORONA



Technology demonstrator for temperature indication in fever patients by printing thermochromic inks onto skin-compatible substrates.



Technology demonstrator for an electrically active wound patch with printed electrodes on flexible substrates.

RESEARCH AND DEVELOPMENT

- MEASUREMENT AND ANALYTIC SYSTEMS
- MEDICAL DEVICE

TECHNOLOGIES AND SYSTEMS FOR SMART HEALTH

In the context of M³Infekt, Fraunhofer ENAS is working in close cooperation with Fraunhofer IIS/EAS on the implementation of an imaging hyperspectral sensor for non-contact detection of pulse and oxygen saturation in blood in combination with motion analysis and localization of the examined person(s) in natural environments. For this purpose, Fraunhofer IIS/EAS will provide a powerful and programmable image sensor (Vision-System-on-Chip, VSoC) for the visible range and Fraunhofer ENAS will develop a tunable filter with an optical aperture of up to 9 mm. To implement the hyperspectral image sensor, both components are combined via interposers. The hyperspectral camera system is thus able to determine spectral characteristics based on the skin image of persons/patients in a spatially and temporally resolved manner and, coupled with suitable evaluation algorithms, to conclude on a possible deterioration of the condition.

beforeFever

Body temperature is an essential indicator for the occurrence of infections and can be used as an indicator for the diseases outbreak already 72 hours before the actual fever (38.1 °C). In the project beforeFever, Fraunhofer ENAS explores manufacturing strategies for flexible and cost-effective wearables for temperature measurement on the human body to enable an initial indication or a follow-up of sick patients. By using and combining conventional printing technologies, flexible polymer films could be coated with graphical indicators and adapted thermochromic pigments with temperature indication from 37 °C. The future use of novel ultra-thin and breathable medical substrate materials is expected to extend the wearing time of the indicators up to 14 days. Therefore, this cost-effective measurement method is very well suited for use even in underserved regions or with very high patient numbers.

PROJECT APFEL

The healing of wounds is an ancient problem that is still not completely understood and solved. Even in ancient times, wounds were rinsed with alcohol, bandaged and stitched. In acute wounds, healing takes place within a few days to weeks, depending on the size of the injury. One speaks of chronic wounds if there are no healing tendencies after three months or if the wound still exists and has not healed.[1] The property of an electrical gradient to induce cells in regenerative tissue to migrate and polarize in a directed manner is the target for the therapy forms developed in the BMBF project APFEL[2] to induce accelerated and improved wound healing via an "intelligent electronic plaster". In collaboration with partners, additive processes are being developed for the manufacture of multilayer flexible electronic systems and the individual components are being evaluated with regard to biocompatibility. To demonstrate the in vitro effect, among other things, a scratch assay was used as an in vitro wound healing assay and the accelerated closure of a gap (scratch) introduced into a cell lawn of keratinocytes (HaCaT cells) was demonstrated. Fraunhofer ENAS developed adapted screen printing processes for the fabrication of conductive and insulating multilayer films on flexible substrates, electrical through-hole plating variants for thin film substrates and assembly and interconnection technologies for the hybrid integration of conventional electronic components and corresponding control electronics for testing the demonstrators.

[1] Schiemann D, Deutsches Netzwerk für Qualitätsentwicklung in der Pflege. Expertenstandard Pflege von Menschen mit chronischen Wunden. DNQP; 2009.

[2] BMBF "KMUinnovativ: Medizintechnik", Förderkennzeichen 13GW0106C.

Photo © RF123 (Oliver Sved)

TECHNOLOGIES AND SYSTEMS FOR SMART PRODUCTION

The business unit “Technologies and Systems for Smart Production” addresses topics relating to automation and digitalization in manufacturing. We focus on providing technologies for sensor-based production monitoring and technologies for product individualization.

We use a portfolio of in-house technologies to develop sensor solutions for production monitoring, for instance optical spectral sensors, which can be highly integrated and allow high performance evaluation using neural networks. We also feature sensor solutions that can withstand particularly demanding environmental conditions and even ensure signal transmission through oils and mud.

We work on and with technologies for the individualization of products within manufacturing. In addition to classic robotics-based systems, we also work with continuous manufacturing systems. In one project, we use inkjet printing in a roll-to-roll manufacturing system to build credit-card-sized sensor systems. These are able to measure environmental conditions and send them wirelessly to mobile devices such as smartphones or tablets. In addition to this application example, we develop solutions to ensure the manufacturing process stability of printed systems on the one hand and their reliability on the other, so that they meet recognized standards and norms.

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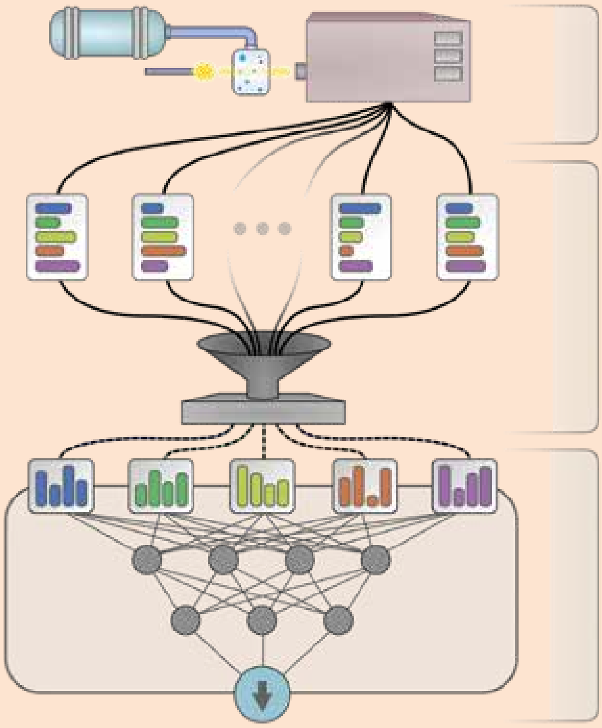
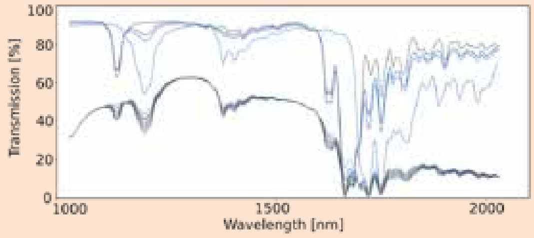
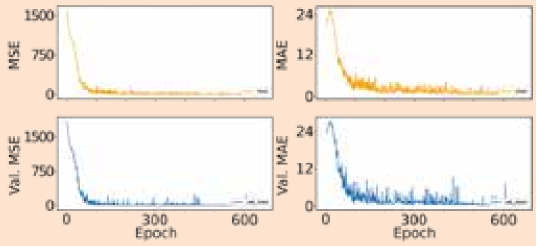


Sampling and data aquisition via spectrometer.

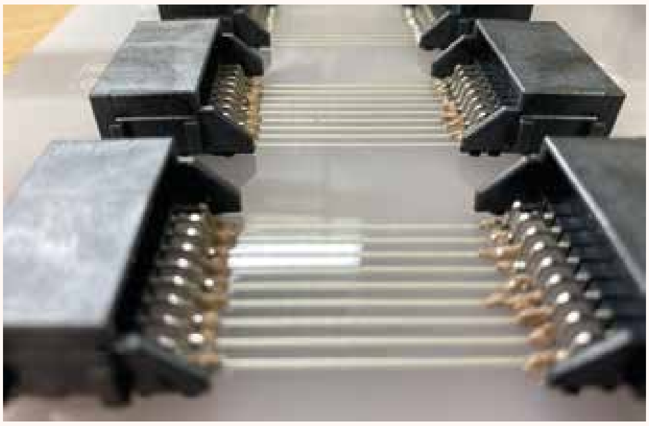
Aggregation and provision of spectral data.



Training of specific neural network and result evaluation.



6-axis robot system with adapted digital printing technology for the production of, among other things, conductor paths on three-dimensional surfaces.



Printed conductors electrically and mechanically contacted on automotive-approved connectors.

RESEARCH AND DEVELOPMENT

- **SENSOR SYSTEMS FOR PROCESS AND CONDITION MONITORING**
- **SMART DIGITAL PRODUCTION**

TECHNOLOGIES AND SYSTEMS FOR

SMART PRODUCTION

INTEGRABLE SPECTRAL SENSORS IN MULTI-REACTOR TECHNOLOGY – USAGE OF NEURAL NETWORKS TO INTERPRET RESULTS

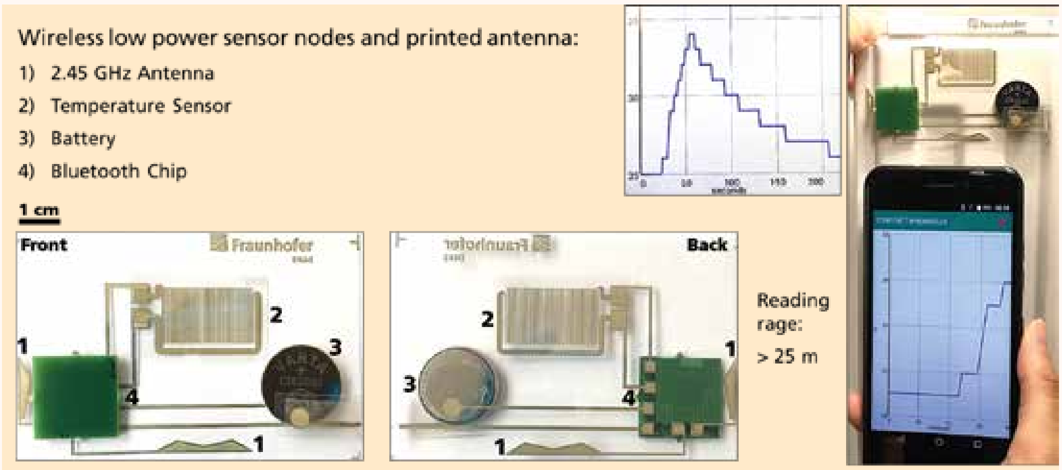
Multi-reactor systems are well established, especially in pharmaceutical research and catalysis. They are characterized by a high degree of automation and parallelization, which ensures high efficiency. However, targeted manipulation of processes requires more precise knowledge about the concentration of the reaction participants during the reaction progression. Here, NIR spectroscopy represents a suitable method. As part of a research project, we integrated a miniaturized spectrometer module into the system architecture of a multi-reactor system. We qualified it for various hydrogenation reactions. We then used machine learning and neural network methods to calibrate the obtained spectral data. Current approaches in neural networks use brute force algorithms to determine factor weights. Therefore, pre-calculated models are advantageous. We run the training using acquired measurement data, algorithmically generated deviations and a specific multi-layer neural network. After one-time adaptation according to the required data format, any input data can be used without further pre-processing. Metadata could be assigned to the measurement data in individual cases to increase accuracy. Individual optimization processes, as required for each measurement data set in classical PLS methods, are no longer necessary. This means a once trained neural network can be applied to accruing measurement data and delivers accurate estimates with regard to previously defined evaluation targets. The results are almost equivalent to the PLS methods we also took into consideration. New measurement data can be added almost effortless. It dynamically adapts a trained network without calling up the computing power of a complete training.

“GO BEYOND 4.0“: INCREASE OF MANUFACTURING PROCESS STABILITY AND RELIABILITY OF PRINTED SYSTEMS

After a four-year runtime, the Fraunhofer lighthouse project “Go Beyond 4.0” was successfully completed on November 30, 2020. Particularly innovative research results were achieved in 2020. These include the increase of process stability of digital printing and laser processes used for the production of individualized products up to quantities of 1, as well as an increase in product reliability (focus: thermal shock resistance) in accordance with industry standards. Together with the Fraunhofer institutes IFAM, ILT and IWU we investigated new control concepts in order to reduce the fluctuations of the printed and post-processed track resistances to below 20 %. As a result, the standard deviation of the track resistances during production was impressively reduced to 1.1 % (jet dispenser) and 4.5 % (screw dispenser), respectively.
The goal of the research carried out in 2020 to increase product reliability was to implement a heterogeneous integration of digitally printed assembly and interconnection structures in classical electronic environments. Fraunhofer ENAS developed a safe electrical and mechanical adhesive connection between printed circuit boards and automotive-approved connectors according to automotive standards, for instance. The connectors and printed traces shown in the photos on the left page have withstood a temperature cycling test of 1000 cycles (– 40 °C to + 125 °C) and are thus fully usable for an automotive application.

The transducer mounted on a PCB, and its housing.

Roll-to-roll inkjet printing of sensors.



Structure and functional test of the developed printed and hybrid sensor system.

RESEARCH AND DEVELOPMENT

- **SENSOR SYSTEMS AND TECHNOLOGIES FOR PROCESS AND CONDITION MONITORING**
- **SMART DIGTIAL PRODUCTION**

TECHNOLOGIES AND SYSTEMS FOR
SMART PRODUCTION

„EHARSH“: SENSOR SYSTEMS FOR EXTREMELY HARSH ENVIRONMENTS, PROOF OF CONCEPT FOR CMUT SIGNAL PERFORMANCE

Conventional piezoelectric transducers, used in acoustic borehole televiewers, are bulky, have high acoustic impedance and narrow bandwidth, and are temperature sensitive. In harsh environments such as high temperature geothermal explorations, these transducers have thermal limitations. Within the framework of Fraunhofer's lighthouse project "eHarsh", Fraunhofer ENAS is investigating the feasibility of using Capacitive Micromachined Ultrasound Transducer (CMUT), which can operate at high temperatures (due to its non-piezo based structure), for borehole imaging.

The transducers tested in this project were single element 2D arrays of CMUT cells fabricated at Fraunhofer ENAS using a wafer bonding process. For testing purposes, the transducer (3 x 3 mm in size) was mounted on a PCB, enclosed in an oil-filled aluminum housing, which incorporates a Teflon acoustic window.

The characterizations were performed individually for transmit and receive performances, in oil and in a laboratory-prepared drilling mud (typically a mixture of bentonite and water). In transmit mode, a calibrated hydrophone was used to measure the acoustic pressure that the transducer generates. The results showed that the encased transducer could provide measurable signals at distances over 5 cm even while immersed in a mimicked borehole drilling mud. In receive mode, a calibrated acoustic wave transmitter (a piezo disc) was employed and the response of the transducer, amplified by a custom designed receive circuit, was recorded. The experimental results obtained are promising and suggest that a CMUT-based probe can be optimally designed for use in borehole imaging applications.

„DIGIMAN“: DEVELOPMENT OF AN R2R PRINTED AND HYBRID SENSOR SYSTEM

After two years, the project "DigiMan" was successfully completed on November 30, 2020. With the project partners Fraunhofer IKTS, C.P.C Solutions Ltd, Kerafol Keramische Folien GmbH & Co. KG, RIIT Ltd. OSTEC Group, PV Nano Cell Ltd., Chemnitz University of Technology and MEPhI, it was researched on developing platinum nano inks as well as a digital manufacturing chain for additive digital printing of environmental sensors. Fraunhofer ENAS focused on the development of a printed and hybrid sensor system for temperature measurement and wireless evaluation of the same by commercially available Bluetooth systems such as smartphones. The sensor system consists of printed circuit boards, a printed 2.45 GHz antenna, a printed temperature sensor as well as a small printed circuit board and a button cell. The printed components were fabricated using a roll-to-roll inkjet printing process. The photo on the left page shows an inkjet print head producing sensor elements on a PET film web in high efficiency and high throughput.

76 PUBLICATIONS

4 DISSERTATIONS

16 PATENTS

6 TRADE FAIRS AND EXHIBITIONS

30 MEMBERSHIPS

Photo © pixabay

HIGHLIGHTS

DISSERTATIONS

September 17, 2020	
PhD:	Apoorva Sharma
Topic:	Correlation Betweeen the Structural, Optical, and Magnetic Properties of CoFeB and CoFeB Based Magnetic Tunnel Junctions Upon Laser or Over Annealing
Institution:	Chemnitz University of Technology

September 24, 2020	
PhD:	Jana Tittmann-Otto
Topic:	Improvement of carbon nanotube-based field-effect transistors by cleaning and passivation
Institution:	Chemnitz University of Technology

October 7, 2020	
PhD:	Alexander Otto
Topic:	Lebensdauermodellierung diskreter Leistungselektronikbauelemente unter Berücksichtigung überlagerter Lastwechseltests
Institution:	Chemnitz University of Technology

December 11, 2020	
PhD:	Martin Möbius
Topic:	Nutzung der Photolumineszenz von Quantenpunkten für die Belastungsdetektion an Leichtbaumaterialien
Institution:	Chemnitz University of Technology

AWARDS AND ACHIEVEMENTS

Best Paper Awards at conferences / Best Innovation Award

The EuroPAT-MASIP team of Fraunhofer ENAS, Besi NL and Amkor received the Outstanding Paper Award at the ASME 2020 InterPACK Conference (Oct 27-28, 2020) for the paper "The systematic study of Fan-Out Wafer Warpage Using Analytical, Numerical and Experimental Methods". The focus was on characterizing the physics of wafer warpage. This is a challenge for many process steps in fan-out wafer-level packaging (FoWLP), a technology used for heterogeneous system integration. The new study provides recommendations and practical guidance for improving the design and optimizing the FoWLP process flow from the perspective of increasing yield and reliability.

The Fuel Cells and Hydrogen Joint Undertaking awarded the MAMA-MEA project with the 2020 Best Innovation Award at European Hydrogen Week. This project is about mass production of MEAs through rapid printing and coating processes. A MEA (membrane electrode assembly) is the core component for the chemical reaction within low-temperature polymer electrolyte membrane fuel cells (PEMFCs). Project partners are Informatics Energy Automation (INEA), Johnson Matthey Fuel Cells Ltd. (JMFC), Nedstack Fuel Cell Technology B.V. (NFCT), System S.p.A., Chemnitz University of Technology (TUC), Universitá degli Studi di Mondena e Reggio Emilia (UNIMORE), and Fraunhofer ENAS. Together, they began in 2018 to evaluating existing printing and coating technologies for their potential for mass production of MEAs.

Research prize of Fraunhofer ENAS

The Fraunhofer Institute for Electronic Nano Systems ENAS awarded its research prize for the tenth time. At the virtual event, Dr.-Ing. Alexander Otto received the award for his research on novel approaches to lifetime modeling with a focus on power electronics devices. He succeeded in making the transition from purely load-based models to stress- and failure-effect-based approaches for lifetime prediction. For practical applications in the industrial environment, this will mean a significant increase in prediction accuracy in the future. Power electronics are used in the field of renewable energies, electromobility and Industry 4.0. The requirements for reliability evaluations for power electronics are increasing more and more as components and functional materials become more complex, more power density and functional integration is required, electronics are used in harsher environmental conditions, and functional safety must be ensured, e.g. for autonomous driving.

EVENTS

National and international conferences, workshops and seminars

In terms of events, the year 2020 was strongly influenced by the corona pandemic. For this reason, only very few attendance events took place.

In January 2020, Rüdiger Röhrig from Sustainable Growth Associates GmbH, Planegg, spoke on the topic of "Sustainability and technology acceleration – how to surf the killer waves" at Fraunhofer ENAS as part of the Chemnitz Industry Talks of the DPG. All other events could not be held in presence as planned.

After some initial difficulties in the digital field, we focused, together with the central administration of the Fraunhofer-Gesellschaft, on the virtual Future Technology Day on September 2, 2020, presenting the results of the lighthouse project "Go Beyond 4.0". The event concentrated on innovative digital printing and laser processes to individualize series production.

After many trade fairs also switched from presence to virtual events or were cancelled altogether, the consortium of the lighthouse project "Go Beyond 4.0" also presented itself at the new virtual format of the Fraunhofer-Gesellschaft – the Fraunhofer Solution Days.

A virtual event organized by Fraunhofer ENAS took place in Mid-December 2020 following the research award ceremony of Fraunhofer ENAS. Thus, on December 17, 2020, the institute management invited to a panel discussion with the topic "Generating added value for both industry and research under the existing innovation pressure". Beside the institute director of Fraunhofer ENAS, Prof. Dr. Harald Kuhn, and the moderator Prof. Stefan Schulz, Dr. Oliver Pyper (Director Research Development Innovation Programs at Infineon Technologies Dresden GmbH & Co. KG), Dr. Steffen Heinz (Managing Director of EDC Electronic Design Chemnitz GmbH), Barbara Meyer (Head of Department for Industry, SMEs and Innovation, Saxon State Ministry of Economy, Labour and Transport), Prof. Dr. Uwe Götze (Deputy President and Vice President for Transfer and Academic Qualification at Chemnitz University of Technology), Dr. Christiane Le Tiec (CTO of the Plasma & Reactive Gas Solution Business Unit of MKS Instruments Deutschland GmbH) and Dr. Stefan Leidich (Senior Manager Microsensorsystems at Robert Bosch GmbH) participated. This new format was very well received by the partners and customers of Fraunhofer ENAS.

1

2

Science meets art

Our long-standing exhibition series "Science meets Art" also had to take new paths in 2020 due to the Corona restrictions.
The 20th exhibition with the title "QUO VADIS" was shown by the Chemnitz artist Dagmar Ranft-Schinke at the institute. We were able to keep it in our rooms until the end of May 2020 thanks to the artist. In February, we welcomed guests together with Dagmar Ranft-Schinke for an artist talk and a guided tour with students. "Science and art have two starting points: these are curiosity and imagination.", Ranft-Schinke said in the artist talk. In her paintings, the artist explores the influence and impact of scientific knowledge on humans and nature.
In the second half of the year, we did not bring an additional exhibition to our institute rooms, but worked with the Chemnitz photographer Ines Escherich on a photo exhibition. "NATURE – HUMAN – TECHNOLOGY 2021" combines meditative nature photographs with portraits from the photo project "Commitment shows face", which the photographer has accompanied for the initiative "Verbundnetz der Wärme" for almost 20 years. For the scientific-technical photographs, we opened our laboratories and let Ines Escherich depict the research topics at Fraunhofer ENAS with her very own creative eye. The result is a photo exhibition that can now be experienced not only in our institute but also online at www.enas.fraunhofer.de/fotoausstellung.

1 Dagmar Ranft-Schinke showed her work "I, the Robot" in February 2020 during the guided tour as part of the artist talk for the exhibition series "Science meets Art" at Fraunhofer ENAS.

www.enas.fraunhofer.de/wissenschafttrifftkunst

Chemnitz company run

In 2020, the Chemnitz company run became a self-runner event. All registered runners were called upon in September to complete the distance of five kilometers alone on their usual running routes at home or at a distance within the team. Everyone has independently submitted their results online at WiC Firmenlauf Chemnitz. A group of employees of Fraunhofer ENAS and the Center for Microtechnologies met for a joint running evening in the forest of Chemnitz Küchwald.
The fastest runner in our team was Patrick Schwarz. He finished 75th in the overall ranking of the men. In the women's race, Doreen Jäger outran everyone and took 27th place in the overall ranking of all female runners.
Many thanks to all 22 runners who participated, even under somewhat unusual conditions this year!

2 The runners from Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology had to miss the Chemnitz company run as a big event in 2020. However, they ran alone or as a group with sufficient distance – and as ONE team.

MEMBERSHIPS

Memberships of Fraunhofer ENAS	
AGENT-3D e.V.	Dresden, Germany
ALPIN – Atomic Layer Processing Innovation Network	Dresden, Germany
biosaxony e.V	Dresden, Germany
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Hzwo e.V.	Chemnitz, Germany
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it's OWL – Intelligente Technische Systeme OstWestfalenLippe e.V.	Bielefeld, Germany
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ZIM Cooperation Network "Scaling of bond technologies for micro- and macroscopic production processes" (SCALE)	Chemnitz, Germany
ZIM Cooperation Network "Environmental Technology and Soil Reclamation" (UtBr)	Berlin, Germany

PUBLICATIONS AND PATENTS

Publications

In 2020, the scientists of Fraunhofer ENAS published their results in 76 articles, books including book chapters and conference proceedings.

You can find our published content within the database Fraunhofer Publica which contains all publications and patents published by Fraunhofer Institutes:

http://publica.fraunhofer.de/starweb/pub09/newPub.htm

Moreover, they are listed on the website of our partner Center for Microtechnologies of Chemnitz University of Technology:

http://www.zfm.tu-chemnitz.de/publications/index.php.en

Electronically available documents can be downloaded via Fraunhofer Publica.

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Patents

In 2020, 16 patents from scientists of Fraunhofer ENAS have been applied, published and/or granted.
In summary, staff of Fraunhofer ENAS are involved in a total of 203 patent applications, disclosed and granted patents, which belong to a total of 66 patent families.

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