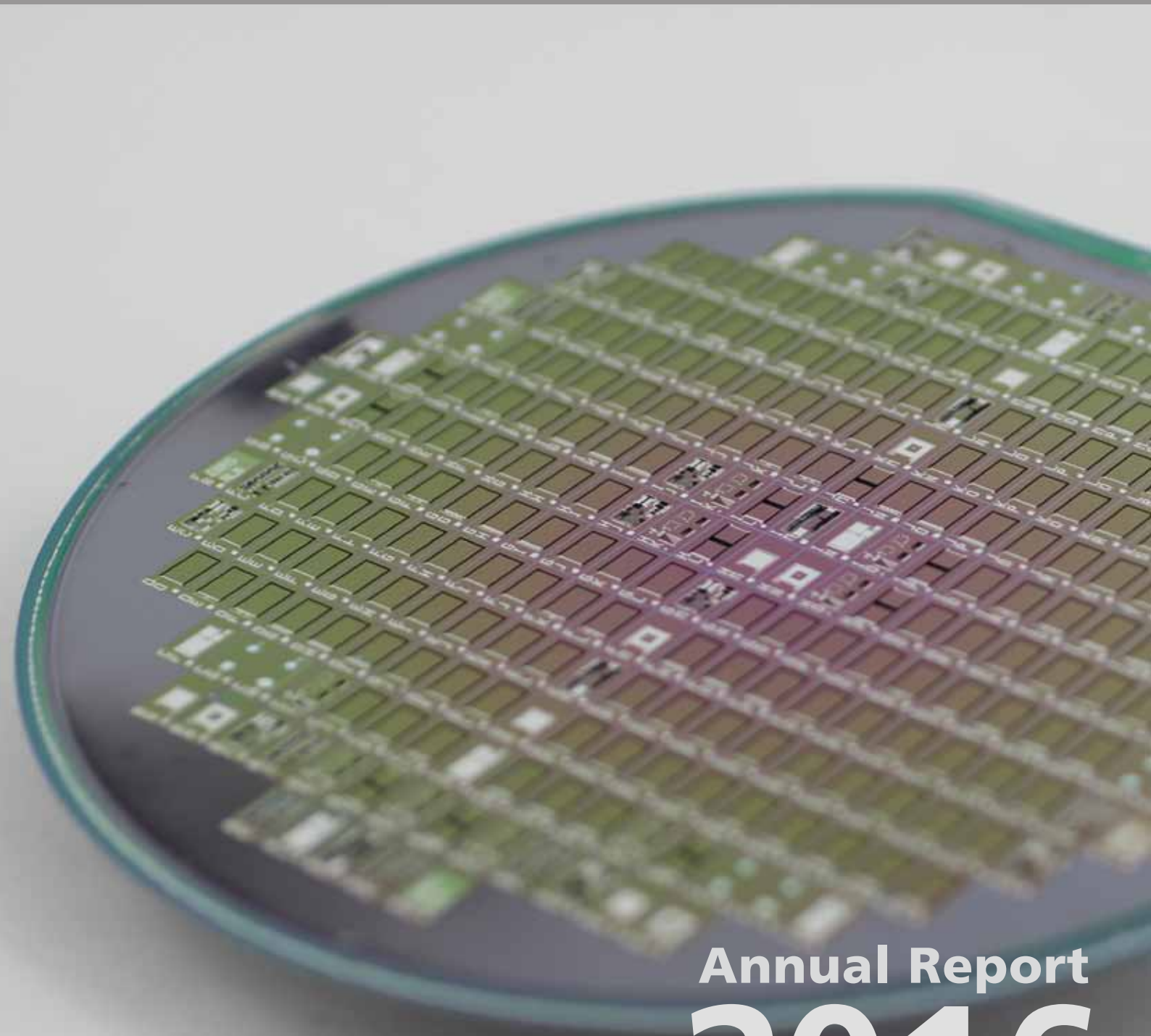
Fraunhofer
ENAS

FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS



Annual Report 2016

CONTENT

Cover page:
Aluminum nitride as piezoelectric transducer for MEMS.
Wake-up micro sensors are produced on wafer level. These so-called power down interrupt generators (PDIG) are designed for sensor modules with very low stand-by current. The MEMS were developed within the German leading-edge cluster program "Cool Silicon" in cooperation with the Center for Microtechnologies (ZfM) of Chemnitz University of Technology and other partners, funded in the research project Cool_PoD by Sächsische Aufbaubank SAB.
photo © Chris Stöckel, Fraunhofer ENAS

PREFACE

photo: Ines Escherich

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

The year 2016 was marked by changes. In May 2016, the director of the Fraunhofer ENAS, Prof. Thomas Gessner died suddenly and unexpectedly. His sudden death shocked us deeply. Prof. Gessner was a visionary and a companion for our scientific and application-focused developments as well as supervisor for our young scientists. On September 8, Chemnitz University of Technology and Fraunhofer ENAS remembered Prof. Gessner, together with more than 550 guests from Germany and abroad, within an honorary colloquium and symposia on the topic of Smart Integrated Systems.

However, we all agreed that the greatest honor we can pay to Prof. Gessner is to successfully continue his life's work. Therefore, we continued the strategical process he started and the results were successfully audited by an external brain trust consisting of representatives from industry, science and politics in September 2016. Within the strategical process, we not only examined and redefined our business units and core competences, but also specified actions we must work on to secure a successful future.

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

Our institute can once again look back at a successful year. A large portion of our research volume is generated by contract-based research, i.e. in the framework of direct orders from the industry and publicly funded projects. We maintained our high industrial revenue in 2016. At this point, we would like to thank our partners and customers for their trust and support.

With pride and joy we look back on what we have accomplished in 2016. However, it also serves as an incentive to keep up the competent and reliable service for our project partners and customers. We continue to work closely with the Center for Microtechnologies of Chemnitz University of Technology. Both facilities are managed in personal union.

With our annual review of 2016, we would like to provide you with an insight into the varied activities of our institute. I invite you to ponder and think ahead. As an institute of the Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., research and development for industrial applications is also our central focus in 2017.

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

photo: iStock (courtneyk)

STRATEGY: THE KEY TO SUCCESS

STRATEGY: THE KEY TO SUCCESS

Fraunhofer ENAS, founded in 2008 as a Fraunhofer research institution and, following a strategical audit in 2010, became a Fraunhofer institute in 2011, can look retrospectively at a very positive development. Thus, Fraunhofer ENAS continuously generates high external revenues and grows constantly. In order to secure and expand its competitiveness in the long run, the management of the Fraunhofer ENAS initiated an in-depth strategical process in May 2015. The results were audited by an external brain trust consisting of representatives from industry, science and politics.

Strategy process

The strategical process is a systematic, continuous and dynamic process for securing the sustainability of the Fraunhofer institute preceded by an in-depth analysis of the status quo. For this purpose, the institute analyzed its portfolio, goals, customers and markets intensely and derived actions and goals both in a top down and a bottom up approach. The finalized documents serve as guidelines and motivation for the management of the institute as well as the staff. In order to adapt to changing challenges and markets, the developed strategy is no rigid concept but is examined and, if need be, readjusted within the framework of an annual strategical meeting. Furthermore, the external viewpoint on the institute's strategy is annually discussed with the Fraunhofer ENAS board of trustees.

Vision

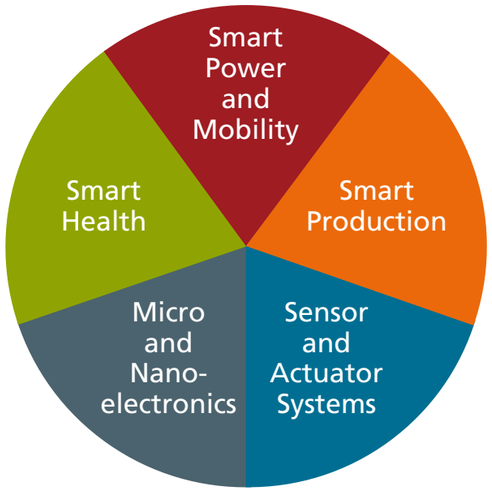
The vision and mission of the Fraunhofer ENAS are deviated from an in-depth analysis and the self-conception of the institute. In accordance with the vision and mission of the Fraunhofer-Gesellschaft, Fraunhofer ENAS equally stands for applied research, innovation for the common good and strengthening of the German and European economy. In addition, Fraunhofer ENAS manages strategic initiatives to meet future challenges and develops technological breakthroughs. Therefore, Fraunhofer ENAS attempts to achieve a well-balanced combination of excellent research and application-oriented development.

Fraunhofer ENAS stands for research and development in the field of smart systems integration by using micro and nano technologies. With its orientation toward smart systems integration, the institute addresses the challenges of a digitized world, the internet of things as well as industry 4.0 and hence, global challenges such as an aging population. On the other hand, Fraunhofer ENAS addresses components industry, systems and material manufacturer, producers of semi-products as well as technology equipment and user industries and hence, is able to sustainably support research and development of small- and medium-sized enterprises and large-scale industry.

Fraunhofer ENAS consequently continues its development in the field of smart systems integration, ranging from the development of single devices in the area of micro and nano systems (MEMS/NEMS) and micro and nanoelectronics, the interface and hardware for data communication, concepts for a power supply of the systems, integration technologies and integration of single components to create a complete system, including the necessary embedded software.

Business units

In subsequent years after the audit 2010, Fraunhofer ENAS realized that the existing business units no longer describe the addressed customer and sectoral structure and are difficult to convey. Based on the criteria that 10 percent of the revenue of the institute is generated within the business unit, three application-oriented business units Technologies and Systems for Smart Power and Mobility, Smart Health and Smart Production and two sectoral, technology-oriented business units Micro and Nanoelectronics and Sensor and Actuator Systems were established.

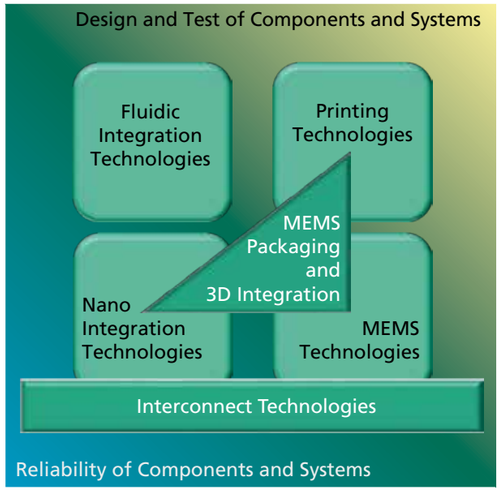


A significant basis for the successful work of Fraunhofer ENAS lies in further developing and expanding its main pillars Micro and Nanoelectronics and Sensor and Actuator Systems. Both business units strongly focus on the integration of nano materials, nano effects and technologies (represented in the new core competence Nano Integration Technologies), the development of novel sensors and actuators and they address new topics in the field of Beyond CMOS for micro and nanoelectronics. Both business units not only serve the respective industrial sector, they also develop components and subsystems which are further developed to an overall system in the application-oriented business units Technologies and Systems for Smart Power and Mobility, Smart Health and Smart Productions.

STRATEGY: THE KEY TO SUCCESS

Core competences

The particular strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the variety of technologies and methods for smart systems integration. While Fraunhofer ENAS addresses customers via its business units, eight core competences represent the inner structure of the technology portfolio. MEMS Technologies, Fluidic Integration Technologies, Printing Technologies and Nano Integration Technologies provide the technological base for the development of individual components. Interconnect Technologies as well as MEMS Packaging and 3D Integration are cross-sectional technologies and interact with both the base technologies and the supporting core competences Design and Test of Components and Systems and Reliability of Components and Systems.



With this redefinition, the core competences established in 2010 were further focused and developed. Furthermore, the newly added core competence Nano Integration Technologies accommodates all aspects of the integration of nano materials and technologies. One of the essential aspects of the development of overall systems is the inclusion of specific software. In this regard, Fraunhofer ENAS already offers various competences, currently represented in the core competence Design and Test of Components and Systems and partially in Fluidic Integration Technologies. By deliberate development, the establishment of a corresponding new core competence is possible in the years to come.

Unique selling points

At a technical level, Fraunhofer ENAS pursues the goal to reinforce existing strength, especially unique selling points, and eliminate weaknesses. The future development of the institute is in particular shaped and secured via unique selling points:

- Broad spectrum of technologies and methods for smart system integration
- Fully covered value chain for high-precision silicon-based MEMS/NEMS (starting from the design up to small batches)
- Integration of various nano materials and technologies for visionary nano systems and Beyond CMOS
- “Design for reliability” – cooperation of design and reliability
- Wafer bonding for MEMS/NEMS and 3D integration of MEMS/NEMS and electronic components
- Fully covered value chain for printed functionalities, starting from the design via simulation, manufacturing of prototypes, characterization up to the point of developing production processes
- Microfluidics: electrolysis-based integrated pumps and valves for point of care diagnostics and actuators for active flow control
- Wafer-level technologies for CNT FETs and CNT-based sensors
- Strong link between simulation and experiment: in the field of reliability assessment as well as for the simulation of technologies (equipment simulation) and devices

photo: Ulf Dahl

FRAUNHOFER ENAS: PROFILE

FRAUNHOFER-GESELLSCHAFT

www.fraunhofer.de

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

At present, the Fraunhofer-Gesellschaft maintains 69 institutes and research units. The majority of the 24,500 staff are qualified scientists and engineers, who work with an annual research budget of 2.1 billion euros. Of this sum, 1.9 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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

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

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

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

FRAUNHOFER ENAS

www.enas.fraunhofer.de

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

The research and product portfolio covers single components, manufacturing technologies and system concepts, system integration technologies and transfers them into production. Fraunhofer ENAS offers research and development services from the idea, via design and technology development or realization based on established technologies up to tested prototypes. If standard components do not meet the requirements, Fraunhofer ENAS provides prompt help in the realization of innovative and marketable products and helps to transfer them into production.

Application areas are i. a. semiconductor industry (equipment and material manufacturer), aeronautics, automotive industry, communication technology, the security sector, logistics, medical as well as mechanical engineering.

In order to focus the activities and to ensure a long term scientific and economic success, Fraunhofer ENAS has defined five business units:

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

They address different markets, different customers and moreover, different stages of the value chain depending on the required research and development services.

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

ORGANIZATIONAL STRUCTURE

Fraunhofer Institute for Electronic Nano Systems ENAS

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

Department
Multi Device Integration
Acting: Dr. S. Kurth / Dr. A. Weiß

Department
Micro Materials Center
Prof. Dr. Sven Rzepka

Department
Printed Functionalities
Prof. Dr. Reinhard R. Baumann

Department
Back-End of Line
Prof. Dr. Stefan E. Schulz

Department
System Packaging
Dr. Maik Wiemer

Department
Advanced System Engineering
Dr. Christian Hedayat

Administration
Deputy head: Michael Jerke
Technical head: Uwe Breng

Marketing / Public Relations
Officer of the Director
Dr. Martina Vogel

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

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

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

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

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

International Offices

Fraunhofer Project Center
at Tohoku University, Japan
Prof. Thomas Otto
Prof. Masayoshi Esashi
Prof. Shuji Tanaka

Office Shanghai, China
SHI Min

Office Manaus, Brazil
Hernan Valenzuela

Chemnitz University of Technology

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

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

Department
Lithography and Pattern Transfer
Dr. Danny Reuter

Department
Layer Deposition
Dr. Sven Zimmermann

Professorship of
Microtechnology
Prof. Dr. Thomas Otto

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

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

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

Faculty of Mechanical Engineering

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

Clusters of Excellence

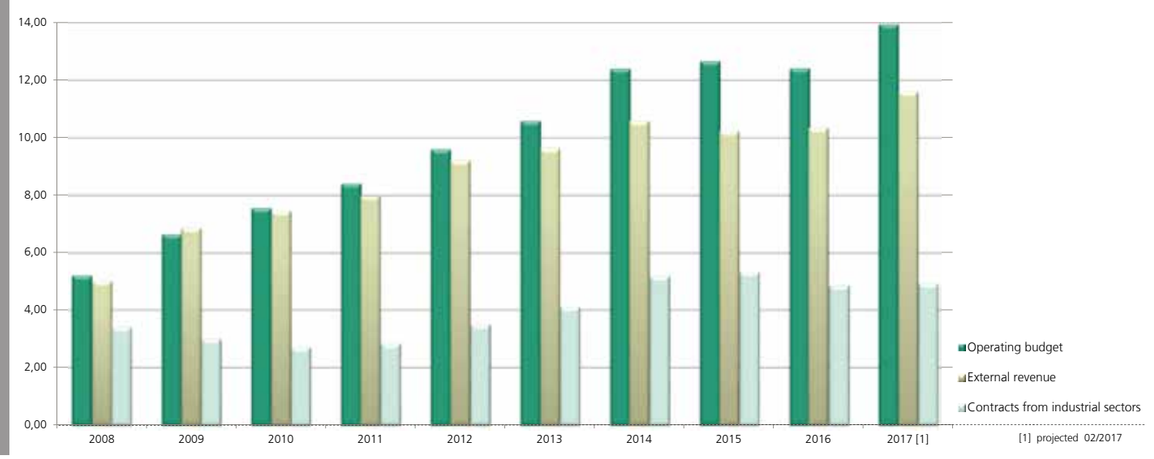
MERGE
Prof. Dr. Thomas Otto
Martin Schüller

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

University Paderborn

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
Operating budget (in million euros)	5.2	6.7	7.6	8.4	9.6	10.6	12.4	14.7	14.4
Increasing of the budget (in relation to 2008)	–	29%	46%	62%	85%	104%	138%	183%	176%
Industrial revenues (in million euros)	3.4	3	2.8	2.8	3.49	4.1	5.2	5.3	5.0
Investment (in million euros)	0.65	5.45	6.8	1.5	1.81	1.44	7.23	2.34	1.89
Staff	63	73	91	102	104	125	129	127	132
Apprentices	0	2	3	5	6	7	7	6	7
Students and student assistants	10	10	20	40	43	51	51	43	43
Publications and oral presentations	61	75	114	119	112	215	198	173	176
Patents	7	5	13	20	8	17	9	9	12
Dissertations	6	0	4	2	3	3	3	5	3
Academic lectures (TU Chemnitz)	17	17	23	27	24	24	24	24	17
Academic lectures (University Paderborn)	8	9	9	8	9	10	7	10	10
Academic lectures (TU Dresden)	0	0	2	2	2	1	0	0	0

Financial situation and investment

In 2016, Fraunhofer ENAS again benefited from a stable economic situation. The continuously growing third-party funds underline the solid development strategy of our institute. Fraunhofer ENAS generated external revenues of 10.34 million euros. The revenue quota is at 83.4 percent. The orders from German and international industrial companies increased to 4.86 million euros which corresponds to an industrial share of 39.2 percent of the operating budget of 12.4 million euros.

The internal equipment investments and investments in furnishing and construction of the building were 1.2 million euros in the last year. The strategic investment in 2016 amounted 0.69 million euros.

Personnel development

The success of any company and of any research institute relies on the minds of its employees, their knowledge about details and correlations, products, technologies, and processes. At the end of the year, 132 people were employed by Fraunhofer ENAS in Chemnitz, Paderborn and Berlin. Eight employees moved from Fraunhofer ENAS to the industrial sector or retired.

Two apprentices successfully completed their training at our institute and have since been employed either by Fraunhofer ENAS or have begun studying. In cooperation with Chemnitz University of Technology and Paderborn University, students and young scientists have successfully defended their graduate theses.

At the end of 2016, Fraunhofer ENAS employed 43 interns, graduate students/master's students and student aids. This employee base continues to prove itself as an excellent source for young scientists and technicians.

Deputy head of administration:
Michael Jerke
Phone: +49 371 45001-207
E-Mail: michael.jerke@enas.fraunhofer.de

BOARD OF TRUSTEES

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

In 2016, the members of the Fraunhofer ENAS board of trustees were:

Chairman:
Prof. Dr. Udo Bechtloff

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

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

Dr. Markus Ulm ended his membership in our board of trustees on December 31, 2016. We thank him for accompanying our institute during the last three years. Dr. Stefan Finkbeiner, CEO from Bosch Sensortec GmbH, will join the board starting in 2017.

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

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

The institute offers research and development services, starting from the idea, via design and technology development or realization based on established technologies up to tested prototypes. If standard components do not meet the requirements, Fraunhofer ENAS provides prompt help 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 MEMS Industry Group, via EPoSS – the European Technology Platform on Smart Systems Integration, Silicon Saxony and IVAM up to the Smart Systems Campus Chemnitz. The complete list is included in the attachment.

Cooperation with industry

Within the working field of smart systems integration, Fraunhofer ENAS is able to strongly support the research and development of many small and medium-sized companies as well as large scale industry. By integrating smart systems in various applications, Fraunhofer ENAS addresses the branches and markets mentioned in the green box.
The most common way of cooperating with industrial partners is contract research. However, if the tasks to be solved are too complex, we offer pre-competitive research. In these cases, teaming up with companies and research institutes, while using public funding support, is more effective than operating solo.
In 2016, Fraunhofer ENAS has cooperated with more than 150 partners from industry worldwide. Fraunhofer ENAS carries out direct research and development orders as well as joint practical projects and pre-competitive research.

Research and development service portfolio

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

Markets and fields of application

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

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

photo: Dirk Hanus

Cooperation with industry within the German leading-edge clusters program

In 2007, the Federal Ministry of Education and Research launched a competition advertised with the slogan "Germany's Leading-Edge Clusters – more innovation, more growth, more employment". Fifteen clusters were selected in three rounds of the competition. Especially the regional concentration of innovative players is a key characteristic of each cluster. The basis for the selection and funding of a leading-edge cluster is the development of common strategic goals and the definition of future development projects in a particular technological area. The involvement of the key players in the region's innovation and value-added chains is also a major prerequisite. Each cluster is funded for 5 years. However, the Fraunhofer Institute for Electronic Nano Systems ENAS is a reliable partner in two of these leading-edge clusters of Germany. One is the cluster "Cool Silicon" in Saxony and the second one is "It's OWL" in North Rhine-Westphalia.

Cool Silicon

The aim of the leading-edge cluster "Cool Silicon" is to build the technology basis for a massive increase of energy efficiency in the information and communications technology (ICT) sector. The cluster started its work in 2009 and got funding until 2014. However, the cluster is still active. Currently there are 60 partners working within the network, dealing with micro and nanotechnologies, integration and application as well as material integration and reliability.

www.cool-silicon.de

It's OWL

Starting in 2012, 174 companies, universities, research institutes of the region East-Westphalia-Lippe are working within the leading-edge cluster "It's OWL". The aim of the cluster is to develop smart technical systems for companies working in mechanical engineering, electrical engineering and automotive. The contribution of the department Advanced System Engineering of Fraunhofer ENAS within this cluster focuses on intelligent self-organized wireless sensor nodes and sensor networks.

www.its-owl.de

Cooperation within the Smart Systems Campus

Fraunhofer ENAS headquarters are located on the Smart Systems Campus Chemnitz. This campus is an innovative network with expertise in micro and nano technologies as well as in smart systems integration. A close cooperation of science, applied research and industry is an everyday reality and reflects a strategy that is being fulfilled. Main partners are Chemnitz University of Technology, Fraunhofer ENAS, young companies within the start-up building and companies within the business park.

Cooperation with universities and research institutes

Fraunhofer ENAS has established a strategic network with research institutes and universities in Germany and worldwide.
Long-term cooperation exists with the Tohoku University in Sendai, the Fudan University Shanghai and the Shanghai Jiao Tong University. Fraunhofer ENAS and the Tohoku University have been cooperating in the field of new materials for microelectronic systems for many years. To intensify their cooperation, they started the Fraunhofer Project Center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University" in 2012. It is not only a platform for common research and development activities but also a platform for offering R&D services to industry.

A very strong cooperation exists with the Chemnitz University of Technology. This cooperation ensures synergies between the basic research conducted at Chemnitz University of Technology and the more application-oriented research at the Fraunhofer ENAS. The main cooperation partner at the Chemnitz University of Technology is the Center for Microtechnologies. The cooperation results in a joint use of equipment, facilities and infrastructure as well as common research projects. Printed functionalities and lightweight structures are topics of the cooperation with the Faculty of Mechanical Engineering. The department Advanced System Engineering, located in Paderborn, continues the close cooperation with the University Paderborn especially in the field of electromagnetic reliability and compatibility, wireless energy and data transmission technology and wireless sensors nodes for mechanical engineering.

www.zfm.tu-chemnitz.de

Multiple excellent – cooperation within clusters of excellence

Germany funds Excellence Initiatives for Cutting-Edge Research at Institutions of Higher Education. In 2012, the grants committee decided on the proposals of the third round of the excellence initiative. All selected proposals are funded over a time period of five years starting from November 2012.
Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology work in two clusters of excellence, which have been accepted in June 2012.

Merge Technologies for Multifunctional Lightweight Structures – MERGE

The Cluster of Excellence of the Chemnitz University of Technology "Merge Technologies for Multifunctional Lightweight Structures - MERGE" is coordinated by Prof. Kroll, Director of the Institute of Lightweight Structures at the Faculty of Mechanical Engineering. The main object of the cluster is the fusion of basic technologies suitable for mass-production, comprising plastic, metal, textile and smart systems for the development of resource-efficient products and production processes. In order to make the products much more intelligent, microsystems,

www.tu-chemnitz.de/MERGE

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

photo: Fraunhofer IPMS


photo: Fraunhofer IPMS

smart sensors, actuators and electronics will be integrated. Currently, there are more than 100 researchers and technicians working in the six domains of the cluster. Fraunhofer ENAS is mainly working in research area D named Micro and Nano Systems Integration.

Center for Advancing Electronics Dresden cfaed

www.tu-dresden.de/cfaed

"The Center for Advancing Electronics Dresden cfaed" aims at inducing breakthroughs in promising technologies which may complement today's leading CMOS technology, in new innovative systems and architectures. Research teams of 57 investigators from 11 institutions are cooperating interdisciplinary in different scientific fields. Scientists of the Center for Microtechnologies of Chemnitz University of Technology and Fraunhofer ENAS work on two paths, the carbon path and the biomolecular assembled circuit (BAC) path. Within the carbon path, CNT FETs have been developed and prototyped using a wafer-level technology. Their application is focused on analoge high-frequency circuits. Within the BAC path, Chemnitz works on structuring on wafer-level which is necessary for the self-assembly of deoxyribonucleic acid.

Cooperation within Fraunhofer-Gesellschaft

Since its foundation, Fraunhofer ENAS is part of the Fraunhofer Group for Microelectronics (VμE). Moreover, Fraunhofer ENAS is a member of the Fraunhofer Alliances Nanotechnology, AutoMOBILE Production and Textiles.
Together with the other institutes of the Fraunhofer Group for Microelectronics, Fraunhofer ENAS participates in the Heterogeneous Technologies Alliance, which is a novel approach for creating and developing microtechnologies, nanoelectronics and smart systems for next-generation products and solutions together with CEA-Leti, CSEM and VTT.
Fraunhofer-Gesellschaft is tackling the current challenges facing industry directly. Its lighthouse projects put the focus on strategic objectives with a view to developing practical solutions from which economies, such as Germany's, can benefit. In addition, Fraunhofer ENAS is coordinating the new lighthouse project "Go Beyond 4.0", for more details please see chapter Smart Production. Within the lighthouse project "Theranostic Implants", Fraunhofer ENAS is working together with 11 other Fraunhofer institutes on strategic objectives.
Moreover, Fraunhofer ENAS is working in two high-performance centers. One of them, the high-performance center "smart production" is currently in the course of formation. The other one, the high-performance center "functional integration of micro- and nanoelectronics" has started its work in 2016.

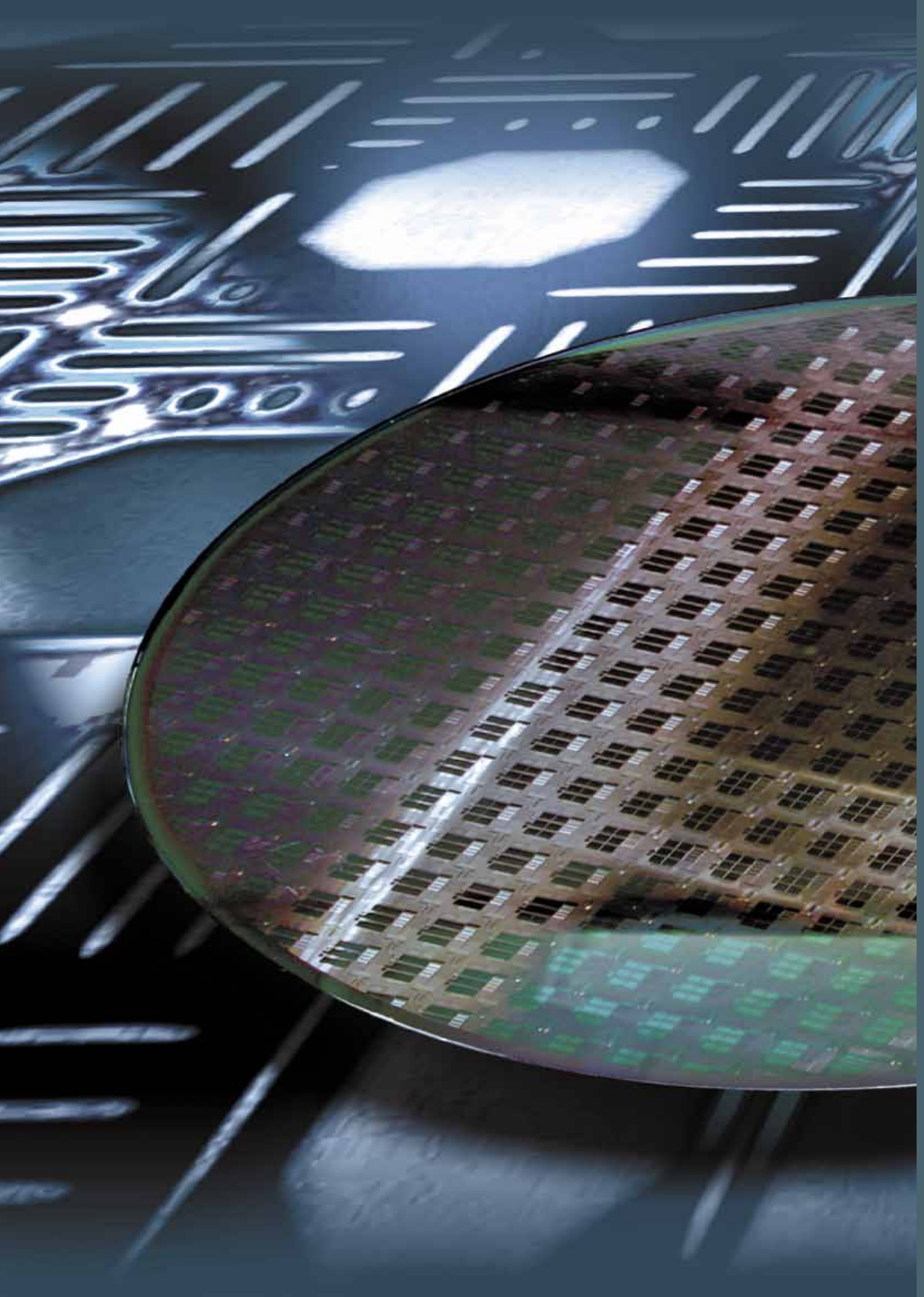
High-Performance Center "Functional Integration of Micro-/Nanoelectronics"

www.leistungszentrum-mikro-nano.de

Nanotechnology and microelectronics permeate all areas of life. Due to the Internet of Things and Industry 4.0, the demand on components and systems increases. Future components not only have to integrate even more functions, they need to be much smaller and need to be connected to the network.
The competitiveness and innovative power of companies in the electronics industry depends on their access to the latest technological developments. Thereby, a rapid and effective development of solutions is required for all aspects of the application.
The Fraunhofer concept of high-performance bundles and combines the competences of institutes and universities in a certain region. In particular, the high-performance center pilot project "functional integration of micro- and nanoelectronics" bundles the experiences of the four Fraunhofer institutes Fraunhofer ENAS, Fraunhofer IPMS, the branch EAS of Fraunhofer IIS and the Dresden department ASSID of the Fraunhofer IZM as well as the Technische Universität Dresden, Chemnitz University of Technology and the Dresden University of Applied Sciences in the field of micro and nanoelectronics.
The aim is to strengthen the competitiveness and innovation power of medium-sized companies in Saxony by means of a rapid transfer of research results into innovative products in the fields of sensor and actuator technology, measurement technology as well as in machine and plant engineering.
Three pillars structure the center: First, the partners develop a common technology and development platform for innovative components and systems, thus, the basis for all further work. Currently, they carry out development work in the areas of system design, innovative components and manufacturing technologies, heterogeneous system integration and reliability assessment.
In order to strengthen the application orientation, a central office for the marketing of R&D results and technology transfer was established. It is intended to enable companies and partners to quickly and easily access the offered services based on the competences of the partners.
Industry-financed innovation projects are the third pillar, this mean direct industrial contracts with the research partners.
The high-performance center is financed from funds of the Free State of Saxony, the Fraunhofer-Gesellschaft and the industrial partners during the two-year pilot phase.
At the end of the pilot phase, the virtual innovation center will be established due to close networking between the universities, Fraunhofer and regional industry.

photo: iStock (Radachynskyi)

BUSINESS UNITS



MICRO AND NANOELECTRONICS

Micro and nanoelectronics are one of the key technologies of the 21st century. The ongoing downscaling (More Moore), the integration of different functionalities (More than Moore) as well as the development of novel non-silicon based materials (Beyond CMOS) are hot topics. The business unit Micro and Nanoelectronics is focusing especially on:

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

The development of individual processes (metal ALD, CVD, ULK processes, dry etching), novel concepts for diffusion barriers and alternative interconnect architectures for the reduction of parasitic effects (air gaps, alternative ULK integration) are the main focus of this topic.

Modeling and simulation of technological processes, equipment and devices

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

Beyond CMOS and RF devices, integrated circuits and technologies

This topic comprises developments of RF MEMS switches, CNT FETs as well as memristive devices and circuits.

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

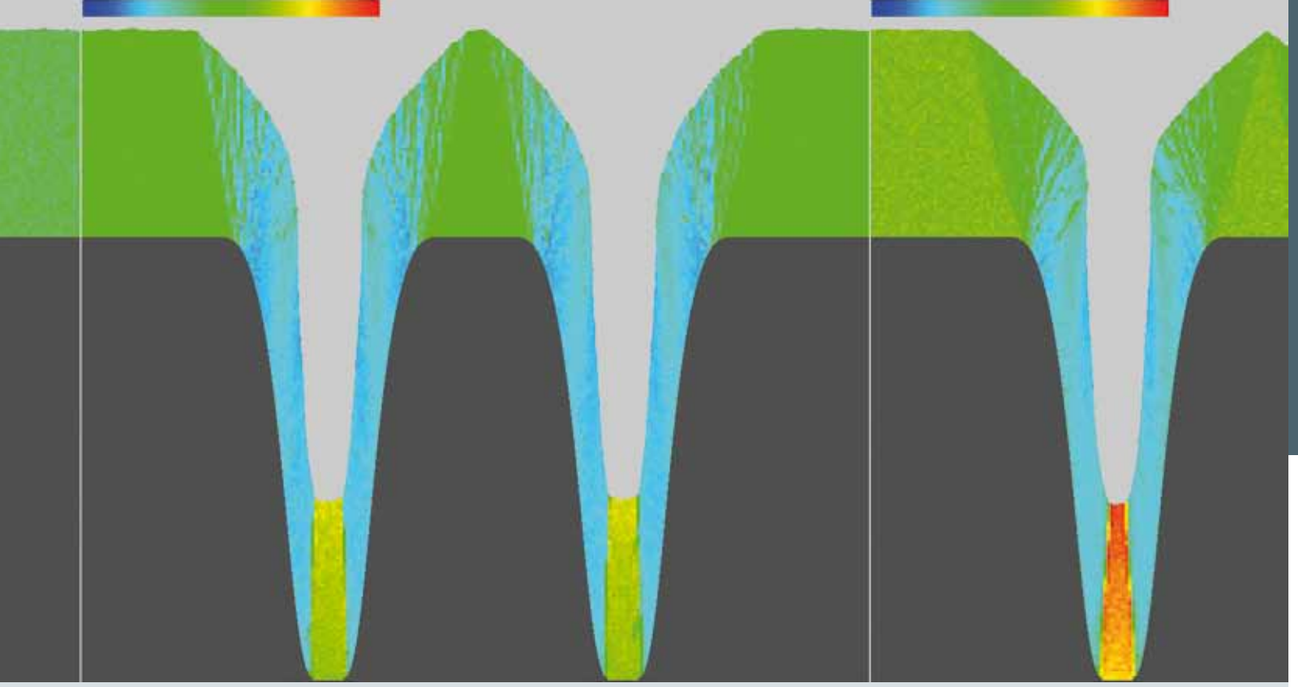
This research and development area focuses on the development of processes for the integration of electronic devices for wafer-level packaging, especially joining and contacting processes, thin film encapsulation and screen printing for metallization and solder.

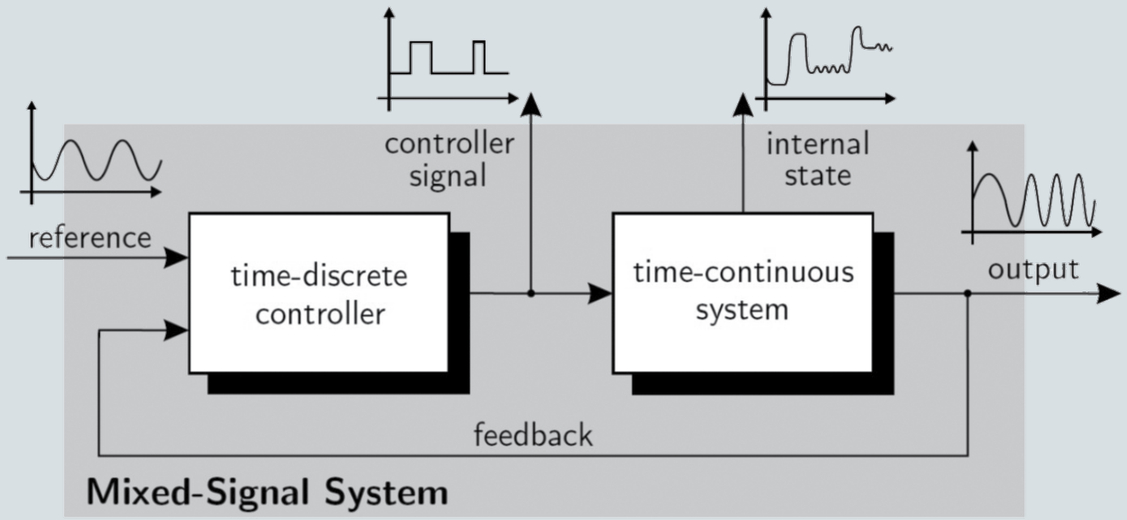
Electromagnetic and thermomechanic characterization and reliability evaluation

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

BUSINESS UNIT MANAGER

Prof. Dr. Stefan E. Schulz
+49 371 45001-232
stefan.schulz@enas.fraunhofer.de





RESEARCH AND DEVELOPMENT

- BACK-END OF LINE AND INTERCONNECTS
- MODELING AND SIMULATION
- BEYOND CMOS AND RF DEVICES

MICRO AND NANOELECTRONICS

SIMULATION OF BARRIER/SEED DEPOSITION FOR THE METALLIZATION OF 28 NM CMOS DEVICES

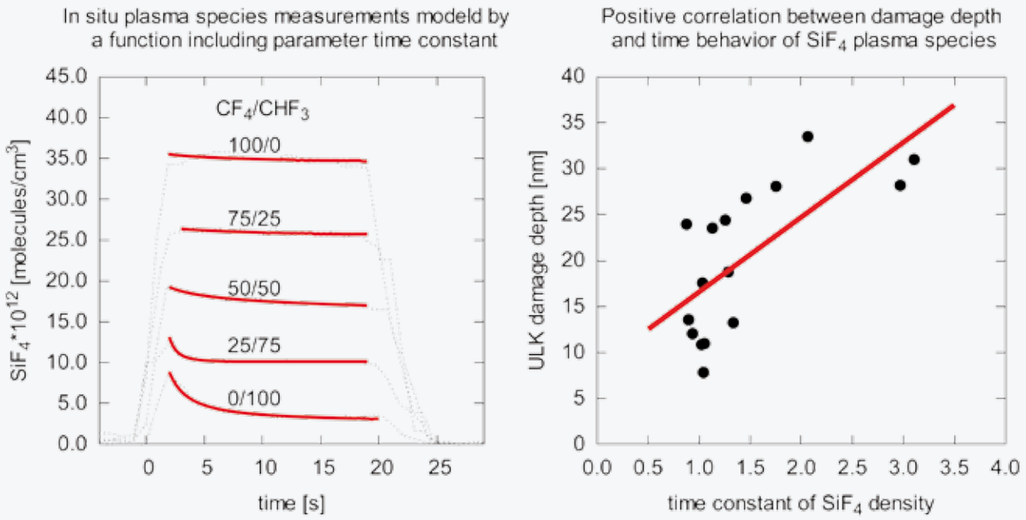
With the ongoing miniaturization of microelectronic devices, new challenges emerge for the production of conformal ultrathin layers using physical vapor deposition (PVD). Narrow trenches, high aspect ratio vias and desired thin films of only a few nanometer thickness across the whole wafer require precise thickness control even on vertical surfaces. At Fraunhofer ENAS, we developed a comprehensive in-house multiscale software suite for the simulation and optimization of every aspect of PVD, from the atomistic surface interactions to the particle transport in the reactor. Recent improvements enable the simulation of PVD on up to 1 µm large surface features with sub-nanometer layer resolution on modern high performance hardware. Through these advancements, we are now able to investigate the full barrier/seed deposition process, such as the TaN-Ta-Cu layer stack, in order to optimize the processes toward time-efficiency, cost-effectiveness and reliability. In the EVOLVE project with the chip manufacturer GLOBALFOUNDRIES, parameters will be identified which yield an optimal barrier/seed deposition process for a wide range of feature geometries in 28 nm CMOS devices.

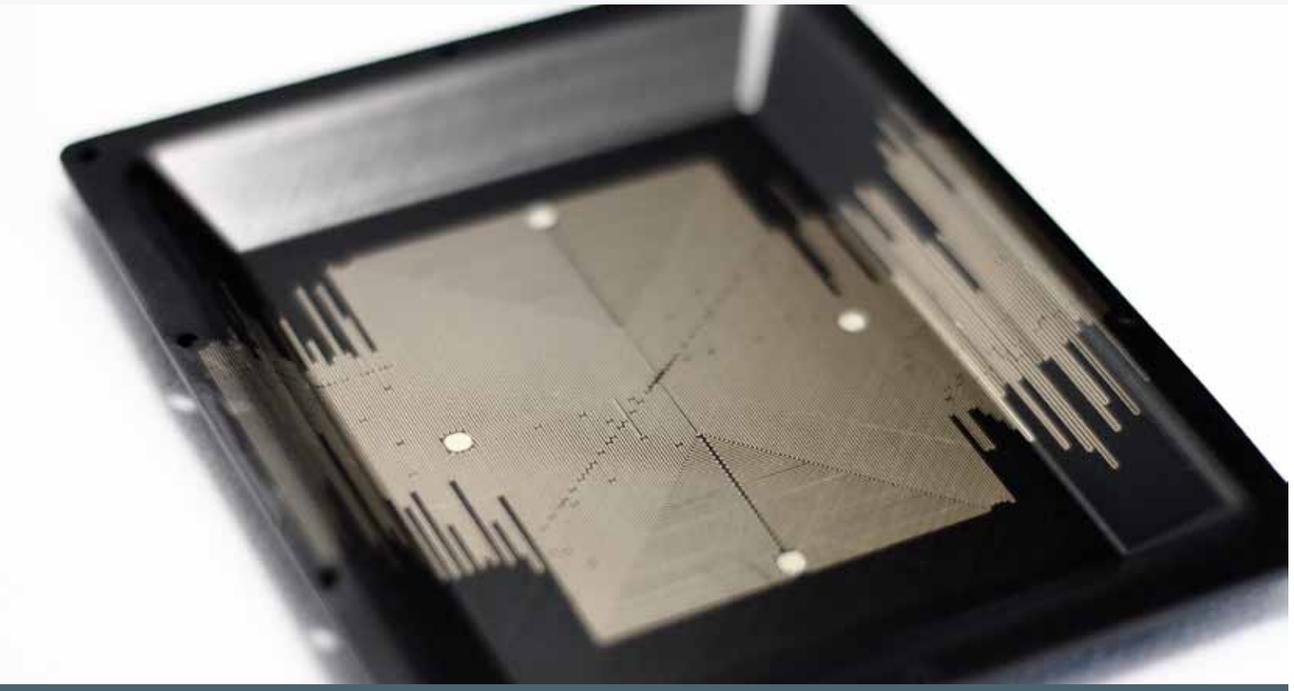
EFFICIENT MODELING AND SIMULATION OF MIXED-SIGNAL PWM SYSTEMS

With increasing complexity of modern electronic systems, their design becomes more challenging. Indeed, electronic systems integrate more and more capabilities based on digital, analog and mixed-signal components that realize power, signal processing and wireless communication functions. However, for the exhaustive characterization of such hybrid systems, efficient simulation models are needed. For typical pulse width modulated systems, such as phase-locked loops or motor control devices, appropriate models covering their highly chaotic behavior and taking into account all non-idealities are needed. At Fraunhofer ENAS, a highly efficient modeling method has been developed in order to enable a very fast and accurate simulative characterization of such systems. The idea behind this is to calculate only the events that trigger the system successively. The resulting event-driven simulator allows a very fast estimation of all possible behaviors, giving the engineer the possibility to ensure a robust design by efficiently analyzing the system for a large range of parameter variations.

THERMAL ALD OF METALLIC COPPER ON COBALT FOR ADVANCED INTERCONNECTS

ALD is a potential process for the deposition of various thin films such as diffusion barriers, liner materials and seed layers, which are required for state-of-the-art interconnects. This layer stack consists currently of TaN, Ta and Cu deposited by PVD. Given that cobalt is a possible replacement for the present liner Ta we have investigated the ALD of copper on in vacuo prepared cobalt substrates. A further possible application for thin Cu films on Co is the formation of Co/Cu multilayers for magnetic sensors.
For this $[(^{n}Bu_3P)_2Cu(acac)]$ was applied as precursor together with H_2 as coreactant at 125 °C. In vacuo X-ray photoelectron spectroscopy (XPS) revealed that the contamination of deposited film are oxygen (9.8 mol%) but no carbon or phosphorus are detectable. Besides, the investigation of the sample composition XPS allows the determination of the oxidation state of the deposited material with mainly metallic Cu. Furthermore, the layer growth is substrate enhanced with an initial GPC of 0.025 Å/cycles compared to a GPC of 0.008 Å/cycles after the nucleation phase.





RESEARCH AND DEVELOPMENT

- INTEGRATION AND PACKAGING
- CHARACTERIZATION AND RELIABILITY

MICRO AND NANOELECTRONICS

INVESTIGATION OF ULK ETCHING PROCESSES BY USING PLASMA DIAGNOSTIC AND CORRELATION ANALYTICS

In situ plasma diagnostics are becoming increasingly important to qualify dry etching processes. As part of an ECSEL project, Fraunhofer ENAS is working with a novel method, the quantum cascade laser absorption spectroscopy (QCLAS), to investigate less damaging plasma etching processes for ultra low-k (ULK) materials. Patterning processes of such materials are widely investigated and still a topic of interest. Especially for leading-edge technologies, research institutes and semi-conductor industry undertake great effort to integrate the material in interconnect circuits. One of the main challenges is the chemical modification of the material during patterning, which leads to an increase of the dielectric constant, the well-known damage of ULK materials. In this light, Fraunhofer ENAS is working on approaches to monitor the damage behavior during the patterning process. In preliminary inves-tigations and by using multivariable data analysis methods it was possible to extract the hidden dependency of the plasma specie SiF_4 and the damage of the ULK.

TAMPER RESPONDENT ENVELOPE SOLUTIONS REALIZED BY ADDITIVE MANUFACTURING – SMART PACKAGING SOLUTIONS FOR SECURE APPLICATIONS

The UNSETH project aims to develop and qualify European-based packaging and assembly technologies applicable to both electronic modules and systems-in-package, compatible with low cost secure solutions, tamper detection features and higher tamper resistance.
Security has become a vital part of European electronic products and equipments as they handle sensitive data in uncontrolled environments and they face more and more IPR protection issues, counterfeiting and cloning issues. New applications combine a challenging set of requirements including low-cost, security and tamper-resistance.
To meet the challenging requirements, Fraunhofer ENAS explores new hardware envelope solutions realized by three dimensional conformal conductive multilayer stacks upon non planar packaging parts. Furthermore, 3D embedded devices and active electronic mesh solutions within PCBs are realized by AT&S Austria Technologie & Systemtechnik AG using secure SiP components with active anti-tamper sensors from NANIUM S.A. as well as the combination of all, focusing on both the electronic modules themself as well as the manufacturing process. For the advanced technologies developed in the project, Thales Global Services brings applications for security and checks manufacturability of the technologies. Epoche and Espri S.L.U. is the security evaluation center and proposes a related protection profile. Fraunhofer ENAS evaluates the reliability of the smart envelope and develops prediction capabilities for life limiting failure mechanisms in the design of the security devices.
Together with partners, Fraunhofer ENAS is developing one module of a new security tool box which can be obtained by introducing functionalized packages with three-dimensional conformal conductive multi-layer stack used as tamper resistant envelope. In the proposed method a polymer (parylene) thin film is used as an insulation layer between the conductive multilayers and the interconnect vias are opened by a fine-tuned laser ablation process. The entire process for conductive multilayer fabrication and via filling is performed by aerosol jet printing (AJP) technique. A test program based on high-temperature storage, thermal cycling and pull tests is followed to compare several configurations, whereas today the solution is capable to withstand several hundred temperature cycles in the range of - 55 °C/125 °C and 1000 hours of thermal storage at 125 °C without significant influence toward the overall performance.

SENSOR AND ACTUATOR SYSTEMS

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

Inertial sensors

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

Optical systems/MOEMS

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

Electromagnetic sensors

Multi-dimensional magnetic sensors based on the GMR and TMR effect, respectively, while using ferromagnetic thin films, are in the focus of this topic. However, they can be applied both in the direct measurements of magnetic fields and in the measurement of distance, position and rotation. Furthermore, sensors for near field measurements of electromagnetic fields and determination of radiation characteristics were developed.

Pressure and power transducer

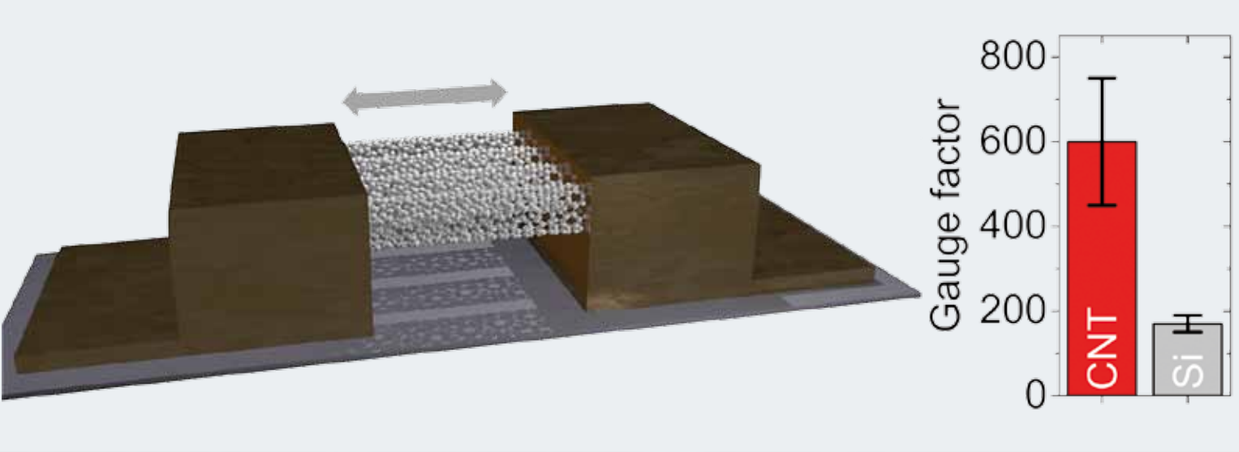
Silicon-based ultrasonic transducer and ambient pressure-sensitive resonators as well as MEMS loudspeaker are developed. Speakers are based on novel materials and technologies, i.e. sputtered metallic glass and printed permanent magnetic layers.

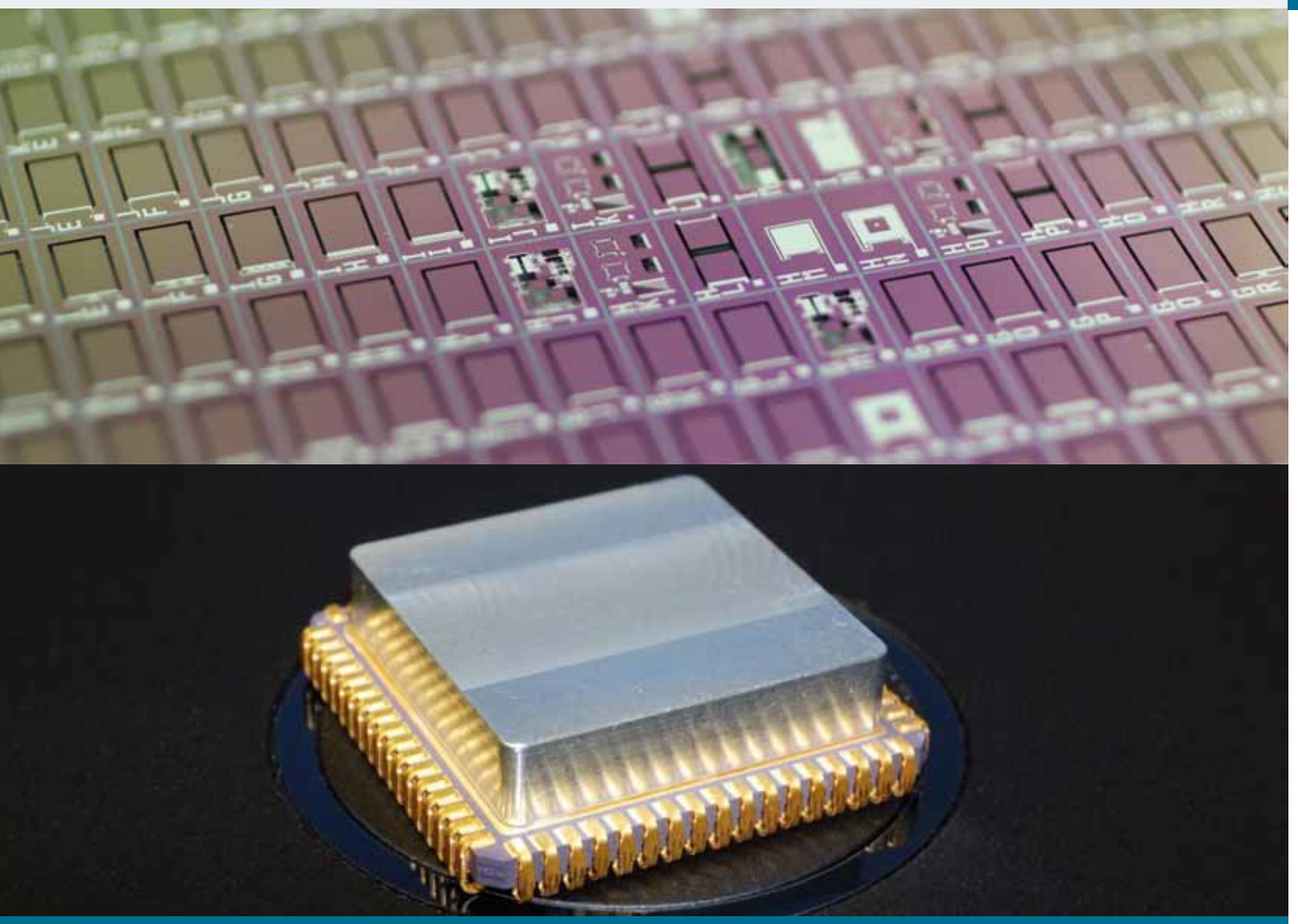
Material and structure sensors

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

BUSINESS UNIT MANAGER

Prof. Dr. Karla Hiller
+49 371 45001-400
karla.hiller@enas.fraunhofer.de





RESEARCH AND DEVELOPMENT

- INERTIAL SENSORS
- PRESSURE AND POWER TRANSDUCER
- MATERIAL AND STRUCTURE SENSORS

SENSOR AND ACTUATOR SYSTEMS

HIGHLY MINIATURIZED STRAIN SENSORS BASED ON GIANT PIEZORESISTIVITY OF CARBON NANOTUBES

Pronounced trends such as Industry 4.0, the Internet of Things or flexible electronics require new and innovative approaches for the scalable integration of novel functional nanomaterials in sensor systems. Due to their unique properties, carbon nanotubes (CNTs) facilitate the realization of strain sensors with superior sensitivity.

In recent years, Fraunhofer ENAS in cooperation with Chemnitz University of Technology developed a technology platform for the scalable integration of CNTs in applications such as MEMS-based sensors. A CNT pressure sensor was realized showing giant piezoresistive gauge factors of up to 600 ($\Delta R\ R_0^{-1}\ \varepsilon^{-1}$) which exceeds the sensitivity of conventional silicon-based strain sensors by the factor of three. Among a variety of conceivable applications for condition monitoring, this new class of sensors also facilitate new device integration strategies for various micro/nano systems as well as flexible electronics.

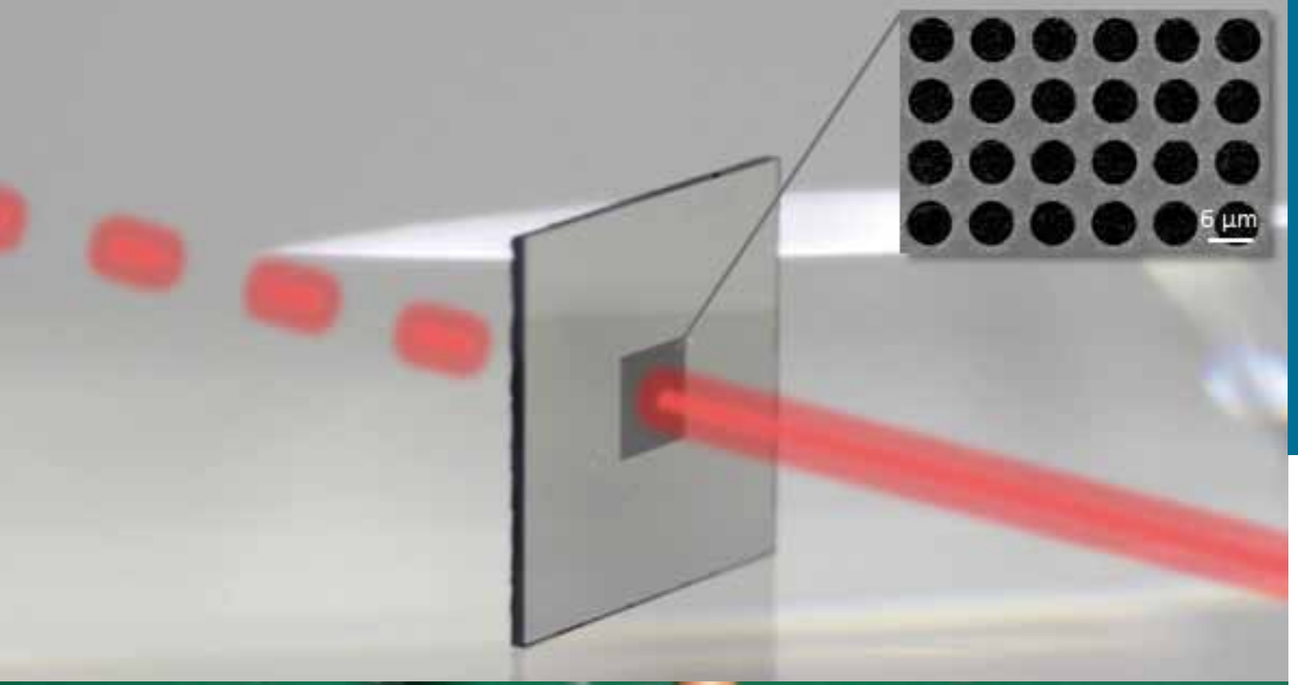
ALUMINUM NITRIDE – INNOVATIVE PIEZOELECTRIC MEMS TRANSDUCER

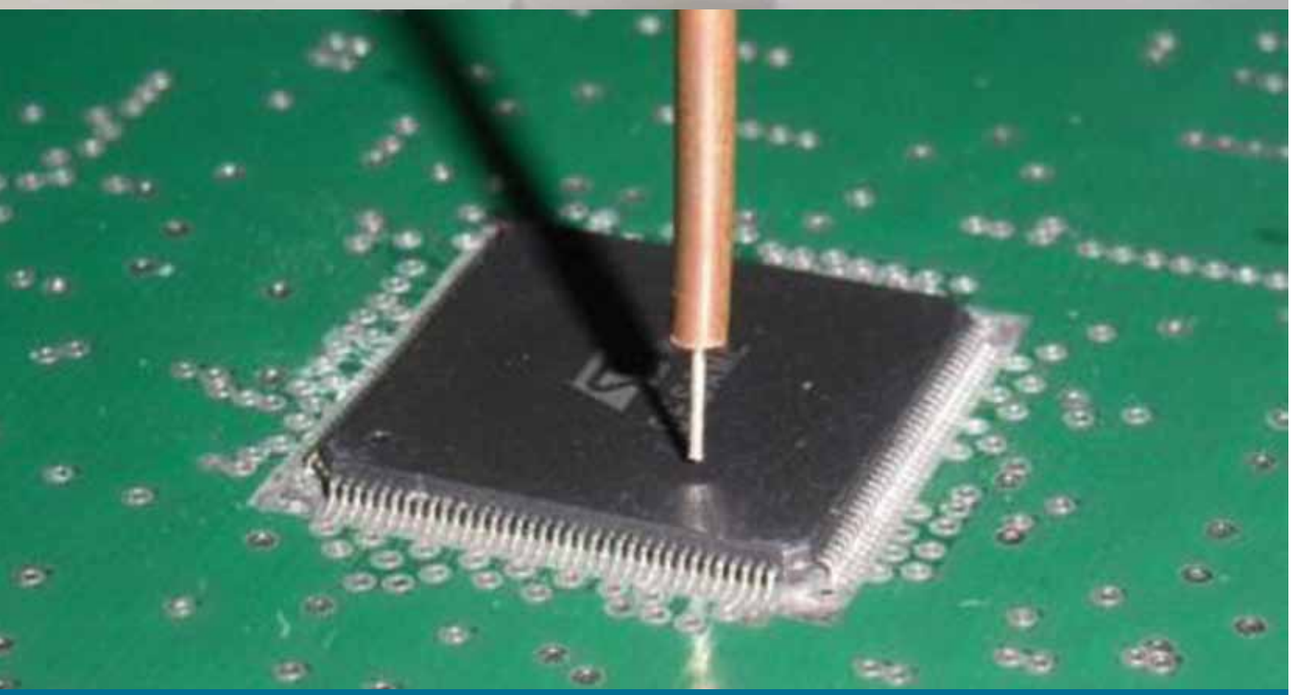
Piezoelectric transducer have high dynamic ranges and high energy densities. The piezoelectric materials generate high mechanical forces and/or have high voltage sensitivities. Therefore, they are perfectly suited for energy harvesting as well as for sensors and actuators, such as inertial sensors, optical systems, acoustic transducer, fluidic sensors, MEMS in medical engineering, Industry 4.0 and many more.

Continuous technological innovations at the research site Chemnitz allow the cost-efficient and reproducible integration of piezoelectric layers in MEMS and enable the use of piezo MEMS on an industrial scale. The piezoelectric material aluminum nitride (AlN) is compatible with microelectronic processes and allows a fast and efficient integration into existing industrial manufacturing processes. In addition, aluminum nitride has no Curie temperature, is nontoxic and shows no ageing effect for the piezoelectric behavior. Wafer-level sputtering enables scaling of the technology up to maturity phase production.

HIGH-PERFORMANCE MEMS GYROSCOPE

One focus of the Fraunhofer ENAS R&D activities is the development of high-precision inertial sensors. In 2016, an industry project related to MEMS gyroscopes has been finished successfully. A gyroscope is an inertial sensor that measures the angular rate without any external references. The challenges of a system with a micromechanical gyroscope are the high requirements with respect to low noise and rate stability. The system itself consists of the mechanical structure that converts the angular rate into a change in capacitances that can be read out with analog front-end electronics. The digital IC of the system is also integrated in the CLDCC68 package and is responsible for demodulation and signal conditioning as well as for the interface to a higher level system. The measurement range of the angular rate sensor is ± 500 °/s with a resolution of 0.0014 °/s (5 °/h) at a data output rate of 2000 Hz. The gyro-specific values for bias instability and angle random walk are < 5°/h and < 0.1°/√h, respectively.





RESEARCH AND DEVELOPMENT

- OPTICAL SYSTEMS/MOEMS
- ELECTROMAGNETIC SENSORS

SENSOR AND ACTUATOR SYSTEMS

MICRO-OPTICAL SHUTTER WITH SUBWAVELENGTH-STRUCTURED SURFACE FOR THERMAL INFRARED

Electrically actuated micro-optical shutters are perfectly suited for ultra-fast, digital modulation of broadband, thermal infrared sources. Even highly optimized micro-thermal infrared emitters, designed for application in miniaturized absorption spectrometers, are limited by their thermal heat capacity to modulation frequencies of several 10 Hz. Higher actuation frequencies lead to a strong decrease in modulation contrast and limit the usability in spectroscopic applications. Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology developed a micro-optical shutter that realizes modulation frequencies of more than 1000 Hz, giving highly miniaturized broadband absorption spectrometers a new application perspective. Technically, a subwavelength-structured, ultra-durable membrane that is made of a stack of high tensile stress LP-CVD silicon nitride and aluminum, is electrically switched between a high reflective and a high transmissible operation state. The micro-optical shutter is working in the thermal infrared between 8 µm and 11 µm wavelength. It was successfully tested with more than 10 million cycles of operation without failure. An example chip is shown in the upper figure. The chip-size is 8.5 mm x 8.5 mm x 0.3 mm (width x length x thickness), with an optical aperture of 2 mm x 2 mm.

NEAR FIELD ELECTROMAGNETIC SENSORS

New efficient power electronic components require reduced switching times. This increases the produced disturbances and the systems become more sensitive to electromagnetic compatibility (EMC) problems. By using appropriate simulation tools, some EMC issues can be predicted. However, this is it not always possible since the ratio between the biggest dimension (PCB) and the smallest structure (bond wire) differ by several orders of magnitude. Indeed, the radiating features directly depend on the switching behavior and the geometric structure.

The near field sensing technique allows to mitigate this problem by precise detection of weak electric/magnetic fields within the µm resolution. Furthermore, it can be employed to determine potential electromagnetic inference (EMI) sources locally and spectrally. In addition, it offers the designer the possibility to quickly identify and correct conception faults at early design stages.

Beside the EMI issues, the high and wide-band sensitivity of the developed near field sensing system allows the electromagnetic analysis of security-relevant systems such as smart cards, showing the weaknesses of such systems and allowing the elaboration of appropriate countermeasures.

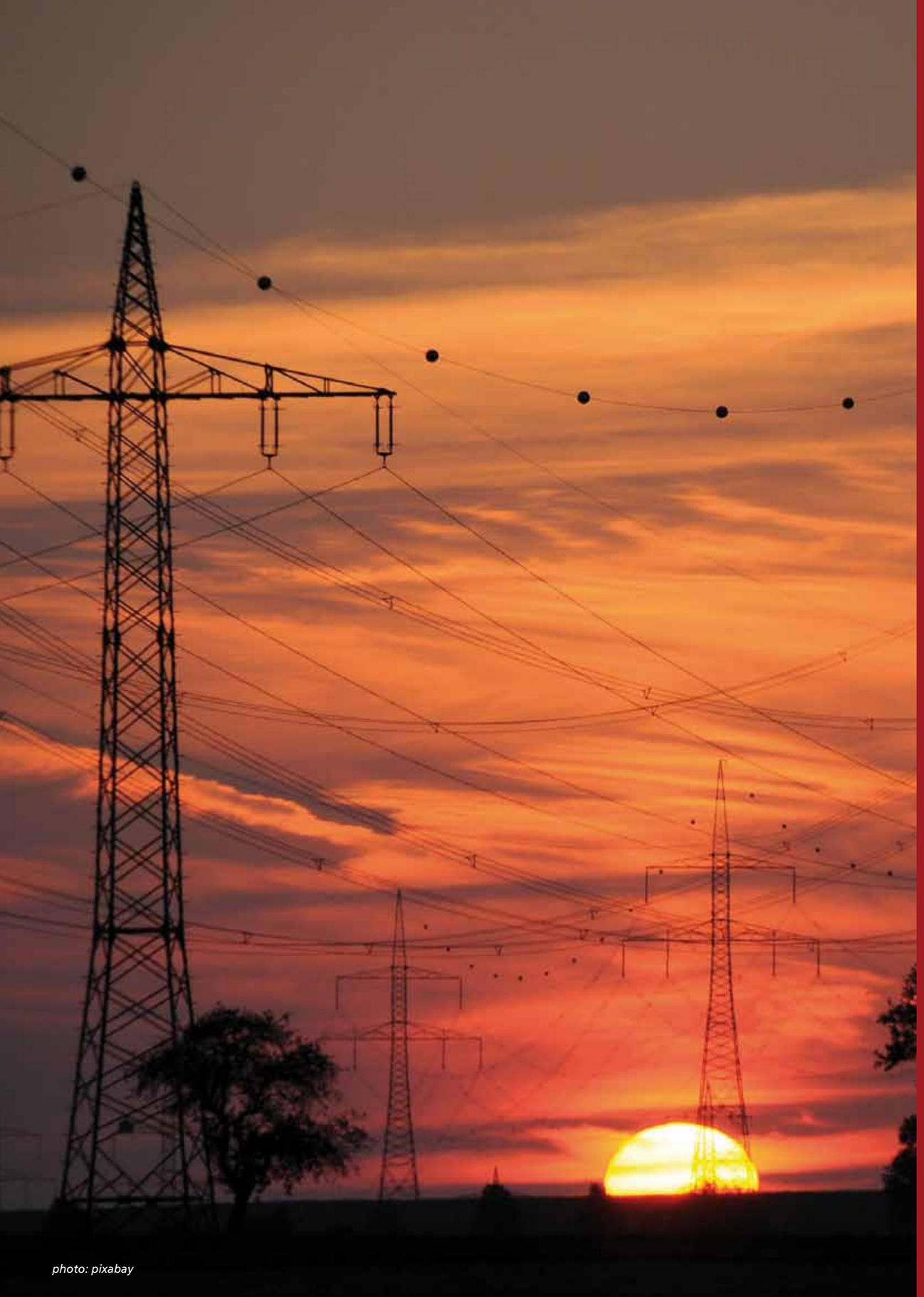


photo: pixabay

TECHNOLOGIES AND SYSTEMS FOR SMART POWER AND MOBILITY

The business unit Technologies and Systems for Smart Power and Mobility comprises the transfer of know-how and technology for the energy supply of mobile devices and vehicles (electro mobility), for the reduction of power consumption of vehicles by integration of actuators and sensors into lightweight structures, and for electric grid monitoring.

Fraunhofer ENAS is pursuing different approaches to wireless transmitting power supply systems for low-power (up to 100 Watt) and for high-power applications. Moreover, the design of flexible, low-cost batteries and the fabrication technology are developed. In the field of electromobility, Fraunhofer ENAS focuses on the reliability of battery management systems with integrated sensors.

The activities in the field of integration of actuators into light weight structures for power saving focus on active flow control. It aims to influence the aerodynamics of aircrafts and vehicles. A further aspect is the technology development for the integration of sensors for Structural Health Monitoring (SHM) into light weight structures.

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

BUSINESS UNIT MANAGER

Dr. Steffen Kurth
+49 371 45001-255
steffen.kurth@enas.fraunhofer.de

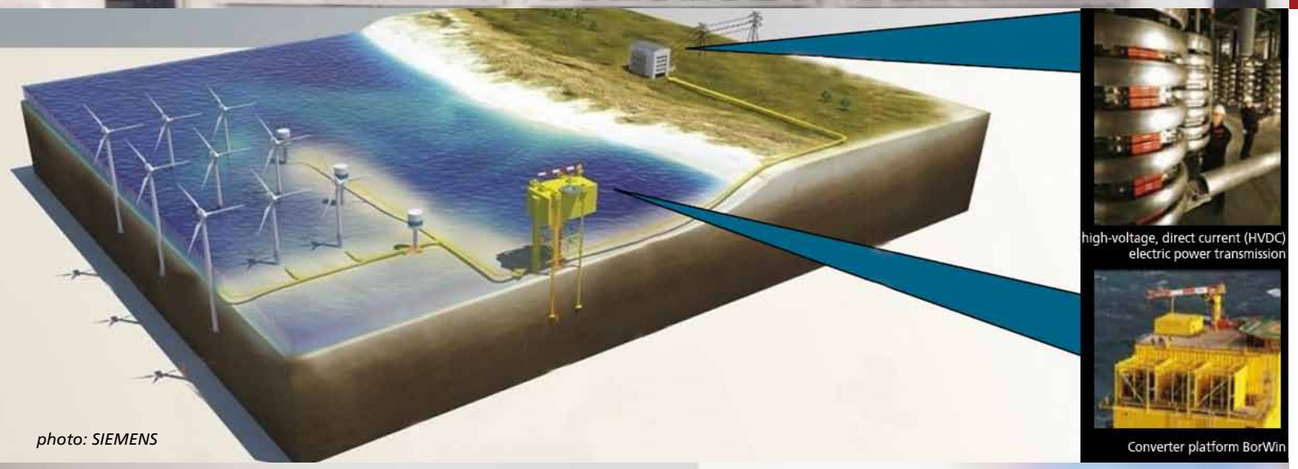
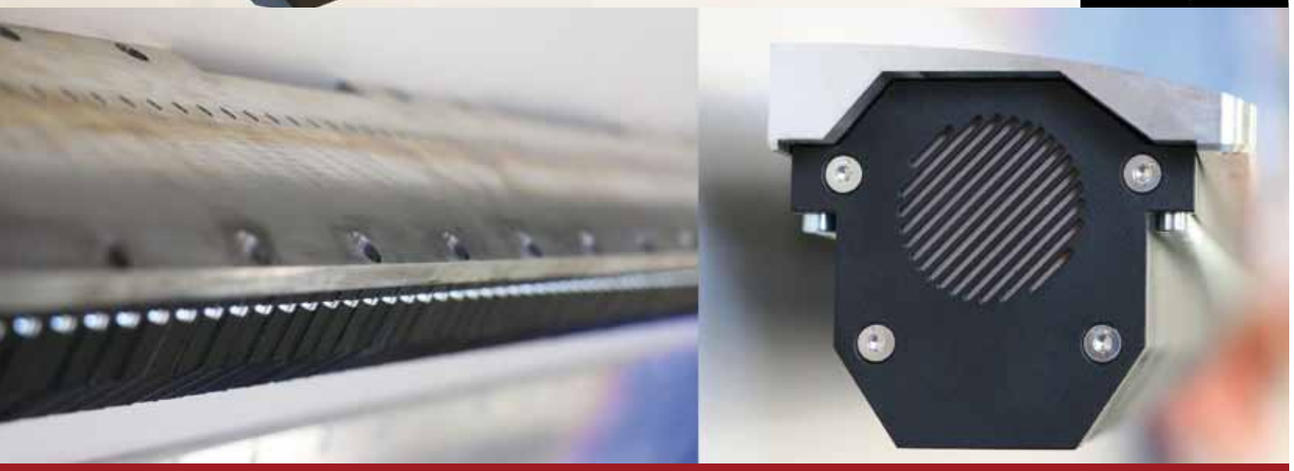


photo: SIEMENS

high-voltage, direct current (HVDC) electric power transmission

Converter platform BorWin



TECHNOLOGIES AND SYSTEMS FOR SMART POWER AND MOBILITY

RESEARCH AND DEVELOPMENT

- NETWORK MONITORING
- REDUCTION OF POWER CONSUMPTION
- ELECTROMOBILITY
- POWER SUPPLY

FLEXIBLE, PRINTED THIN FILM BATTERIES WITH INCREASED DISCHARGE CURRENT

Fraunhofer ENAS has been working on the production of printed primary batteries and application developments in close cooperation with the Chemnitz University of Technology for 10 years. Primary batteries have the advantage that they are fully charged after the manufacturing process and can be used immediately. Form (so far 1 cm² to 300 cm² in size realized) and voltage (1.5 to 30 V) can be varied within wide limits. The capacity for a single cell is up to 5 mAh/cm² and scales linearly with the pattern area. Due to its internal resistance, the established battery solution makes sense for applications that require a maximum of 1 mA of current. Higher currents lead to a significantly lower operating voltage for the consumer. To increase the current flow significantly, the battery cells are manufactured with an additional layer of silver conductor. This allows a reliable voltage supply at 10 mA current flow. This is particularly necessary in the field of sensor systems, since the current demand exceeds 1 mA for a short time and was not feasible with the battery systems available so far.

RELIABLE THERMO-MECHANICAL DESIGN OF HIGH VOLTAGE PLANAR TECHNOLOGY SOLUTIONS FOR SMART WIND POWER MODULES

The developments of smart grid and green energy, in particular the use of wind generators and high voltage direct current transmission requires converters, which allow the transformation of high power at high voltage. High-power insulated-gate bipolar transistor (IGBT) modules are one key component of the hardware platform. In the project EHLMOZ a new buildup and interconnection technology based on silver sintering and electroplated copper interconnects has been developed, denoted as high voltage planar interconnect technology (HVPT). Advantages of the technology result mainly from the replacement of the bonding wires. In particular, no silicone potting is needed. Evaluations of short circuit cases have shown that the reduction of the amount of insulating material can significantly reduce explosion effects and hence, housing stability requirements. One aim of the investigations was to optimize the stress and fatigue behavior of the power stacks by simulation. Fully coupled electrical-thermo-mechanical finite element simulations were used to get realistic transient temperature loadings as well as mechanical stresses. Improved thermal performance of the HVPT could be shown. Simulation studies were made to minimize failure risks of planar structures based on damage modeling. Significant reliability improvements dependent on the materials and geometric features were achieved.

ACTUATORS AND SYSTEMS FOR ACTIVE FLOW CONTROL

Active flow control for aviation and other applications, such as automotive and wind energy systems, can only be realized if efficient and robust actuators are available. Fraunhofer ENAS develops actuators with and without mass flow. Especially the latter, so called synthetic jet actuators, were developed to a higher degree of maturity in the projects AFLoNext and Clean Sky 2. By using novel transducer systems and integration concepts, actuators with outlet velocities larger than 100 m/s were feasible. Moreover, robustness tests were carried out which represent an important step toward application of the actuators. Within the Cluster of Excellence MERGE, Fraunhofer ENAS was able to demonstrate the integration of actuators and the related peripherals into composite materials: Actuators with outlet velocities larger than 100 m/s; new actuating and control concepts; successful robustness tests on actuators; demonstration of the integration of actuators in composites and automobile structures. The achieved results are an important step toward a higher degree of maturity of actuators and actuator systems, thereby creating an important basis for the transfer from aeronautical applications to novel applications in automotive and wind energy systems.

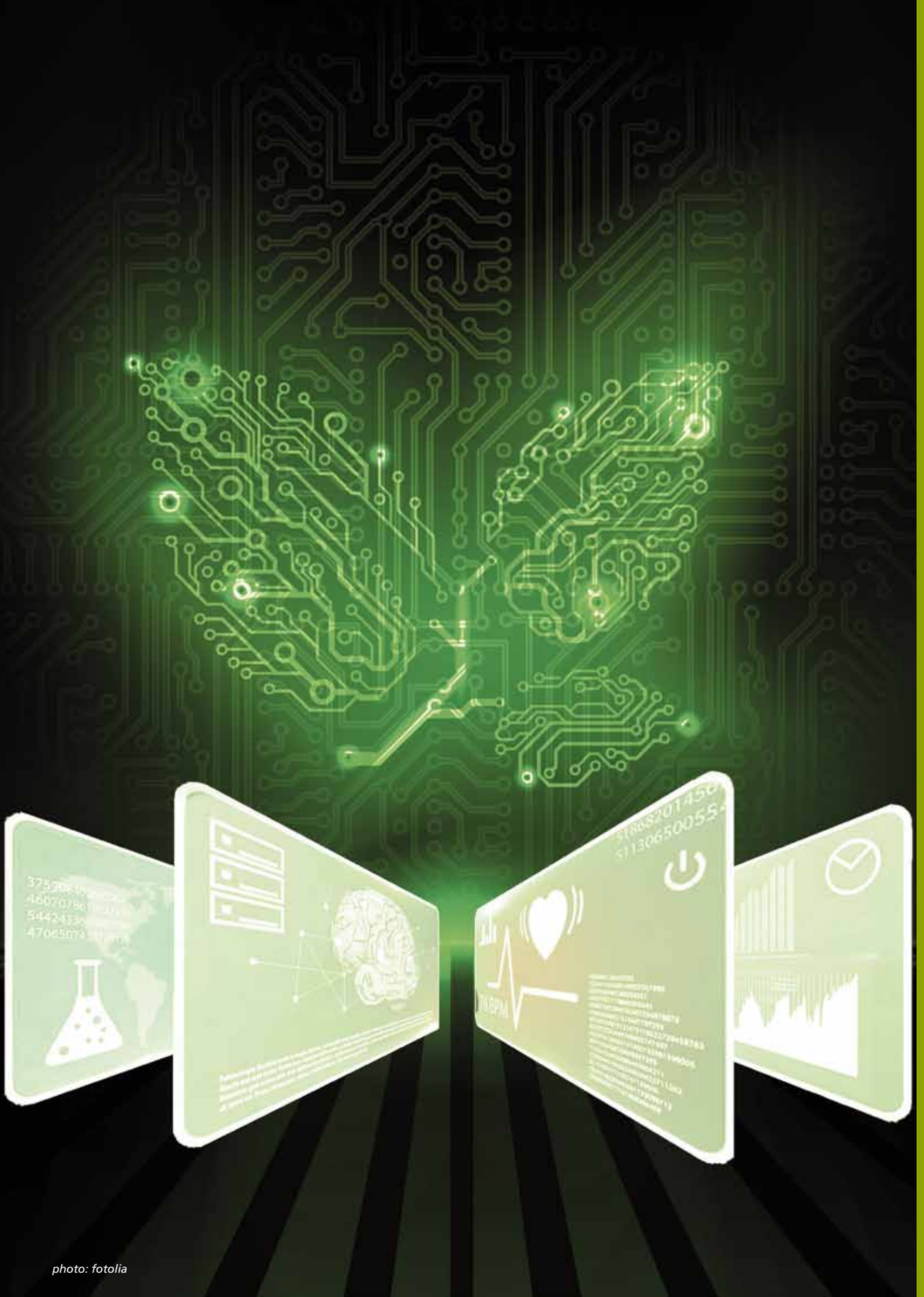


photo: fotolia

TECHNOLOGIES AND SYSTEMS FOR SMART HEALTH

The business unit Technologies and Systems for Smart Health combines R&D activities with applications in the field of health and life sciences. Our research is focused on the technical and technological aspects, especially in using micro and nanotechnologies for applications in the field of medical science, biology, and healthy living.

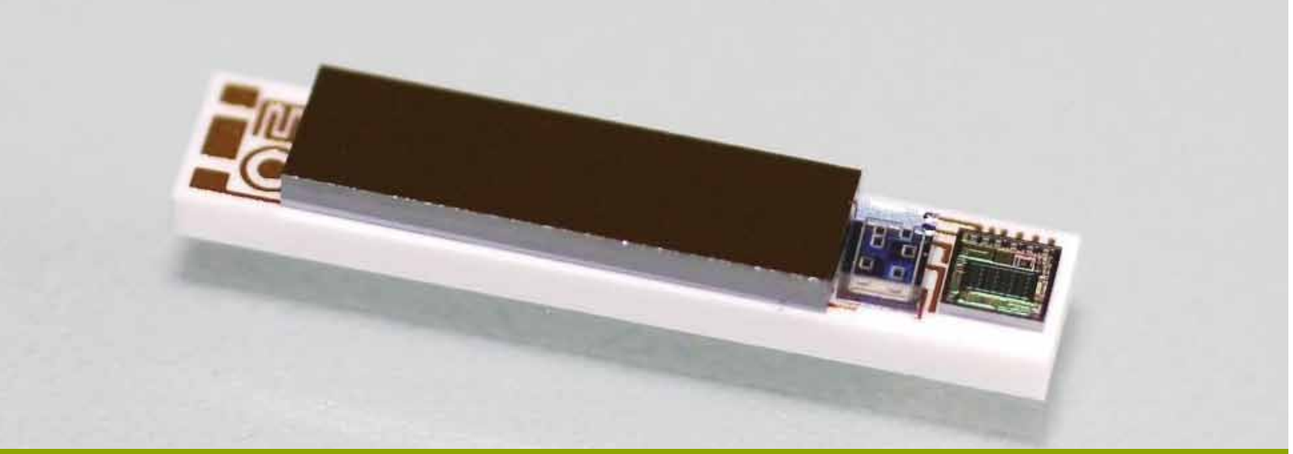
Our research projects include, among others, developments for miniaturized sensor and actuator systems including system integration and biocompatible encapsulation for medical implants. The main motivation for implantable sensors and actuators is the replacement, restoration and improvement of human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

In addition, integrated sensors and actuators can also be utilized in surgical tools and smart medical devices for the monitoring of patients. Main research activities are biocompatible materials, especially for the interface between biological tissue and technical devices as well as the utilization of MRI-compatible materials and wireless data and energy transfer.

Integrated sensor and actuator systems are also applicable within the field of measurement technology and analytics. The research and development activities at Fraunhofer ENAS include, among others, microfluidic and spectroscopic analysis systems as well as wireless data and energy transfer.

BUSINESS UNIT MANAGER

Dr. Mario Baum
+49 371 45001-261
mario.baum@enas.fraunhofer.de



RESEARCH AND DEVELOPMENT

- MICROFLUIDIC AND SPECTROSCOPIC ANALYSIS
- MEDICAL DEVICES
- IMPLANTS

TECHNOLOGIES AND SYSTEMS FOR
SMART HEALTH

POINT-OF-CARE TESTING FOR ANTIBIOTIC RESISTANCE

Europe and India are facing an epidemic of obesity and Type 2 diabetes. Resulting from a reduction of protective sensation, type 2 diabetics are at higher risk of developing diabetic foot ulcers, i.e. chronic wounds with delayed wound healing caused by bacterial infections. For a proper treatment a fast identification of dominant species and existing antibiotic (AB) resistances is crucial. In the project „Microfluidic Based Detection of Microbial Communities and Antibiotic Responses in the Management of Diabetic Foot Ulcers" (MIDARDI) Fraunhofer ENAS joined a team of German (Fraunhofer IZI-BB, BiFlow systems GmbH) and Indian (Manipal University, Achira Labs) experts. The consortium is funded by the BMBF and the Indo-German Science and Technology Centre (IGSTC). The task of Fraunhofer ENAS in the project is the integration of a fast and reliable sample preparation including rapid thermal processes into a microfluidic lab on chip system.

DEVICES FOR NEUROCONTROL AND NEUROREHABILITATION (DENECOR)

Incompatibility of therapeutic implants and medical devices with key diagnostic tools such as Magnetic Resonance Imaging (MRI) systems has impaired widespread application of implantable electronics and neuromodulation systems. As a result, these devices are considered as the last therapy option, despite their significant therapeutic or health-check benefits for the patient. With a consortium of 21 partners from 7 EU countries, the DeNeCoR project aimed at addressing this incompatibility issue and demonstrating the coexistence of therapeutic and diagnostic systems by the development of new MR compatible sensors and devices. As part of this project Fraunhofer ENAS, in collaboration with other partners, has developed a MR compatible micro endoscope capable of simultaneously capturing live camera as well as ultrasound images of the target tissue. This demonstrator is intended as an intraoperative diagnostic tool for brain surgery and would help the surgeon to better visualize small areas of the target tissue and more accurately plan the therapeutic procedure.

THERANOSTIC IMPLANTS – A FRAUNHOFER LIGHTHOUSE PROJECT

Theranostic implants are complex implantable medical products, which combine both diagnostic and therapy features in one system. Vital parameters are observed continuously to obtain guidance for therapeutic intervention.
Within the Fraunhofer Lighthouse project 12 Fraunhofer Institutes are working cooperatively on three subprojects focused on skeletal, cardiovascular, and neuromuscular demonstrators.
Fraunhofer ENAS is researching within two subprojects on miniaturized sensors, energy transfer and storage, communication, and last but not least on packaging and integration aspects as well as biocompatible encapsulation technologies.
For the cardiovascular demonstrator a multisensor module was developed consisting of a pressure, an acceleration, a temperature, a voltage, and an impedance sensor. In order to achieve the required miniaturization the acceleration and the pressure sensor are made in a MEMS (micro-electro-mechanical system) technology. Any other sensors elements are integrated in the main ASIC. All components are mounted on a multilayer ceramic interposer module that is also containing a coil as an inductive link.
This work was carried out by the Fraunhofer Institutes IMS and ENAS. Here, the design of the really tiny acceleration sensor, the sensor fabrication, and the integration and encapsulation was done by Fraunhofer ENAS. Fraunhofer IMS developed the electronics for controlling the MEMS sensors, the coil, and provide the integrated circuit. Now the first demonstrators were silicone molded and tested for implantation.

photo: RF123 (Oliver Sved)

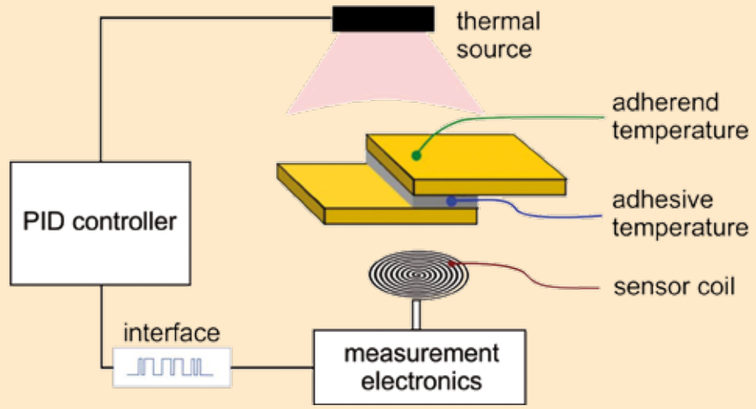
TECHNOLOGIES AND SYSTEMS FOR SMART PRODUCTION

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

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

BUSINESS UNIT MANAGER

Dr. Ralf Zichner
+49 371 45001-441
ralf.zichner@enas.fraunhofer.de



RESEARCH AND DEVELOPMENT

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

TECHNOLOGIES AND SYSTEMS FOR
SMART PRODUCTION

DIGITAL MANUFACTURING IN MASS PRODUCTION

Beyond Industry 4.0 (automation and digitalization of manufacturing), the markets are looking for technologies to mass manufacture customized and individualized products. To provide the industry with the needed technologies a new innovative Fraunhofer project called "Go Beyond 4.0" was granted in 2016.

The concept is to integrate digital manufacturing processes like inkjet printing and laser manufacturing modularly in existing mass manufacturing environments. With this concept, the manufacturing of a huge variety of products can be mass manufactured down to batch size one.

Within the project, digital manufacturing in mass production will be demonstrated in three applications which addresses the major markets automotive, aerospace and lighting: smart door, smart wing and smart luminaire.

The Fraunhofer Institute for Electronic Nano Systems ENAS coordinates the consortia consisting of the Fraunhofer Institutes ENAS, IFAM, ILT, IOF, ISC and IWU. These institutes are leaders in the areas of mechanical engineering, digital printing, electro technique, photonics and material sciences.

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

WIRELESS SENSOR SYSTEM FOR MEASURING OF ADHESIVE TEMPERATURES

In industry more and more product components are assembled by adhesives. At room temperature adhesives usually need several hours or days to cure. By heating up the adhesive this time can be significantly shortened to some seconds or minutes. The material dependent ideal temperature variation for curing must not exceed an interval of ± 10 °C, otherwise the quality of the junction decreases dramatically. Therefore, the knowledge of the temperature of the adhesive is essential for the control system to obtain an optimal curing process. To measure wirelessly the adhesive's temperature, an inductive measurement technique has been developed and tested. By using magnetic sensitive particles as filling material for the adhesive and the corresponding Curie effect, the temperature dependent permeability of these sensor particles can be measured, giving direct information about their temperature. With an appropriate mixture of ferrites a temperature span from 135 to 170 °C can be monitored. Within this span the inductance of a suitable coil sensitively changes and gives reliable information about the curing temperature.

WIRELESS SENSOR SYSTEM FOR STRUCTURAL HEALTH MONITORING

To support the industry with smart production technologies a radio frequency identification transponder (RFID tag) for a structural health monitoring application of industrial rubber belts was developed. These belts are widely used for power transmission applications or for goods transportation in various industries. Integrated RFID tags can help to optimize the logistic value chain and to sense and transmit wirelessly the changes in physical parameters of the rubber belts.

The scientific challenges are related to the required reliability of the wireless sensor functionality. Especially various issues such as unknown dielectrical parameters of rubber materials, bending effects and high-temperature vulcanization of rubber belts become a challenge. Besides, a coped challenge was to overcome damages of the RFID tag itself during the integration into a rubber belt by vulcanization. Another solved challenge was to design an optimized antenna which is able to work inside a rubber belt of unknown dielectric material properties. For simulation of the antenna properties a 3D model was used.

176 PUBLICATIONS

82 CONFERENCES

27 LECTURES
3 DISSERTATIONS

12 PATENTS

18 EXHIBITIONS
AND TRADE FAIRS

72 MEMBERSHIPS

photo: MEV Verlag GmbH

HIGHLIGHTS

DISSERTATIONS


photo: Fraunhofer-Gesellschaft


photo: Cornelia Schubert

Dissertations in 2016

January 20, 2016

PhD:	Marco Haubold
Topic:	Erarbeitung einer Fertigungstechnologie und Charakterisierungsmethode für die Herstellung hochsensitiver Vibrationssensoren unter Nutzung des Mikroschweißprozesses
Institution:	Chemnitz University of Technology

October 17, 2016

PhD:	Chris Stöckel
Topic:	Piezoelektrische Aluminiumnitrid-Dünnschichten für mikroelektromechanische Systeme
Institution:	Chemnitz University of Technology

December 16, 2016

PhD:	Dileep Dhakal
Topic:	Growth Monitoring of Ultrathin Copper and Copper Oxide Films Deposited by Atomic Layer Deposition
Institution:	Chemnitz University of Technology

Highlights in 2016

On April 20, 2016, the researcher Dr. Ralf Zichner, Printed Functionalities department of Fraunhofer ENAS, has been awarded as one of the first graduates of the Fraunhofer research management program. He received his award from Fraunhofer President Prof. Reimund Neugebauer and Executive Vice President Technology Marketing and Business Models Prof. Georg Rosenfeld. Based on his newly acquired knowledge, he was able to work as business unit manager of the new business unit smart production during the strategy process. Within this new business unit, Fraunhofer ENAS is addressing the automation and digitization of production. The focus is on providing of technologies for flexibilization and sensor-based monitoring of production.

The director of the Fraunhofer project center NEMS/MEMS devices and manufacturing technologies at Tohoku University Prof. Masayoshi Esashi has been honored with IEEE Jun-ichi Nishizawa Medal in New York on June 18, 2016. This medal was established in 2002 in honor to a former president of Tohoku University, Prof. Jun-ichi Nishizawa's outstanding achievements. The presentation of this medal recognizes Prof. Esashi's numerous world-leading achievements, ranging from fundamental studies to the commercialization of MEMS.

For the sixth time, the Fraunhofer Institute for Electronic Nano Systems ENAS awarded the Fraunhofer ENAS Research Award to a scientist for his excellent scientific research results in microelectronics and/or micro system technologies. On December 20, 2016, the engineer and scientist Frank Roscher has been awarded. Focus of his work is the deposition of nanoparticle inks on different materials by aerosol jet printing.

www.enas.fraunhofer.de/en/news_events

CONFERENCES

photo: Kristin Schmidt

Honorary colloquium and honorary symposium in remembrance of Prof. Thomas Gessner

On September 8, 2016, more than 550 guests from Germany, Europe, China and Japan attended the honorary colloquium and honorary symposium in remembrance of Prof. Thomas Gessner in Chemnitz. The director of the Center for Microtechnologies and Professor of Microtechnology at Chemnitz University of Technology and director of the Fraunhofer Institute for Electronic Nano Systems ENAS passed away suddenly and unexpectedly in Tokyo on May 25, 2016, at the age of 61. Chemnitz University of Technology and Fraunhofer ENAS invited partners from industry, science and politics, former doctoral students, employees and friends to honor and commemorate him in a colloquium. The subsequent scientific symposium focused on smart systems integration from the different points of view. Thomas Gessner represented like nobody else represents different activities in the context of smart systems, especially in Europe. Professor Gessner not only belonged to the founders of EPoSS, the European Platform on Smart Systems Integration, but he also launched the Smart Systems Integration Conference and Exhibition initially in 2007. This scientific conference was successfully established under his supervision as a chairman and developed into a competitive international conference.

International conferences and workshops

The 10th Smart Smart Systems Integration Conference and Exhibition was held March 9–10, 2016, in Munich. For the fourth time, the conference was co-located with the European Technical Congress of MEMS and Sensor Industry Group. At the SSI2016 more than 290 attendees discussed the key topics smart systems, hardware of the Internet of Things and printed, large area, flexible and stretchable electronics as well as design, manufacturing technologies, integration technologies and applications.

The 12th Fraunhofer Symposium in Sendai was held on November 24, 2016. The symposium was focused on smart integrated systems for different applications and served as honorary symposium in remembrance of Prof. Thomas Gessner in Sendai.

Chemnitz workshops on nanotechnology, nanomaterials and nanoreliability

The Chemnitz workshop series on nanotechnology, nanomaterials and nanoreliability have been successfully continued in 2016.
The department System Packaging invited to the workshop “System Integration Technologies” on June 14 and 15, 2016. On the first day, the focus was on MEMS sensors and actuators as well as their application in medical devices. On the second day, Fraunhofer researchers and guests discussed about current research and development results on wafer bonding and packaging technologies.
On November 30, 2016, the department Multi Device Integration organized the workshop “Microsystems: from the idea to prototype”. Different MEMS, manufacturing technologies as well as applications have been presented.

In 2016, the scientists of Fraunhofer ENAS presented their research results at more than 80 conferences. Moreover selected scientists collaborated within committees of 17 international conferences.

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

Smart Systems Integration Conference (co-organizer)	Munich, Germany	Mar 9-10, 2016
Open Source Workshop "3D-Druck in der Elektronik", SMT Hybrid Packaging 2016	Nuremberg, Germany	Apr 27, 2016
Conference "Microclean 2016"	Gröditz, Germany	May 12-13, 2016
International Symposium on Flexible Organic Electronics	Thesaloniki, Greece	Jul 4-7, 2016
Honorary Symposium on Smart Integrated Systems	Chemnitz, Germany	Sep 8, 2016
Printing for Fabrication 2016 (NIP32)	Manchester, UK	Sep 12-15, 2016
4th European Expert Workshop on Smart Systems Reliability – EuWoRel 2016 (co-organizator)	Berlin, Germany	Oct 18-19, 2016
CMP Wet User Meeting	Grenoble, France	Oct 27-28, 2016
OE-A Working Group Meeting	Santa Clara, USA	Nov 15, 2016
12th Fraunhofer Symposium	Sendai, Japan	Nov 24, 2016

EXHIBITIONS AND TRADE FAIRS

Science meets arts

Since 2010, Fraunhofer ENAS invites to an art exhibition twice a year. In 2016, we proudly presented the great and well-known Chemnitz artist Osmar Osten. In his art works, he combines oil paintings and graphic reproductions with written questions and statements to face the contemplator with an alternative view. Not only the words on the pictures, but also the titles invite to take a closer look. During the gallery talk, the Fraunhofer ENAS staff and the visitors discussed together with Osmar Osten about the influence of sciences and arts on daily life as well as society.

In 2016, the curator of our exhibitions "Sciences meet arts", Georg Felsmann, celebrated his 75th birthday. We took this opportunity to invite him for an exhibition of his manifold graphic reproductions into our institute. Georg Felsmann, living in Chemnitz since 1982, founded the working group "Malen und Zeichnen" in Chemnitz. He worked as research fellow in the NSG (Neue Sächsische Galerie) and as teacher for the Schlossbergmuseum Chemnitz until 2008. Today, he teaches arts at the Volkshochschule Chemnitz. With his 50 years of experiences in the field of arts, he accompanies and counsels our institute. We feel honored that he showed one of his rare exhibitions in our headquarters in Chemnitz.

Chemnitz company run

Five women and 20 men, our team of employees of Fraunhofer ENAS and the Center for Microtechnologies of Chemnitz University of Technology, participated in the 11th Chemnitz company run which took place on September 7, 2016.
Among 7405 runners Phillipe Hahn was our best male starter and finished on place 29. Our best female starter was Julia Hann. She reached the finish line on position 211. With the best team of four, the men we won place 16 and the women place 20.
Congratulation! We are looking forward to the Chemnitz company run 2017.

European 3D Summit 2016	Grenoble, France	January 18–20, 2016
nano tech 2016	Tokyo, Japan	January 27–29, 2016
Smart Systems Integration 2016	Munich, Germany	March 9–10, 2016
SEMICON China 2016	Shanghai, China	March 15–17, 2016
LOPEC 2016	Munich, Germany	March 6–7, 2016
China Chongqing Hi-Tech Fair 2016	Chongqing, China	April 21–24, 2016
HANNOVER MESSE 2016	Hanover, Germany	April 25–29, 2016
Printed Electronics Europe 2016	Berlin, Germany	April 27–28, 2016
SENSOR + TEST 2016	Nuremberg, Germany	May 10–12, 2016
MEMS Engineer Forum 2016	Tokyo, Japan	May 11–12, 2016
SIT 2016	Chemnitz, Germany	May 31 – June 2, 2016
ILA – Berlin Air Show 2016	Berlin, Germany	June 1–4, 2016
SEMICON Russia 2016	Moscow, Russia	June 8–9, 2016
11th Silicon Saxony Day 2016	Dresden, Germany	June 22, 2016
MEMS Sensing & Network System 2016	Yokohama, Japan	September 14–16, 2016
MST Fachtagung 2016	Chemnitz, Germany	October 25–26, 2016
SEMICON Europa 2016	Grenoble, France	October 25–27, 2016
COMPAMED 2016	Düsseldorf, Germany	November 14–17, 2016

MEMBERSHIPS

Memberships of Fraunhofer ENAS

AGENT-3D e.V.	Dresden, Germany
AIOTI Alliance for Internet of Things Innovations	Brussels, Belgium
ALD Lab Dresden	Dresden, Germany
biosaxony e.V	Dresden, Germany
Cool Silicon e.V.	Dresden, Germany
Dresdner Fraunhofer-Cluster Nanoanalytik	Dresden, Germany
Eureka Cluster Metallurgy Europe	Ulm, Germany
European Center for Micro and Nanoreliability EUCEMAN	Berlin, Germany
European Platform on Smart Systems Integration EPoSS	Berlin, Germany
Fraunhofer Alliance AutoMOBIL Production	Germany
Fraunhofer Alliance Nanotechnology	Germany
Fraunhofer Alliance Textile	Germany
Fraunhofer Group Microelectronics	Germany
Fraunhofer-Cluster 3D Integration	Dresden and Chemnitz, Germany
Industrieverein Sachsen 1828 e.V.	Chemnitz, Germany
InnoZent OWL e.V.	Paderborn, Germany
it's OWL - Intelligente Technische Systeme OstWestfalenLippe e.V.	Bielefeld, Germany
IVAM Microtechnology Network	Dortmund, Germany
MEMS & Sensors Industry Group®	Pittsburgh, USA
Micromachine Center	Tokyo, Japan
Nano Technology Center of Competence "Ultrathin Functional Films"	Dresden, Germany
Organic Electronics Association OE-A	Frankfurt/Main, Germany
Organic Electronics Saxony e.V. OES	Dresden, Germany
Semiconductor Equipment and Materials International (SEMI)	San Jose, USA
Silicon Saxony e.V.	Dresden, Germany

PUBLICATIONS AND PATENTS

Publications

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

You can find our published content:

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

Electronically available documents can be downloaded via Fraunhofer publica.

Publications:
Anke Geike
Phone: +49 371 45001-202
E-Mail: anke.geike@enas.fraunhofer.de

Patents

In 2016, 12 patents from scientists of Fraunhofer ENAS have been published and/or granted. In summary, staff of Fraunhofer ENAS holds 134 patents in 46 patent families.

Patents:
Dr. Andreas Bertz
Phone: +49 371 45001-402
E-Mail: andreas.bertz@enas.fraunhofer.de

EDITORIAL NOTES

Editor
Fraunhofer Institute for Electronic Nano Systems ENAS
Technologie-Campus 3
09126 Chemnitz
Germany

Phone: +49 371 45001-0
Fax: +49 371 45001-101
E-mail: info@enas.fraunhofer.de
Internet: www.enas.fraunhofer.de

Director (acting): Prof. Dr. Thomas Otto

Editorial
Dr. Martina Vogel
Dr. Bianca Milde

Layout
Andrea Messig-Wetzel

Photos
Fraunhofer ENAS
other sources are written directly on the photo

Print production
Förster & Borries GmbH & Co. KG

Fraunhofer Institute for Electronic Nano Systems ENAS

www.enas.fraunhofer.de