



**Fraunhofer**  
ENAS

FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS



Annual Report  
**2013**

*Figure on front page:*

*Two sensor nodes of the autonomous sensor network for condition monitoring of high voltage power lines ASTROSE® are collecting data on the 110 kV power lines during the field test. The system consists of numerous sensor nodes measuring the inclination, the temperature and the line current of the spans of the high voltage power line.*

*(see article on page 65).*

*photo © Sven Voigt.*

*Titelbild:*

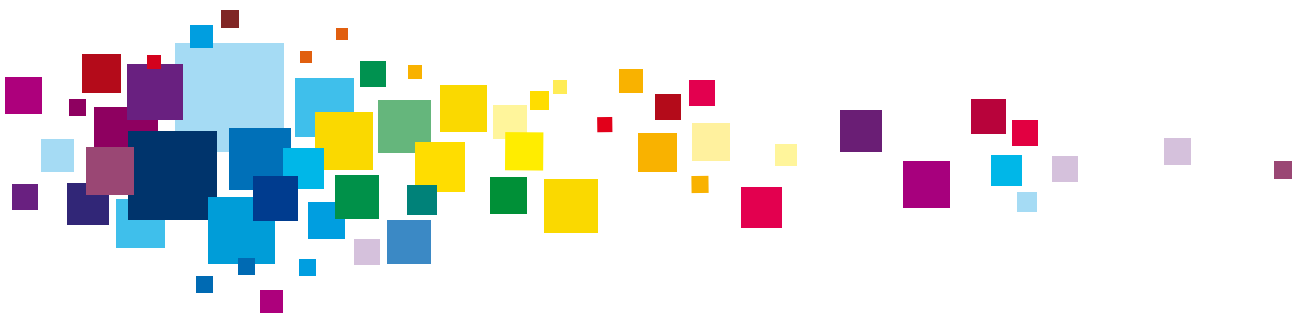
*Zwei Sensorknoten des autonomen Sensornetzwerkes zur Zustandsüberwachung von Hochspannungsleitungen ASTROSE® sammeln während eines Feldtestes Daten an 110-kV-Hochspannungsleitungen. Das System besteht aus mehreren Sensorknoten, die Neigung, Temperatur und Stromdurchfluss der Leitungen messen.*

*(Artikel ab Seite 65)*

*Bild © Sven Voigt*

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# ANNUAL REPORT 2013



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# PREFACE

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

“Pánta chorei kai oudèn ménei.” (short: panta rhei) – “Everything flows and nothing is staying as it is.” of the greek philosopher Heraklit was valid formerly and is still valid today.

2013 was a year of rethinking and transformation especially in microelectronics. So, the European Commission proposed a New European Industrial Strategy for Electronics in May 2013. The central point is the new Joint Technology Initiative ECSEL. It combines three initiatives of the 7th framework ARTEMIS (Advanced Research & Technology for EMbedded Intelligence and Systems), ENIAC (European Nanoelectronics Initiative Advisory Council) as well as EPoSS (European Technology Platform on Smart System).

Fraunhofer ENAS can look back on five years of successful development within the Fraunhofer-Gesellschaft. We have placed our topics on the market and we are developing them further. Also our annual report has been realigned on the application fields of smart systems.

In March 2013, our main partner at the Tohoku University Sendai, Professor Esashi, has been retired. We thank him for the fruitful cooperation. We are glad that he continues to work as a director of the Fraunhofer Project Center “NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University”. We continue our cooperation with his successor Professor Tanaka, who belongs also to the directors of the Fraunhofer Project Center since fall 2013.

The manager of the department Micro Materials Center, Dr. Sven Rzepka, became the honorary professor for reliability of smart systems at the faculty for Electrical Engineering and Information Technology of the Technische Universität Chemnitz in October 2013.

Today, we look with happiness and pride on what we have achieved. However, it also serves as an incentive to keep up the competent and reliable service for our project partners and customers.

Based on our retrospection to 2013 I want to invite you to reflect and to think ahead. In our capacity as a research institution of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., research and development for industrial applications belong to our prime and natural concerns also in 2014.

Director of the Fraunhofer Institute for Electronic Nano Systems



Prof. Dr. Thomas Gessner

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# VORWORT

Liebe Freunde und Partner des Fraunhofer-Instituts für Elektronische Nanosysteme,  
sehr geehrte Leserinnen und Leser,

„Panta chorei kai oudèn ménei.“ (kurz: panta rhei) – „Alles bewegt sich fort und nichts bleibt.“  
des griechischen Philosophen Heraklit galt einst und gilt auch heute.

2013 war speziell im Bereich der Mikroelektronik ein Jahr des Umdenkens und der Veränderung.  
So schlug die Europäische Kommission im Mai 2013 eine neue europäische Industriestrategie  
für die Elektronik vor. Das für die Elektronikindustrie zentrale Vorhaben ist das neue Programm  
ECSEL (Electronic Components and Systems for European Leadership). Dieses bündelt drei  
Initiativen aus dem 7. Rahmenprogramm unter einem Dach: ARTEMIS (Advanced Research &  
Technology for EMbedded Intelligence and Systems), ENIAC (European Nanoelectronics Initiative  
Advisory Council), sowie die Plattform EPoSS (European Technology Platform on Smart System).

Als Fraunhofer ENAS konnten wir 2013 auf eine 5-jährige erfolgreiche Entwicklung als For-  
schungsinstitut der Fraunhofer-Gesellschaft zurückblicken. Wir haben unsere Themen am Markt  
platziert und entwickeln sie weiter. Ein Ausdruck dessen ist auch der vorliegende Jahresbericht mit  
einer neuen Ausrichtung auf die Anwendungsfelder von Smart Systems.

Im März 2013 wurde Prof. Esashi, unser wesentlicher Kooperationspartner an der Tohoku Univer-  
sity Sendai, emeritiert. Wir danken ihm für die konstruktive Kooperation und freuen uns, dass er  
auch weiterhin im Fraunhofer Project Center „NEMS / MEMS Devices and Manufacturing Tech-  
nologies at Tohoku University“ als Direktor mitarbeitet. Wir setzten die erfolgreiche Kooperation  
nun mit seinem Nachfolger Prof. Tanaka, der im Herbst 2013 auch in den Kreis der Direktoren des  
Fraunhofer Project Centers aufgenommen wurde, fort.

Im Oktober 2013 wurde Dr. Rzepka, Abteilungsleiter des Micro Materials Centers, Honorarprofes-  
sor für Zuverlässigkeit von Smart Systems an der Fakultät für Elektrotechnik/Informationstechnik  
der Technischen Universität Chemnitz.

Wir blicken mit Stolz und Freude auf das Erreichte. Es ist uns aber auch Ansporn, unseren Projekt-  
partnern und Auftraggebern auch in Zukunft kompetent und zuverlässig zur Seite zu stehen. Mit  
unserem Jahresrückblick 2013 lade ich Sie zum Nach- und Vorausdenken ein. Als Einrichtung der  
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. ist auch 2014 Forschung  
und Entwicklung für industrielle Anwendungen unser zentrales Anliegen.

Der Leiter des Fraunhofer-Instituts für Elektronische Nanosysteme



Prof. Dr. Thomas Geßner







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**FRAUNHOFER ENAS**

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# FRAUNHOFER ENAS

The particular strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the development of smart integrated systems for different applications. Such systems combine electronic components with nano and micro sensors as well as actuators and communication units. Fraunhofer ENAS develops single components, technologies for their manufacturing as well as system concepts and system integration technologies and transfers them into production. That means, the institute offers research and development services from the idea, via design and technology development or realization based on established technologies to tested prototypes. If standard components do not meet the requirements, Fraunhofer ENAS provides prompt help in the realization of innovative and marketable products.

[www.enas.fraunhofer.de](http://www.enas.fraunhofer.de)

The product and service portfolio of Fraunhofer ENAS covers high-precision sensors for industrial applications, sensor and actuator systems with control units and evaluation electronics, printed functionalities like antennas and batteries as well as material and reliability research for microelectronics and microsystem technology. The development, the design and the test of MEMS/NEMS, methods and technologies for their encapsulation and integration with electronics as well as metallization and interconnect systems for micro and nanoelectronics and 3D integration are especially in the focus of the work. Special attention is paid to security and reliability of components and systems. Application areas are semiconductor industry, medical engineering, mechanical engineering, security sector, automotive industry, logistics as well as aeronautics.

With the working field smart systems integration Fraunhofer ENAS is able to support strongly the research and development of many small and medium sized companies as well as large scale industry. By integration of smart systems in different applications Fraunhofer ENAS addresses the above mentioned branches.

In order to focus the activities and to ensure a longterm scientific and economic success Fraunhofer ENAS has defined the three business units: Micro and Nano Systems, Micro and Nano Electronics / Back-End of Line as well as Green and Wireless Systems. They address different markets, different customers and moreover different stages of the value added chain depending on the required research and development services.

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

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# FRAUNHOFER ENAS

Die besondere Stärke des Fraunhofer-Instituts für Elektronische Nanosysteme ENAS liegt in der Entwicklung von Smart Systems - sogenannten intelligenten Systemen für verschiedenartige Anwendungen. Die Systeme verbinden Elektronikkomponenten, Mikro- und Nanosensoren und -aktoren mit Schnittstellen zur Kommunikation. Fraunhofer ENAS entwickelt Einzelkomponenten, die Technologien für deren Fertigung aber auch Systemkonzepte und Systemintegrationstechnologien und überführt sie in die praktische Nutzung. D.h. Fraunhofer ENAS begleitet Kundenprojekte von der Idee über den Entwurf, die Technologieentwicklung oder Umsetzung anhand bestehender Technologien bis hin zum getesteten Prototyp. Wenn Standardkomponenten den Anforderungen nicht gerecht werden oder an Grenzen stoßen, versucht das Fraunhofer ENAS eine kundenspezifische Lösung zu finden.

[www.enas.fraunhofer.de](http://www.enas.fraunhofer.de)

Die Produkt- und Dienstleistungspalette von Fraunhofer ENAS reicht von hochgenauen Sensoren für die Industrie, Sensor- und Aktuatorssystemen mit Ansteuer- und Auswerteelektronik, über gedruckte Funktionalitäten wie Antennen oder Batterien bis hin zur Material- und Zuverlässigkeitsforschung für die Mikroelektronik und Mikrosystemtechnik. Im Fokus stehen die Entwicklung, das Design und der Test von siliziumbasierten und polymerbasierten MEMS und NEMS, Methoden und Technologien zur deren Verkappung und Integration mit Elektronik sowie Metallisierungs- und Interconnectsysteme für die Mikro- und Nanoelektronik und die 3D-Integration. Spezielles Augenmerk wird auf die Sicherheit und Zuverlässigkeit der Komponenten und Systeme gerichtet. Die Anwendungsfelder sind die Halbleiterindustrie, die Luft- und Raumfahrt, der Automobilbau, die Sicherheitsbranche, die Logistik, die Medizin- und Prozesstechnik sowie der Maschinenbau.

Mit der Ausrichtung auf die Smart Systems Integration ist das Fraunhofer ENAS in der Lage, die Forschung und Entwicklung sowohl von KMUs als auch von Großkonzernen zu unterstützen. Durch die Integration intelligenter Systeme in die verschiedenartigsten Anwendungen adressiert Fraunhofer ENAS die oben aufgeführten Branchen.

Um die Aktivitäten des Fraunhofer ENAS zu fokussieren, wurden die Schwerpunkte im Technologieportfolio und in der Marktbearbeitung auf die drei Geschäftsfelder Micro and Nano Systems, Micro and Nano Electronics / Back-End of Line sowie Green and Wireless Systems gelegt. Jedes Geschäftsfeld verfügt über ein eigenes Kundenprofil, das in Abhängigkeit der benötigten Forschungs- und Entwicklungsleistungen verschiedene Stellen der industriellen Wertschöpfungsketten anspricht.

Organisatorisch ist Fraunhofer ENAS in die sechs Fachabteilungen Multi Device Integration, Micro Materials Center, Printed Functionalities, Back-End of Line, System Packaging und Advanced System Engineering sowie die Verwaltung gegliedert. Der Hauptstandort des Fraunhofer ENAS ist Chemnitz. Die Abteilung Advanced System Engineering ist in Paderborn angesiedelt. Die Abteilung Micro Materials Center hat eine Projektgruppe in Berlin-Adlershof.

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# DEPARTMENT MULTI DEVICE INTEGRATION

The strategic direction of the Multi Device Integration department is focused on the integration of MEMS and NEMS into functional modules and the development of MEMS and NEMS using silicon based and non-silicon materials (nanocomposites, ceramics and polymers).

## **MEMS/NEMS design and development**

Novel modeling and simulation techniques are essential for designing micro and nano electro-mechanical systems. Coupled field analyses enable accurate predictions of MEMS and NEMS functional components and devices behavior. In consideration of process-induced geometric tolerances, the whole simulation chain is feasible. This includes the layout, process emulation, behavioral modeling of components with the help of the Finite Element Method and model order reduction up to system design.

## **Microoptics**

The Fraunhofer ENAS develops microsystem based optomechanical setups and packages using a parameterized design, including thermal and mechanical simulations. Examples for the activities in the field of microoptics are the development and validation of infrared MEMS spectrometers and chemical sensors. Such systems can be configured for different wavelength bands and hence be used in various applications. Food studies, environmental, condition and process monitoring, medical diagnostics, metrology or the physical forensic analysis belong to the fields of application.

## **Fluidic integration and system technologies**

Microfluidics has become an important tool for many applications, e.g. in the fields of medical diagnostics, health care, food and environmental monitoring, chemical processing and consumer products. Microfluidic systems enable faster analyses, lower sample and reagent volumes, new methods of detection, advanced cooling mechanisms and the processing of macroscopically difficult to control chemical reactions. The integration of additional functionality into such microfluidic systems leads to smart, autonomous devices, reduces fluidic interfaces and requires less complex control and readout instrumentation.

## **Measurement, test and characterization**

A method for the extremely fast determination of dimensional and material parameters based on a combination of the Finite Element Method (FEM) and the measurement of Eigenfrequencies has been developed in recent years and is now improved and adapted to different classes of MEMS devices. In fabrication sequence, the Eigenfrequencies are measured by optical vibration detection and electrostatic excitation of the sample by external optical transparent electrodes. A further step calculates the dimensions or material parameters by estimation algorithms, being performed in less than two seconds and at wafer-level.

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# DEPARTMENT MICRO MATERIALS CENTER

Founded by Prof. Bernd Michel, the Micro Materials Center at today's Fraunhofer ENAS has a 20 years long expertise in research and services dedicated to functional safety and reliability of microelectronics and smart systems. Best in class numerical simulation seamlessly combined with innovative experimental analyses are employed to let novel ideas on smart systems architectures and technologies become real industrial products. Other than research demonstrators, sellable products need to provide their full functionality safely for the entire lifetime promised to the customer - under all operational and environmental conditions they are specified for. Design for reliability by virtual prototyping based on physics of failure strategies is the path to reach this goal in minimum time. The Micro Materials Center has been developing the tools and schemes required for the implementation of this strategy into industrial practice. This has been done in close cooperation with our partners from all major companies in the field of smart systems technology. We are continuously widening the field of coverage and the accuracy of the reliability methodology developed.

## Competences:

- Microreliability and nanoreliability of components, systems and devices
- Thermo-mechanical reliability analysis
- Crack avoidance strategies
- Reliability for avionics and space applications (JTI Clean Sky, ESA Projects etc.)
- Microreliability for electronics and smart sensor systems in electrical, hybride, and ICE vehicles
- Solder reliability for micro nano interconnects
- Reliability for packaging in the micro/nano integration field
- Reliability for nano electronics and smart systems (3D integration, More than Moore)
- Physics of failure analysis, fatigue and creep analysis
- Design for manufacturability and reliability based on numerical methods fully calibrated and validated
- Virtual prototyping for minimum time-to-market in smart system product development
- Local deformation analysis (microDAC, nanoDAC, fibDAC, nanotom, Raman, EBSD, X-ray etc.)
- Analysis of internal stresses with highest spacial resolution (in MEMS, thin film stacks, BEOL structures etc.)

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# DEPARTMENT PRINTED FUNCTIONALITIES

The department Printed Functionalities focuses on printing technologies for the manufacturing of printed products which do not solely address the human visual sense but employ these deposition technologies for the application of functional materials. These printed functionalities range from simple conductivity, semiconductivity and isolation up to chemical activity e.g. in batteries or catalysis. These functionalities can improve and enhance the performance and the architecture of smart systems e.g. by printed interconnections or printed power modules. In future thus equipped products will have functionalities beyond color, enabling them to perceive their neighborhood and their own state, allow the interaction with a user and the communication with computer networks, in short: convey them to an intelligent item of the internet of things.

In our understanding the term “Printed Functionality” goes far beyond color and we envision that the functionalities electrical conductivity, adapted dielectric properties, electrical semi-conductivity, electric power, electro-uminescence / light emission, sensing environment, surface protection, intelligence via chip or even catalysis will be manufactured by employing press and post-press technologies. And we expect that the digital printing technology inkjet will contribute substantially by enabling the deposition of very small amounts of expensive functional materials.

Our equipment enables us to deposit and process various types of materials in form of inks. We have the machinery available to scale-up inkjet printing from single nozzle deposition in flatbed mode to industrial level in web-fed systems. This enables us to go for digital fabrication generally. For thicker layers and higher throughput we employ screen and/or gravure printing – both in flatbed or web-fed mode. For sophisticated postpress treatment we have a Novacentrix® PulseForge® installed in a web-fed system.

Additionally we focus in our research on the customization of printed batteries to power appropriate applications and we excel in the design, development, manufacturing and characterization of printed antenna systems.

All activities are carried out in close cooperation with the Technische Universität Chemnitz and industrial partners.

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# DEPARTMENT BACK-END OF LINE

The department Back-End of Line focuses on

- Materials and process development
- Process integration
- Modelling and simulation

for interconnect systems in ultra large-scale integrated CMOS devices (ULSI) as well as MEMS and NEMS components.

Special emphasis is placed on integrating low-k, porous ultra low-k materials and airgaps into copper damascene interconnect systems. Adapted etching and cleaning techniques, k-restore processes after patterning, diffusion barrier and copper CMP processes and barrier compatibility are investigated.

New architectures for interconnect systems and nanosystems are under investigation with respect to the integration of carbon nanotubes. Development and optimization of the complete technology are accompanied by electrical characterization and modeling/simulation of carbon nanotube containing systems.

3D and system integration require metallization solutions for redistribution layers, specific wafer bonding techniques and, of course, for high aspect ratio "through silicon vias" (TSVs). PVD, CVD and ALD barrier and seed layers, copper CVD and electroplating (ECD) are provided to address different feature geometries and various applications. For wafer thinning of different substrate materials, processing solutions are developed using grinding, spin etching and CMP. Fraunhofer ENAS is developing advanced models and simulation tools for PVD, CVD and ALD processes as well as for interconnect systems and nanosystems.

Advanced optical, mechanical, thermal and electrical characterization techniques are available to support the technology development.

## Competences and research fields

The main competences and research fields of the department BEOL are:

- Integration of low-k and ultra-low-k (ULK) dielectrics and airgaps
- Metallization for micro and nanoelectronics as well as for 3D and system integration
- Process and equipment modeling and simulation
- Modeling and simulation of interconnect systems and nanosystems
- Planarization and surface modification for BEOL and MEMS/NEMS fabrication
- Wafer-level integration of carbon nanotubes for interconnects, CNT-FETs and sensors
- Magnetoresistive sensors based on spin-valve systems

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# DEPARTMENT SYSTEM PACKAGING

The department System Packaging is working in the fields of packaging technologies for MEMS and NEMS covering topics from zero level packaging up to second level packaging. The potentials and the importance of packaging and system integration are manifold, ranging from hybrid integration of the components on application-specific substrate carriers over monolithic integration of electronic, sensing, and actuating components on a silicon substrate, to the vertical integration, in which 3D stacking takes place on chip and wafer-level. In addition to the increasing functionality and reliability, the miniaturization and the smart systems integration are the greatest challenges for 'More-than-Moore' development. Current packaging technologies are not only applied to passive elements such as inertial or gas sensors, but also to active elements like micro mirrors and print heads. In view of the further advanced system integration, electronic components can also be implemented into the MEMS packaging. A new approach for the department is the medical use of packaged micro devices. Therefore MEMS packaging techniques and thin film encapsulation technologies were investigated and characterized in terms of hermetical and biocompatible properties. With the department's research work this trend results in new, customer-specific applications. Besides different wafer bonding techniques, such as silicon direct bonding, anodic, eutectic, adhesive, and glass frit bonding, technologies such as laser assisted bonding, reactive bonding as well as low-temperature and thermo-compression bonding are researched and adapted for special application areas. All wafer bonding techniques are characterized in terms of their bonding quality, strength and hermiticity. The competence of the department involves the dicing, the chip and wire bonding as well as technologies for the integration of complex, miniaturized and even smart systems.

In order to make use of the nano effects in MEMS packaging, the department System Packaging analyzes nano scale intermediate layers and layer systems using PLD, PVD and aerosol-jet deposition. Furthermore, surface and material effects are investigated and characterized on the basis of metallic nanostructures. These nanostructures are applied to new bonding techniques on chip and wafer-level. The aim of these investigations is to achieve a permanent and hermetic sealed joint between two wafers, using the lowest process temperature possible. Furthermore, new application fields for nano patterns realized by nano imprint lithography and pattern transfer are e. g. optics, electronics, and medical technology.

The department System Packaging focuses on:

- Wafer bonding and wafer-level packaging
- Characterization and measurement
- Nanoscale effects and imprinting
- Aerosol-jet and screen printing
- MEMS packaging and 3D integration

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# DEPARTMENT ADVANCED SYSTEM ENGINEERING

The department Advanced System Engineering focuses on developing simulation methods for heterogeneous micro and nano electronic systems as well as for specific wireless devices such as RFID-systems. The goal of all these activities in close collaboration with the University of Paderborn is the characterization and optimization of complex electronic systems in order to assess their electromagnetic reliability as well as the signal and clock integrity at high frequencies at the IC-level, for packages, modules and PCB. This research provides a crucial contribution to the development of reliable miniaturized systems.

Main competences and long-term experiences are:

- Wireless energy transmission
- Mobile wireless and RFID smart sensor systems
- Advanced modeling and analysis of EMC and SI-effects
- System modeling and simulation
- Model based development methods for customer-specific heterogeneous systems
- Advanced 3D near-field scanning (high resolution up to 6 GHz)
- RF & EMC measurement on wafer-level up to 20 GHz
- Multiphysical modeling and simulation using CST  $\mu$ Wave Studio, AnSys (HFSS) and Cadence (HSPICE/Spectra)

Today's electronic development is much more complicated than just some years ago. While electronic components become smaller, the signal to noise ratio as well as the absolute signal level decreases. In this context the competences of the department concerning electromagnetic reliability and model driven design can support the system designer with efficient fast simulation methodologies (like black box modeling and event-driven modeling).

Not all parasitic and coupling effects of complex high density systems can be predicted with the help of such EDA tools and the associated simulation approaches during the design phase. Therefore it is very helpful for the system designer to have the possibility to visualize the EM-field of first prototypes with the help of the new 3D near-field scanning technology developed by Fraunhofer ENAS department Advanced System Engineering. This technology provides a powerful methodology allowing the precise detection of coupling paths and the characterization of antenna patterns (e.g. RFID design) and facilitates the efficient design procedure.

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### University Paderborn

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# ADVISORY BOARD

The advisory board of Fraunhofer ENAS was reorganized after working for four years in 2013. Especially, Fraunhofer ENAS would like to thank Dr. Jiri Marek, Robert Bosch GmbH, and Dr. Udo Nothelfer, UNTeC Technology Consulting, supporting the institute during our first years as independent research unit of the Fraunhofer-Gesellschaft. As new members we welcomed Dr. Wolfgang Buchholtz, GLOBALFOUNDRIES, Dr. Christiane Gottschalk, ASTeX GmbH, and Dr. Markus Ulm, Robert Bosch GmbH.

The advisory board is an external advisory body attached to the institute and consists of representatives of science, industry, business and public life. The members of the advisory board 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 2013, the members of the Fraunhofer ENAS advisory board were:

Chairman:

Prof. Dr. Udo Bechtloff, CEO, KSG Leiterplatten GmbH

Deputy chairman:

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

Members of the advisory board:

MRn Dr. Annerose Beck, Saxon State Ministry of Science and Art

Dr. Wolfgang Buchholtz, Manager Project Coordination, GLOBALFOUNDRIES

Prof. Dr. Maximilian Fleischer, Siemens AG

Dr. Christiane Gottschalk, CTO, ASTeX GmbH

Dr. Arbogast M. Grunau, Director Product Development, Schaeffler KG

RD Dr. Ulrich Katenkamp, Federal Ministry for Education and Research

MDgin Barbara Meyer, Saxon State Ministry of Economy, Technology and Transportation

Prof. Dr. Ulrich Schubert, School of Chemistry and Earth Sciences, Jena University

Uwe Schwarz, Manager Development MEMS Technologies, X-FAB Semiconductor Foundries

Dr. Markus Ulm, Department Manager Engineering Advanced Concepts, Robert Bosch GmbH

Prof. Dr. Arnold van Zyl, Rector, Chemnitz University of Technology

Helmut Warnecke, CEO, Infineon Technologies Dresden GmbH & Co. OHG

Fraunhofer ENAS thanks the advisory board for supporting our institute.



# FACTS AND FIGURES

## Development of the Fraunhofer ENAS / Entwicklung des Fraunhofer ENAS

	Year					
	2008	2009	2010	2011	2012	2013
Operating budget (in million euros) / Betriebshaushalt (in Mio. €)	5.2	6.7	7.6	8.4	9.6	10.6
Increasing of the budget (related to 2008) / Steigerung des Haushalts (bezogen auf 2008)		29 %	46 %	62 %	85 %	104 %
Industrial revenues (in million euros) / Wirtschaftsertrag (in Mio. €)	3.4	3	2.8	2.8	3.49	4.1
Investment (in million euros) / Investitionen (in Mio. €)	0.65	5.45	6.8	1.5	1.81	1.44
Staff / Mitarbeiterinnen und Mitarbeiter	63	73	91	102	104	125
Apprentices / Auszubildende	0	2	3	5	6	7
Students and student assistants / Studenten und Hilfskräfte	10	10	20	40	43	51
Publications and oral presentations / Publikationen und Vorträge	61	75	114	119	112	215
Patents / Patente	7	5	13	20	8	17
Dissertations / Promotionen	6	0	4	2	3	3
Academic lectures / Vorlesungen (Technische Universität Chemnitz)	17	17	23	27	24	24
Academic lectures / Vorlesungen (Universität Paderborn)	8	9	9	8	9	8
Academic lectures / Vorlesungen (Technische Universität Dresden)	0	0	2	2	2	1

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# FACTS AND FIGURES

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## Financial situation and investment

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The year 2013 was a successful one. Fraunhofer ENAS was able to increase the third-party funds as well as the number of projects. So within 2013, Fraunhofer ENAS reached increased external funds of 9.53 million euros. The revenues quota is again excellent with 92.0 percent. Contracts from German and international industry as well as trade associations reached just 4.10 million euros. This is almost 40.1 percent of the total operating budget of 10.58 million euros.

Own equipment investment and investment in basic equipment for the building of 1.44 million euros was realized in 2013.

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## Human resources

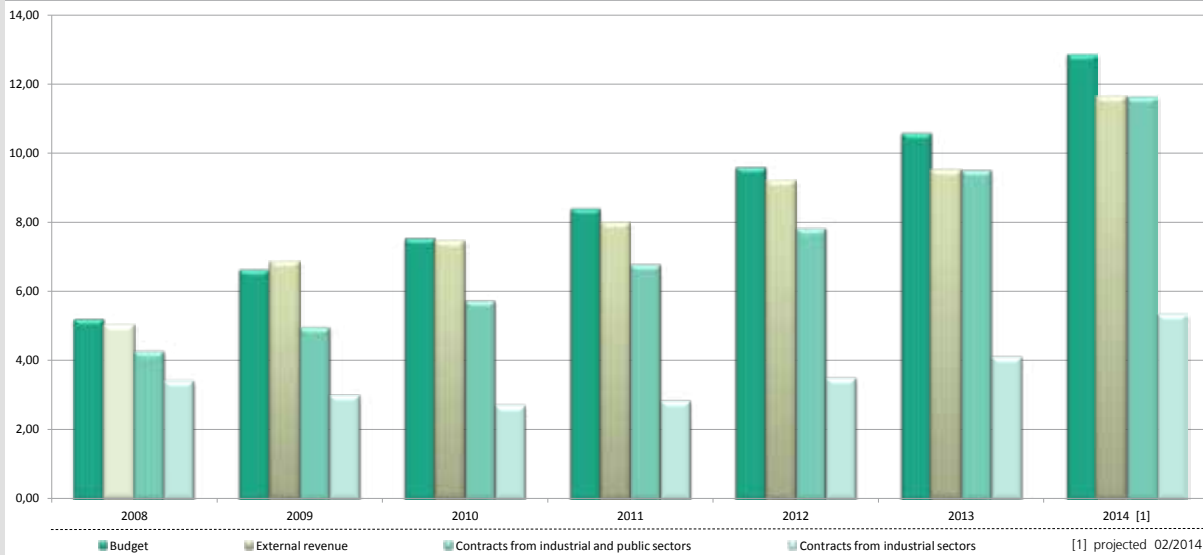
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The institute's success is rooted in the minds of its employees and their knowledge of details and relationships, products, technologies and processes. Second time our own apprentice finished his vocational training successfully. In cooperation with the Technische Universität Chemnitz and the University of Paderborn students and young scientists have successfully defended their thesis. Some of them belong now to our staff.

Sixteen employees joined the team, bringing the total staff at Fraunhofer ENAS in Chemnitz, Paderborn and Berlin to 122 at the end of 2013. The majority of our staff are qualified scientists and engineers. Fraunhofer ENAS offers job training as micro technology technicians. Currently there are seven apprentices employed.

At the end of 2013 there were 58 interns, student assistants and students working on their Bachelor, Master or Diploma thesis employed. These regular team members belong to our source for coming new scientists and technicians.

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*enas.fraunhofer.de*



## Finanzielle Situation und Investitionen

2013 war für Fraunhofer ENAS ein erfolgreiches Jahr. Sowohl die Drittmittelträge als auch die Anzahl der Drittmittelprojekte sind gestiegen. In 2013 erreichte Fraunhofer ENAS externe Erträge in Höhe von 9,53 Millionen Euro. Die Ertragsquote liegt bei sehr guten 92,0 Prozent. Die Aufträge aus deutschen und internationalen Industrieunternehmen erreichten 4,10 Millionen Euro, was einem Industrieanteil von 40,1 % am Betriebshaushalt von 10,58 Millionen Euro entspricht.

Die eigenen Geräteinvestitionen und Investitionen in die Ausstattung des Gebäudes im vergangenen Jahr betragen 1,44 Millionen Euro.

Verwaltungsleiter:

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## Personalentwicklung

Der Erfolg eines jeden Unternehmens und auch jeder Forschungseinrichtung steckt in den Köpfen der Beschäftigten, ihrem Wissen über Details und Zusammenhänge, Produkte, Technologien und Verfahren. 2013 schloss unser zweiter Jahrgang Azubis erfolgreich die Ausbildung ab. In Kooperation mit der TU Chemnitz und der Universität Paderborn haben Studentinnen und Studenten sowie junge Wissenschaftlerinnen und Wissenschaftler ihre Graduierungsarbeiten erfolgreich verteidigt. Einige von ihnen verstärken jetzt unser Team.

Es wurden sechzehn Mitarbeiterinnen und Mitarbeiter eingestellt, sodass zum Ende 2013 122 Personen an den Fraunhofer ENAS Standorten Chemnitz, Paderborn und Berlin beschäftigt waren. Fraunhofer ENAS bildet seit 2009 Mikrotechnologen aus. Zurzeit befinden sich sieben Mikrotechnologen in der Ausbildung.

Ende 2013 waren darüber hinaus 58 Praktikanten, Diplomanden / Masterstudenten und studentische Hilfskräfte bei Fraunhofer ENAS beschäftigt. Dieser Mitarbeiterstamm erweist sich in wachsendem Maße als Quelle für den Nachwuchs von Wissenschaftlern und Technikern.

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# FRAUNHOFER-GESELLSCHAFT

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.

[www.fraunhofer.de](http://www.fraunhofer.de)

At present, the Fraunhofer-Gesellschaft maintains 67 institutes and independent research units. The majority of the more than 23,000 staff are qualified scientists and engineers, who work with an annual research budget of 2 billion euros. Of this sum, more than 1.7 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 Länder 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.

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# DIE FRAUNHOFER-GESELLSCHAFT

Forschen für die Praxis ist die zentrale Aufgabe der Fraunhofer-Gesellschaft. Die 1949 gegründete Forschungsorganisation betreibt anwendungsorientierte Forschung zum Nutzen der Wirtschaft und zum Vorteil der Gesellschaft. Vertragspartner und Auftraggeber sind Industrie- und Dienstleistungsunternehmen sowie die öffentliche Hand.

[www.fraunhofer.de](http://www.fraunhofer.de)

Die Fraunhofer-Gesellschaft betreibt in Deutschland derzeit 67 Institute und selbstständige Forschungseinrichtungen. Rund 23 000 Mitarbeiterinnen und Mitarbeiter, überwiegend mit natur- oder ingenieurwissenschaftlicher Ausbildung, erarbeiten das jährliche Forschungsvolumen von 2 Milliarden Euro. Davon fallen rund 1,7 Milliarden Euro auf den Leistungsbereich Vertragsforschung. Über 70 Prozent dieses Leistungsbereichs erwirtschaftet die Fraunhofer-Gesellschaft mit Aufträgen aus der Industrie und mit öffentlich finanzierten Forschungsprojekten. Knapp 30 Prozent werden von Bund und Ländern als Grundfinanzierung beigesteuert, damit die Institute Problemlösungen entwickeln können, die erst in fünf oder zehn Jahren für Wirtschaft und Gesellschaft aktuell werden.

Internationale Kooperationen mit exzellenten Forschungspartnern und innovativen Unternehmen weltweit sorgen für einen direkten Zugang zu den wichtigsten gegenwärtigen und zukünftigen Wissenschafts- und Wirtschaftsräumen.

Mit ihrer klaren Ausrichtung auf die angewandte Forschung und ihrer Fokussierung auf zukunftsrelevante Schlüsseltechnologien spielt die Fraunhofer-Gesellschaft eine zentrale Rolle im Innovationsprozess Deutschlands und Europas. Die Wirkung der angewandten Forschung geht über den direkten Nutzen für die Kunden hinaus: Mit ihrer Forschungs- und Entwicklungsarbeit tragen die Fraunhofer-Institute zur Wettbewerbsfähigkeit der Region, Deutschlands und Europas bei. Sie fördern Innovationen, stärken die technologische Leistungsfähigkeit, verbessern die Akzeptanz moderner Technik und sorgen für Aus- und Weiterbildung des dringend benötigten wissenschaftlich-technischen Nachwuchses.

Ihren Mitarbeiterinnen und Mitarbeitern bietet die Fraunhofer-Gesellschaft die Möglichkeit zur fachlichen und persönlichen Entwicklung für anspruchsvolle Positionen in ihren Instituten, an Hochschulen, in Wirtschaft und Gesellschaft. Studierenden eröffnen sich aufgrund der praxisnahen Ausbildung und Erfahrung an Fraunhofer-Instituten hervorragende Einstiegs- und Entwicklungschancen in Unternehmen.

Namensgeber der als gemeinnützig anerkannten Fraunhofer-Gesellschaft ist der Münchner Gelehrte Joseph von Fraunhofer (1787–1826). Er war als Forscher, Erfinder und Unternehmer gleichermaßen erfolgreich.

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# COOPERATIONS

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## Cooperation with industry

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The main task of Fraunhofer ENAS is to bring research and innovation into products. Fraunhofer ENAS addresses different markets and different customers starting from SMEs up to large companies working in different branches. Application areas are semiconductor industry, medical engineering, mechanical engineering, automotive industry, logistics as well as aeronautics. The institute offers research and development services from the idea, via design and technology development or realization based on established technologies to tested prototypes. In 2013 Fraunhofer ENAS has cooperated with 156 partners from industry worldwide. Fraunhofer ENAS carries out basic research, practical joint projects and direct research & development orders for the industry.

Based at the Smart Systems Campus Chemnitz Fraunhofer ENAS is a reliable partner for the young SMEs and well established companies at the campus, among them 3D Micromac AG, EDC Electronic Design GmbH Chemnitz, BiFlow systems GmbH and nanotest.

Fraunhofer ENAS works also within two German Leading Edge Clusters. The Federal Ministry of Education and Research launched this competition in the summer of 2007 under the slogan „Germany’s Leading-Edge Clusters – more innovation, more growth, more employment“. There were 15 clusters selected within three rounds of the competition. The Fraunhofer Institute for Electronic Nano Systems is a reliable partner in the cluster “Cool Silicon” in Saxony and the “it’s OWL”.

In order to support industry Fraunhofer ENAS works in different regional and international industry driven networks, like EPoSS – the European Platform on Smart Systems Integration, Silicon Saxony, IVAM, MEMS Industry Group. A complete list is given in the attachment.

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## Cooperation with research institutes and universities

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Interdisciplinary cooperation is the key for success. In order to realize research targets Fraunhofer ENAS has established a strategic network with research institutes and universities in Germany and worldwide. In summary Fraunhofer ENAS cooperates with 107 universities and research institutes worldwide.

A very strong cooperation exists with the Technische Universität Chemnitz especially with the faculties of Electrical Engineering and Information Technology, Natural Sciences and Mechanical Engineering. The main cooperation partner at the Technische Universität Chemnitz is the



Center for Microtechnologies. The cooperation results in a common use of equipment, facilities and infrastructure as well as in the cooperation in research projects. Printed functionalities and lightweight structures are topics of the cooperation with the faculty for Mechanical Engineering. The department Advanced System Engineering located in Paderborn continues the close cooperation with the University Paderborn.

Germany funds Excellence Initiatives for Cutting-Edge Research at Institutions of Higher Education. Fraunhofer ENAS and the Center for Microtechnologies of the Chemnitz University of Technology work in two of these clusters of excellence, which have been accepted in June 2012.

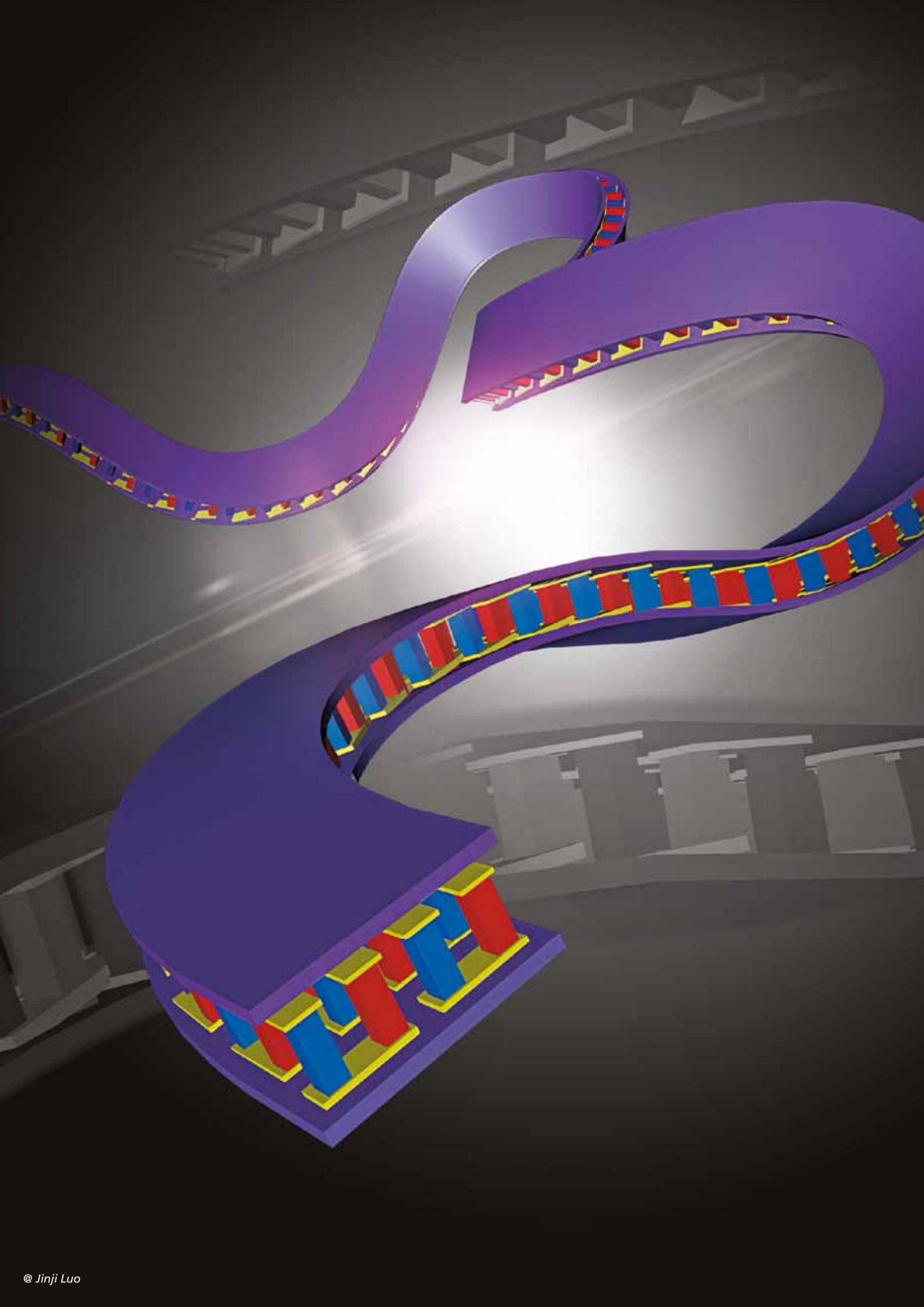
- Merge Technologies for Multifunctional Lightweight Structures – MERGE of the Technische Universität Chemnitz
- Center for Advancing Electronics Dresden – cfAED of the Technische Universität Dresden

Fraunhofer ENAS maintains a close contact with numerous other universities and research institutes via participation in projects and European technology platforms. So Fraunhofer ENAS belongs to the Fraunhofer Group for Microelectronics V $\mu$ E since its foundation. Moreover Fraunhofer ENAS belongs to the Fraunhofer Alliance Nanotechnology and the Fraunhofer AutoMOBILE Production Alliance.

Together with the other institutes of the Fraunhofer Group Microelectronics Fraunhofer ENAS participates in the Heterogenous Technologies Alliance. Together with CEA-Leti, CSEM and VTT joint research projects are acquired and done.

In Asia, long-term cooperation exists with the Tohoku University in Sendai, the Fudan University Shanghai and the Shanghai Jiao Tong University. The cooperation of both, Fraunhofer ENAS and also Center for Microtechnologies, with the Tohoku University Sendai in Japan is a very successful one. As a principal investigator Prof. Dr. Thomas Gessner got an own WPI research group belonging to the division Device/Systems within the WPI Advanced Institute for Material Research. This cooperation has been strengthened by the Fraunhofer project center “NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University” which started to work in April 2012.

Together with Fudan University Shanghai, the Shanghai Jiao Tong University, the Fraunhofer Institute for Microintegration and Reliability IZM, the Technische Universität Chemnitz and the Technische Universität Berlin Fraunhofer ENAS works within the international graduate school “Materials and Concepts for Advanced Interconnects and Nanosystems”.



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## **HIGHLIGHTS 2013**

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# R&D AND PROJECT HIGHLIGHTS

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## R&D and Project Highlights

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### **Piezoelectric MEMS – aluminum nitride**

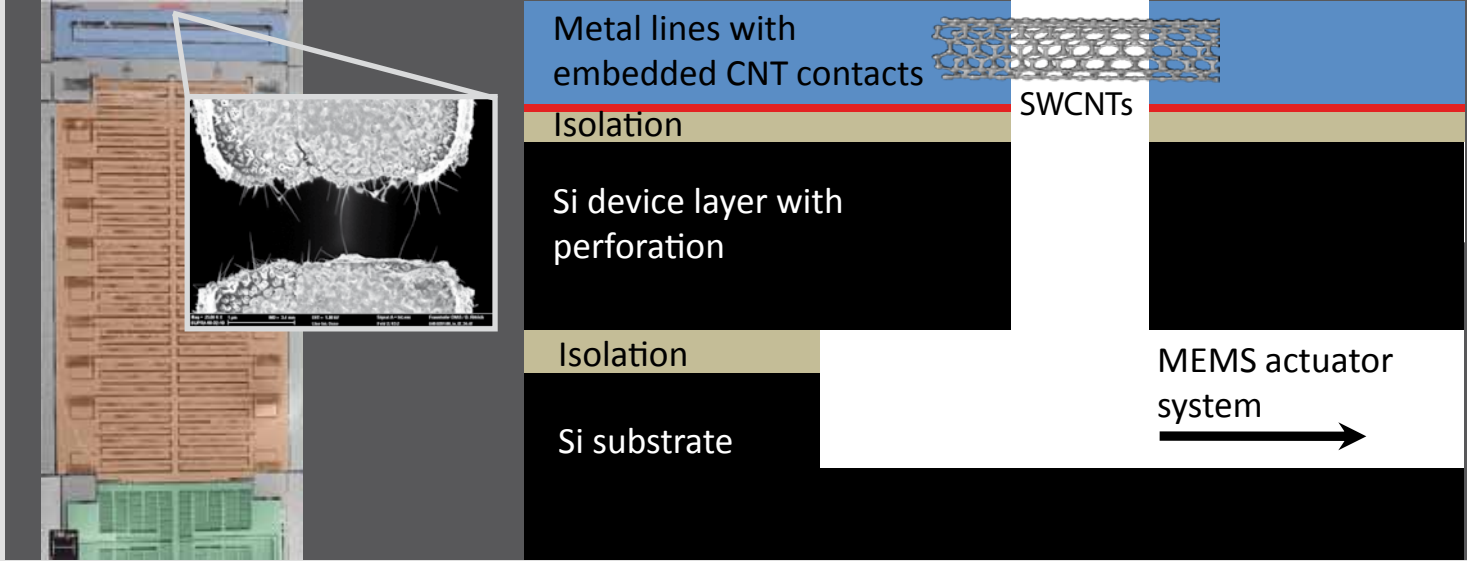
Aluminum nitride (AlN) micro-devices can offer significant improvements compared to capacitive or piezoresistive transduction schemes. High coupling coefficients, moderate piezoelectric coefficients, high sensitivity or a good CMOS integration characterize the eco-friendly AlN, compared to PZT (Plumbum Zirconate Titanate) or quartz crystals. Therefore, the Fraunhofer ENAS develops piezoelectric reactive sputtered thin film Aluminum nitride layers in cooperation with the Center for Microtechnologies (ZfM) and fully integrates the films into MEMS applications. Furthermore, extensive and unique measurement techniques and methods are available. This measurement equipment and know-how allows an inimitable characterization of the piezoelectric thin film material behavior for AlN and other piezoelectric layers. Ultra-low-power devices were developed within the CoolSilicon cluster project Cool\_PoD, micro and nano analytics in the project PECMAN as well as industrial sensors for a versatile field of applications.

### **Hybrid composite materials for energy conversion applications**

With the ability to turn the waste heat into electricity, thermoelectric (TE) generators offer a green approach for the energy technology. Beside the semiconductor based conventional TE materials, polymeric materials start to draw attention as more economical alternatives to conventional TE materials with their tunable thermoelectric properties. The possibility of solution processing enables the application of printing technologies for large-scale deposition of lightweight TE materials on flexible substrates. In addition, the intrinsically low thermal conductivity of polymeric materials makes them promising materials for TE applications. Within the IRTG research program, the thermoelectric properties of polymer and polymer/inorganic hybrid composite are investigated with the goal to develop a flexible thermoelectric generator.

### **Design for structural reliability of fiber reinforced composites**

An innovative procedure has been developed for simultaneously capturing elastic properties as well as failure/damage effects of fiber reinforced composites. Samples designed to exhibit multi-axial stress state in dedicated local areas even during simple tension tests were loaded up to complete rupture. Finite element models were calibrated by these experiments to take



into account the anisotropic elastic properties of the composite material as well as matrix and fiber failures at the same time. Based on them, the failure patterns and the propagation of damage and crack within the specimens were reproduced very well by 3D simulations. Furthermore, good agreement between simulation and experiment has been achieved for samples with various fiber orientations in relation to the force direction.

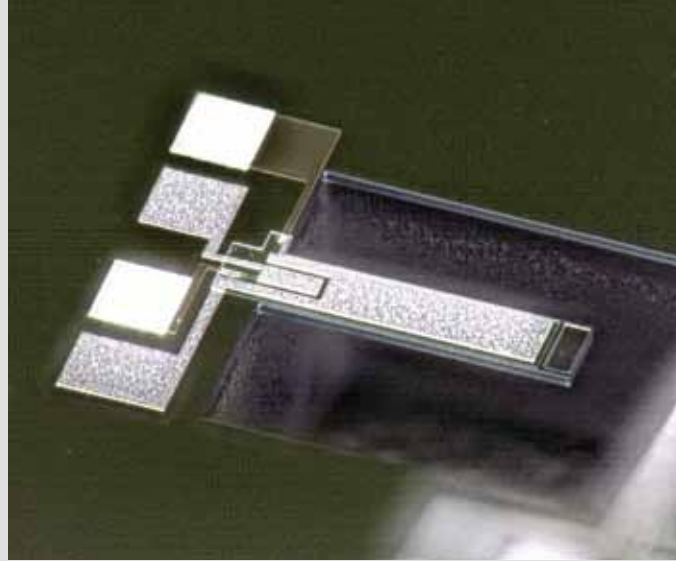
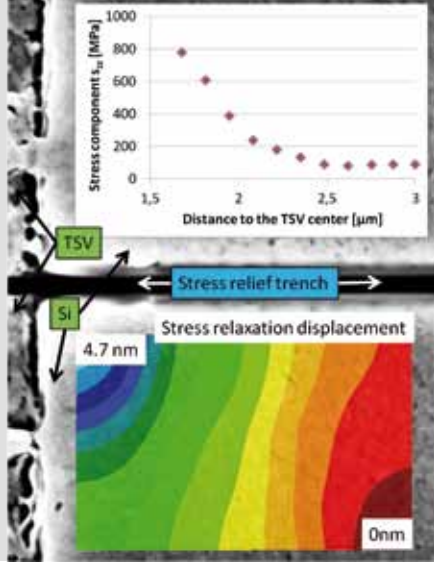
As a result, an efficient scheme of virtual testing is in place that reduces the experimental complexity and expense significantly. Utilizing this approach within enhanced simulation models of complex electronic assemblies and smart systems allows more precise lifetime estimations as basis for optimum design.

### CNT based sensor applications

Due to physical and technological reasons, sensor sensitivity of inertial sensors dramatically decreases when shifting to higher operation frequency or smaller physical dimensions. In future applications, like condition monitoring or miniaturized smart systems, there is a big interest in expanding those boundaries by introducing new sensor concepts. Within the Forschergruppe (FOR1713) und a VW-Stiftung funded project this challenge is tackled by a joint work of three research groups working on the design of a nanotestplatform (Chair Microsystems and Precision Engineering, TU Chemnitz), the integration of single-walled carbon nanotubes (SWCNTs) in micro electromechanical systems (MEMS) (Center for Microtechnologies of TU Chemnitz / Fraunhofer ENAS) as well as investigation of system reliability (Chair Materials and Reliability of Microsystems, TU Chemnitz). A goal is the usage of SWCNTs as ultra sensitive piezoresistive displacement sensors.

In the group CNT Integration and Applications (part of professorship Nanoelectronics Technologies and the department Back-End of Line) a technology was developed to integrate SWCNTs into a MEMS nano test platform on wafer-level. Recently this was successfully demonstrated for the first time, Fig. 1, which laid the foundation for CNT based inertial sensors. Therefore, the whole process chain for CNT integration was holistically considered including dispersion preparation, site selective CNT assembly on wafer-level, contact formation, fusion with MEMS technology and characterization. With the fabrication of a nano test platform it is possible to study the piezoresistive properties as well as mechanical properties of strained CNTs and contacts. Moreover, a widely applicable tool was realized to characterize also other micro and nano materials under strain.

1 MEMS Nano test platform with integrated carbon nanotubes on wafer-level.



### Stress measurement with high spatial resolution

A mechanical stress measurement kit has been developed to support reliability assessments in a flexible and efficient manner. Among the applied methods are stress relief measurements by fibDAC, microRaman and stress chip applications. Highest spatial resolution can be achieved in FIB equipment based measurements. Ion milling is used to create very local stress relief volumes. Respective relaxation displacement fields are captured applying digital image correlation on SEM micrographs. Extracted stresses refer to and represent the tiny stress relief volume. Most materials, including nanocrystalline and amorphous one, can be treated with the method. As a consequence stress measurements are feasible, e.g., in multilayer systems as in BEOL stacks or MEMS and in 3D IC integration components. Lateral spatial resolution of less than 1  $\mu\text{m}$  and depth resolution of approximately 50 nm have been demonstrated. The depicted example regards to the evaluation of stress built-up, approaching the metal-silicon interface at a through silicon via (TSV), Fig. 2.

Currently, Fraunhofer ENAS cooperates with European industry and RTO partners in an EC collaborative project to make available this powerful method as a validated, routine and cost-efficient tool for product designers. Combining these stress measurements with recent approaches for local material property measurement, a new quality of assured FEM input data for advanced reliability analyses on microtechnology products is envisaged.

### Innovative microsystems comprised of semiconductor nanocrystals

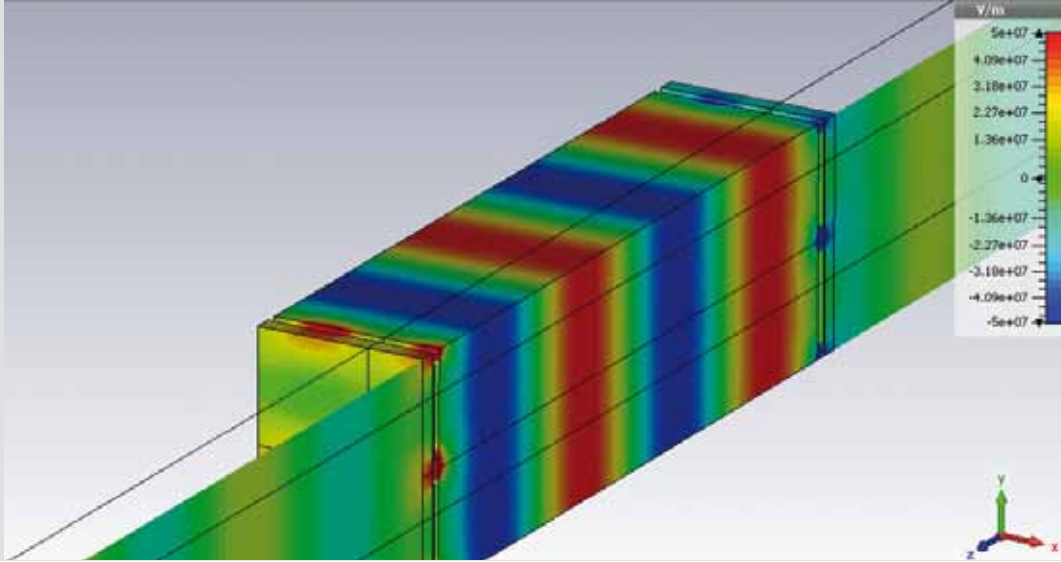
Semiconductor nanocrystals, so-called quantum dots, with a typical diameter range of 3 – 7 nm exhibit several exceptional properties. Among them is high quantum efficiency regarding fluorescence, but also high sensitivity against electrical charges and fields. Consequently, quantum dots are not only innovative light emitters, but also excellent building blocks for nanosensors.

At Fraunhofer ENAS solution processable quantum dot LEDs have been manufactured by combining inkjet printing and spin-coating technology. Fabricated quantum dot light sources are characterized by small bandwidth emission and very low switch-on voltages of smaller than five volts. Perspectively such LEDs are excellent light sources for numerous applications, such as ambient lighting, optical microscopy, sensor technology, and so on.

Furthermore, new optical quantum dot sensors for detection, storage and visualization of (over-) loads on mechanical structures are currently developed and investigated. First laboratory samples have been manufactured together with partners from TU Chemnitz and Fraunhofer

2 Stress measurement (fibDAC) at through silicon vias with 100 nm lateral resolution.

4



IAP Potsdam-Golm. Main part of the sensor arrangement is a double layer consisting of a piezoelectric and a quantum dot film, which is applied to the mechanical component. The special sensor layer transforms mechanical overloads into optical contrast pattern. Thus, it is now possible to visualize overloads directly on structural components, even within a limited time after the exposure to the force.

### Polymer based SENSors (polySENS)

Novel application fields become accessible by merging existing technologies. Combining lightweight, functional polymer and microtechnologies lead to a new research topic "Integrated and embedded polymer based SENSors (polySENS)" which facilitate developments of new functionalities in lightweight structures. As a result of the Cluster of Excellence MERGE and the nano system integration network of competence nanett trend-setting applications for structural health monitoring and the functionalization of lightweight compound structures are proposed, example see Fig. 3. In cooperation with further Fraunhofer Institutes and the Technische Universität Chemnitz a consolidated technology alliance is formed to establish a new path of smart systems integration.

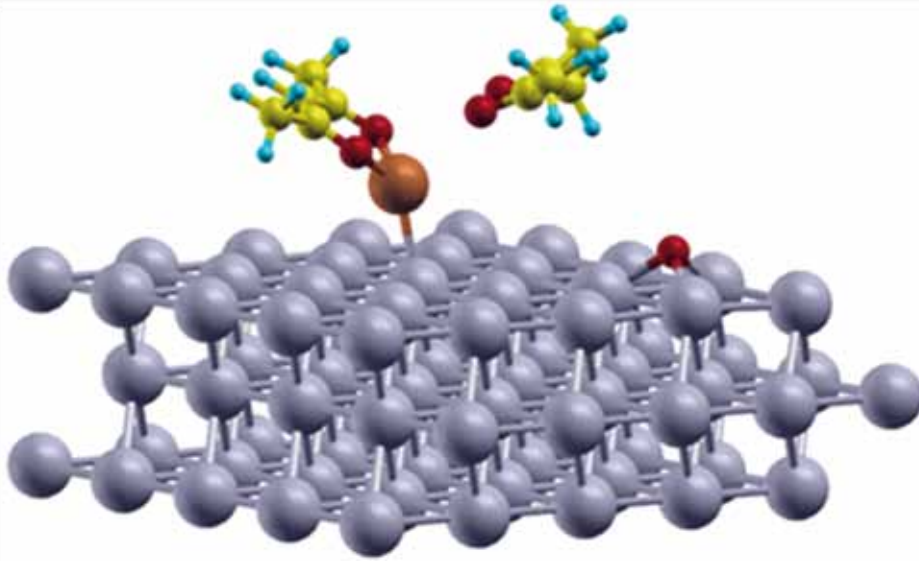
### Subwavelength grating reflectors in MEMS tunable Fabry-Pérot infrared filters with large aperture (nano3pt)

An applications of nanotechnologies was pursuit by substituting the distributed Bragg reflectors in tunable Fabry-Pérot filters by subwavelength gratings (SWG). It leads to a reduction of cost and fabrication effort. The SWGs consist of uniformly arranged disc resonators which are made of 100 nm thick aluminum at 200 nm  $\text{Si}_3\text{N}_4$  membrane carriers that stand freely after fabrication. The dimensions of the subwavelength structures were optimized based on finite difference time domain (FDTD) analysis. The fabrication sequence comprises silicon MEMS technology steps like deposition and patterning of electrodes and of isolation layers, silicon etching, and wafer bonding, and it includes nano imprint lithography for forming the subwavelength structures at wafer-level. The samples have an aperture of 2 mm and are mechanically tuned by electrostatic forces with tuning voltages up to 80 V. They show the typical characteristics of FP filters but with high peak transmittance within a remarkably large wavelength range ( $T > 50\%$  @  $2.5 \mu\text{m} \dots 6.5 \mu\text{m}$ ) spanning over 5 interference orders of the optical resonator. The optical performance was measured by Fourier transform infrared spectrometer and compared to the simulation results. It shows a widely good agreement between calculation and measurement.

3 *Piezoelectric aluminum nitride cantilever for micro and nano analytic applications.*

4 *Y-Component of the E-field at pass band wavelength  $3.4 \mu\text{m}$  with resonator gap of  $7.02 \mu\text{m}$  between the aluminum surfaces (simulation result).*





### DIGINOVA

For the EU-project DIGINOVA, Innovation for Digital Fabrication, 2013 was the second year, during which the current status of Digital Fabrication across material domains and application domains in Europe was established, followed by the identification of the most promising technology and business propositions as well as business drivers, key technology challenges, and barriers. The findings of the coordinated work, including substantial stakeholder involvement, will be combined in the Digital Fabrication Roadmap, outlining future technological and business research topics. The roadmap will be presented at the final Dissemination Event in February 2014, organized by the work package leader Fraunhofer ENAS department Printed Functionalities. The project is funded by the EU with a contribution of over 1.4 million euros. The DIGINOVA consortium, consisting of 4 large companies, 7 SMEs and 9 research institutes, is contributing broad research and development experience and covering a wide range of materials and applications.

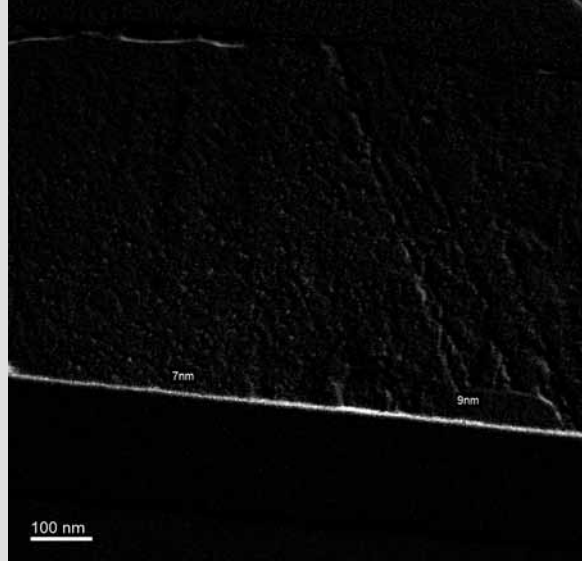
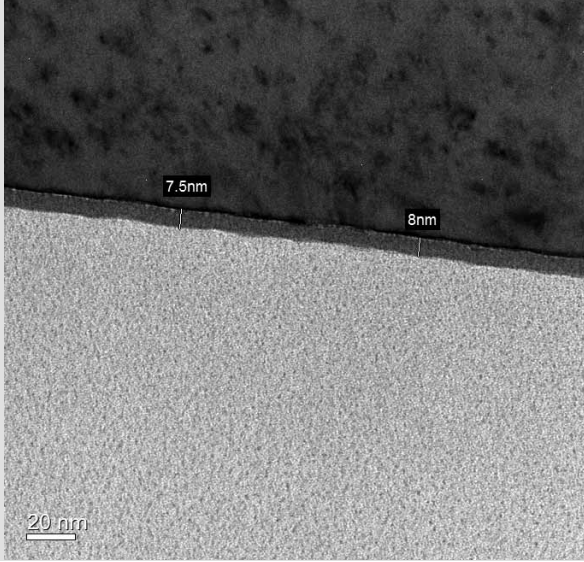
### Atomic layer deposition – ALD

Atomic Layer Deposition (ALD) is a field of active research and development in the department Back-End of Line. Equipments are available for both thermal and plasma-assisted ALD processes, allowing for wafer sizes up to 200 mm. While processes of oxides such as  $\text{Al}_2\text{O}_3$  and transition-metal nitrides like TiN are being established as standard processes for various applications, the focus of the research activities is on the ALD of metallic films. Metal ALD is considerably more challenging than, for example, the ALD of base metal oxides. One major reason for these challenges are fundamentally different surface chemical processes involved with the ALD from transition metal precursor such as Cu, Co or Ni. For studying the surface chemistry and optimizing both precursors, co-reactants and the complete ALD processes, in situ X-ray photoelectron spectroscopy (XPS) is an indispensable method. A 200 mm cluster tool, featuring two ALD chambers for oxides, nitrides as well as metals, provides the ability for XPS analyses without vacuum break.

The experimental work is complemented by modeling and simulation activities, Fig. 5. This work ranges from atomistic simulations of surface chemical processes occurring during the ALD up to reactor simulations for optimizing complete ALD processes. In this respect, computational fluid dynamics approaches are applied to study the precursor distribution within the reactor during the ALD pulses in order to optimize the cycle time while maintaining a high film quality.

5 *Ab-initio simulation of an intermediate product during the decomposition of  $[(^n\text{Bu}_3\text{P})_2\text{Cu}(\text{acac})]$  used as precursor for copper oxide ALD on a Ta surface.*





The ALD work is targeted to the following application areas:

- formation of diffusion barriers, liners and seed layers for interconnect systems in highly integrated microelectronic devices,
- functionalization of carbon nanotubes for applications in sensor devices,
- conformal coatings on high aspect ratio features, such as MEMS devices or through-silicon vias (TSVs).

### Metallization for on-chip interconnects

Within the project CuDOT funded by the Free State of Saxony, Fraunhofer ENAS is performing basic investigations to self forming barriers by deposition of Cu alloys. Alloying elements are Mn, Ti or Zr which have high affinity to silicon oxide. Under thermal treatment the alloying element diffuses out of Cu and reacts with the dielectric so that a self forming barrier is resulted. Basic questions of the investigations are the minimum amount of alloying element for self forming barrier, the electrical resistivity of Cu alloy after deposition and heat treatment, Cu grain size and the effectiveness of the self forming barrier against Cu diffusion during Bias Temperature Stress (BTS). The electrical resistivity of Cu alloy layers is increased by the fraction of alloying element and with Zr the values are the highest. With heat treatment in forming gas the electrical resistivity is decreasing but is staying 2 – 10 times higher than for pure Cu layers. On one hand side the residual alloying element in the Cu layer increases the resistivity, however, the drastically reduced Cu grain size contributes also to this increase. The formation of the barrier for alloying elements was proved by EELS and TEM analysis, Fig. 6 and Fig. 7. No Cu diffusion was detected during the performed BTS investigation at 300 °C. So, all 3 investigated alloying elements are applicable as self forming barriers.

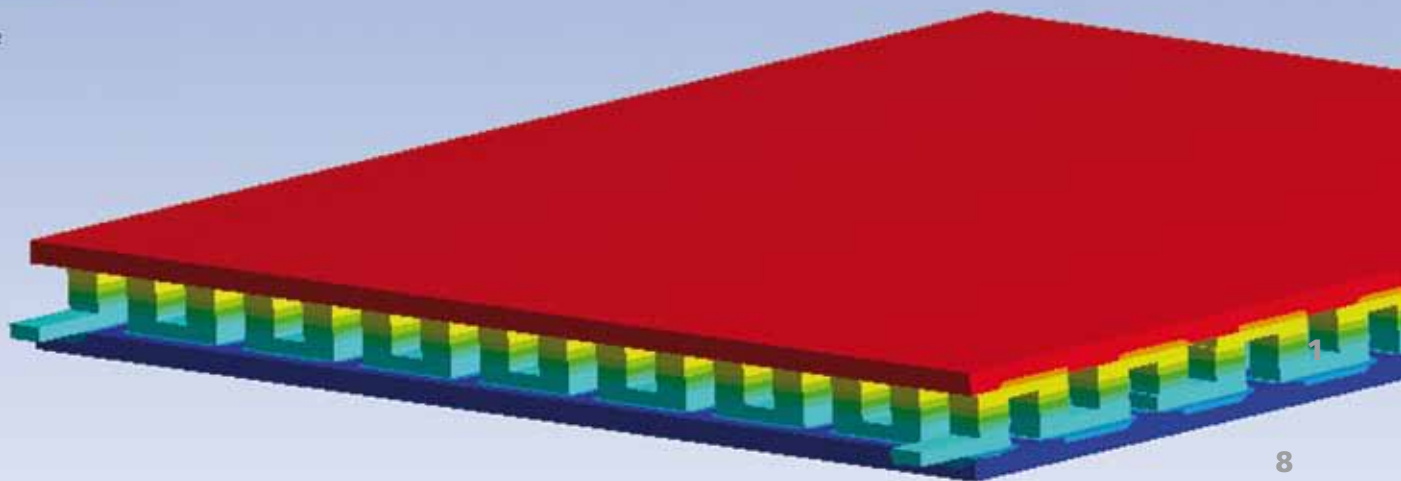
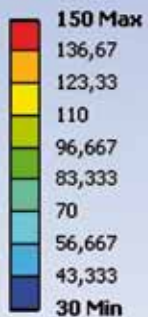
- 6 TEM image of a self formed barrier from Cu-Mn alloy after temperature treatment at 400 °C/1 h in  $N_2/H_2$ .
- 7 Energy filtered TEM of Mn map.

### Development and characterization of hermetic CuCu wafer bonding

3D integration technologies show increasing importance for high volume applications while realizing the smallest system dimensions at least. Therefore vertical interconnect and wafer bonding technologies were optimized and adapted to reach a high yield using quite narrow contact areas and bond frames. Recent results show that Cu is an adequate material for electronic metallization systems but also for intermediate bonding layers. It fulfills the requirements for a strong hermetic bond and electrical conductivity. Electrical measurements are still being conducted on single TSV's as well as on TSV chains. First promising results yield a single TSV resistance of  $R = 11 \text{ m}\Omega$  and a 4-point TSV resistance of  $R = 76 \text{ m}\Omega$ . At least the hermeticity was kept until several months when the wafers are still showing deflected membranes and no tracer gas could be detected after storage.

## B: Thermal-electrical analysis

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### HOTGAMS

In the HOTGAMS project, led by Benteler Automobiltechnik GmbH, Fraunhofer ENAS department ASE worked together with the University of Paderborn on the development of a high temperature long term stable thermo generator (TEG) with very high efficiency for automotive applications. In this from the German Federal Ministry of Education and Research (BMBF) funded project, this TEG should use the thermal energy available in the area of the exhaust elbow of an engine and convert it into electric energy for the supply of the vehicle board net. Due to limited temperature mechanical stability of the classical materials, especially of solder and thermo materials in a high temperature environment, thermo generators are up to now not available on the market for such applications. Within HOTGAMS this challenge has been subdued and a high temperature compliant interconnection technology, based on silicide alloy has been developed.

By means of continuous thermal and electrical simulations, Fig. 8, in different simulation environments, it could be shown that there is not only one optimum design for a TEG with maximum efficiency, but every TEG must be adjusted individually to the respective purpose. When compared to the measuring results carried out by the University of Paderborn, it was shown that the computing models developed at Fraunhofer ENAS, department ASE, allow a good prediction of the TEG efficiency and lead to interesting energy saving potentials.

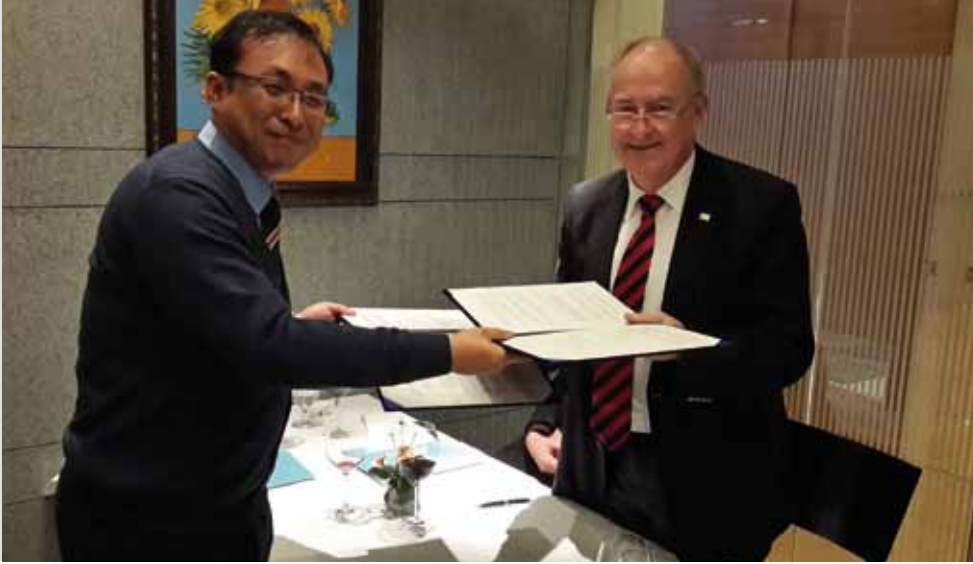
8 *Thermal-electrical analysis of a thermo generator.*

### IT'S OWL

Having been awarded in the Leading-Edge Cluster competition of the German Federal Ministry of Education and Research, the cluster Intelligent Technical Systems OstWestfalenLippe (it's OWL) is regarded as a pioneer for Industry 4.0 and contributes significantly to Germany's competitiveness as an industrial base.

174 companies, research institutes and organizations cooperate in 45 projects with a total budget of 100 million euros within the technology network. World market leaders in the fields of mechanical engineering, electrical and automotive supply industries collaborate with top-level research institutes. In a joint effort of economy and science, they approach the innovation leap from classical mechatronics towards intelligent technical systems.

The department ASE of Fraunhofer ENAS works actively in the cross-sectional project intelligent networking. The aim of the research project is to establish a plug-and-play functionality



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known from the IT area also for devices, machines and production plants. The development of such intelligent components and systems will be done by design and combination of a variety of hardware and software components, which are provided on a platform. Besides, above all the demands of the cooperation of different components, the reliability and the integration ability should be considered in resource efficient equipment.

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## New Projects

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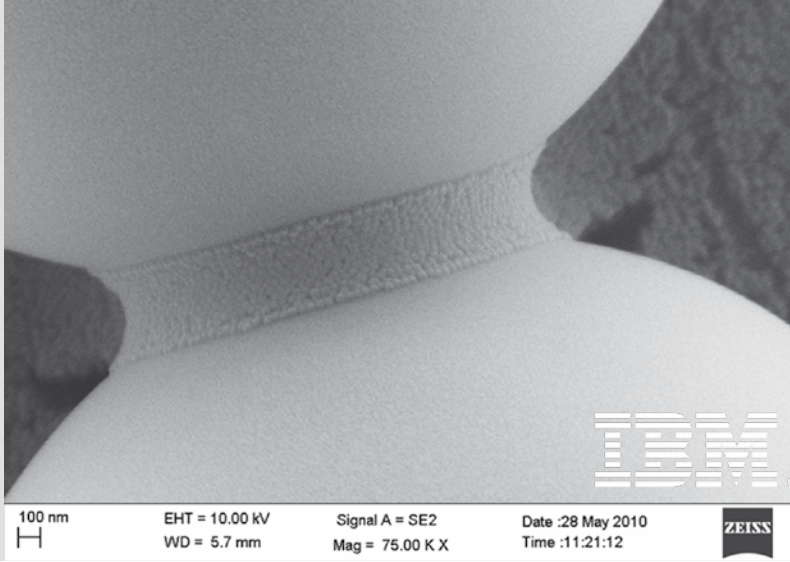
### HICEL

In 2013, the contracts for a joint research and development project with the South Korean partner company HICEL Co., Ltd., Republic of Korea, were signed, Fig. 9. The cooperation will start in January 2014 for 4 and a half years. The partners will develop an optimized manufacturing process for the production of flexible circuit boards for integration in smartphones employing printing technologies. The 650,000 euros project is funded by the Korean Ministry of Commerce, Industry and Energy, which invests a remarkable amount of money into research and development in the field of printed electronics in order to remain one of the world leaders in communication technology. The Fraunhofer ENAS department Printed Functionalities and VTT Technical Research Centre of Finland are the only non-Korean partners in this ambitious governmental research plan. The main contribution of the Chemnitz scientists will be the development of an inkjet-rework process for the manufacturing of flexible printed circuit boards.

9 *Prof. Baumann signed the project contract with HICEL Co., Ltd. in Korea*

### DeNeCor

Aging of population results in an increased incidence of neurological diseases. Often, several diseases may affect the same patient, and the diagnosis techniques or the therapy for one may be incompatible with the techniques needed to address the other one. The objective of the ENIAC JU project DeNeCor is to demonstrate the coexistence by design between implanted neuromodulation therapy devices and key diagnostic systems. DeNeCoR will remove the main roadblock of incompatibility between the neuromodulation therapy (DBS & TMS) and the neurological diagnostic systems (EEG, MRI & US) inducing a higher preference rate among clinicians. The compelling evidence of efficacy and safety will result in further deve-



developments of neurostimulation therapy and will generate strong intellectual property. This will be an important business accelerator, enabling Europe to leapfrog the competition, to increase its market share in therapy devices and strengthen its leading position in the diagnostic systems, raising the bar for new competitors intending to enter the profitable health-care market.

Within the German consortium Fraunhofer ENAS will develop a multifunctional micro endoscope for diagnosis and therapy of brain diseases like Alzheimer. Furthermore the endoscope should be made of MRI compatible materials to enable an investigation under MR conditions.

### HyperConnect

The electrical interconnect density (solder ball pitch) has not decreased at the same pace as the transistor pitch, limiting the communication and power delivery to integrated circuits. In general, the world economy and the society in the information dominated age will be negatively affected by limited improvements in integration density, performance and efficiency of electronic devices. One possible approach to support further device miniaturization is the so called 3D chip stacking. Thereby, individual semiconductor dies are stacked on top of each other and are electrically connected. A major challenge today, and therefore a limitation, is the reliable joining of dissimilar materials supporting efficient heat dissipation and sufficiently small electrical interconnect pitches within and to the chip stack.

Within the consortium Fraunhofer ENAS is working on the investigation of nano effects as intermediate material for self assembled thermal interconnects.

10 *Nanoparticle neck formed between micron-sized filler particles by capillary bridging resulting in advanced thermal underfills. (by courtesy of IBM Research Zurich)*



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## New Equipment

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### High-temperature shock test system

Deduced from the actual mission profiles of the prospective products, the Micro Materials Center at Fraunhofer ENAS develops comprehensive test schemes that cover the actual load situation highly efficiently.

In order to meet the increased demands of the industry with respect to the maximum operation temperature, a new combinable high-temperature test system was established, where testing temperatures of up to 500 °C can be realized. The system consists of a two-zone thermal shock test chamber (cold chamber: –70 to 150 °C, warm chamber: 50 to 250 °C), specified for a temperature range between –70 and 250 °C and an industrial high-temperature furnace for a temperature range between room temperature and up to 500 °C.

A handling system, consisting of an industrial robot system and a specially designed sample rack, is responsible for transferring the test samples between the different temperature chambers, Fig. 11. That way, thermal shocks of new smart system structures can be performed in a temperature range as wide as –70 to 500 °C meeting all requirements of the desired accelerated cyclic tests. In addition, both furnaces can be used individually, to maximize the benefits of the system.

First test samples of the new system are high-temperature resistant MEMS devices and novel SiC power electronic components.

The new test methods allow studying the true failure mechanisms including all significant interactions in an accelerated way fitting to industrial research and innovation schedules. They also provide the input needed for deducing accurate lifetime models the virtual prototyping schemes are based upon.

### Mixing option for aerosol-jet

A technical upgrade of the aerosol-jet system enables printing of functional graded materials and other combinations of two different aerosol inks. A second process module and a mixing device as well as a second pneumatic atomizer allow the mixing during the gas flow of the two aerosols. With that option it is possible to print electrical paths with different materials or alloys, regulating the sintering properties and creating new functionalities on printed surfaces.

**11** *High-temperature shock test system with thermal shock test chamber and industrial high-temperature furnace and industrial robot system for transferring the test samples.*





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## Major projects

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### **Nano system integration network of competence – nanett**

On September 12th 2013 the German Federal Ministry of Education and Research (BMBF) welcomed delegates from all the 17 initiatives of the program “Leading-edge Research and Innovation in the New German Länder” in the Umweltforum Auferstehungskirche in Berlin to a conclusion workshop. The speakers of the different initiatives presented their preliminary results and allowed insight in the sustainable establishment of the research networks. In a vivid manner Prof. Geßner explained the progress in the technological research areas of the nano system integration network of competence – nanett – for all the involved institutes. Furthermore, he described the successful structural effects on the main location, the Smart System Campus Chemnitz, with the Technische Universität Chemnitz, the Fraunhofer Institute for Electronic Nano Systems ENAS and the Leibniz Institute for Solid State and Materials Research. The workshop gave a lot of opportunities for discussions with officials from the BMBF and the project executing organization Jülich as well as delegates from the other initiatives. At the end, Mr. Hiepe moderated an inspiring panel discussion regarding the cooperation effects before the background of societal and scientific changes.

### **DFG research unit 1713 “Sensoric Micro and Nano Systems”**

The Deutsche Forschungsgemeinschaft has established the research unit 1713 “Sensoric Micro and Nano Systems” at the Technische Universität Chemnitz for a period of three years, starting in March 2011. The research unit joins the research of three partners - the Fraunhofer ENAS, Technische Universität Chemnitz and the Leibniz IFW in Dresden – to work on novel sensor principles in micro and nanoelectronics. The scientific focus relies on three main competence fields:

- Component and system design, which includes multi-scale sensor modeling with innovative approaches to incorporate quantum mechanical effects in classical sensor modeling,
- Material and technology integration, starting from the fabrication and functionalization of rolled-up smart tubes or carbon nanotubes and ending up in their heterogeneous integration in multi-functional sensor structures,
- Characterization and reliability investigations of nano structures including new, high resolution methods to characterize nano structures and their long-term stability.

More information about the DFG research unit can be found on its web page <http://www.zfm.tu-chemnitz.de/for1713/>.

*The DFG research unit 1713 on its annual meeting in monastery Nimbschen in April 2013.*




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## International cooperations

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### International Research Training Group (IRTG) “Materials and Concepts for Advanced Interconnects and Nanosystems”

In 2013 the International Research Training Group (IRTG) “Materials and Concepts for Advanced Interconnects and Nanosystems” was established the 8th year. Seven new PhD students started their PhD program, among them three women. Andreas Zienert and André Clausner finished their doctoral degree with excellence and Mr. Zienert gained the Edgar Heinemann Award of TU Chemnitz, too. The annual summer school was organized by Fudan University Shanghai and all German PhD students participated. Furthermore, four German PhD students worked and lived in Shanghai for three months within the exchange program of the IRTG, while eight Chinese PhD students came to Chemnitz.

The IRTG is an international graduate school between the Technische Universität Chemnitz, the Technische Universität Berlin, Fraunhofer ENAS and Fraunhofer IZM, as well as Fudan University Shanghai and Shanghai Jiao Tong University. The IRTG is jointly sponsored by the German Research Foundation (DFG) and the Chinese Ministry of Education (MoE).

### Fraunhofer Project Center “NEMS/MEMS Devices and Manufacturing Technologies at Tohoku University” in Sendai, Japan

In 2012 Fraunhofer ENAS and WPI-Advanced Institute for Materials Research (WPI-AIMR) of Tohoku University did set-up a joint strategic research initiative by establishing a research and development (R&D) unit at the Tohoku University in form of a Fraunhofer Project Center (FPC). Within the Fraunhofer Project Center “NEMS/MEMS Devices and Manufacturing Technologies at Tohoku University” active exchange between German and Japanese scientists enables innovative research in the field of application of novel materials.

In 2013 the research was focused on the application of metallic glass as membrane material for acoustic micro transducers as well as room temperature solid liquid interdiffusion (SLID) bonding of semiconductor substrates. Three scientists from Germany, dispatched from Fraunhofer ENAS, stayed several months each at the Fraunhofer Project Center in Sendai and contributed strongly to the results.

Directors of the Fraunhofer Project Center in Sendai are: Prof. Masayoshi Esashi, Prof. Shuji Tanaka and Prof. Thomas Gessner.

*In November 2013, the president of Tohoku University, Professor Susumu Satomi, and the rector of the Technische Universität Chemnitz, Professor Arnold van Zyl, have signed an agreement on academic exchange between both universities.*

*From left to right: Prof. Thomas Gessner (Director of Fraunhofer ENAS and the Fraunhofer Project Center in Sendai, Director of ZfM at the TU Chemnitz), Takeshi Nakane (Ambassador of Japan in Germany), Prof. Arnold van Zyl (Rector of TU Chemnitz), Prof. Susumu Satomi (President of Tohoku University), Emiko Okuyama (Mayor of the City of Sendai), Prof. Motoko Kotani (Director of the WPI-AIMR, Tohoku University).*

*(Photo @ Tohoku University)*

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# APPOINTMENT / DISSERTATIONS

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## Appointment in 2013

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On October 14th 2013, Dr.-Ing. habil. Sven Rzepka got an appointment as an honorary professor of the faculty for Electrical Engineering and Information Technology of the Technische Universität Chemnitz. Within a special workshop of the faculty he gave a presentation about reliability of smart systems.

Prof. Sven Rzepka is the head of the department Micro Materials Center of the Fraunhofer ENAS. He joined Fraunhofer in 2009 after working as principal simulation at Qimonda, Back-End development, and at Infineon, Back-End of Line reliability department. He is graduated from Technische Universität Dresden with PhD and habilitation degree. In total, Dr. Rzepka has been working in BEOL and packaging technologies for 25 years with 20 years experience in microelectronics and smart systems reliability and simulation.

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## Dissertations in 2013

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January 11, 2013

PhD: Andreas Zienert  
Topic: Electronic transport in metallic carbon nanotubes with metal contacts  
Institution: Technische Universität Chemnitz

May 6, 2013

PhD: Alexander Weiß  
Topic: Entwicklung optischer Sensoren zur Qualitätssicherung und Zustandsüberwachung von Schmierfetten in Wälzlagern  
Institution: Technische Universität Chemnitz

May 29, 2013

PhD: Ralf Zichner  
Topic: Hochfrequenzkommunikation gedruckter Antennen in herausfordernden dielektrischen und metallischen Umgebungen  
Institution: Technische Universität Chemnitz



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# AWARDS

**Best apprentice:** In 2013 the apprentice Joachim Ziesche finished his vocational training at Fraunhofer ENAS. He graduated with "sehr gut" (very good) and was honored as one of the best apprentices in the Fraunhofer-Gesellschaft. On November 6, 2013 he was awarded as the best apprentice in microtechnologies in Saxony by the state secretary Mr. Fiedler, too.

**Edgar Heinemann Prize of Technische Universität Chemnitz:** Dr. Andreas Zienert has been selected as one of the prize winners of the Edgar Heinemann Prize of the Technische Universität Chemnitz 2013. This prize is handed to excellent scientists of engineering or natural sciences of the Technische Universität Chemnitz.

**Innovation award of Schaeffler Stiftung:** Schaeffler Stiftung selected Alexander Weiß for the innovation award 2013 in the field of product innovation for the development of optical sensors for quality assurance and condition monitoring of grease in rolling contact bearings.

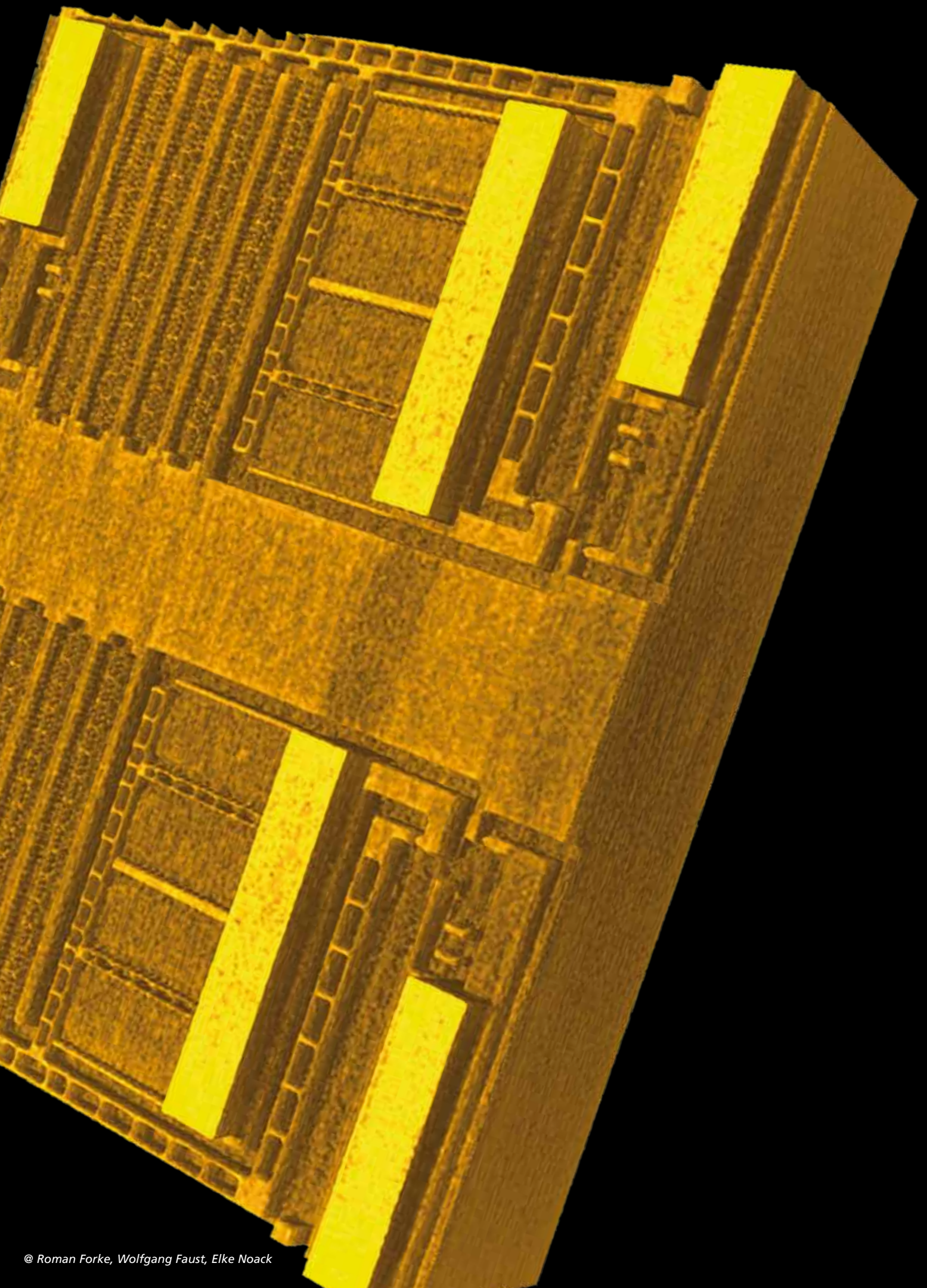
**Research award 2013 of Fraunhofer ENAS:** The researcher Ralf Zichner has received the research award 2013 of Fraunhofer ENAS for his outstanding scientific work and research in the field of RF communication of printed antennas in dielectric and metallic surroundings.

**Prize for best publicly funded project at the LOPE-C 2013:** The SIMS project was awarded with the prize for best publicly funded project at the organic and printed electronics conference, LOPE-C 2013, in Munich on the 12th June 2013. The team has developed a revolutionary diagnostic device for measuring cholesterol by integrating printed biosensors, displays and batteries onto a flexible plastic substrate, which was demonstrated with a prototype at the conference.

**SUPA:** At the end of 2012 the SUPA wireless GmbH has been founded to commercialize the SUPA technology. Since June 2013 the Fraunhofer-Gesellschaft holds 25 percent of the capital fund. The GmbH received the first prize at the fourth day of IKT.NRW Young IT.

**Fellow Fraunhofer ENAS:** Due to her excellent research in the field of microsystems, Prof. Karla Hiller, deputy director of the Center for Microtechnologies of the Technische Universität Chemnitz, became the first Fellow of Fraunhofer ENAS.

**Best poster award on INC9:** At INC9 Dr. Sascha Hermann received a best poster award for his poster on wafer-level technology for piezoresistive electromechanical transducer based on carbon nanotubes. Three posters, one from USA, one from Japan and one from Europe, have been awarded.



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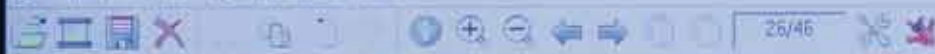
## RESEARCH REPORTS





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# SMART ELECTRONICS

Smart electronics addresses micro and nanoelectronics which is one of the key technologies of the 21st century. Not only the ongoing downscaling, known as More Moore, but also the integration of different functionalities, known as More than Moore, as well as the development of new non-silicon based materials, known as Beyond CMOS, are hot topics Fraunhofer ENAS is dealing with. Fraunhofer ENAS addresses:

- Materials, processes and technologies for advanced Back-End of Line schemes in micro and nanoelectronics,
- Process technology for 3D integration, micro and nano systems,
- Modeling and simulation of processes, equipments as well as complete interconnect systems
- Characterization and reliability assessment, starting from BEOL components towards complete chip-package interactions including 3D integrated systems.

Within the following articles some of these fields are presented in more detail. One article describes results of the cluster of excellence cfAED – Center for Advancing Electronics. Fraunhofer ENAS cooperates with the Technische Universität Dresden and the Technische Universität Chemnitz in developing of field effect transistors based either on carbon nanotubes (carbon path) or on folded deoxyribonucleic acid (DNA) in the bio path.

Moreover a customer specific solution for the 3D integration of MEMS is presented. A new packaging approach using silicon interposers is based on backside connections of the MEMS in combination with bumping technology.

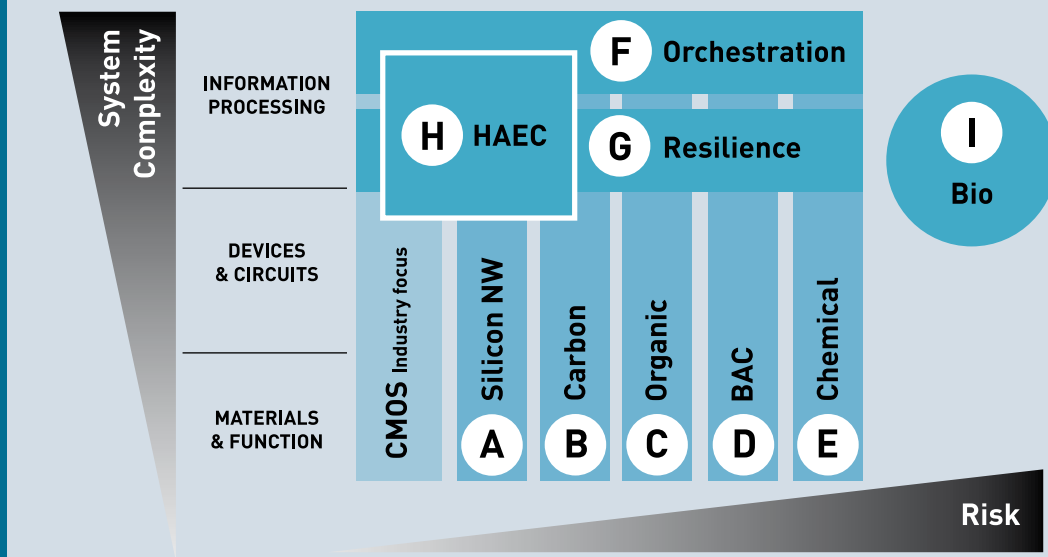
In order to develop a reliable assembling and packaging technology for microelectronics and microsystems, which can be applied for temperatures up to 300 °C, system integration approaches of combining semiconductor technologies, packaging and substrate material development are necessary.

Smart Electronics adressiert die Mikro- und Nanoelektronik, welche nach wie vor eine der Schlüsseltechnologien des 21. Jahrhunderts ist. Dabei spielen sowohl More Moore, More than Moore als auch Beyond CMOS eine wesentliche Rolle. Fraunhofer ENAS bearbeitet folgende Themen:

- Materialien, Prozesse, Technologien für die Mikro- und Nanoelektronik
- 3D-Integration von Elektronik und Sensorik
- Modellierung und Simulation technologischer Prozesse und Ausrüstungen (Equipments) sowie vollständiger Interconnect-Systeme
- Charakterisierung und Zuverlässigkeitsbewertung von BEOL-Komponenten bis hin zur Chip-Package-Wechselwirkung.

In einem nachfolgenden Artikel werden Ergebnisse aus dem Exzellenzcluster cfAED vorgestellt. Fraunhofer ENAS arbeitet hier in Kooperation mit der TU Dresden und der TU Chemnitz an Feldeffekttransistoren zum einen basierend auf Kohlenstoffnanoröhren und zum anderen auf Basis gefalteter DNA-Stränge.

Darüber hinaus werden eine kundenspezifische Lösung für eine 3D-Integration von MEMS, eine neue Technologie zur Realisierung von vertikalen elektrischen Durchführungen und die Entwicklung einer zuverlässigen Aufbau- und Verbindungstechnik für Mikrosysteme und Mikroelektronik bis 300 °C Betriebstemperatur beschrieben.



## ADVANCING ELECTRONICS – FINDING ALTERNATIVES TO CURRENT CMOS TECHNOLOGY

Jana Tittmann, Christian Helke, Sascha Hermann, Jörg Nestler, Stefan E. Schulz

### Introduction

In 2012, the Center for Advancing Electronics Dresden (cfAED) achieved the status of a Cluster of Excellence with a funding of 34 million euros until October 2017. It aims inducing breakthroughs in promising technologies which may complement today's leading CMOS technology, since it will be facing physical limits in performance enhancement soon. Therefore research teams of 57 investigators from 11 institutions are interdisciplinary cooperating in different scientific fields, as can be seen in Fig.1. Within the carbon path, Chemnitz acquired one research group leader and one PhD student position and therefore represents the center of the technological work package. Moreover, the Center for Microtechnologies at the Technische Universität Chemnitz is involved into the innovative research field of the biomolecular assembled circuits (BAC) path with one PhD student.

### Carbon path

Transistors, being the most important electrical devices, have a wide range of application potential. Due to further shrinking of integrated circuits, industry increasingly faces problems (e.g. short-channel effect and electromigration) in conventional CMOS technology.

Therefore, the Back-End of Line (BEOL) department at Fraunhofer ENAS in close cooperation with the Center for Microtechnologies at the TU Chemnitz and together with scientists from Dresden, contributes to the design and construction of carbon nanotube based field-effect transistors (CNTFET). Those devices have the potential for outperforming CMOS transistors in terms of linearity and power consumption. In particular in this project we aim the realization of analogue circuits for high frequency applications in the field of wireless communication.

The efforts at Fraunhofer ENAS include designing of different transistor structures for evaluation of their performance as well as fabrication of prototypes on wafer-level. For that purpose a bottom-up approach has been chosen to facilitate detailed characterization of CNTs and devices during preparation. Also the work focuses onto development of a process

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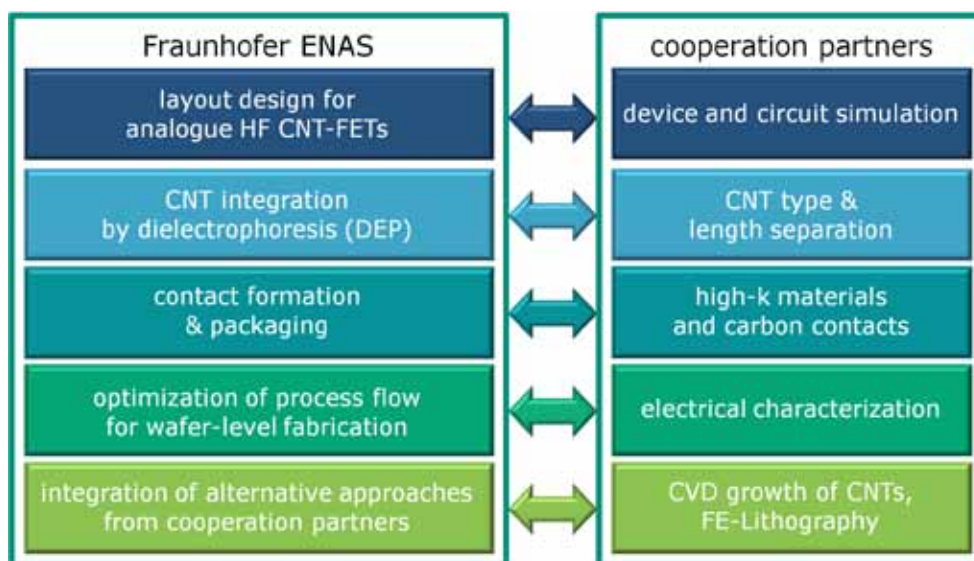
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chain compatible to current fabrication steps in industry and delivery of reliable and reproducible devices, which is quite challenging at the nano-scale. Recently the formation of suitable substrates with embedded gate structures and palladium electrodes have been successfully demonstrated.

For placing the nanotubes between electrodes, the so-called dielectrophoretic approach (DEP) is applied, using dispersed CNTs in solution. This method allows precise positioning of a controlled number of CNTs directly between a pair of electrodes, avoiding extensive wafer contamination, Fig. 2. A special DEP equipment, designed within the department BEOL allows the ramp up of this procedure to wafer-level and delivers reproducible results. Characterization of the devices e.g. by I/V measurements, Raman spectroscopy, AFM, TERS and SEM is carried out at Fraunhofer ENAS and collaborating institutions, like the TU Chemnitz and TU Dresden.

Ongoing work concentrates on improvement of electrical contact formation, process control of CNT assembly and passivation to improve device lifetime.

Within the carbon path, cooperating research groups tackle different aspects of the process chain, Fig. 3.



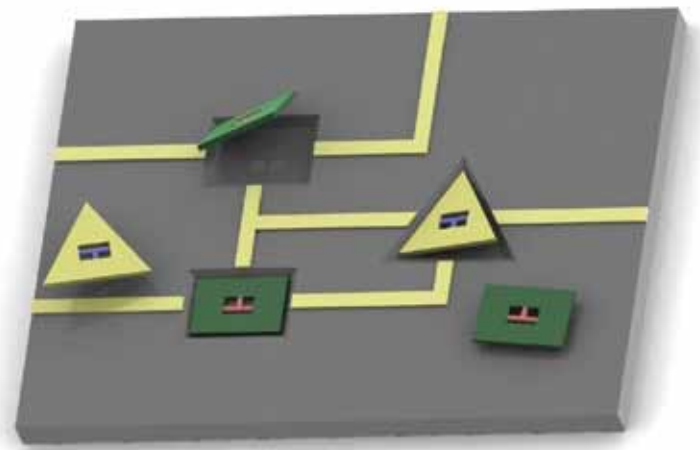
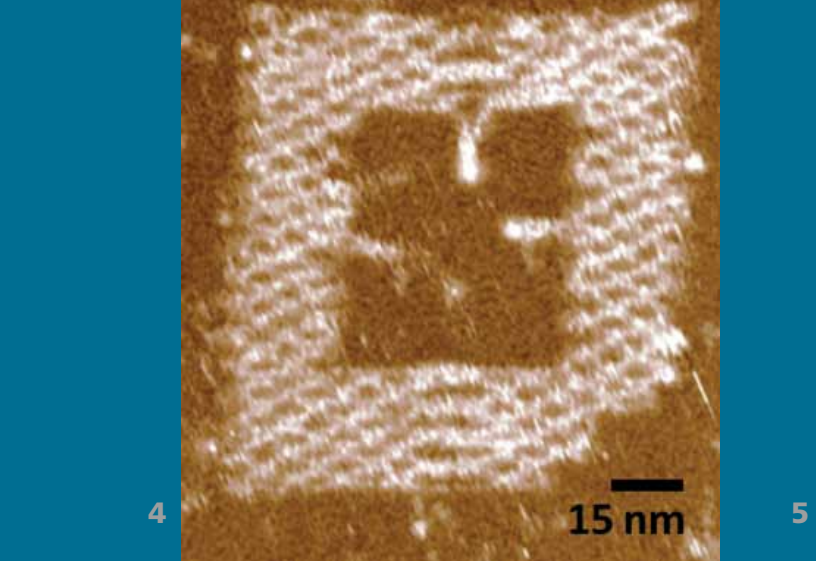
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1 Organization structure within the cfaED as a 'more shots on one goal' approach with 9 separated paths.

2 SEM image of deposited CNTs within a comb-shaped transistor geometry.

3 Main work packages and cooperation within the carbon path.





As synthesis of CNTs always generates different types of nanotubes with a variety of properties accordingly (e.g. length, diameter and band gap), the separation concerning different characteristics is crucial for the performance of CNT-FETs. In this scope, researchers in Dresden apply a density gradient ultracentrifugation to isolate especially long semiconducting CNTs. Moreover, several groups of modeling experts are simulating the transistors. Starting at an atomistic scale to define the influence of single defects in the carbon lattice or molecules attaching to the CNT, up to the device scale with different gap sizes between electrodes, a wide variety of components and parameters are checked to support and improve the fabrication of the transistors.

#### The BAC (Biomolecular assembled circuits) path

In the BAC path the development of novel strategies for a controlled bottom-up fabrication of artificial nanostructures with tailored electronic and optical properties (realized by functionalization with nanoparticles, quantum dots, ...) is proposed by the use of the unique self-assembly and molecular recognition capabilities of biomolecules.

The self-assembly of deoxyribonucleic acid (DNA) into smallest functional units, the so-called 'transistor pads' (tPads©, produced by TU Dresden, see Fig. 4) will focus on the development of novel strategies for a hierarchical self-assembly of circuits.

An achievable concept is to develop a self-assembly strategy to integrate tPads© into microsystems, implying recognition interfacing to patterned surfaces and controlled two-dimensional and three-dimensional (2D and 3D) stacking of functional units. This research should bridge the gap between micro and nanotechnology resulting from lacking methods to manipulate inorganic material at molecular scale.

In our approach the tPads© will be positioned in geometrical complementary 3D hydrophilic cavities on a hydrophobic substrate, Fig. 5. In a first step the structuring of a sub-nm thin hydrophobic layer system to achieve hydrophobic/ hydrophilic cavities has been verified with standard silicon microtechnologies. In further steps the adaption of the proved microtechnological processes to lateral nanostructuring technologies at wafer-level such as nano imprint lithography (NIL) will be realized. Therefore structure dimensions in X, Y and Z, regarding the tPads© itself (100 nm in X,Y and 10 nm in Z) will be achievable and will result in the aimed cavity structure concept. Furthermore, this developed technology concept focuses the electrical connecting of the tPads© which have to be below 50 nm. In addition, in a strong collaboration with TU Dresden, chemical and molecular bond positions

4 tPad© structure fabricated by DNA origami. (property of TU Dresden)

5 Schematic of the hierarchical self-assembly of DNA based circuits.



are addressed to develop a further and more locally self-assembly opportunity within the described cavity concept of the tPads©.

Subsequently, the integration and self-assembly of the tPads© will be accomplished by a microfluidic processing chip in a characterization platform which is used to prove the overall circuit properties of the tPads©.

#### Acknowledgement

This work is partly supported by the German Research Foundation (DFG) within the Cluster of Excellence 'Center for Advancing Electronics Dresden'.

Our cooperation partners at the cfaED:



TECHNISCHE UNIVERSITÄT  
CHEMNITZ



TECHNISCHE  
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Werkstoffforschung  
Dresden

**namlab**  
nanoelectronic materials laboratory

**MEINSBERG**  
**KST**

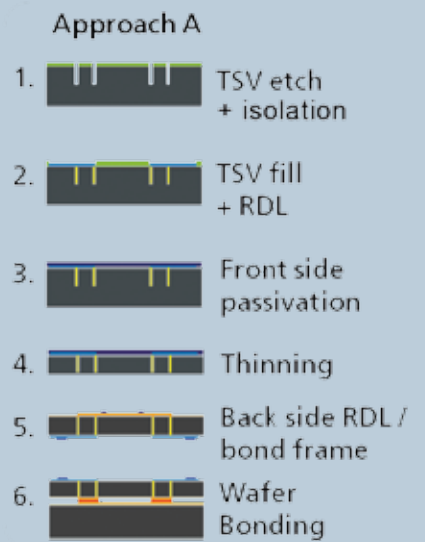
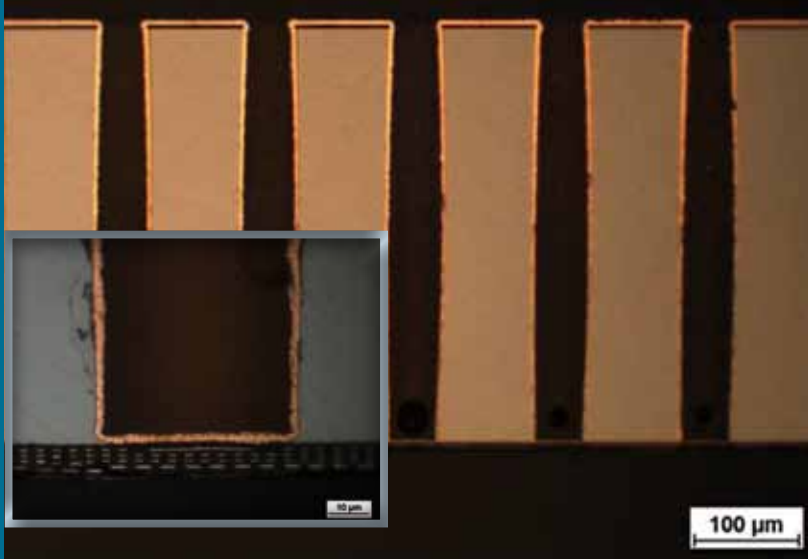
## ZUKÜNFTIGE ELEKTRONIK – ALTERNATIVEN ZUR CMOS- TECHNOLOGIE

Das Exzellenz-Cluster cfaED, das 2012 startete, hat ein Gesamtvolumen von 43 Mio € über eine Laufzeit von 4,5 Jahren. In 9 unterschiedlich ausgerichteten Pfaden sind 57 Forschungsgruppen aus 11 Instituten an der Initiative beteiligt, die sich um eine Ergänzung/Verbesserung zur aktuellen CMOS-Technologie bemüht.

Das Fraunhofer ENAS ist in Kooperation mit der TU Chemnitz in 2 Pfaden vertreten:

- Carbon: Ziel ist der Entwurf und die Herstellung von Feldeffekt-Transistoren mit integrierten Kohlenstoff-nanoröhren für analoge Hochfrequenz-Anwendungen (z.B. Mobiltelefone). Dabei liegt der Fokus auf reproduzierbaren Prozessabläufen, die sich auf Wafer-Ebene umsetzen lassen.
- Biomolekular arrangierte Schaltkreise (BAC): Feldeffekt-Transistoren auf Basis gefalteter DNA-Stränge. Die in Chemnitz durchgeführte Entwicklung realisiert dabei die notwendige Strukturierung im sub-µm Bereich auf Wafer-Ebene zur Selbstanordnung der gefalteten DNA-Origami in einer zukünftigen Charakterisierungs-Plattform.





## 3D TECHNOLOGIES FOR SMART SYSTEMS

*Lutz Hofmann, Knut Gottfried, Stefan E. Schulz, Mario Baum, Dirk Wünsch, Maik Wiemer*

Fraunhofer ENAS develops customized solutions for 3D integration of MEMS but also for CMOS related applications, Fig 1. Compared to the 3D solutions in pure microelectronics, 3D MEMS integration comes with different challenges, such as complex functionalities (mechanical, optical, fluidic) and the use of various materials (silicon, glass, metal and polymer) thereby, each application has its own specific requirements.

3D integration for MEMS may be achieved in different approaches, as for example shown in Fig. 2 (approach A: TSVs before bonding, approach B: TSVs after bonding).

For each approach different single process steps are to be chosen out of the process toolbox. Deep reactive ion etching (DRIE) for instance is suitable to obtain TSVs with very high aspect ratios. TSV insulation is either done by thermally grown oxide or by TEOS ozone; the latter in case of a required low temperature budget. The type of TSV metallization (full/partial filling) strongly depends on the TSV dimensions (depth, AR) and on resulting TSV properties (mechanical stress). MO-CVD is applied to deposit highly conformal TiN based diffusion barriers and adhesion layers as well as Cu seed layers for the following electro chemical deposition of Cu.

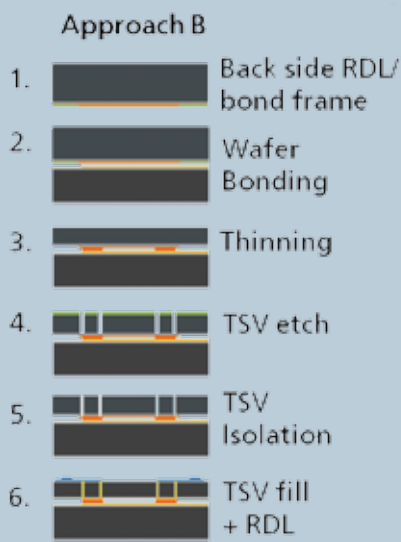
Wafer thinning ensures the desired device thickness and helps to minimize external packaging size. It comprises a two-step mechanical grinding (coarse and fine) followed by a wet or dry etching step in order to release the stress caused by grinding. Silicon thicknesses as low as 50 μm have been achieved using a Disco DAG 810 grinding tool. Final surface qualities after etching are in the range of a few nanometers (typical Ra = 4 nm). Chemical mechanical planarization (CMP) enhances the surface quality further (Ra = 0.2 nm for Si) as necessary for subsequent direct wafer bonding techniques.

Moreover, grinding, Si etching and CMP are required for the TSV reveal in approach A, Fig. 2. Depending on the application, the particular process flow (grinding/CMP or grinding/etching/CMP) may vary. Finally, the exposed Cu is connected using a back side redistribution layer (RDL) realized by PVD and ECD.

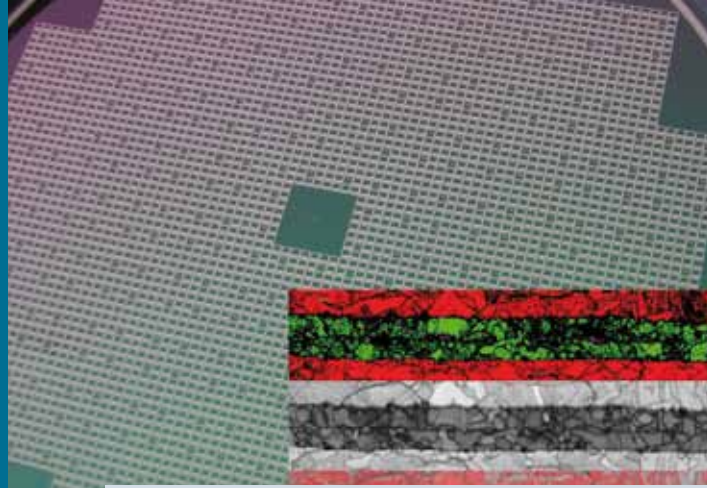
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### 3D-TECHNOLOGIEN FÜR SMART SYSTEMS

Fraunhofer ENAS entwickelt kundenspezifische Lösungen für eine 3D-Integration von MEMS. Aufgrund der enormen Vielzahl von unterschiedlichen MEMS-Typen mit einer ebenso großen Breite an Funktionalitäten und Materialien sind bei einer 3D-Integration von MEMS im Vergleich zur reinen Mikroelektronik vielfältige Anforderungen zu erfüllen. Vielmehr entwickeln sich für unterschiedliche Randbedingungen verschiedene Lösungsansätze. Im Allgemeinen besteht die 3D-Prozessabfolge aus den Schritten Formierung der Durchkontakte mit Tiefenstrukturierung (Deep reactive ion etching - DRIE), Isolation (thermisches Oxid, TEOS-Ozon), Metallisierung der Durchkontakte (PVD, CVD, ECD), Waferdünnen, Planarisieren (Grinden, Spin ätzen, CMP), permanentes und temporäres Waferbonden. Diese Schritte können in verschiedenster Reihenfolge kombiniert werden, so dass sich unterschiedliche Prozessabläufe ergeben.

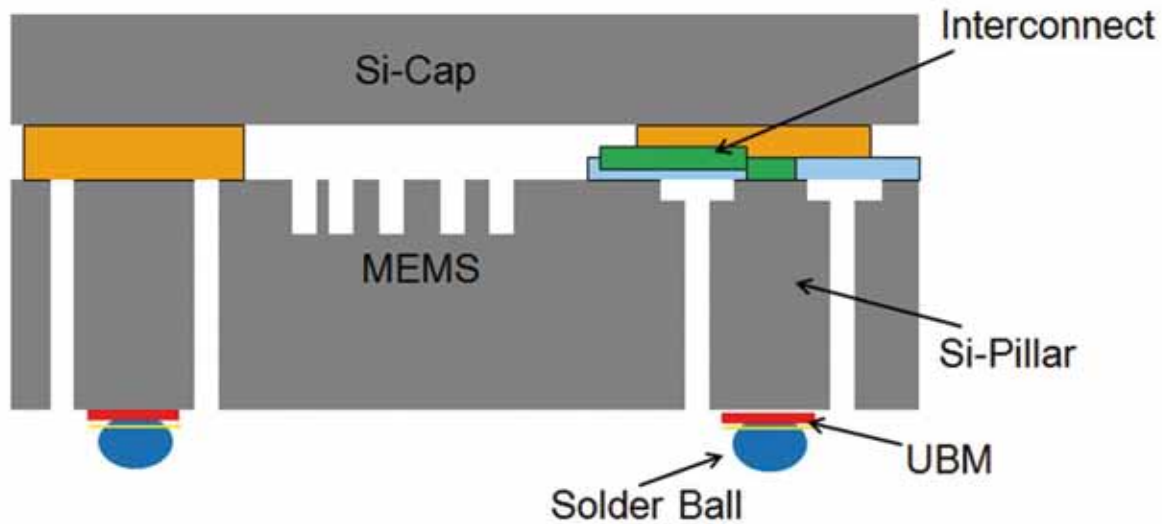
Permanent wafer bonding technologies for vertical stacking of wafers were used to realize the mechanical connection and stability as well as the electrical interconnection between each layer. One major requirement for 3D integration is low temperature processing (below 400°C), when CMOS chips will be integrated with sensor chips. When the electrical interconnect is implemented after the stacking (approach B) a broad range of bonding technologies like direct or anodic bonding but also polymer based bonding could be considered. Otherwise, when having TSVs applied as in approach A, the process is limited to metal or polymer based technologies. Hereby, thermo compression bonding (Cu-Cu, Al-Al or Au-Au) was investigated for 3D integration as well as liquid phase bonding technologies like eutectic or SLID bonding, Fig. 3.

Besides permanent bonding also the temporary wafer bonding and debonding become a key technology in 3 dimensional smart system integrations. One important step is the wafer bonding of the device to a carrier wafer prior to wafer thinning by using a temporary adhesive layer. This adhesive bonding material must be stable to withstand temperature of up to 300°C during the subsequent process steps and must be resistant to a wide range of smart system chemicals (solvents, etchants and cleaning agents). Finally, the important debonding process must realize the separation of device and carrier wafer without cracks, defects and adhesive residues on the fragile device wafer. ENAS focused on room temperature temporary bonding material.

#### Acknowledgement

The authors thank X-FAB in Erfurt for the confidence they placed in the cooperative TSV development.

- 1 *Highly conformal Cu-metallization in HAR-TSV-last approach. (CMOS based application together with X-FAB, Erfurt).*
- 2 *Two exemplary technology approaches for 3D integration.*
- 3 *CuSn bonding frame after deposition including interface EBSD analysis after SLID bonding.*



## DEDICATED HIGH PRECISION MEMS PACKAGING BY USING REAR SIDE CONNECTIONS (PROJECT SIMEIT)

Andreas Bertz, Christoph Robert Meinecke, Knut Gottfried

Within the SAB project SIMEIT (Stressarme Integration hochpräziser MEMS- und Elektronikkomponenten mittels neuartiger Interposer-Technologie) the contributing research institutes and industrial partners are looking for new packaging approaches using silicon interposers. A favored solution is based on backside connections of the MEMS in combination with bumping technology. So Fraunhofer ENAS and the Center for Microtechnologies (ZfM) of the TU Chemnitz are developing a through silicon via (TSV) approach.

### Evaluation of basic concepts

The introduction of silicon interposer architectures as primary package solution of high precision MEMS including ASICs offers strong advantage with respect to the thermo-mechanical matching of silicon devices and the silicon package. Additionally, the silicon interposer technology is ready for mass fabrication. Thus packaging costs could be reduced markedly. On the other hand there are at least two challenges for the MEMS geometry which have to be solved. First, the MEMS thickness has to be reduced because of the desired simplified interposer cross-section (total thickness, avoid additional cavities). Second – in order to enable soldering – an appropriate under bump metallization (UBM) film stack has to be deposited on top of the pad. While this is available for electronic devices, a MEMS UBM structure generation is limited by the complicated cross-section: a thick silicon cap which protects the fragile silicon structures inside the device wafer from the environment, carrying holes for wire bonding. Because wire bonding has to be replaced by soldering, a modification of the MEMS layout as well as its fabrication process is required.

Among others, like thin film packaging and capless stealth dicing in combination with encapsulation of the whole interposer, a novel “silicon pillar” approach is developed. For this, electrical conductive silicon pillars, isolated by surrounding air gaps, were used. The corresponding MEMS cross-section is shown in Fig. 1.

This kind of silicon based electrical feedthrough enables the electrical and mechanical integration of the MEMS as well as downscaling of the total sensor chip size.

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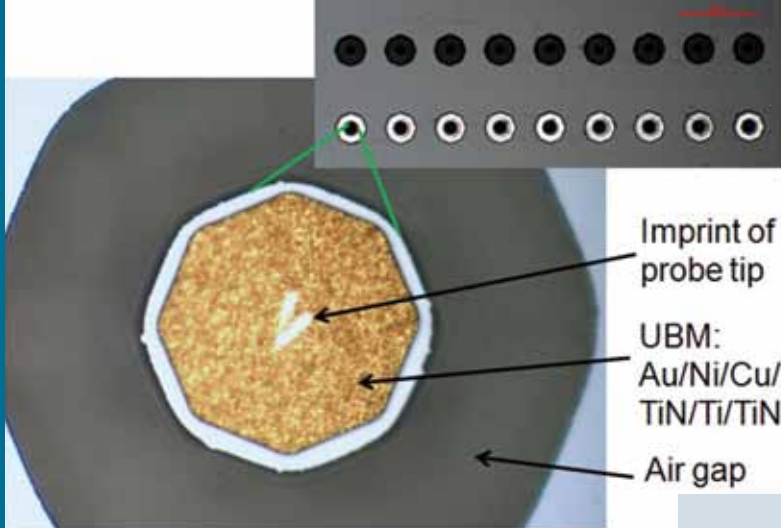
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### First results at sensor level

In principle the high precision low g inertial sensor is processed by AIM (Airgap Insulation of Microstructures) technology which is used for the fabrication of several other types of sensors and actuators too. The device wafers are 300  $\mu\text{m}$  thick and have to be highly doped in order to detect even very small capacitance changes. For this project especially the interconnect layer and the bonding layer have to be modified. After finishing the device processing and wafer bonding of the cap wafer, the new developed backside process module starts. Fig. 2 shows microphotographs with an overview (top right) of a set of Si-pillars carrying the UBM films and the detail of one Si-pillar (bottom left). Please note, on top of the overview picture a set of "dummy pads" is established in order to ensure the required mechanical stability of the MEMS by fixing through soldering.

First electrical measurements indicate that the sensor is ready for integration. Furthermore it has been successfully demonstrated that the cap wafer can be thinned down to a residual thickness of about 50  $\mu\text{m}$ . Further characterisation of the devices and UBM films are in progress. Handing over a set of MEMS to project partners, the development of the silicon interposer technology will be continued by soldering processes.

### Acknowledgement

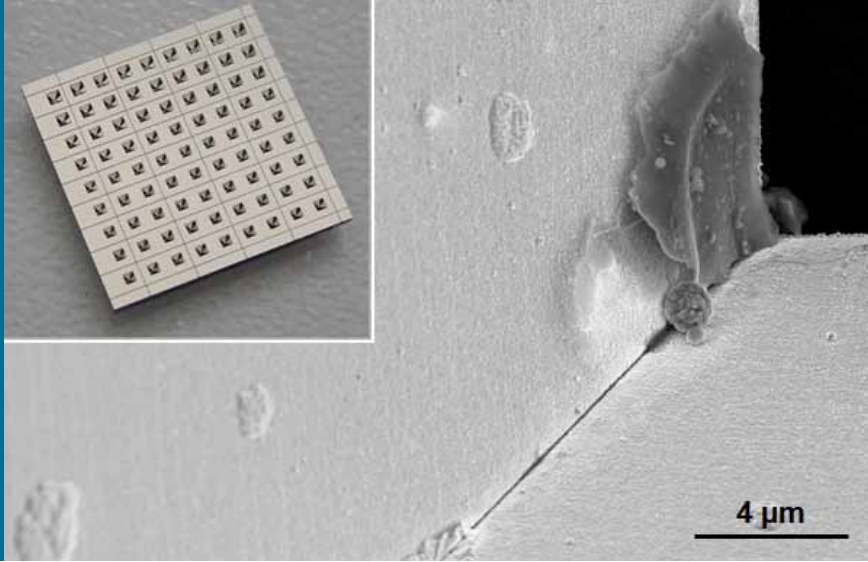
The project described has been funded by the European funding for regional development (EFRE) of the European Union and by funds of the Free State of Saxony (FKZ: 100097078).

## INTEGRATION VON HOCHPRÄZISEN MEMS UND ELEKTRONIKKOMPONENTEN MITTELS INTERPOSERTECHNOLOGIE

Dieser Beitrag beschreibt eine neuartige Technologie zur Realisierung von vertikalen elektrischen Durchführungen, die rückseitig durch einen MEMS-Wafer führen. Dazu werden „Silizium-Säulen“ generiert, welche durch einen Luftspalt vom umgebenden Silizium isoliert sind. Diese Art von Si-Durchführungen ermöglicht neben den elektrischen und mechanischen Integrationsmöglichkeiten des MEMS eine gleichzeitige Verringerung der Größe des Sensorchips. Im Vordergrund des Vorhabens steht dabei die Technologieentwicklung und -anpassung für hochpräzise Beschleunigungssensoren. Es wird u.a. gezeigt, dass strukturiertes Aufbringen (pattern plating) einer Bondgrundierung (Under Bump Metallization – UBM) sowie das folgende Siliziumtiefenätzen der Rückseitenkontakte möglich ist. Somit steht eine Technologie zur Verfügung, die vollständig in MEMS-Fertigungstechnologie integrierbar ist. Durch eine Rückdünnung des Verschlusswafers auf bis zu 50  $\mu\text{m}$  kann zudem die Bauhöhe des MEMS weiter deutlich reduziert werden. Schließlich stehen nach dem Vereinzeln verkapselte MEMS mit Siliziumssäulen (Si-TSVs), auf denen sich die UBM-Pads befinden, zur Integration in ein Silizium-Interposer-Package bereit.

- 1 Cross-section of MEMS structure with backside contact based on silicon pillars.
- 2 Microphotographs showing an overview (top right) of Si-pillars carrying the UBM films and the detail of one Si-pillar (bottom left).





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## RELIABLE TECHNOLOGIES FOR MICROSYSTEMS OPERATING IN HIGH TEMPERATURE ENVIRONMENTS

*Felix Gabler, Ralf Döring, Frank Roscher, Alexander Otto*

Modern electronic and mechatronic systems are more and more frequently required to meet harsh environmental conditions while reducing costs at the same time. In many fields of technology, as for example in automotive industry, power engineering and industrial metrology, the high temperature stability is stretched to today's limits of feasibility. A further increase of operating temperature is requested to be close to the process of interest, but needs new system integration approaches of combining semiconductor technologies, packaging and substrate material development. This is where the Fraunhofer joint project MAVO HOT-300 comes in with its technological and methodical research. High temperature stable MEMS and CMOS components are joined together with novel ceramic technologies and interconnection systems in a way that an operation up to 300 °C becomes possible without compromising functionality. In parallel, reliability analysis, modeling and prediction as well as defect diagnostics are of utmost importance.

### Development of multifunctional sensor

As exemplary MEMS component a sensor with multiple sensing functionalities is developed. This multifunctional sensor includes a capacitive micromachined ultrasonic transducer (CMUT) along with a capacitive pressure sensor and a Pt based temperature sensor. The existing CMUT technology at Fraunhofer ENAS is advanced towards higher operating temperatures. Key point of this advancement is the development of a temperature stable composite membrane which is carried out by a combination of temperature-dependent measurements on deposited layers together with extensive numerical simulations. This approach leads to temperature-dependent models based on the actual mechanical properties of the deposited layers.

### Wafer-level packaging and interconnections

In order to join the MEMS components together with ceramic substrates, a suitable wafer-level bonding technology needs to be developed. As one promising method the anodic bonding of silicon and ceramic is investigated. The ceramic (LTCC) is matched to silicon with respect to its thermal expansion coefficient (3.4 ppm/K) and contains sodium ions

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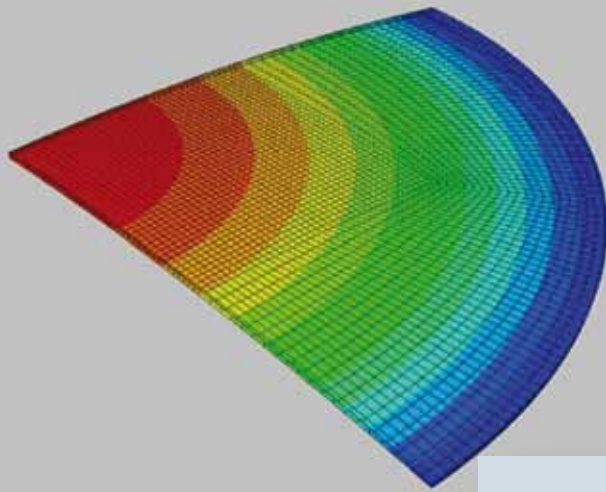
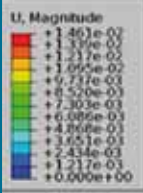
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which become movable at increased temperatures making the material anodically bondable. To achieve sufficient bond strength, the surface roughness of LTCC needs to be reduced down to < 10 nm. In this respect an efficient combination of fine grinding and chemical mechanical planarization (CMP) is utilized.

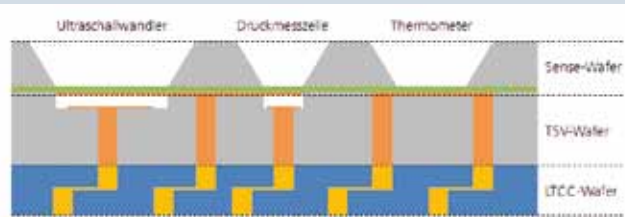
Further investigations focus on the electrical interconnections between the substrates. To reduce stress inside the package through silicon vias (TSVs) with thin sidewall metallization instead of completely filled vias are preferred. In terms of high temperature stability also alternative via metallizations are investigated. For expensive metals like platinum this is always a trade-off between cost and custom-specific requirements.

### Reliability and lifetime

High operating temperatures result in new temperature-driven mechanisms of degradation and material interactions which are only marginally covered until now. Consequently, the extraction of reliability information for the new packages is an important part of the research. The intended operating temperature of 300 °C is considerably above common testing temperatures. In this respect it is necessary to develop novel accelerated test methods, adjust detection techniques and determine material parameters. With the acquired data, reliability models are generated and validated which allow reliable predictions and risk evaluations for the new requirements. The results are not only valid for this specific project but can be applied to all harsh environment packages in principle.

## ZUVERLÄSSIGE TECHNOLOGIE FÜR MIKROSYSTEME, DIE IN HOCHTEMPERATUR-UMGEBUNGEN ARBEITEN

Das Fraunhofer ENAS baut mit seiner Beteiligung an der Fraunhofer Vorlaufforschung MAVO HOT-300 seine Kompetenzen im Bereich Smart Electronics weiter aus. Ziel ist die Erarbeitung einer zuverlässigen Aufbau- und Verbindungstechnik für Mikrosysteme und Mikroelektronik bis 300 °C Betriebstemperatur. Im Fokus des Fraunhofer ENAS stehen insbesondere der Entwurf und die Fertigung eines temperaturstabilen Multifunktionsensors mit Silizium-Durchkontaktierungen (TSV) sowie dessen Integration auf keramischen Substraten (LTCC). Dabei sind prozessbegleitende Simulationen und Zuverlässigkeitstests mit entsprechenden Defektanalysen sowie die Erstellung von Lebensdauermodellen wichtige Bestandteile der Forschungsaktivitäten.



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- 1 *Delamination after thermal cycling of TSV test structures with Pt metallization.*
- 2 *Numerical simulation of composite membrane deflection.*
- 3 *Schematic illustration of multifunctional sensor integration.*





# SMART MEDICAL SYSTEMS

In medical engineering Fraunhofer ENAS addresses the following topics:

- Diagnostics and monitoring, especially
  - Highly integrated lab-on-a-chip solutions for point of care diagnostics
  - Fabry Pérot interferometer, NIR/MIR MEMS spectrometer
  - Energy supply of printed systems, e.g for measurement of cholesterol content in blood
- Surface modification, nano imprinting for medical applications
- Reliability of smart systems for medical engineering
- Implants
  - Miniaturized sensors for medical applications
  - Biocompatible packaging

Three projects, the point of care platform for diagnosis of tropical diseases, biocompatible packaging and a Fabry-Pérot interferometer for monitoring anaesthesia gases are described more in detail in the following articles. Two developments are shown in other chapters. More information concerning measurement of the cholesterol content in blood is given in chapter smart power. This system integrates printed components – biosensors, displays and batteries – onto a flexible plastic substrate.

The MEMS spectrometer is presented in chapter smart monitoring. It is based on micro mirrors and works in the NIR and MIR range. This spectrometer can be used not only for fetal fat measurement but for monitoring gases, liquids and solids in general.

In the field of reliability Fraunhofer ENAS focuses on stress and lifetime evaluation of biomedical products. These evaluations combine experiment and simulation, include accelerated tests for the thermo-mechanical aging under different environmental conditions and material characterization.

At Fraunhofer ENAS there are different technologies available for micro and nano structuring of surface Especially patterning of surfaces by nano imprint lithography is suitable method for tissue engineering and application in cell research like adjustable growth of bio material.

In der Medizintechnik adressiert Fraunhofer ENAS Themen aus den Bereichen

- Diagnostik und Monitoring, u.a.
  - hochintegrierte Lab-on-a-Chip-Lösungen
  - Fabry-Pérot-Interferometer, NIR/MIR-Mikrospiegel-Spektrometer
  - Energieversorgung von drucktechnisch hergestellten Systemen, u.a. für Messung des Cholesteringehalts des Bluts
- Oberflächenmodifikation, Nanoimprinting für medizinische Anwendungen
- Zuverlässigkeit von intelligenten Systemen für die Medizintechnik inklusive Werkstoffcharakterisierung
- Implantate
  - Miniaturisierte Sensoren für medizintechnische Anwendungen
  - Biokompatible Aufbau- und Verbindungstechnik

Drei Projekte werden in den nachfolgenden Artikeln näher vorgestellt. Informationen zur Messung des Cholesteringehalts im Blut mittels drucktechnisch hergestellter Systeme sind im Abschnitt Smart Power zu finden. Das MEMS-Spektrometer wird unter Smart Monitoring vorgestellt.

Im Bereich Zuverlässigkeit liegen die Schwerpunkte auf der Beanspruchungs- und Lebensdauer-Bewertung biomedizinischer Produkte durch Kopplung von Experiment und Simulation, der Durchführung beschleunigter Prüfungen zur thermo-mechanischen Alterung unter verschiedenen Umweltbedingungen, der Identifizierung von Schwachstellen sowie der Werkstoffcharakterisierung.

Am Fraunhofer ENAS stehen vielfältige Technologien zur Mikro- und Nanostrukturierung von Oberflächen zur Verfügung. Insbesondere die Strukturierung von Oberflächen mittels Nanoimprint-Lithographie bietet Anknüpfungspunkte für Anwendungen im Zellforschungs- und Tissue-Engineering-Bereich.

## PODITRODI: POINT-OF-CARE PLATFORM FOR THE DIAGNOSIS OF TROPICAL DISEASES

*Andreas Morschhauser, Thomas Otto*

The diagnosis and discrimination of infectious diseases (such as leishmaniasis, dengue, malaria, HIV, chagas,...) in geographic regions with poor or low-density medical infrastructure is of high socioeconomic importance. While so-called “rapid in-vitro diagnostic (ivD) tests” for single diseases are already on the market, more complex analytical protocols are necessary to clearly identify a certain tropical disease AND to determine the status of the disease – the latter being crucial for proper treatment. In the PodiTrodi project 8 European partners and 5 partners from Brazil aim to overcome the current technological drawbacks and to develop an all integrated microfluidic platform for the parallel protein and nucleic acid based detection of tropical diseases.

### Microfluidic cartridge for safe and fast operation

Providing quality healthcare services poses a major challenge in developing and emerging countries. Especially citizens in rural areas cannot benefit from medical developments requiring a cost intensive medical infrastructure. Applying the advantages of microfluidics rapid in vitro diagnostic (ivD) testing and point of care systems respectively promise the vision of high quality diagnostics in low resource environments. In contrast to traditional laboratory testing these systems neither require trained personnel nor additional laboratory equipment. By the reduction of sample volumes the time to result as well as the use of cost intensive bio chemistry decrease significantly. Simple protein based test systems (immunoassays) are well established (e.g. pregnancy tests, drug tests,...) on the market.

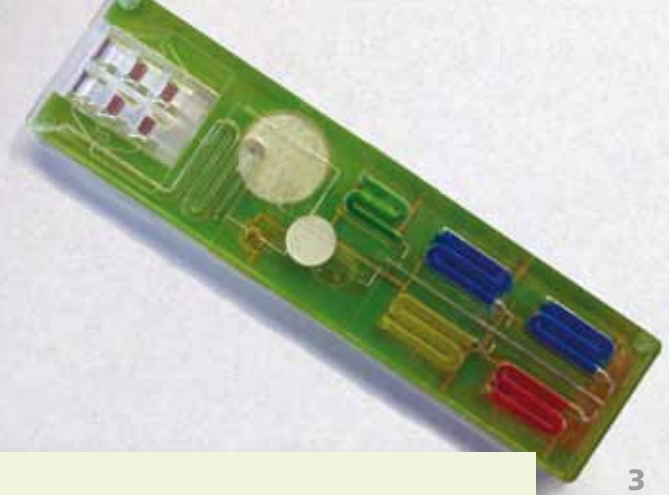
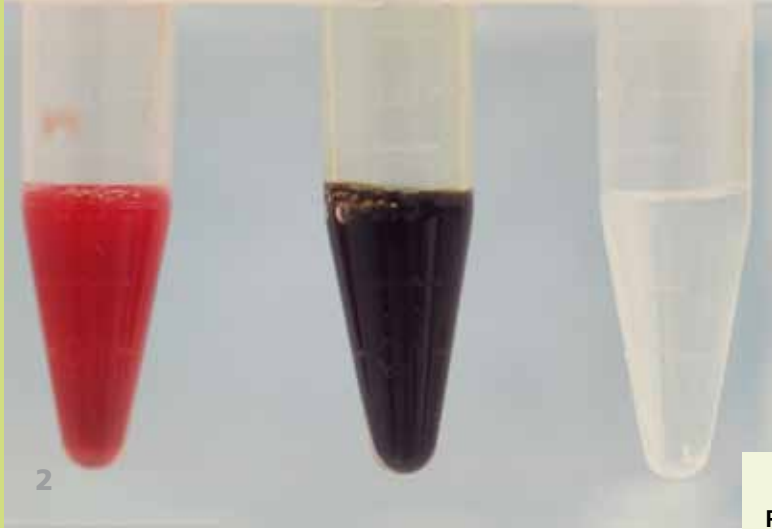
### Integration of the whole sample preparation

The main technological hurdle for nucleic acid based rapid ivD testing systems is the lack of suitable integrated and automated sample preparation procedures. While protein based immunoassays require little to no sample processing before the detection nucleic acids need a complex procedure of metering, lysis of cells and isolation of nucleic acids. In the PodiTrodi cartridge silica membrane based DNA isolation was chosen as a robust and stable extraction method. For the integration into the polymer based cartridge alcohol free extraction and washing buffers were developed by CEA Leti (Grenoble, France) and successfully tested

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with samples of 200 µl of whole blood. After the extraction the parasite's DNA is transferred to a real-time PCR chip (developed by ST Microelectronics, Italy) for amplification and detection.

**Platform: Vision of sustainability**

Chagas disease was chosen as a first model for infectious diseases: On the one hand, resulting from the long latency period and the increased personal mobility, the diseases affects third and first world countries alike and on the other hand protein and nucleic acid based methods can be applied for the detection of the protozoan parasite. Since the basic testing procedures can be applied to other diseases by exchanging the used biochemistry the PodiTrodi platform can be applied to other infectious diseases as well. As a vision for the future multiplexing, i.e. the parallel testing of multiple parameters/diseases, will be applied in the PodiTrodi platform in order to provide a tool for the discrimination between diseases with similar symptoms.

**Acknowledgements**

The project is partly funded by the European Commission under the 7th Framework Programme in the area of EU-Brazil Research and Development cooperation under Grant Agreement no. 287770. The Brazilian funding is provided by CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico under Grant Agreement 590032/2011-9.

**PODITRODI: PLATTFORM ZUR VORORT-DIAGNOSE VON TROPENKRANKHEITEN**

Im europäisch-brasilianischen Kooperationsprojekt PodiTrodi wird eine mikrofluidische Plattform für die Vorort-Detektion tropischer Infektionskrankheiten entwickelt. Am Beispiel Chagas werden die Vorteile der Technologie (verkürzte Analysezeit, sichereres Handling) demonstriert. Schlüsselkomponente der Plattform ist die integrierte und automatisierte Probenvorbereitung. Dafür verwendet das System neben einer polymerbasierten Mikrofluidikkartusche speziell entwickelte Alkohol-freie Extraktions- und Waschpuffer (CEA Leti, Frankreich) sowie einen realtime-PCR Chip (St Microelectronics, Italien) zur DNA-Vervielfältigung und -Detektion. Das volle Potenzial der Technologie wird im Multiplexing, d.h. der parallelen Detektion mehrerer Krankheitsmarker, gesehen. Somit könnte ein effizientes und sicheres Werkzeug zur Unterscheidung von Infektionskrankheiten mit ähnlicher Symptomatik bereitgestellt werden.

- 1 *Close up of channel structures in the transparent injection moulded first generation microfluidic cartridge.*
- 2 *Comparison of whole blood, lysed whole blood and eluted (extracted) DNA (from left to right).*
- 3 *First generation microfluidic cartridge realizing the automatic extraction of DNA from lysed whole blood.*



## DENECOR – DEVICES FOR NEUROCONTROL AND NEUROREHABILITATION

*Marco Haubold, Nooshin Saeidi*

### Abstract

Aging is one of the biggest challenges for the future of healthcare in Europe. By 2025 more than 20% of Europeans will be 65 or older. Incompatibility of therapy and diagnosis for these co-occurring medical conditions is a problem which can impede comprehensive screening and treatment procedures. DeNeCor project aims to address this issue by developing novel electronic devices to demonstrate coexistence of therapy and diagnosis techniques.

### Introduction

The aging population has a significant influence in increasing incidence of neurological disorders such as Alzheimer's disease, Parkinson's disease, brain tumor and stroke, chronic pain, epilepsy and so on. Often, a patient may suffer from more than one disease, while the diagnostic and therapeutic techniques for one may be incompatible with those of the others.

On the other hand, neuromodulation has increasingly become a therapeutic technique to treat neurological conditions. Many patients are (and will be) using active implants. Some of these implants are not compatible with the key neurological diagnostic techniques such as electroencephalography (EEG) and magnetic resonance imaging (MRI). This incompatibility has made neurologists unwilling to prescribe neuromodulators for their patients as the primary solution; rendering these devices as the last resort treatments. Currently, none of the neuromodulation systems available in the market is 'MRI' safe. For example, MRI which is a worldwide used and extremely accurate disease detection technique is still considered unsafe for a patient with an implant such as a pacemaker. DeNeCor consortium will demonstrate coexistence of therapeutic devices and diagnostic systems. The consortium consists of over 20 research and industrial partners from 7 European countries. The System Packaging department of Fraunhofer ENAS will contribute to this project by investigating the application of MRI safe ultrasound imaging devices as well as developing a packaging technology for encapsulating such devices.

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### Aim

The project will focus on creating coexistent therapeutic and diagnostic systems and introduce nanoelectronic neuromodulators in the healthcare market and extend the European market for diagnostic and imaging systems.

The key objectives of DeNeCor project are:

- Extracting the requirements for both therapeutic and imaging systems and validating the technical specification for MRI safety considerations of active implants.
- Extending the application of the technical specification to other diagnostic systems and the interaction between diagnostic systems and non-invasive electrical neuro-modulation. This will be performed in three major steps: i) demonstration of an MRI compatible transcranial magnetic stimulator (TMS) with focused spatial localization, ii) development of MRI and TMS compatible sensor and packaging technology for invasive and noninvasive neural sensing, iii) demonstration of an MRI-guided endoscopic system with integrated ultrasound system.
- Developing test methods to evaluate therapeutic and diagnostic systems independently and in parallel.

### Impact

DeNeCor will encourage clinicians and neurologists to prefer neuromodulation therapies. This will enable the healthcare systems to benefit from the technological advancements in therapeutic and diagnostic techniques.

DeNeCoR will accelerate European business; because the consortium will deliver a set of coexistent devices for simultaneous neuro therapy and diagnosis.

### Acknowledgement

The project is funded by the European ENIAC Joint Undertaking (JU) and the German Federal Ministry of Education and Research (BMBF).

## DENECOR – MRT-VERTRÄGLICHE THERAPIEWERKZEUGE ZUR NEUROSTIMULATION

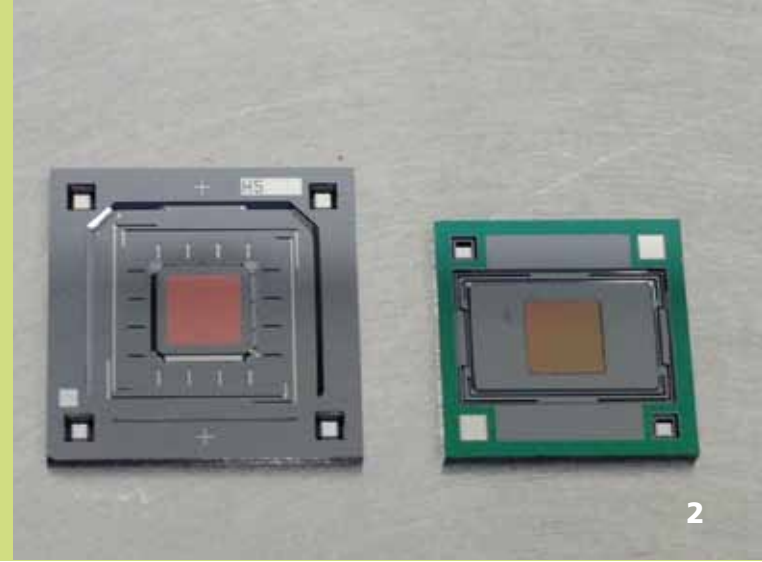
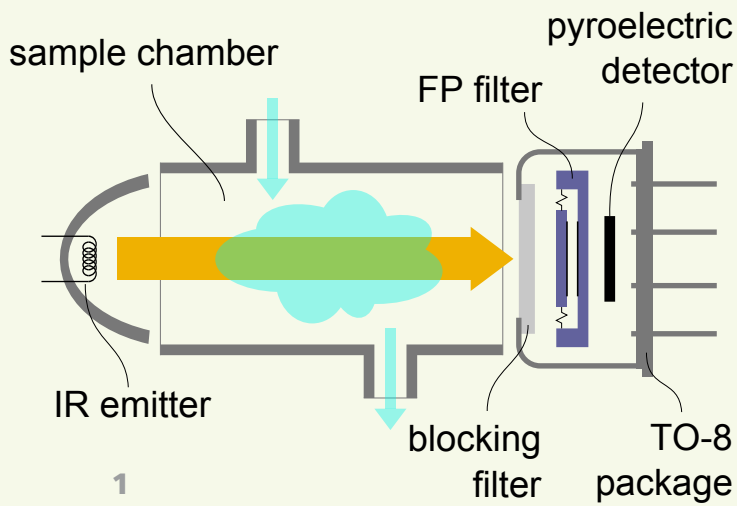
Neurologische und neurodegenerative Erkrankungen des Gehirns nehmen insbesondere im höheren Alter zu. Dem Einsatz von Geräten zur Neustimulation steht derzeit entgegen, dass sie nicht verträglich sind mit den gängigen Diagnosesystemen wie z.B. der MRT (Magnetresonanztomographie).

Das Projekt DeNeCor im Rahmen des europäischen ENIAC Vorhabens verfolgt die Entwicklung eines Therapiewerkzeuges mit Verträglichkeit zur etablierten MRT Bildgebung. Es wird die Integration der elektroakustischen Funktionalität in ein miniaturisiertes Endoskop angestrebt. Die Funktionserweiterung erlaubt die Ergänzung der optischen Visualisierung um die ultraschallbasierte Bildgebung und Stimulation.

Das Werkzeug soll erstmalig kompatibel zu MRT-Verfahren sein und die parallele Nutzung erlauben. Da der für das Wandlerelement vorhandene Bauraum ungefähr dem Volumen eines Sandkorns entspricht, ist eine innovative, sichere und MRT-taugliche Kapselungstechnologie der Komponente erforderlich. Die miniaturisierten Systeme werden dadurch als medizinische Implantate nutzbar und ermöglichen neue Heilungsmöglichkeiten auf dem Gebiet der tiefen Gehirnstimulation.

1 *Micro endoscope and MRT equipment (@ Philips).*





## TUNABLE IR FABRY-PÉROT FILTERS APPLIED IN GAS SENSING MICROSPECTROMETERS

*Steffen Kurth, Marco Meinig, Karla Hiller, Mario Seifert, Christian Helke, Norbert Neumann, Martin Ebermann*

Infrared spectroscopy is a powerful analysis method for both natural science and engineering. Many substances can be reliably distinguished by their unique absorption spectra. Fraunhofer ENAS and TU Chemnitz have been working on Fabry-Pérot (FP) filters for tuneable IR detectors together with InfraTec GmbH Dresden for more than 10 years. The filters are aimed for gas analysis e.g. in medical diagnostics, especially the detection and monitoring of carbon dioxide and anesthetic gases, such as halogenated ethers and nitrous oxide, in respiratory gas. Therefore they are combined with an IR detector in a compact TO-8 housing and integrated in a spectrometer set-up as shown in Fig. 1.

The filters consist of an optical cavity as basic element which is built between two parallel aligned and high reflective mirrors. The transmitted wavelength is mainly influenced by the distance between the mirrors; by changing this gap size the filter can be tuned. As silicon is transparent in IR light, it can be used to build the reflector carriers as well as the electromechanical tuning system.

Two electromechanical design approaches and the respective technology flows have been developed. Both of them apply electrostatic forces in a vertical capacitor setup in order to tune the gap size of the optical resonator. The 1M approach, Fig. 2 left, consists of one moveable and one fixed reflector carrier. The tuning voltage is applied to the upper Si substrate and to a separate electrode on the lower substrate. This construction allows for a closed-loop control of the filter; however, it is more sensitive to possible unintended wavelength change caused by forces from gravitation and vibration. The 2M approach solves this problem by a design with two equally sized, movable reflector carriers. Both reflector carriers are nearly equally deflected by the acceleration forces and the optical cavity length remains unaffected, which is particularly necessary for transportable spectrometers. Therefore, the maximum control voltage for tuning the full wavelength range or the chip size can be significantly reduced, Fig. 2 right.

Specific bulk technologies combining wet and dry etching of the Si substrates in order to form the reflector carriers, the elastic suspension, the cavities and the electrodes have been developed. In order to cover a large wavelength range (3...12  $\mu\text{m}$ ), the dielectric stack reflectors

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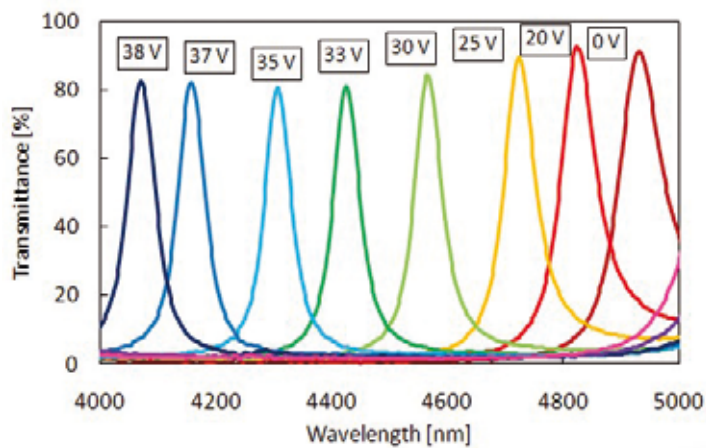
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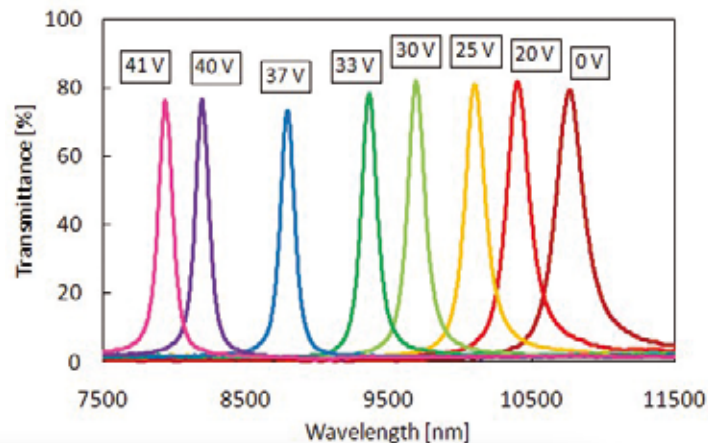
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3 A



B

### DURCHSTIMMBARE IR FABRY-PÉROT-FILTER FÜR DIE GASANALYSE MITTELS MIKROSPEKTROMETER

Fraunhofer ENAS, TU Chemnitz und InfraTec GmbH Dresden entwickeln seit mehr als 10 Jahren gemeinsam Fabry-Pérot Filter für durchstimmbare Infrarot-Detektoren. Diese Filter können in der Gasanalyse, z.B. in der medizinischen Diagnostik bei der Überwachung von Anästhesie-Gasen, eingesetzt werden. Dazu werden sie mit einem IR-Detektor in einem kompakten TO-8-Gehäuse kombiniert und in ein Mikrospektrometer, Abb. 1 integriert. Es wurden zwei verschiedene Filter-Designs mit einem (1M) bzw. zwei (2M) beweglichen Reflektorträgern sowie die entsprechenden spezifischen Fertigungstechnologien entwickelt, Abb. 2. Diese kombinieren nasschemische und plasmachemische Prozesse zur Silizium-Strukturierung, um die Reflektorträger, die elastischen Befestigungen, die Spaltabstände und die Elektroden für die elektrostatische Ansteuerung zu erzeugen. Die Reflektoren an den Innenflächen der Filter entstehen durch selektive Abscheidung von dielektrischen Schichten mit hohem (Ge) und niedrigem (z.B. ZnS) Brechungsindex. Diese Technologie wurde gemeinsam mit der Jenoptik Optical Systems GmbH Jena entwickelt. Mittels Direktem Bonden werden die vorstrukturierten Wafer gefügt. Es entstanden Filter für verschiedene Arbeitsbereiche (3 ... 3,8  $\mu\text{m}$ , 4 ... 5  $\mu\text{m}$  und 8 ... 11,5  $\mu\text{m}$ ). Ausgewählte Ergebnisse sind in Abb. 3 gezeigt.

consist of Ge (high refractive) and ZnS (low refractive) and a third material with low refractive index. These layers are deposited selectively by an ion assisted evaporation process (IAD), using a shadow mask technology, before mounting the pre-patterned wafers. For bonding the two wafers together, methods have been chosen which allow a precise adjustment of the optical gap with only 100 nm tolerance, preferably Silicon Fusion bonding without any further intermediate layer.

For both 1M and 2M approaches and for different wavelength ranges, filters have been fabricated and tested successfully. The characteristics of a dual band filter (1st/2nd order) fabricated with a 2M approach is shown in Fig. 3. A high tuning range of 2800 nm was reached with a tuning voltage of only 41 V. The peak transmittance is > 75 % and the FWHM is < 200 nm in the upper range and < 100 nm in the lower range. For filters with 1M and 2M designs, operated in a spectral range 3.1 ... 3.8  $\mu\text{m}$  and in higher interference order (3rd or 4th), it is possible to reduce the bandwidth to 20 ... 30 nm, and hereby to increase the resolution of the filters. It is also found that the 2M design can enhance the stability against vibration and gravitation by a factor of 2 ... 6. Furthermore, the latest samples of silicon fusion bonded 2M filters show very low temperature coefficients of the transmission wavelength of  $-0.25 \dots -0.85 \text{ nm/K}$ .

This project is presently supported by the German Federal Ministry of Education and Research, contract number 13N9489, and the results will be further exploited together with our industrial partners InfraTec GmbH Dresden (spectrometer system) and Jenoptik Optical Systems GmbH Jena (optical layer deposition).

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- 1 *Microspectrometer setup.*
- 2 *Chip photographs of an 1M design (left) and a 2M design with reduced chip size of 7 mm x 7mm (right).*
- 3 *Transmission characteristics of a dual band filter with 2M design with respect to tuning voltage (A: lower band; B: higher band).*



# SMART POWER

In the chapter smart power Fraunhofer ENAS addresses powering of smart systems and devices as well as autonomous, energy self-sufficient sensor networks for optimizing the capacity utilization of power lines. Main working fields are:

- Development and manufacturing of printed batteries
- Reduction of the energy consumption of smart systems
- Power line monitoring
- Reliability of components and systems
- Wireless energy supply of mobile devices – SUPA technology.

The following four articles address all topics except reduction of energy consumption. This is described in detail in chapter smart monitoring, namely in the article related to the nanosystem integration network of competences nanett. Here energy efficient sensor nodes based on MEMS wake up receivers have been developed. The system itself is waked up only if an incident occurs. This ensures a low energy consumption of the sensor system in the sleeping mode. In the present case it will be applied for monitoring lightweight structure components consisting of fiber reinforced polymers.

Smart systems need power for their operation. A smart integrated miniaturized sensor (SIMS) system has been commonly developed in an European project. The SIMS device combines a printed biosensor, a printed electrochromic (EC) display, and an organic electronics circuit – all powered by a tailored printed battery. The printed battery has been developed and manufactured at Fraunhofer ENAS. It can be adapted also for other applications.

The ASTROSE system, the autonomous and energy self-sufficient sensor network for optimizing the capacity utilization of power lines has reliably worked in two field tests. In 2014 a pilot line in the Harz mountains will be equipped with 60 nodes.

Reliability is a hot topic for all applications. Efficient energy management, needed for e-cars or power grids, requests power modules designed for high temperatures up to 300°C. In order to guarantee a reliable operation of such power modules it is necessary to develop innovative assembling and packaging technologies especially high temperature interconnection technologies.

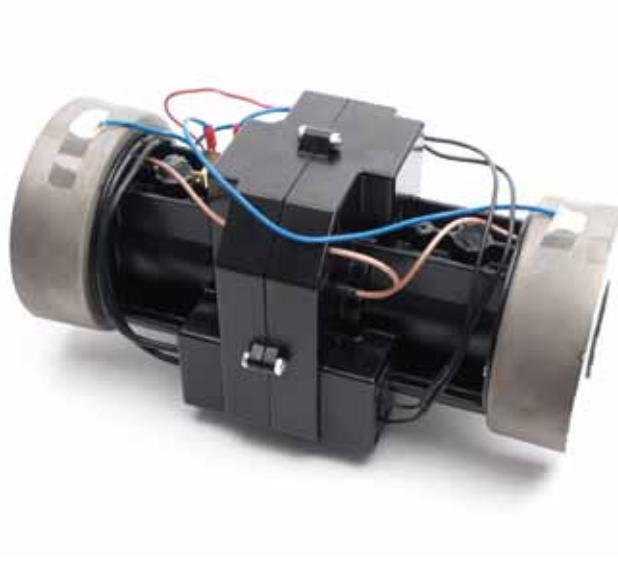
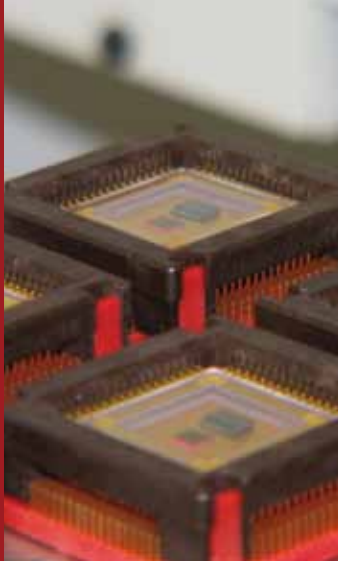
Currently, each mobile device needs its own docking station for recharging batteries. Based on SUPA technology they can be recharged by simple placing them on a conference table or on a desk.

Smart power adressiert die Energieversorgung von intelligenten Systemen und von Geräten sowie autonome Sensornetzwerke für die Optimierung der Kapazitätsauslastung von Hochspannungsleitungen. Die Wissenschaftlerinnen und Wissenschaftler des Fraunhofer ENAS arbeiten auf folgenden Gebieten:

- Drucktechnische Herstellung von Batterien für intelligente Systeme
- Reduzierung des Energieverbrauchs intelligenter Systeme
- Freileitungsmonitoring von Stromnetzen (100 kV, 220 kV, 380 kV)
- Zuverlässigkeit von Komponenten und Systemen
- Drahtlose Energie- und Datenübertragung für mobile Geräte mittels SUPA-Technologie

Der Punkt Reduzierung des Energieverbrauchs intelligenter Systeme wird im Kapitel Smart Monitoring betrachtet. Hier geht es um energieeffiziente Sensorknoten.

In den nachfolgenden Artikeln werden auch Ergebnisse aus den Projekten „HotPowCon“ und „Propower“ vorgestellt. Dabei geht es um die Entwicklung neuer Fügwerkstoffe, Verfahren und Anlagentechniken zur Herstellung von Leistungselektronik für Hybrid- und Elektrofahrzeuge bzw. kompakte Elektronikmodule mit hoher Leistung für Elektromobilität, Antriebs- und Beleuchtungstechnik. In beiden Projekten bearbeitet Fraunhofer ENAS die thermomechanische Zuverlässigkeit.



1

## ASTROSE® – AUTONOMOUS SENSOR NETWORK FOR CONDITION MONITORING OF HIGH VOLTAGE POWER LINES: IN PREPARATION OF AN EXTENSIVE PILOT TEST

*Sven Voigt, Steffen Kurth*

In the research project ASTROSE funded by the German Federal Ministry of Education and Research (BMBF) a basic concept of a monitoring system for high voltage power lines was developed. The system consists of numerous sensor nodes measuring the inclination, the temperature and the line current of the spans of the high voltage power line. A single sensor node consists of a microcontroller, a real-time clock, an electronic energy management, a 2.4 GHz transceiver and the corresponding sensors. Equipped with two antennas and an additional antenna filter the components are housed in a cylindrical and conducting hull with a slot for easy mounting to the power line. The sensor node needs no battery. Instead the electrostatic fringing field of the high voltage power line is used as power source. The collected data is passed along the sensor chain and transmitted to a base station, Fig. 1.

This autonomous and energy self-sufficient sensor network is used to monitor the sag and therefore the safety distance of the power lines. Especially the increasing development of renewable energies as well as their fluctuating supply, particularly of wind and solar power let the distribution networks reaching their load limits. With the help of the ASTROSE® system the capacity utilization of the power lines can be optimized finally.

### **Further development and testing**

With the end of the research project an extensive test run was started in September 2012 and is still running. The test takes place on a 110 kV power line near Chemnitz. For the necessary assembly works the power line could be easily turned off and on.

Together with Fraunhofer IZM, Microelectronic Packaging Dresden GmbH, KE Automation, envia NSG and MITNETZ STROM a lot of improvements were implemented during the year 2013. For example, a protection circuit has been added to protect the transceiver against high transients. These conditions occur when high voltage is switched on the power line as well as when environmental lightning strikes. Tests of the protection circuit in the laboratory showed that direct lightning discharges of more than 10 kV can be diverted successfully. In addition to other small improvements in the hardware, the software of the sensor nodes and the receiving station has been improved. The synchronization and data transfer among the nodes is more reliable and less susceptible to interference.

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*In cooperation with*

*Fraunhofer IZM,*

*Microelectronic Packaging*

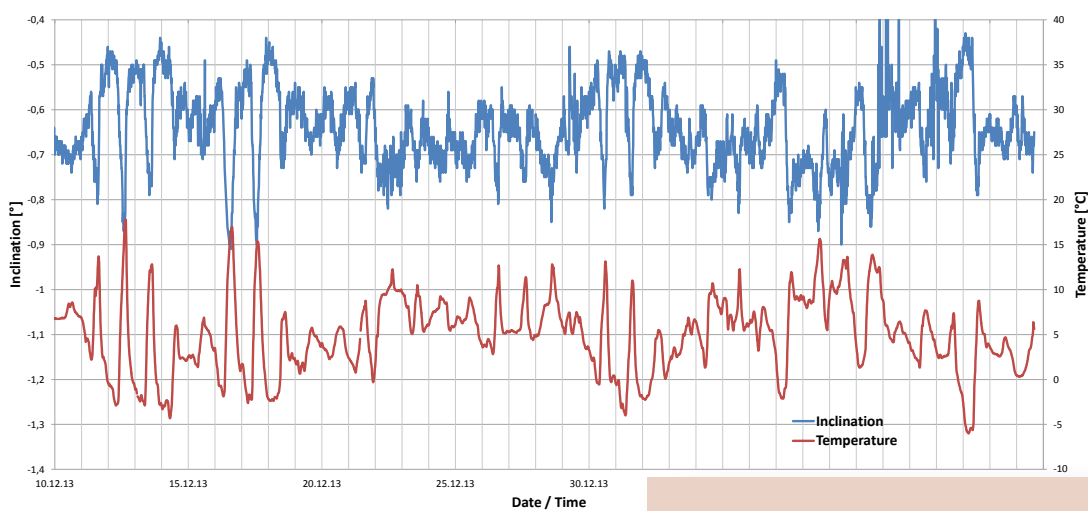
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*MITNETZ STROM*



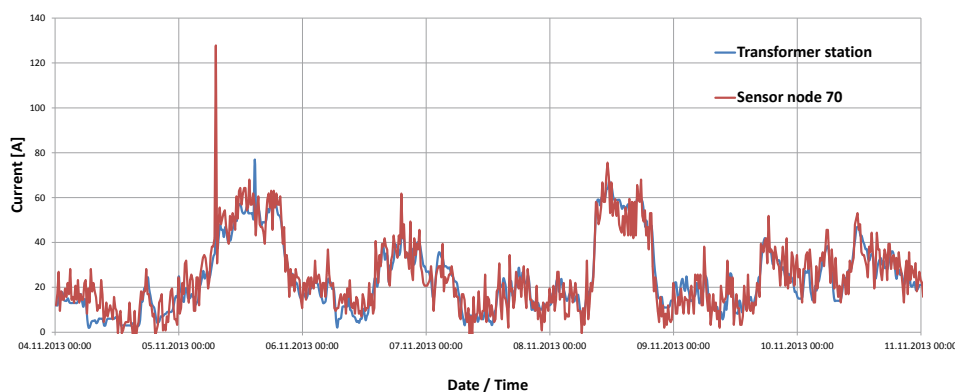


In parallel, the recorded data (inclination, temperature and current) were analyzed and compared with weather data of the test area and current load values of the power line. Figure 2 shows the typical correlation of temperature and inclination. Higher temperature leads to higher negative inclination, and it is to be seen that the inclination sensor resolves the fluctuation much faster than the temperature sensor that has a certain measurement delay due to its thermal capacitance and limited thermal conductance between the temperature sensor and the power cable. Figure 3 shows the comparison of the current sensor inside one node with the load current which was measured at the transformer station. The internal current sensor node shows differences of only a few amperes and operates sufficiently accurate.

### Planning of pilot test

For the upcoming pilot test a 110 kV power line in the Harz mountains has been selected and will be equipped with around 60 sensor nodes. The pilot line has various special geographic features. Because of the high altitude of this region ice loads during winter will be expected. Furthermore, the line passes through a dense forest area. Here, the wind cooling of the conductor is reduced, thereby overheating can occur.

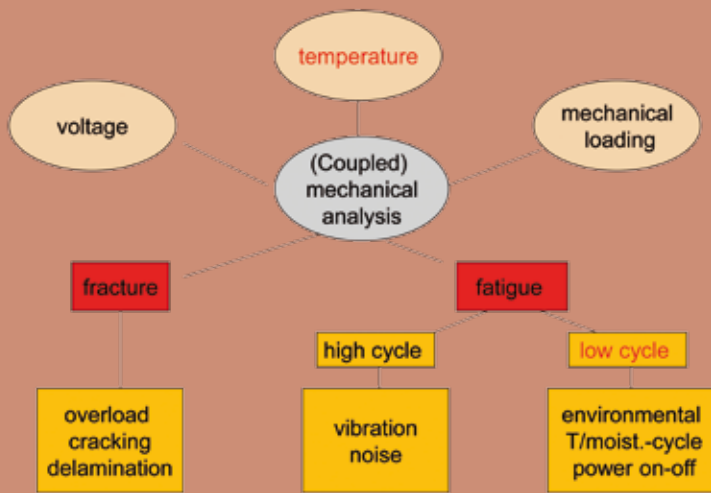
The pilot test is targeted to demonstrate the benefits of the power line monitoring system ASTROSE®, and finally to make the distribution networks more reliable and efficient.



## ASTROSE – VORBEREITUNG EINES ERWEITERTEN PILOTVERSUCHS

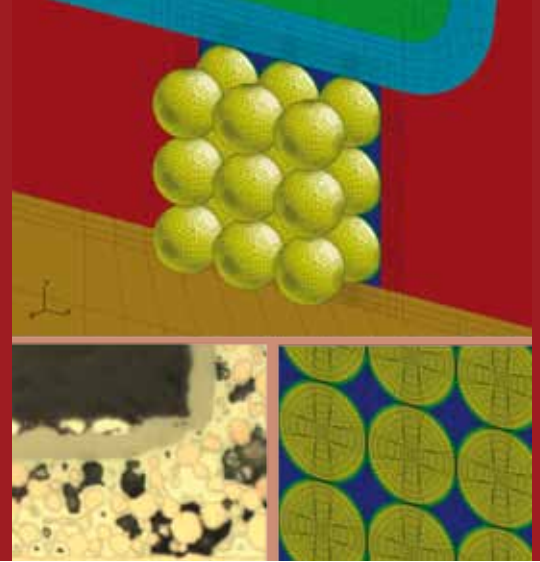
Das autarke Sensornetzwerk ASTROSE® wurde im gleichnamigen Forschungsprojekt entwickelt und dient zur Überwachung und Optimierung der Auslastung von Hochspannungsleitungen. Das Netzwerk besteht aus zahlreichen Sensorknoten, die direkt am Leiterseil der Freileitung montiert sind. Das System arbeitet autark. Die Energieversorgung der Sensorknoten erfolgt aus dem elektrischen Streufeld der Hochspannungsleitung. Die Knoten nehmen die Temperatur, die Neigung des Leiterseils sowie den Strom, der durch die Leitung fließt, auf. Diese Messdaten werden anschließend von Sensorknoten zu Sensorknoten bis zur Basisstation per Funk übertragen. In der Basisstation, welche sich im Umspannwerk befindet, werden die Daten aufbereitet und in Form eines Webservers mit Datenbanksystem der Leittechnik zur Verfügung gestellt. Im Auftrag von MITNETZ STROM wird das ASTROSE®-System zusammen mit den Partnern Fraunhofer IZM und ENAS, Micro-electronic Packaging Dresden GmbH und KE Automation weiterentwickelt und auf einen im Jahr 2014 startenden umfangreichen Pilotversuch vorbereitet. Hierfür wurden zahlreiche Verbesserungen auf Hard- und Softwareseite durchgeführt und auf einer 110-kV-Hochspannungsleitung nahe Chemnitz ausgiebig getestet.

- 1 ASTROSE® sensor nodes include high-precision sensors detecting inclinations with a resolution of 0.01 °. Two slid antennas enable the directed communication along the sensor chain.
- 2 Inclination and temperature variation during field test.
- 3 Comparison of the current sensor inside one node with the load current from transformer station.



1

2



## THERMO-MECHANICAL RELIABILITY FOR HIGH TEMPERATURE INTERCONNECTION TECHNOLOGIES

Rainer Dudek, Ralf Döring, Peter Sommer, Elke Noack

Electrical connection and mechanical fixation are basic needs for any kind of microelectronic system. The ongoing process of replacement of lead in solder interconnects as well as the need for high temperature interconnections is the driving force for the development of new highly temperature resistant interconnection technologies. On one hand they are needed due to the strongly increasing use of microsystems in harsh environments, e.g. pressure sensors with evaluation electronics in automotive applications. On the other hand, efficient energy management needed from e-cars to power grids, e.g. for wind power plants, is not possible without power modules designed for high temperature robustness. The technological developments have in common that they should not differ fundamentally from the soft soldering technologies currently in use, neither in terms of the process flow nor in terms of the processing temperature range. However, an unique replacement of the traditional soldering technologies are not in sight. Other technologies, which address not only a simple replacement but offer new high temperature properties in terms of creep and fatigue resistance, are under development. Silver sintering and transient liquid phase soldering are to be mentioned in the first place.

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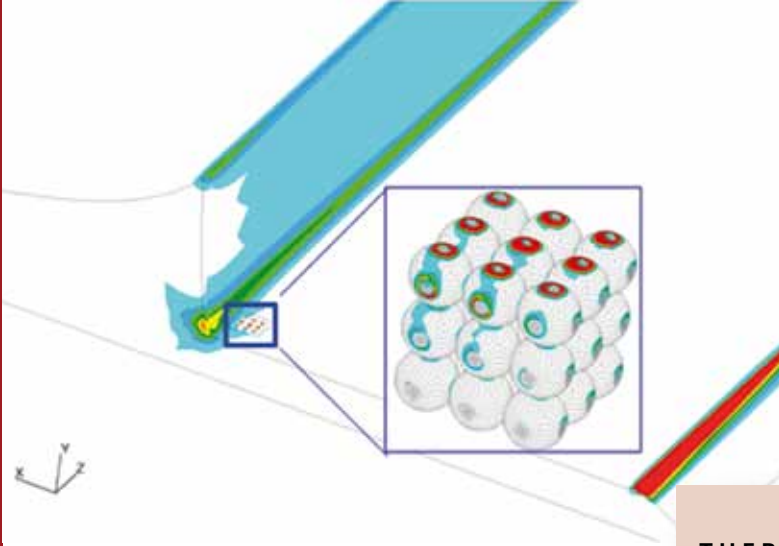
### Failure risks relevant for the new interconnection technologies

Because of the change in material stiffness and strongly decreasing ductility of the joining material, the potential failure modes of an assembly made by transient liquid phase soldering or silver sintering change compared to conventional soft solders. In particular, the characteristic low cycle fatigue solder failures become unlikely and are replaced either by metallization fatigue, brittle failure of intermetallic compounds, components, or interfaces. However, the occurrence of these more or less brittle failure modes depends greatly on the stress in relation to the different strength' present in the assembly. If these stresses do not exceed the safety limits, a high reliability can be achieved by both technologies.

### Theoretical evaluation of critical loadings

Computer based simulation methods are the basis for theoretical analyses. In particular, finite element analysis (FEA) are used for reliability modeling in interconnection technology. Various effects can be considered in FEA like different loading types and field coupling as shown in Fig. 1.





The interconnect materials, which are formed in both interconnection technologies, have in common a strong technology dependence of their mechanical properties caused by an inhomogeneous microstructure. That means, modeling must consider size differences from the millimeter to the micrometer range. This difficulty is overcome by global macro and local micro modeling. One example of this kind of modeling for a transient liquid phase (TLP) soldered interconnect is shown in Fig. 2.

#### Failure prediction and failure analysis

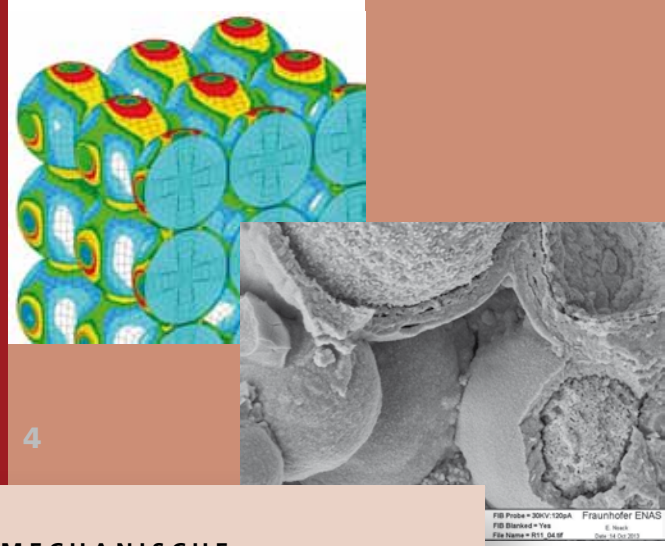
Two kinds of temperature loadings are essential for power electronic systems: passive thermal cycling and active power cycling, the latter simulated as field coupled analyses. As brittle fracture is the most serious reliability concern in TLP joints, the minimum temperature, which occurred in passive cycling, is the worst case loading. Because of the overall geometric factors as well as because of locally inhomogeneous structure, strongly localized plastic deformations occur, as depicted in Fig. 3. Stress concentrates in the joined areas, where diffusion processes formed the intermetallic interconnect. For temperature changes exceeding a temperature swing of  $> 300$  K, this stress can cause fracture between the particles, as shown in Fig. 4.

#### Acknowledgements

The work was funded by the projects "HotPowCon" and "Propower". This funding by the German ministry BMBF was gratefully appreciated.

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### THERMOMECHANISCHE ZUVERLÄSSIGKEIT FÜR HOCHTEMPERATUR-VERBINDUNGSTECHNIKEN

Elektrische Verbindungen und mechanische Fixierung sind Grundvoraussetzungen für jede Art von mikroelektronischen Systemen. Zunehmend treten jedoch hohe Spitzentemperaturen auf, die mit traditionellen Füge-techniken nicht mehr zu beherrschen sind. Es werden deshalb neuen Füge-technologien entwickelt, die durch Ausbildung thermisch stabiler intermetallischer Phasen oder von Ag-Sinterschichten eine hochtemperaturfeste Fügeverbindung bilden. Im Rahmen dieser Entwicklungen stellen sich aber auch eine Reihe von Fragen bezüglich der Zuverlässigkeit der mit den neuen Materialien gefügten Verbindungen. Es wurden daher gekoppelte makro-mikro Finite-Elemente Modelle zur Bestimmung thermo-mechanischer Beanspruchungen entwickelt, die in Verbindung mit Experimenten Zuverlässigkeitsprognose und -optimierung erlauben.

- 1 Overview on failure modes to be evaluated.
- 2 TLP joint of a ceramic component on substrate and FE global-local model.
- 3 Plastic deformation in a the TLP joint subjected to temperature loading.
- 4 Stress concentration and brittle fracture in a the TLP joint subjected to temperature loading.



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## SUPA – THE INVISIBLE REVOLUTION

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*Maik-Julian Bucker, Ulrich Hilleringmann, Christian Hedayat*

The conference table of the future will show no more cables: Notebooks will be supplied directly via the desktop with power and will be connected by wireless USB or WiFi to the local network and to the beamer. To let this vision become reality, the department ASE has developed the base of this innovative technology together with a consortium of industrial companies within the scope of the project SUPA (Smart Universal Power Antenna).

SUPA is the wireless infrastructure of the future for the data transfer and energy supply of mobile devices. The inductive power supply system consists of a transmitter and a receiver unit. The challenge of this development is to insure that the complete furniture surface can be used for the power transfer and that a maximum power of 50 W can be supplied to each single device on the table.

Because the power antenna also serves as a data antenna, various devices can be wirelessly connected by this technology. Besides, the working range for data and energy transference is consciously minimized (5 cm to 10 cm). This leads to a low radiation level and reduces the risk of interception of the data networks.

The start-up company „SUPA wireless GmbH“ has been founded end of 2013 with the aim to introduce the technology into the market. Various prospective applications, such as the integration of the transmit antennas into office desks are considered. Together with the department ASE of Fraunhofer ENAS the start-up continues to adapt the concept toward a market relevant product. It is continuously acquiring industrial partners as well as technological investors in order to accelerate the commercial breakthrough.

### **SUPA – the new technology**

The basis of wireless power supply for electrical devices relies mainly on the principle of electrical induction with transmitter and receiver coils. In order to make the system easily integrable within any surface and inside any small portable device, these coils are made from extremely flat conventional printed circuit boards, up to 125 microns thin. While the invisible transmitter unit is installed in a working surface or in any transmitting device by means of an antenna structure for power and data transmission both, the reception module is integrated in a smartphone, an ultrabook or any medical electronic implant.

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The special feature of SUPA is related to the fact that the coils are fabricated on the same device level than the electronic driving system i.e. on the PCB itself. This permits the furnishing of larger areas and an easy integration into existing devices with low costs fabrication procedure. In addition to its wireless energy core operation, the system can very easily integrate annex functionalities such as data transferring technologies like WLAN or W-USB within the same fabrication process.

To enable a secure energy transfer, an internal property narrow bandwidth digital communication protocol is superimposed on the energy signal in order to detect the presence or absence of a receiver and to switch off the energy transmission if a disallowed receiver is present.

The rising research and development effort contributes to improve the efficiency which is about 80% over a typical transmission range of 20 mm. With minor degradation of the efficiency the range can even be extended to 50 mm with a comparable positioning tolerance. This feature demarcates SUPA considerably from its competitors.

Existing solutions usually require that the reception devices are powered at precisely defined locations. With SUPA the user can freely place his device on any location of the supplying surface, the power transmission being guaranteed on it.

### SUPA – the awards

This work was honored by numerous awards in 2011 and 2012. In 2013 it received the following  
Gründerwettbewerb IKT innovativ IKT.NRW Young IT trifft Investoren  
– March 2013 – 1st place audience award



### SUPA – the project

The initial project SUPA was promoted by the Federal Ministry of Economy and Technology (BMWi), approved by the AiF and was conducted within a ZIM frame in collaboration with Christmann Informationstechnik + Medien GmbH & Co. KG, Hotoprint Elektronik GmbH & Co. KG, the University of Paderborn and Euskirchen Manufaktur.

## SUPA – DIE UNSICHTBARE REVOLUTION

Die kontaktlose Versorgung mobiler Endgeräte mit Strom und die gleichzeitige Übertragung von Daten sind die Ziele von SUPA. Die Herausforderungen der Entwicklung sind vielfältig:

- gleichmäßige und zuverlässige Energieversorgung an allen Positionen auf großen Flächen
- Verbindung von Energie- und Datenübertragung für miteinander kommunizierende Geräte
- Entwicklung einer idealen Reichweite für die Energieübertragung zur Verringerung von Strahlenbelastung und Verbesserung der Abhörsicherheit von Datennetzwerken
- größtmögliche Vermeidung elektromagnetischer Emissionen

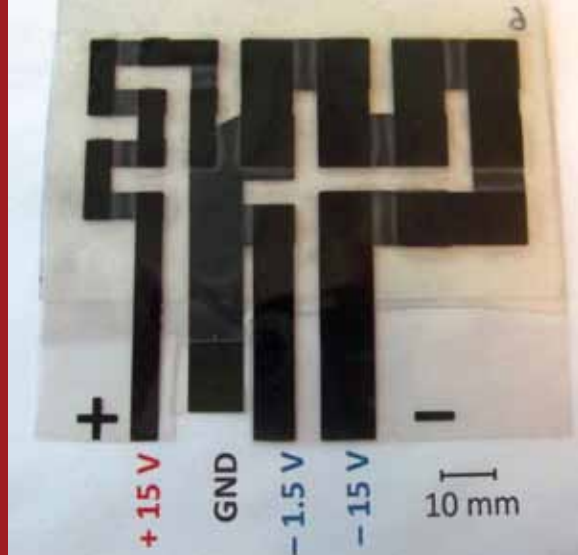
Das start-up SUPA wireless GmbH und die Abteilung ASE des Fraunhofer ENAS arbeiten mit Industriepartnern und Investoren an der kommerziellen Etablierung der Technologie.

- 1 SUPA array of sending antennas on flexible PCB.
- 2 Different electronic devices powered by SUPA.



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## PRINTED DIAGNOSTIC CHOLESTEROL SENSOR DEVICE POWERED BY A TAILORED PRIMARY BATTERY

Andreas Willert, Reinhard R. Baumann

Numerous at-home tests for monitoring a person's health condition (e.g. blood pressure, glucose, cholesterol) are available. Many of them require test strips connected to a mobile device for analysis. For easier operation an all-integrated device would be helpful. In a joined European research project investigations have been carried out to develop a smart integrated minaturised sensor (SIMS) system. The SIMS project [1] target is to develop a point of care diagnostic device by the application of fully organic and printed electronics. By employing printing technologies, these devices are mass producible at very low cost. Furthermore, due to the full integration it is extremely simple to use them compared to traditional strips and meters. The SIMS device combines a printed biosensor, a printed electrochromic (EC) display, and an organic electronics circuit – all powered by a tailored printed battery. The contribution of Fraunhofer ENAS was dedicated to its expertise of tailored battery solutions.

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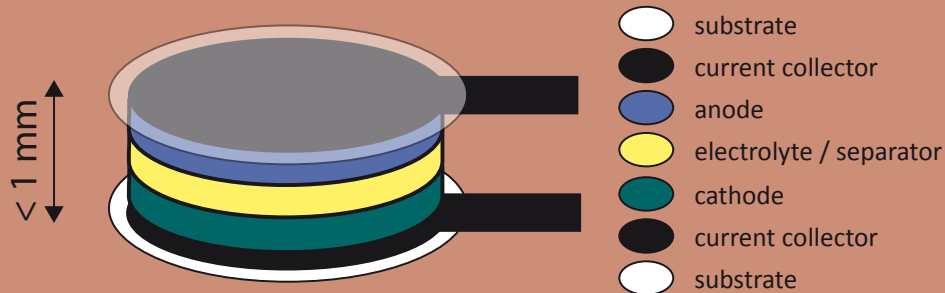
### Tailored printed battery approach

Printed primary batteries are unique in their capability of providing tailored electrical energy to different applications. These batteries are based on the well known zinc manganesedioxide material system that is usually used in cylindrical form factor and standardized as e.g. AA, C or D battery cells [2]. In the SIMS project the electrochemically active materials of these traditional batteries are formulated as printing inks for the silk screen printing processes and layer by layer applied by printing onto a flexible plastic foil. Following this route batteries with multiple battery cells resulting in multiple voltages of up to 30 V are producible [3]. Benefits of such primary batteries are: they are completely charged during the manufacturing process, their energy content can be adapted by the size of the cells, and flexibility is achieved by choosing polymer foil as the substrate. One appropriate application for this type of energy supply is the application in single-use sensor devices used for blood testing. Such sensor systems require finite and well-defined energy supplies.

### Battery solution for driving Si electronics

During the SIMS development an intermediate step was the integration of an EC-display, the biosensor as well as the battery on just one piece of PEN (polyethylene naphthalate) foil





employing printing technologies. For this first demonstrator Si electronics was chosen to drive the circuitry. The energy requirement of this application was to have a power supply of  $>2.5\text{ V @ }1\text{ mA}$  for at least 10 mins. This has been fulfilled by a tailored battery.

This prototype of the SIMS project has been awarded by the OE-A as the “Best Publicly Funded project demonstrator” at the LOPE-C 2013.

#### Battery solution for driving organic electronics

In case of driving the demonstrator by a circuit made from organic materials a significantly more complex battery system needs to be available. To drive the appropriate organic amplifier the circuit requires voltages of  $+15\text{ V}$  and  $-15\text{ V}$ . The maximum current was calculated to be  $300\text{ mA}$  during the operation time of the device of  $5 - 10$  mins. Additionally a reference voltage of  $-1.5\text{ V}$  had to be supplied.

Fig. 2 shows the battery solution for this approach to drive an organic circuit by a printed battery. To meet all requirements a battery setup of 23 single cells were designed and manufactured delivering voltage levels of  $+15\text{ V}$ ,  $\text{GND}$ ,  $-1.5\text{ V}$ , and  $-15\text{ V}$ . Discharge experiments validated that this battery design completely meets the described specifications.

#### Acknowledgement

The research activities described here were partially funded by the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement no 257372.

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### GEDRUCKTES SENSOR-BASIERTES CHOLESTERIN-MESSSYSTEM MIT ANGEPASSTER PRIMÄR-BATTERIE ALS ENERGIEQUELLE

Die Herstellung eines flexiblen, integrierten Cholesterin-Messsystems ist das Projektziel von SIMS [1]. In diesem mit EU-Mitteln im 7. Rahmenprogramm geförderten Vorhaben wurde von den Projektpartnern erfolgreich die Integration mittels Druckverfahren von elektrochromem Display, Nanosensor und Primärbatterie gezeigt. Hierfür hat Fraunhofer ENAS applikationsspezifisch die gedruckte Batterie entsprechend der geforderten Leistungsdaten entwickelt.

Die Batterie zum Betrieb der organischen Schaltkreise erfordert Spannungen von  $+15\text{ V}$ ,  $\text{GND}$ ,  $-1,5\text{ V}$  und  $-15\text{ V}$ . Dies konnte erfolgreich realisiert werden.

Gedruckte Batterien stellen somit eine gut anpassbare Art der Spannungsversorgung dar.

- 1 Cholesterol device with printed EC-display, sensor and battery.
- 2 Manufactured battery with  $+15\text{ V}$ ,  $\text{GND}$ ,  $-1.5\text{ V}$  and  $-15\text{ V}$  terminals.
- 3 Printed battery stack.





# SMART MOBILITY

All forms of transport, mobility and their necessary infrastructure demand steadily increasing levels of safety, efficiency and environmental performance. Smart systems play thereby an important role as they offer e.g. an optimization of vehicle control, navigation and logistics as well as minimization of errors.

Fraunhofer ENAS addresses especially:

- Highly integrated systems and components
- Energy management optimization, smart battery management system for Li-ion batteries
- Avionics – Clean Sky
  - Reliability testing for avionics and lifetime estimation models
  - Accelerated testing methodology for fiber reinforced polymers fatigue prediction
  - Active flow control actuator technologies
  - Wireless sensor and communication technologies

With respect to safety of trains Fraunhofer ENAS together with the Center for Microtechnologies of the Technische Universität Chemnitz is working in the joint research project »Entwicklung eines mikrotechnisch aufgebauten intelligenten Sensor- und Monitoringsystems zur Fahrgestellüberwachung und Vermeidung von Entgleisung im Schienenverkehr« (MikroMonitor), which is funded by the German Federal Ministry of Education and Research BMBF.

Possible causes for derauling of trains, underground railways and light rail transits like defect axle boxes, wheel flats at the gear set or axle fractures can be detected by measuring and analyzing accelerations and oscillations in the wheel bearing for initiating actions early enough in order to protect passengers and machinery. Currently, there is no smart sensor system for monitoring such incidents available on the world market. A promising approach for solving this problem is the integration of smart systems. At this point the joint research project is starting. The aim of the consortium, which consists of Lenord, Bauer & Co. GmbH, GEMAC GmbH and the Center for Microtechnologies of the Technische Universität Chemnitz, is the realization of such a monitoring system including high precision and robust MEMS acceleration sensors, intelligent data processing and the integration of the system directly in the wheel bearing of trains.

The main challenge is the development of a high performance acceleration sensor with the needed measurement range, accuracy and robustness for this application. Conventional sensors do not meet the conditions regarding the geometrical dimensions for integration in the wheel bearing. Existing micromechanical sensors are small enough, but they have a lag in robustness against mechanical impact and in lifetime as well as a big temperature drift. The Center for Microtechnologies together with the Fraunhofer ENAS will therefore develop a new generation of high precision acceleration sensors, based on a proprietary technology.

Die Schwerpunktthemen von Fraunhofer ENAS im Bereich Smart Mobility sind:

- integrierte Systeme und Komponenten
- Optimierung des Energiemanagements, z.B. smartes Batteriemanagementsystem für Li-Ionen Batterien
- Luftfahrt – Clean Sky
  - Zuverlässigkeitstests und Lebensdauervorhersagen
  - Beschleunigte Testmethoden für die Vorhersage der Ermüdung faserverstärkter Polymere
  - Aktortechnologien zur aktiven Strömungsbeeinflussung (AFC)
  - Drahtlose Sensor- und Kommunikationstechnologien

Hinsichtlich Sicherheit von Zügen arbeiten Fraunhofer ENAS und ZfM der TU Chemnitz im Forschungsprojekt »Entwicklung eines mikrotechnisch aufgebauten intelligenten Sensor- und Monitoringsystems zur Fahrgestellüberwachung und Vermeidung von Entgleisung im Schienenverkehr« (MikroMonitor), welches durch das BMBF gefördert wird.



## FLUIDIC ACTUATORS FOR ACTIVE FLOW CONTROL (AFC)

*Martin Schüller, Mathias Lipowski, Perez Weigel, Eberhard Kaulfersch, Jörg Nestler, Thomas Otto, Sven Rzepka, Bernd Michel*

### Introduction

Within Clean Sky Fraunhofer develops innovative fluidic actuator concepts that are both used for active flow control but are entirely different in their working principle and construction: synthetic jet actuators (SJA) and pulsed jet actuators (PJA). A new concept implies the application of two membrane transducers into a SJA and increases the efficiency and output velocity vastly. In contrast to most of the known systems the new PJA is based on the usability of micro fabricated valves to switch the flow.

### Fraunhofer AFC actuators

Active flow control on aircraft wings is proven to be capable of enhancing lift and delaying separation. Suction or continuous blowing can be applied as well as pulsed blowing feeding rapidly switching valves with pressurized air. SJAs have the advantage of not requiring pressurized air. They generate a momentum flux greater than zero locally while the global net mass flux remains zero [1]. An application specific design of SJA requires high quality models. Equivalent electric circuit models are insufficient. Instead, the electromechanical transducer and the acoustic/fluidic subsystems need to be modeled separately. Combining network analysis and finite element methods accordingly [2], Fraunhofer ENAS has developed a new SJA concept of increased performance: A Helmholtz resonator is equipped with two transducers. The piezoelectric membranes generate the volumetric flow symmetrically from both sides of the chamber. A common outlet connects them to the acoustic far field. In the new actuators also a newly developed contacting concept of the membranes has been employed. There are no more soldered cables. The electrical connection is made via the clamping. This has the advantage of a minimized scattering in the resonance frequency and higher performance of the membranes. Due to this fact multiple actuators can be easily driven in parallel.

A network model [2] was used for designing and optimizing the SJA, Fig. 1. The comparison of the analytical model and the LEM, discussed in previous publications [3], showed a high level of compliance of the results [4]. Although using two transducers does not fully double the exit velocity [4], it still shows major improvement over conventional SJA with single transducers.

PJAs, Fig. 2, are micro fluidic devices which are used for different applications that require a directed and pulsed air flow. The source of the airflow is a chamber filled with pressurized air whose inlet is

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## FLUIDISCHE AKTUATOREN ZUR AKTIVEN STRÖMUNGSBEEINFLUSSUNG

connected to an air supply and the outlet is formed as a nozzle. To achieve a pulsed air flow, a valve is necessary which is placed closed to the outlet. In contrast to most of the known systems Fraunhofer ENAS investigates the usability of micro fabricated valves to switch the flow. The new actuators use a very flat, layer based design called "laminated" PJA. They are directly integrated into an optimized chamber and controlled by sensors.

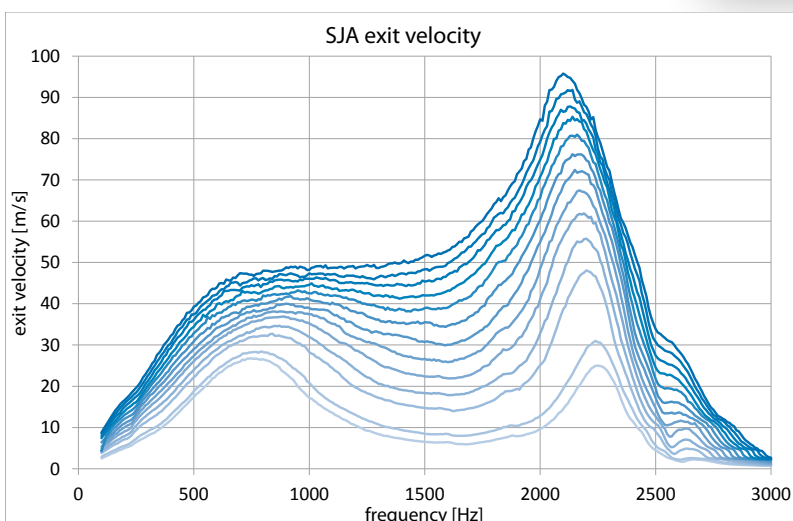
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Forscher am Fraunhofer-Institut für Elektronische Nanosysteme ENAS in Chemnitz entwickeln im Rahmen des JTI Clean Sky Aktoren für die aktive Strömungsbeeinflussung. Dazu gehören Synthetic Jet Aktoren (SJA) und Pulsed Jet Aktoren (PJA).

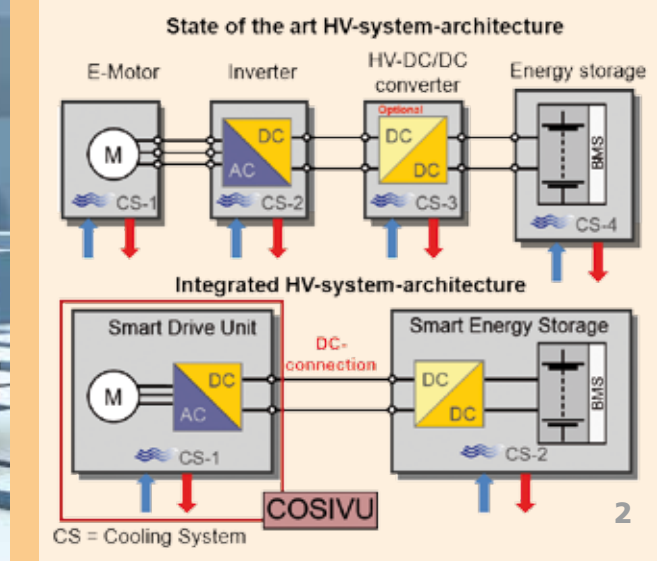
SJAs bestehen üblicherweise aus einer Kammer mit einem gegenüberliegenden Auslass in Form einer Düse, die zudem durch eine Membran begrenzt ist. Diese schwingt und verändert somit periodisch das Kammervolumen, wodurch Luft durch den Auslass strömt. Die SJAs konnten nun derart optimiert werden, dass durch Verwendung von zwei Membranen die Strömungsgeschwindigkeit deutlich erhöht wurde. Zudem sind die neuen Aktoren kleiner: Statt vier bis fünf Zentimeter sind sie nur etwa einen Zentimeter breit.

Auch die PJAs wurden im Rahmen von Clean Sky optimiert. Bei diesen strömt Druckluft aus einem Ventil am Boden, füllt die Kammer und entweicht über eine Bohrung an der Flügeloberfläche. Hierfür wurde ein Ventil nun mit Hilfe der Mikrofertigung so gestaltet, dass es direkt unter dem Auslass Platz findet. Dies führt neben einer verbesserten Leistung zu einer erhöhten Integrierbarkeit.



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- 1 Synthetic jet actuator: panel side view, panel bottom view, single actuator.
- 2 Pulsed jet actuator: panel side view, array of actuator elements.
- 3 Measurement results: exit velocities of SJA for different driving voltages.



## COSIVU – COMPACT, SMART AND RELIABLE DRIVE UNIT FOR FULLY ELECTRIC VEHICLES

Alexander Otto, Sven Rzepka

### Introduction

The main driving forces behind the movement towards an electrified mobility are climatic protection targets as well as economic interests, such as reduction of greenhouse gas emissions, lowering of consumption of primary energy sources based on liquid fuels as well as minimization of noxious gas emissions and of noise produced by transport. Limitations in driving range and ‚up-time‘, suboptimal energy efficiency, and high price per unit are major hurdles for a rapid market penetration of fully electrical vehicles (FEV) despite all the advantages listed before. The joint research project ‚COSIVU‘ addresses the mechatronic propulsion unit, which is the most critical technical part in fully electrical vehicles besides the energy storage system, by developing a novel electric drive-train concept with extended information and communication technology functionalities. The COSIVU consortium consists of nine partners from three European countries, which comprise the full value chain: VOLVO Technology AB, ELAPHE d.o.o., HELLA Fahrzeugkomponenten GmbH, SENSITEC GmbH, TranSiC AB, Berliner NANOTEST und Design GmbH, Swerea IVF, Technische Universität Chemnitz, Fraunhofer ENAS and Fraunhofer IISB. They aim at a new system architecture by developing a smart, compact, and durable single-wheel drive unit with integrated electric motor, compact transmission, full SiC power electronics (switches and diodes), a novel control and health monitoring module with wireless communication, and an advanced ultra compact cooling solution.

### New drive-train architecture

The main approach of the new system architecture consists in substituting the central drive-train, as known from conventional vehicles, by compact and smart drives attached to the individual wheels, coordinated and controlled by a central vehicle computer via bi-directional and fail safe communication. This will not only reduce weight, space and costs e.g. by removing large and heavy transmission units and differentials between the wheels, but also improve drivability, performance and driving safety e.g. due to torque vectoring possibilities. The main focus of the COSIVU project will be on the smart system, consisting of power and control / communication modules, and its integration into the next generation type of traction system

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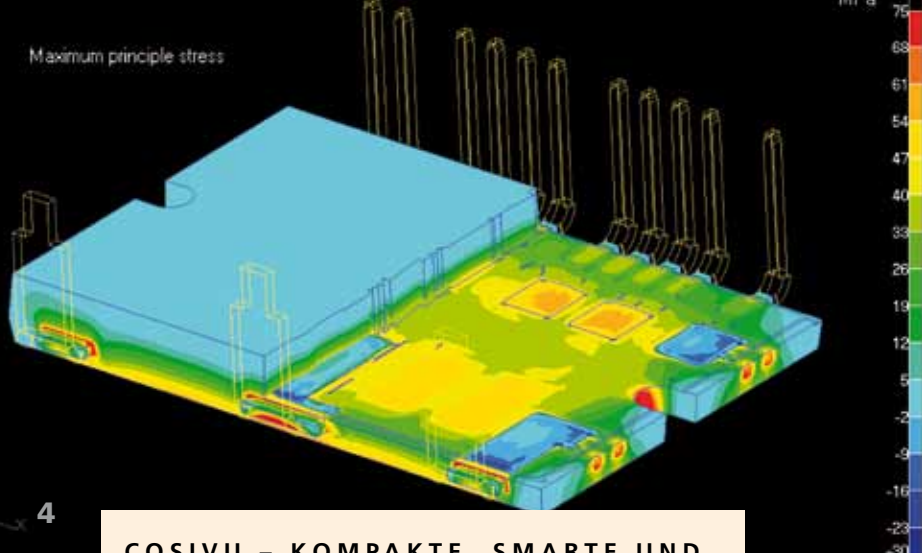
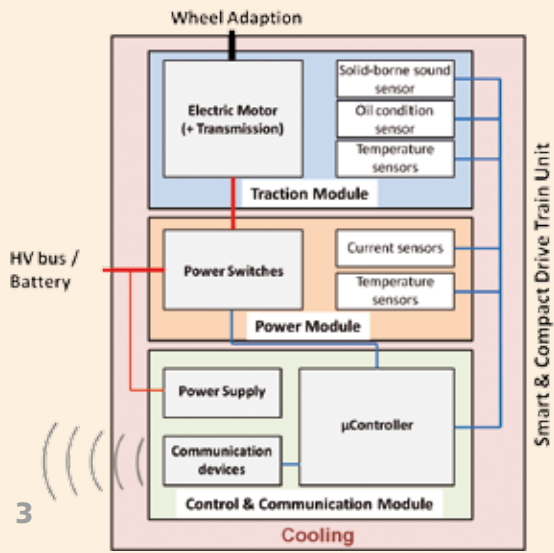
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## COSIVU – KOMPAKTE, SMARTE UND ZUVERLÄSSIGE ANTRIEBSEINHEIT FÜR ELEKTROFAHRZEUGE

Das Ziel des EU-Projektes COSIVU besteht in der Entwicklung eines neuartigen Antriebskonzepts für Elektrofahrzeuge mit erweiterten Informations- und Kommunikationsfunktionalitäten. Ziel ist dabei die Realisierung einer intelligenten, ultra-kompakten und robusten Einzelrad-Antriebseinheit mit integriertem E-Motor, Getriebe und einer auf Siliziumkarbid basierenden Leistungselektronik sowie den dazugehörigen Steuereinheiten.

Weitere Entwicklungsschwerpunkte sind innovative Kühlkonzepte, zuverlässige Kommunikationsstrategien sowie neuartige Gesundheitszustandsüberwachungskonzepte für die mechanischen sowie die leistungselektronischen Komponenten. Die ambitionierten Ziele sollen vorrangig an Nutzfahrzeugen demonstriert, aber auch auf andere Fahrzeug-Plattformen adaptiert werden können.

(electric motor + transmission) on VOLVO commercial vehicle, Fig. 1. Besides the weight loss, this mechatronic solution will reduce the system complexity, as only two DC connections are needed instead of eight as for the current HV systems, Fig. 2. Likewise, the new solution shall be applicable to other types of vehicles as well, proved by ELAPHE within this project. Hence, COSIVU intends to develop a general new standard of high-performance FEV drive-train architecture, Fig. 3, with substantial advantages over existing technologies.

Further project objectives are the implementation of closed hardware in the loop technologies at three stages (local, global short-term and global long-term), integration of innovative functional and health monitoring features for the transmission and the power electronic units as well as improvement in durability and total driving range.

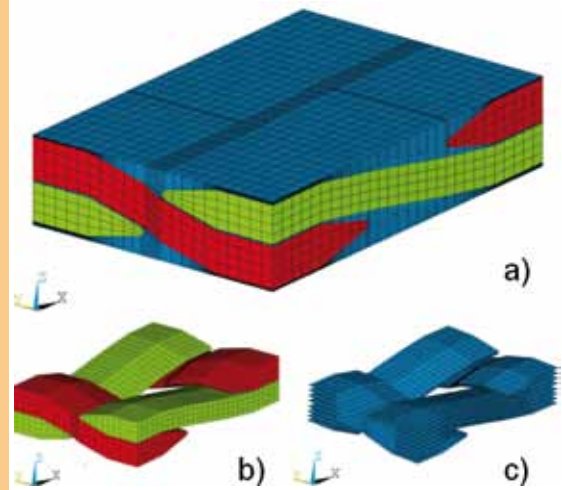
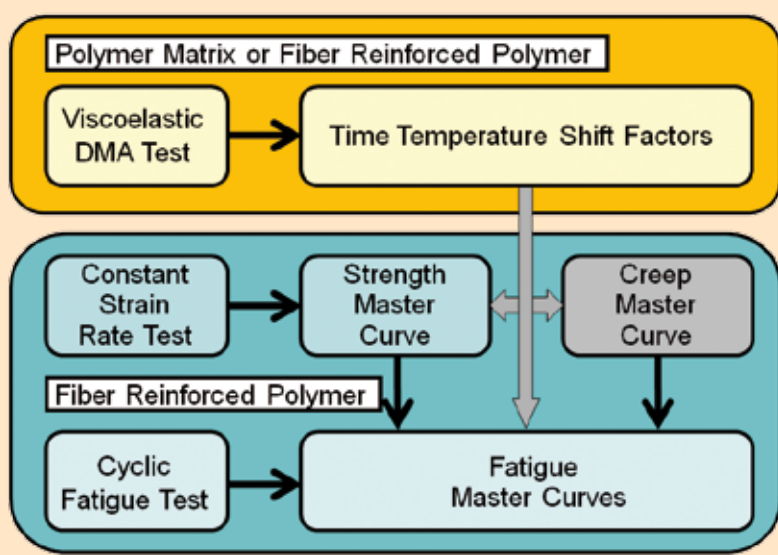
### Reliability aspects

Fraunhofer ENAS is in this project mainly responsible for assessing and optimizing the reliability of critical components within the COSIVU system by combining latest FE simulation techniques with innovative accelerated lifetime testing measures. Main object of investigations are BJT SiC power modules, Fig. 4, where different cooling concepts will be benchmarked against each other.

### Acknowledgement

The project described is supported by the European Commission, grand agreement number 313980.

- 1 The ‚Gryphin‘ wheel loader concept model from VOLVO (figure @ [http://www.volvoce.com/constructionequipment/corporate/en-gblinnovation/concept\\_vehicles/gryphin\\_loader/Pages/gryphin\\_loader.aspx](http://www.volvoce.com/constructionequipment/corporate/en-gblinnovation/concept_vehicles/gryphin_loader/Pages/gryphin_loader.aspx)).
- 2 State of the art and novel integrated HV-system-architecture (figure @ Fraunhofer IISB).
- 3 Block diagram of the COSIVU drive-train concept.
- 4 Thermo-mechanical simulation of power module during cooling down phase.



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## TOOLBOX FOR VISCO-ELASTIC MATERIAL MODELING OF SMART LIGHTWEIGHT STRUCTURES

*Eberhard Kaulfersch, Remi Pantou, Birgit Brämer, Sven Rzepka*

Lightweight structures made of fiber reinforced polymers (FRP) are applied in automotive and aviation to reduce the weight and the energy consumption of the whole system. Today's trends show that, more and more functionalities are integrated into lightweight structures. This complex situation in regards to reliability requires a systematic and scalable methodology capable of predicting possible failure risks. This article reports our efforts to develop an expansion to the well-established accelerated test methodology of Miyano et al [1]. To reduce the number of tests required to determine the lifetime of an FRP structures, this method considers a set of dynamic mechanical analysis (DMA) followed by constant strain rate (CSR) and cyclic fatigue tests. In all three cases, master curves are compiled. According to the fundamental hypothesis of the methodology, the time-temperature shift function (TTSF) determined by DMA does not only control the visco-elastic (VE) behavior of the polymer but also the onset of failure in CSR and fatigue tests. As handy as it is, this methodology has a number of substantial limitations: It considers only 1) one level of moisture content, 2) one particular laminate stack, and 3) one basic loading mode at the time. As soon as any of these factors is changed, the set of tests needs to be repeated. In the optic to overcome these limitations, a set of toolboxes has been developed to quantify by numerical simulation these three aspects.

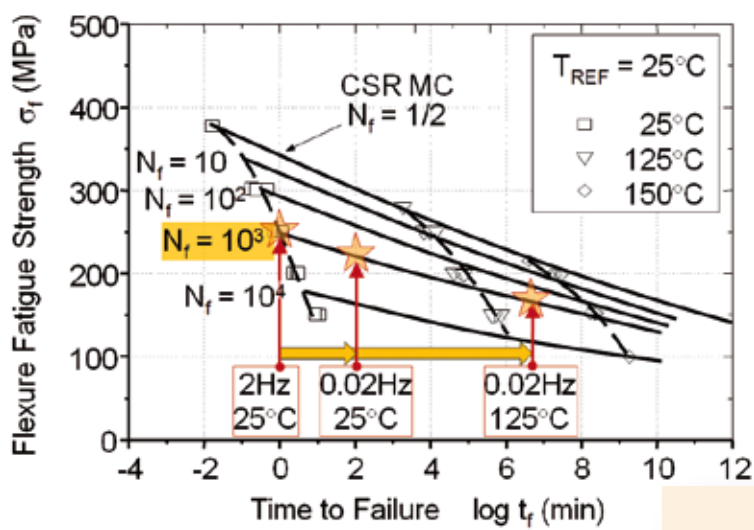
- 1) The effect of water uptake on VE master curve was experimentally quantified showing that the characteristic time dependency of the FRP has widely been the same for 'dry' and 'wet' samples. The differences in the master curves could be covered by a hydro effect term added to the shift function to obtaining a grand shift function. Based on this add-on, lifetime prediction at different humidity situations can be based on only one set of grand master curves.
- 2) The multiply extension follows a 3-steps concept published in [2] but widely expanded to fully account for visco-elasticity, strength, and fatigue effects. First, the behavior of the single ply is studied by means of a 3D detailed model. Afterwards, the laminate theory is applied to transfer the material data obtained in the first step to a simplified layered model. In the third step, the respective layer models are stacked according to the ply scheme so that the stiffness of the full FRP structure can be computed.

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Multiaxial extension was possible through a detailed model able to replicate the local 3D deformation and stress fields. Here, one cell already suffices for performing virtual tension tests, by means of which the model is calibrated. Afterwards, groups of three and four elementary cells are used for respectively simulating bending and shear tests without changing any parameter anymore. Thus, the detailed model can be used for determining the engineering stiffness values of orthotropic specimen.

Moreover, the 3D detailed model also captures the VE behavior. Additional features like interconnect, vias and embedded components may now be introduced. The modeled structure will realistically show the actual time dependency in response to mechanical loads. This is true for small-scale responses like VE reactions but also holds for the large-scale impacts ultimately leading to fatigue and fracture. Hence, this new modeling approach allows, after a phase of comprehensive validation, to lower the necessity of repeating the full test program whenever the stack configuration is changed and to build a library of fully calibrated ply models over time.

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## METHODENSATZ FÜR DIE MODELLIERUNG VISKO-ELASTISCHER MATERIALIEN FÜR SMARTE LEICHTBAUSTRUKTUREN

Faserverbundkunststoffe sind geeignet, das Gewicht mechanischer Strukturelemente und damit den Energieverbrauch mobiler Systeme deutlich zu verringern. Das Integrieren elektronischer smart Systems erlaubt dabei eine vielfältige Erweiterung der Funktion dieser Verbundwerkstoffe. Allerdings erhöht sich dadurch die Inhomogenität und damit die Risiken für die thermo-mechanische Zuverlässigkeit. Die oftmals extremen Einsatzbedingungen für diese Systeme (Flugzeug, Off-shore-Windkraftanlage, Fahrzeuge und Maschinen jedweder Art, ...) verschärfen diese weiter.

Das Micro Materials Center am Fraunhofer ENAS erforscht einen erweiterbaren Satz an Methoden, der Zuverlässigkeitsprognosen auch für diese stark erhöhten Anforderungen effizient möglich macht. An typischen Epoxidharz-Glasfasergewebe-Strukturen der Elektronikindustrie wurden Untersuchungen begonnen, die bekannte Prüfmethode nach Miyano [1] auf das Einbeziehen 1) verschiedener Feuchtegrade im Polymer, 2) unterschiedlicher Laminataufbauten und 3) komplexer Belastungszustände so zu erweitern, dass dabei nicht jeweils der komplette Satz an Tests wiederholt werden muss.

- 1 Methodology for accelerated lifetime testing of FRP structures.
- 2 Finite element mesh of the 3D detailed model:
  - a) Complete elementary cell – polymer only (blue), fiber bundles (green, red), b) Fiber bundles – polymer part, c) Fiber bundles – reinforcing fibers (REINF265[9]).
- 3 A fatigue master curve allows predicting the lifetime of FRP structures for many load cases.



# SMART MONITORING

Smart Monitoring addresses the development of system solutions for the condition monitoring using MEMS/NEMS based systems and optimized data analysis and communication. In the focus of Fraunhofer ENAS are:

- Silicon based micro opto electromechanical systems MOEMS in miniaturized spectrometers for gas analysis, environmental monitoring and medical applications
- Power line monitoring for utilizing the capacity of power lines
- Condition monitoring in mechanical engineering
- Structural health monitoring of lightweight structures, including reliability assessments

Current industrial trends in mechanical engineering and plant manufacturing address condition monitoring mainly to minimize system failures. The implementation of sensors, electronics for signal conditioning, wireless signal transmission (necessary due to rotating parts) and self-sustaining power supply allows an autonomous and efficient operation of such systems for various applications. Examples are grease monitoring systems or the monitoring of seals.

The integration of microelectronic components and sensors into hybrid structures leads to the improvement of the performance and functional density of hybrid components. One highly innovative approach is that of insitu functionalization of fiber reinforced polymers during production by means of in-mould coating techniques and integration of sensors films.

The following articles describe:

- Special developments within the cluster of excellence MERGE – Merge technologies for functional lightweight structures,
- Special developments within the nano system integration network of competence,
- A system for monitoring gases, liquids and solids,
- A special application in mechanical engineering, a grease monitoring system.

More information to power line monitoring is given in the chapter smart power. This condition monitoring aims at the optimization of the capacity utilization of energy transport while guaranteeing hazard free operation. The system allows a decentralized monitoring of high-voltage transmission networks (110 kV, 220 kV and 380 kV) using autonomously working sensors nodes.

Visco-elastic material modeling of smart lightweight structures is described in the chapter smart mobility as fiber-reinforced polymers are used in automotive and aviation.

Smart Monitoring adressiert die Entwicklung von Systemlösungen für das Zustandsmonitoring basierend auf Mikrosystemen sowie optimierter Datenanalyse und Kommunikation. Fraunhofer ENAS arbeitet in den Schwerpunkten:

- Siliziumbasierte Aktoren und entwickelt miniaturisierte Spektrometer für Gasanalyse, Umweltmonitoring und Medizintechnik
- Freileitungsmonitoring zur Gewährleistung der Auslastung des Netzes
- Zustandsmonitoring im Maschinenbau
- Monitoring von Strukturleichtbauteilen

In den nachfolgenden Artikeln werden auch Ergebnisse aus dem Exzellenzcluster MERGE und dem Kompetenznetzwerk nanett vorgestellt. Darüber hinaus sind ein Spektrometer für die Überwachung von Gasen, Flüssigkeiten und Feststoffen sowie ein System für die Überwachung von Fetten im Maschinenbau beschrieben.

Näherer Informationen zur Überwachung von Hochspannungsleitungen enthält der Abschnitt Smart Power. Dieses System ermöglicht durch den Einsatz von autarken Sensorknoten ein dezentrales Monitoring von Hochspannungsstromnetzen (für 100 kV, 220 kV und 380 kV), um deren Kapazitätsauslastung zu optimieren und die Sicherheit der Freileitungen zu gewährleisten.



## MICRO AND NANO SYSTEM INTEGRATION FOR HYBRID STRUCTURES

*Martin Schüller*

The next generation technologies and products will be measured by the increase of resource and energy efficiency as well as by securing the competitiveness, taking into account an effective climate and environmental protection. For the combination of diverse material groups, such as metals or plastics respectively, and the integration of active components like sensors and actuators, currently separated manufacturing processes have to be combined by fusion and linkage to integrated mass-oriented technologies for the production of high performance structures. Such a technology consolidation is characterized by substantial energy and material savings and by the increase of functional density. The integration of microelectronic and micromechanical components in hybrid structures enables their functionalizing by sensors, actuators and electronics and therefore a further improvement of performance and functional density of hybrid components. The Technische Universität Chemnitz and the Fraunhofer Institute for Electronic Nano Systems ENAS are participating in the Cluster of Excellence MERGE. In the sphere of the integrated research domain D micro and nanosystem integration in composite structures new approaches for microelectronic components in hybrid structures are developed.

### Integration concept for fluidic actuators

Fluidic actuators such as synthetic jet actuators (SJA) or pulsed jet actuators are fluidic elements that are known to be suitable for the uses in active flow control applications e.g. for high lift devices in aircrafts or in wind turbines [1]. Modern wind turbines are manufactured using composite materials. Consequently, the integration of such fluidic devices must fit the manufacturing process and the material properties of the composite structure. The challenge is to integrate temperature-sensitive active elements and to realize fluidic cavities at the same time. The design concept of the actuators as well as the integration concept is based on the MuCell® technology. MuCell® allows combining the advantages of a closed surface and low density in the center of the injection molded part [2]. Since low process forces are necessary, the inserted actuator elements are less stressed compared to classical injection molding technologies.

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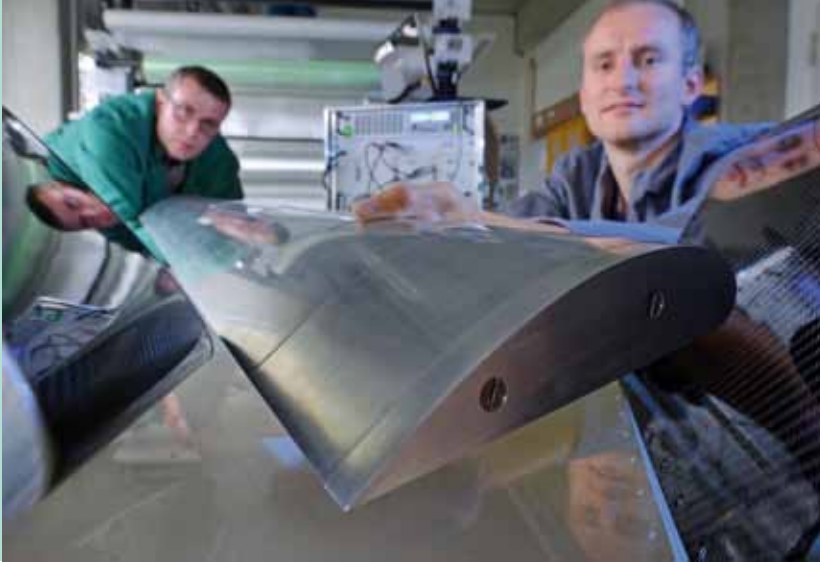
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### Foil based sensors

The focus of integrating polymeric foils in lightweight structures is to design and manufacture energy self-sufficient sensor systems, which allow the detection, storage and visualization of mechanical overloads. These loads generate electrical charges within the piezo material, which are then transferred to the quantum dot layer leading to fluorescence quenching. Thus component areas which faced a mechanical overload exhibit lower fluorescence intensity or a color change, depending on system design. This optical information can be stored for a certain time within the material as signature of possible damage. Mechanical loads can be visualized spatially resolved directly on the component. Key feature of the sensor is a double layer consisting of a piezoelectric and a quantum dot based foil, that can be integrated by laminating or injection molding. The emphasis here is on mass producible processes, such as printing and injection molding processes. A first appropriate multi layer sensor design was carried out and it could be shown, that layers can be manufactured and the main important material properties of the respective layers and the general cross-sectional profiles were discussed and preliminary defined.

### Metamaterials for communication and energy transmission

The integration of multiple wirelessly communicating electronic sensor nodes into lightweight structures will open the way for distributed sensing and for structural health monitoring. Future electronics and even some recent developments exhibit very low energy consumption, so microwaves become a reasonable way of powering. The major benefit will be a completely wireless sensor system. The integration of metamaterials in planar lightweight structures will allow communication and energy transmission.

Metamaterials enable the production of efficient antennas by focusing or diverting electromagnetic waves. Thereby, electrical performance and information can be absorbed into the work piece and allocated without additional cabling. Integrated sensors, microcontroller or energy storages would be conceivable, being supplied with energy and able to communicate by incident microwave radiation. It is expected that printing of conductive patterns on dielectric substrate, application of embroidery technology for mounting of conductive sequins on isolating fabric, both in combination with moulding will generate lightweight material component parts with integrated antenna functionality. A second objective of the integration of metamaterials is to enable material integrated sensing. The behavior of metamaterials at high frequency is changed by environmental impacts, such as crack formation and resulting water climbing. Suitable measuring instruments detect these modifications and conclusions can be drawn about the condition of a component.

**1** 3D images of devices are created by using computer tomography at the Fraunhofer ENAS. Failures or damages inside the devices are analyzed on the basis of these images. (photo @ Hendrik Schmidt)

**2** Within the Federal Cluster of Excellence EXC 1075 "MERGE Technologies for Multifunctional Lightweight Structures", integration opportunities are investigated for functional elements of active flow control systems, here for a metallic segment of a wing structure. (photo @ Hendrik Schmidt)

### Silicon based sensor integration

The monitoring of the condition and health of composite structures can be done by the use of well-known microtechnology based sensors such as stress sensors. The main challenges are, on the one hand, integration as well as to be supplied with energy and enable to communicate. On the other hand, reliability aspects have to be taken into account especially during the manufacturing process. For this reason, silicon based sensors in composite structures shall be analyzed, in this context giving special attention to organize the manufacturing process of sensor integrated semi-finished products mass producible. Therefore, a textile based preform with integrated conductive wires for energy and data transmission is developed. This smart textile can be made of materials, which are usual for reinforcing thermosetting plastic lightweight structures. The conductive wires consist of carbon fibers, which are also strengthening the favored structural element. By means of the micro injection molding technology, a printed circuit board, the so called interposer, is fixed and electrically contacted with electrically conductive thermoplastics that need to be adjusted to the specific application. This interposer is the interface between the smart textile and the silicon based sensor. For guarding the sensor and to finish the fixation, an encapsulation is the last step prior to integrate the overall system for different purposes like structural health monitoring.

### Acknowledgement

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

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## MIKRO- UND NANOSYSTEM- INTEGRATION FÜR HYBRIDSTRUKTUREN

Die Integration von mikroelektronischen Bauelementen in Hybridstrukturen ermöglicht die Funktionalisierung durch Sensoren, Aktoren und Elektronik und somit eine weitere Leistungssteigerung und Funktionsdichteerhöhung hybrider Bauelemente. Die Integration von Wandlern und Elektronik erfordert Lösungen für Kontaktierung und Kommunikation sowie innovative Verbindungs- und Integrationstechnologien. Bedeutende Forschungsziele sind die Steigerung der Leistungsfähigkeit und Zuverlässigkeit von Hybridstrukturen mit Sensoren und Aktoren sowie die Energieversorgung und Datenverknüpfung unter Berücksichtigung kostengünstiger Produktionsverfahren. Die Forschungstätigkeiten werden alle Aspekte solcher funktionalisierter Leichtbaustrukturen und -systeme berücksichtigen, und beinhalten folgende Forschungsbereiche: Entwicklung neuartiger Bemessungsverfahren mit dazugehöriger in situ Technik für die Integration elektromechanischer Wandler in heterogene Bauteile, Strategien zur In-line Produktionstechnik für folienbasierte Sensoren und Generatoren, und die Integration von Silizium-basierten Sensorsystemen. Außerdem wird die Integration von Stromversorgung und Kraftübertragung sowie Kommunikationsmethoden für diese Sensoren und Aktoren durch integrierte Metamaterialien untersucht.







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## MICRO AND NANO SENSOR SYSTEMS FOR SMART MONITORING APPLICATIONS

*Danny Reuter, Thomas Otto, Stefan Schulz, Steffen Kurth, Olaf Ueberschär, Christian Spudat*

Smart monitoring is an emerging field today. On the one hand it is driven by the needs of application-oriented trends like industry 4.0, smart house, ambient assisted living and smart power. Apart from that, the increasing complexity of technical systems creates a demand for automatic monitoring. On the other hand, the permanent enhancement of micro- and nano-technologies, embedded systems and wireless communication is enabling the development of multifunctional, autonomous, highly integrated and cost-efficient smart monitoring systems.

However, to bring smart monitoring systems into a wide range of applications, some critical issues have to be tackled: high precision and robustness of sensor systems, power supply and energy consumption for autonomous systems, distributed functionality for huge devices and constructions as well as production costs.

Further miniaturization of components and the integration of nanotechnologies in nano systems are promising approaches for realizing these requirements. Therefore the nano system integration network of competence – nanett – is working on these approaches, aiming to nano systems for energy efficient sensor networks. The network is integrating the competences of eight renowned scientific institutions in the field of applied nanotechnologies: Technische Universität Chemnitz, Fraunhofer Institute for Electronic Nano Systems ENAS, Fraunhofer Institute for Reliability and Microintegration IZM, Fraunhofer Institute for Applied Polymer Research IAP, Leibniz Institute for Solid State and Materials Research Dresden, Leibniz Institute of Polymer Research Dresden, Leibniz IHP Frankfurt and the University of Applied Sciences Mittweida.

### Novel magnetic field sensors

Within the flagship project A “Nano scale material systems for magnetoresistive sensors”, headed by Prof. Stefan Schulz from Fraunhofer ENAS, the partners are working on novel magnetoresistive sensors on the base of the giant magnetoresistance effect (GMR). The aim is the development of monolithically integrated multi-axes spin valve structures for high precision

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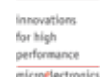
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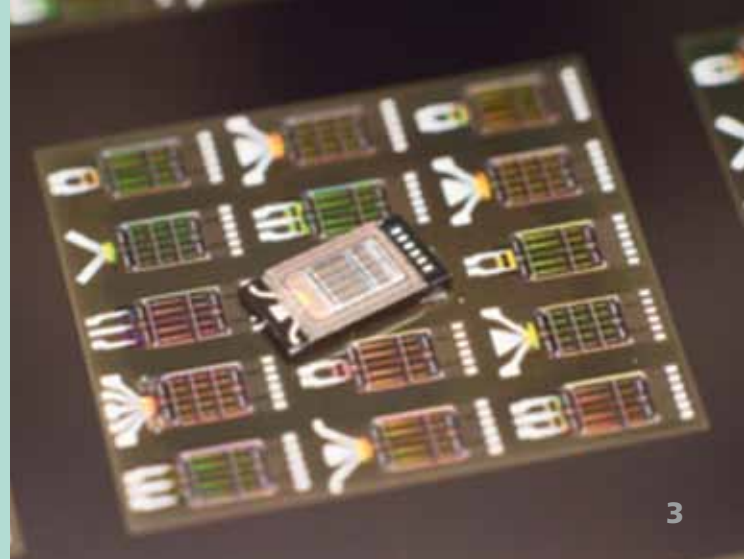
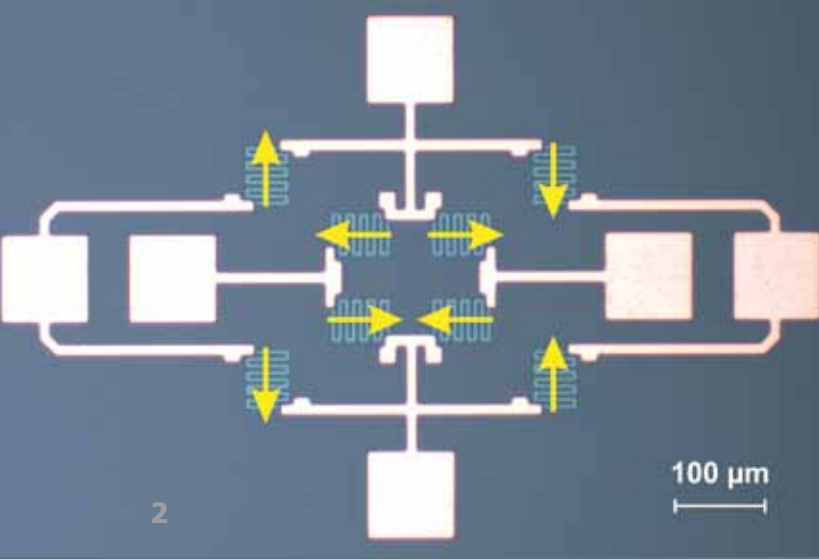
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and highly integrated magnetic field sensors. In comparison to commercial products, which are working mostly on the base of the AMR effect, the level of integration will be higher and the spatial resolution will be significantly increased.

For the lateral directions, two full Wheatstone bridges of the multilayer stack have to be designed and patterned by ion etching or fs-laser ablation. In that course the change of material properties, which are important for the sensor function, have to be avoided. The most challenging task is the local setting of the exchange bias perpendicular to the resistor stripes of a meander structure, and with opposite directions in adjacent meanders, Fig. 2. This is done by laser treatment in close cooperation with the group of Prof. Exner at the University of Applied Sciences Mittweida.

In order to measure the out-of-plane direction (Z-axis) of a magnetic field multilayer systems with vertical anisotropy are investigated and optimized with respect to spin valve properties and suitable patterning processes. This structure would give the opportunity of fabricating monolithically integrated three-dimensional magnetic field sensors, which can be used for monitoring the absolute position of an object within a magnetic field.

### Autonomous sensor nodes

The amount of miniaturized sensor nodes for monitoring applications is expected to reach huge numbers in a few years. Currently the application fields automation technology, condition monitoring of tools, machinery and buildings, the energy sector and safety systems are being investigated. Important issues for these nodes are the data rate and the energy consumption. For current systems the data rate is small but it will increase drastically in the future. This demands the usage of ultra-wideband communication techniques at the same time with efficient communication strategies because of the limited processing power and energy supply of miniaturized sensor nodes.

In the flagship project B "Integration of NEMS, MEMS and electronics for energy efficient sensor nodes", which is headed by Dr. Steffen Kurth, the scientists are developing technologies for the next generation of sensor networks. Besides data compression, smart routing, radio frequency electronics, integration technologies and energy management, especially energy efficient wireless communication is in the focus of the scientists from Fraunhofer ENAS.

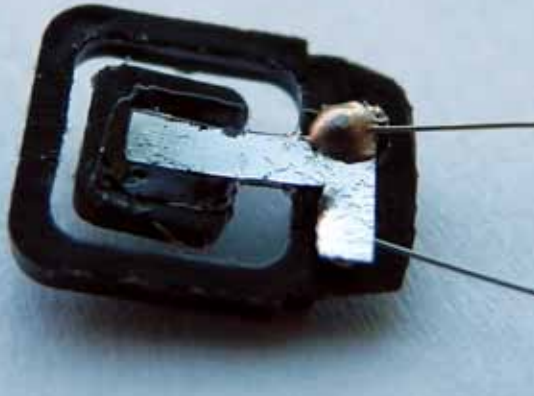
For ad-hoc asynchronous data transmitting the transceiver has to be permanently in the on state. Using a transceiver with a stand-by listening mode can overcome this problem. For this purpose a wake-up receiver (WuRx), Fig.3, has been developed in the nanett project. The WuRx has been realized by a passive MEMS RF mixer with integrated filter for permanently monitoring the radio

1 (previous page) At Fraunhofer ENAS, various functional nanocomposites are developed. Within the nanett consortium fluorescent nano crystals are integrated, which can be excited by UV light. The diameter of the nano crystals defines the emitted wavelength. Thus, tailor-made coatings of selected colors can be realized on various substrates.

2 Microscopic image of the focused double full bridge 2D GMR spin valve sensor in monolithic integration. The yellow arrows illustrate the locally set magnetization of the pinned layers.

3 Micromechanical wake-up receiver with bonded glass cover manufactured in airgap insulated microstructures (AIM) technology.

4 Polymer based piezoelectric accelerometer fabricated by the novel polySENS technology.



channel and activating the transceiver if a signal is detected. Together with the Center for Microtechnologies and the Leibniz IHP the MEMS are monolithically integrated in one chip with the RF electronics in SiGe:C BiCMOS technology.

#### Nanocomposite based sensor systems

The use of lightweight structures in constructions, aircrafts or the automotive sector is an emerging field. Due to its typical failure mechanisms lightweight components should be monitored. Especially for fiber reinforced polymers structural health monitoring is an important issue. The aim of flagship project C "Material integrated sensors based on nano effects" is the development of a smart component which can detect and visualize temporary load states in an indicative polymer layer. The flagship project C is led by Prof. Thomas Otto.

The idea is to realize sensor functions within the polymer material instead of integrating discrete sensor systems. Therefore sensor and actuator functions like piezoelectricity or fluorescence have to be integrated into the polymer material by using nanoparticles. Fig. 4 shows a polymer based accelerometer fabricated by injection molding. Thus, the advantages of nano effects can be used by mass fabricated products.

A further system, which is developed within the nanett project, is detecting the load state by a piezoelectric layer, which is generating electrical charges. Since a permanent monitoring of the whole component is economically and technologically not reasonable, the storage of the load state is an important issue. The group of Dr. Jörg Martin at Fraunhofer ENAS is therefore developing a fluorescent layer by integrating quantum dots in the polymer matrix, Fig. 1. The charges are guided to the quantum dots, being stored inside of the nano particle, and switching the fluorescence property off, as long as the charge is trapped.

#### Acknowledgement

The nano system integration network of competence – nanett – is funded by the Federal Ministry of Education and Research (BMBF) within the initiative "Spitzenforschung und Innovation in den Neuen Ländern". Financial support is gratefully acknowledged.

## MIKRO- UND NANOSENSORSYSTEME FÜR INTELLIGENTE MONITORING-ANWENDUNGEN

Zustandsüberwachung gewinnt eine steigende Bedeutung durch Technologietrends wie Industrie 4.0, Ambient Assisted Living oder Smart Power, aber auch aufgrund der stetigen Steigerung der Komplexität technischer Systeme. Forschungsbedarf besteht in diesem Zusammenhang hinsichtlich hochpräziser und robuster Sensoren, energieeffizienter Technologien für drahtlos vernetzte autonome Sensorknoten, verteilter Funktionalität in großflächigen Bauteilen und Steigerung des Integrationsgrades bei Reduzierung der Herstellungskosten. Das Kompetenznetzwerk für Nanosystemintegration nanett entwickelt Lösungsansätze durch die Nutzung und Integration von Nanotechnologien. Das Fraunhofer ENAS fokussiert dabei auf GMR-basierte mehrdimensionale Magnetfeldsensoren, Polymer-Nanokomposite für materialintegrierte Sensoren und energieeffiziente drahtlose Kommunikation für autonome Sensorknoten.

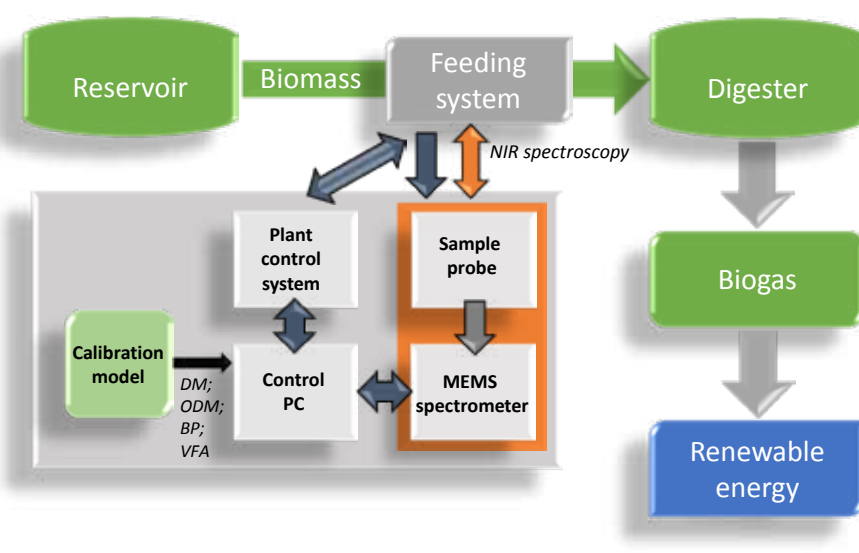
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## EFFICIENCY IMPROVEMENT OF BIOGAS PLANTS USING MEMS BASED MONITORING SYSTEMS

Ray Saupe, Thomas Seider

### Biogas production

Among renewable energies, the biogas production plays an important role. This is largely due to its ability to operate at peak load times and decentralized, as well as it is complete independent of the weather.

In order to maximize the biogas plants energy production, the entire installed power and biogas production capacity has to be used. Current plant utilization is significantly lower in many areas, since the biochemical process responds to fluctuations in boundary conditions such as varying substrate conditions and compositions. Monitoring of important process parameters combined with a smart control and regulation concept enables process stabilization and, consequently, a significant efficiency improvement [1].

### Measurement device

A convenient in-line capable analysis method is near-infrared spectroscopy, which allows quantitative determinations of various key values of the biogas production process. The practical implementation of this method requires a low-cost and compact analysis system. Additionally, it has to be resilient with respect to mechanical influences and temperature fluctuations, due to the prevailing environmental conditions in a biogas plant. Therefore, a ruggedized measurement system based on a MEMS NIR spectrometer was realized.

This spectrometer operates according to the principle of scanning grating spectrometers, containing entrance and exit slits, a diffraction grating, InGaAs detectors as well as collimating and focusing optics. Wavelength selection is performed by an electrostatically driven micro mirror (MEMS), which leads the entered radiation to the grating and varies its angle of incidence [2].

The sensor system was installed on the screw conveyor system in the pump station of the biogas plant, Fig. 1. An optimal sample presentation was achieved by diffuse reflectance measurement. Therefore, an adapted integration sphere has been developed. The optical-mechanical

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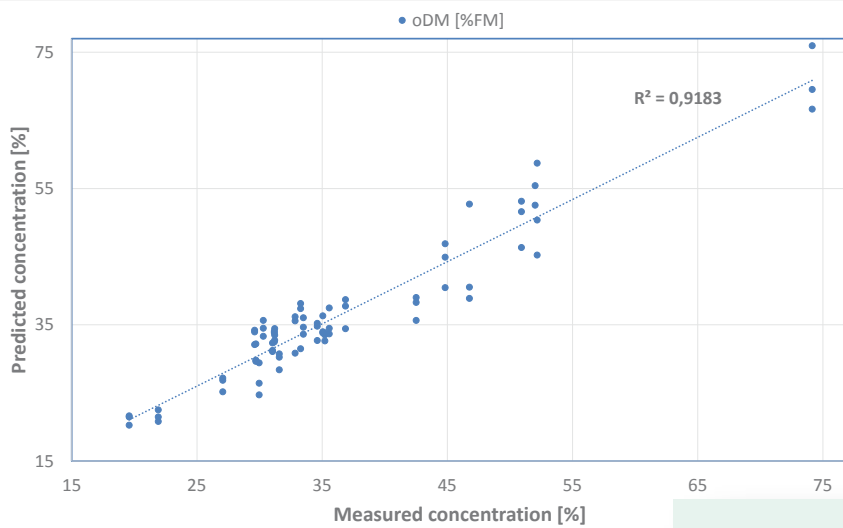
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set-up was mounted on the screw conveyor tray. Hence, a section of the conveyor system was replaced with a specially designed connector containing a sapphire window.

### Measurement results

At first, the spectroscopic analysis of the biogas substrate was performed by means of the realized system in the laboratory and, subsequently, directly on the biogas plant. At the same time, substrate samples were taken and determined with reference laboratory methods in order to develop suitable PLS calibration models. Correlations between spectra and reference values were created for diverse parameters. Especially, good results were achieved for the parameters dry matter content ( $R^2=93$ ), organic dry matter content ( $R^2=92$ ), volatile fatty acids ( $R^2=76$ ) and biogas production potential ( $R^2=78$ ). Figure 2 shows as an example the PLS calibration of organic dry matter content. An extended measurement campaign with more evaluations is intended and will lead to improved calibration models and to an extension of biogas parameters.

### Acknowledgement

This work has been supported by the German Ministry of Education and Research within the project "Entwicklung leistungsfähiger und praxisingerechter Mess-, Steuerungs- und Regelungskonzepte für Biogasanlagen" (project number 033R052B).

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## ERHÖHUNG DER EFFIZIENZ VON BIOGASANLAGEN DURCH DEN EINSATZ VON MEMS-BASIERTEN ÜBERWACHUNGSSYSTEMEN

Im Hinblick auf eine effiziente Energieproduktion in Biogasanlagen, sollten diese mit einem Auslastungsgrad von über 90 Prozent betrieben werden, was in der Praxis aber meistens nicht erreicht wird. Ursachen sind zugrunde liegende biochemische Prozesse, die auf schwankende Randbedingungen mit Leistungseinbußen reagieren. Eine verbesserte Auslastung gelingt durch eine kontinuierliche Überwachung wichtiger Biogasparameter verbunden mit einer angepassten Anlagensteuerung. Eine vorteilhafte inline-fähige Analysemethode ist die NIR Spektroskopie, da diese eine schnelle quantitative Bestimmung verschiedener Schlüsselgrößen wie den Trockensubstanzgehalt im Ein- und Ausgangssubstrat der Anlage ermöglicht. Der Einsatz der Methode erfordert eine kostengünstige, robuste und gut integrierbare Sensorik. Deshalb wurde ein Messsystem auf Basis eines MEMS NIR-Spektrometers realisiert. Die Anbindung der zu messenden Substanzen erfolgt mit Hilfe einer speziell designten Reflektionsanordnung, die mit dem Fördersystem der Anlage verbunden ist. Die Eignung des Analysesystems konnte anhand umfangreicher Labormessungen und praktischer Tests auf der Anlage demonstriert werden.

- 1 *Intended biogas plant control circuit based on spectroscopic analysis.*
- 2 *PLS calibration of organic dry matter content.*





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## CONDITION MONITORING OF GREASES IN ROLLING BEARINGS

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*Alexander Weiß*

### Introduction

Approximately 95 per cent of all rolling bearings are lubricated with grease. If the grease is aged or contaminated, rolling bearing damage is unavoidable. Around three quarters of all rolling bearing failures occur in conjunction with the lubricant, for example, due to insufficient lubrication, lubricant contamination or ageing of the lubricant [1]. Up until now, it has not been possible to analyze greases in rolling bearings during operation. It is for this reason that greases are usually replaced long before the end of their operating life as part of preventive maintenance in order to prevent damage to the rolling bearings and therefore prevent expensive downtime and failure of machinery and plant. Alternatively, an incorrect concept of safety leads to overgreasing, which can have a negative effect on the function and operating life of the bearing. In jointly cooperation with the Schaeffler Technologies GmbH & Co. KG, Freudenberg Sealing Technologies GmbH & Co. KG and the lubricants expert Klüber Lubrication München KG, a grease sensor has been developed that can be used to analyze the condition of the grease in the rolling bearing during ongoing operation.

### Disadvantages of previous methods

At present it is possible to detect defects in machines at an early stage by means of condition monitoring, such as analysis of vibrations. This, in turn, enables maintenance measures to be precisely scheduled, thereby preventing secondary damage to bearings and transmission components. The disadvantage of this method is that damage must already be present in the machine in order for a signal to be detected. As a result, at least one component must be replaced during the next maintenance operation. Using the newly developed grease sensor and the associated electronic evaluation system, it is now possible to detect changes in the condition of the grease long before any damage to the rolling bearing occurs.

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## ZUSTANDSÜBERWACHUNG VON SCHMIERSTOFFEN IN WÄLZLAGERN

Als Grundlage einer zustandsabhängigen Instandhaltung gewinnt auch die aktive Diagnostik von Wälzlagern kontinuierlich an Bedeutung, da deren systembedingte Vorteile wie zum Beispiel geringere Reibungsverluste mit der Notwendigkeit der Reduzierung von Ermüdungsausfällen gekoppelt sind. Zur Erhöhung der Wälzagerlebensdauer ist daher die Kenntnis der Schmiereigenschaften innerhalb der Lagerauflflächen obligatorisch, da mehr als 75 Prozent der Lagerausfälle direkt oder indirekt durch das Schmiermittel verursacht werden. Bisherige Messtechniken erlauben keine Analyse des Schmierfettes innerhalb des Betriebes im Wälzlager. Um Schäden an Wälzlagern zu vermeiden, werden daher, lange bevor das Ende der Gebrauchsdauer erreicht ist, zeitabhängige Wartungsintervalle zur Nachschmierung durchgeführt. Mit dem vorliegenden Fettsensor werden optisch der Wassergehalt, die Trübung, thermischer und mechanischer Verschleiß und die Fetttemperatur direkt in der Lagerung gemessen. Diese Informationen in der Auswerteeinheit in ein analoges Signal gewandelt, welches den Anwender schnell und einfach über den Zustand des Fettes informiert.

### Sensor and electronics

The sensor head, see Fig. 1, which measures just five millimetres in diameter, is embedded directly in the lubricant. The optimum measurement point varies from application to application. In this connection, it is advisable to draw on the know-how of the Schaeffler Group application engineers, who can specify precisely where the sensor should be positioned in the specific application. During the validation phase, precise analysis was carried out to determine the influence of individual contaminants in greases on the signal. Four parameters can be detected with the aid of the optical infrared reflection method: Water content, cloudiness, thermal or mechanical wear and temperature. An intelligent electronic evaluation system generates an analog signal from these, which informs the user about the condition of the grease both rapidly and simply. If a threshold value is set, a direct indication of whether the grease condition is good or poor can be provided by a signal.

### Conclusion

Due to the intensive partnership work, a grease sensor incorporating an electronic evaluation system that enables the condition of grease in bearings to be analyzed during operation has been developed. It enables the schedule for replacing the grease to be precisely planned and any changes in the condition of the grease to be detected, long before any damage to the rolling bearing occurs.

### References

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- 1 Basic set-up of the sensor.
- 2 Set-up for presentations.

**70 MEMBERSHIPS**

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**ATTACHMENT**

# EVENTS

## **Chemnitz workshops on nanotechnology, nanomaterials and nanoreliability**

The department System Packaging invited to the 16th Chemnitz workshop "Special Packaging Solutions" on June 25 and 26, 2013. Fraunhofer researchers and guests introduced current research and development results on wafer bonding and packaging technologies. The 17th Chemnitz workshop took place on November 5, 2013. The department Multi Device Integration and invited speakers presented research results on materials and lightweight structures.

## **First science campus in Chemnitz and Freiberg**

The Fraunhofer Gesellschaft invited together with Fraunhofer ENAS, Fraunhofer IWU, TU Chemnitz and TU Bergakademie Freiberg to the first Science Campus in Chemnitz and Freiberg, Germany. Female students of mathematics, engineering, natural science and information technologies attended workshops and presentations, got the opportunity to look for advice and to look behind the scenes of the research institutions. The Science Campus was awarded with the HR Excellence Award 2013.

## **International conferences and workshops**

The 7th conference on Smart Systems Integration was held in Amsterdam, The Netherlands, in March 2013. The conference welcomed 291 participants from 24 countries. The experts from industry and science from 24 countries used the platform to discuss smart systems, manufacturing technologies, integration issues and applications.

In November 2013, the Fraunhofer ENAS organized the MINAPIM workshop 2013 in Manaus, Brazil. The topic "Smart Systems Solutions for a Sustainable Forest" was represented within five sessions. The speakers introduced solutions for environmental monitoring, water and waste water treatment, renewable energy and political strategies for sustainable use of environment.

## **Chemnitzer Seminare**

Zum 16. Chemnitzer Seminar unter dem Titel „Special Packaging Solutions“ lud die Abteilung System Packaging am 25. und 26. Juni 2013 nach Chemnitz ein. Im Rahmen des Seminars und dem darauffolgenden Workshop zum Waferbonden stellten Fraunhofer-Wissenschaftler und Gäste aktuelle Forschungs- und Entwicklungsergebnisse zu Waferbondverfahren und Packaging-Technologien vor. Das 17. Chemnitzer Seminar am 5. November 2013 wurde von der Abteilung Multi Device Integration ausgerichtet. Im Mittelpunkt der Veranstaltungen standen Nano- und Leichtbaumaterialien.

## **Erster Wissenschaftscampus in Chemnitz und Freiberg**

Die Fraunhofer-Gesellschaft veranstaltete gemeinsam mit dem Fraunhofer ENAS, dem Fraunhofer IWU, der Technischen Universität Chemnitz und der TU Bergakademie Freiberg den ersten Wissenschaftscampus. Dabei hatten Studentinnen der Mathematik, Ingenieurwissenschaften, Naturwissenschaften und Informatik vier Tage lang die Möglichkeit, sich in Workshops und Vorträgen weiterzubilden, beraten zu lassen und Blicke hinter die Kulissen der Forschungseinrichtungen zu werfen. Der Wissenschaftscampus wurde mit dem HR Excellence Award 2013 prämiert.

## **Internationale Konferenzen und Workshops**

Die siebente Smart Systems Integration Konferenz SSI 2013 fand in Amsterdam, Niederlande, statt. 291 Teilnehmer aus 24 Ländern diskutieren über intelligente Systeme, Herstellungstechnologien, Integration und Anwendungen.

Im November organisierte Fraunhofer ENAS den MINAPIM Workshop 2013 in Manaus, Brasilien zum Thema „Smart Systems Solutions for a Sustainable Forest“. In fünf Sessions wurden Lösungen für Umweltmonitoring, Wasser- und Abwassernutzung, erneuerbare Energien und politische Strategien für eine nachhaltige Nutzung der Umwelt präsentiert.



### Sciences meets Arts

The exhibition series "Science meets Arts" has been continued at the Fraunhofer ENAS. The gallery talk with the Chemnitz artist Axel Wunsch was the first highlight in 2013. His exhibition "pastell-zeichnungen" was shown at the institute until April 2013. Afterwards we welcomed Gudrun Höritzsch with the exhibition "Geh dem Grasband nach ...". The pictures decorated our rooms from May to October 2013. In cooperation with researchers of the Fraunhofer ENAS, Christiane Wittig developed the light sculpture "reflectere". The sculpture and further works of the Chemnitz artist are shown in the exhibition "Die schöne Nichtigkeit" since November 2013. We thank the companies EDC GmbH, Linear electronic GmbH and Schilderwerk Beutha GmbH for supporting Ms. Wittig.

### Team Sports

A team of four women and eight men – staff of Fraunhofer ENAS and ZfM of the TU Chemnitz – started to the 8th Chemnitz Firmenlauf on September 4, 2013.

In March 2013, four employees of Fraunhofer ENAS and ZfM achieved the 5th place in volleyballs at the Chemnitz Indoor Beach Cup 2013.

### Christmas party for kids

Fraunhofer ENAS celebrated a christmas party with children and grand children of the staff on December 13, 2013. The kids prepared small gifts in baking or doing handicrafts. They had much fun in the kids theater of the Umweltbühne Chemnitz. At the end of the day, the 24 children got gifts from Santa Claus.

### Wissenschaft trifft Kunst

2013 wurde die Ausstellungsreihe „Wissenschaft trifft Kunst“ am Fraunhofer ENAS fortgeführt. Den ersten Höhepunkt des Jahres bildete das Galeriegespräch mit dem Chemnitzer Künstler Axel Wunsch. Seine Ausstellung „pastell-zeichnungen“ war bis April 2013 am Institut zu sehen. Danach begrüßten wir Gudrun Höritzsch mit Ihrer Ausstellung „Geh dem Grasband nach ...“, die von Mai bis Oktober 2013 die Institutsräume zierte. In Zusammenarbeit mit Wissenschaftlern des Fraunhofer ENAS entwickelte Christiane Wittig die Lichtskulptur „reflectere“, die gemeinsam mit weiteren Arbeiten der Chemnitzer Künstlerin in der Ausstellung „Die schöne Nichtigkeit“ seit November 2013 gezeigt wird. Wir danken den Firmen EDC GmbH, Linear electronic GmbH und Schilderwerk Beutha GmbH für die Unterstützung von Frau Wittig beim Aufbau der Lichtskulptur.

### Sportliche Teamleistungen

Ein Team von vier Mitarbeiterinnen und acht Mitarbeitern des Fraunhofer ENAS und des ZfM an der TU Chemnitz startete zum 8. Chemnitzer Firmenlauf am 4. September 2013.

Im März 2013 stellte das Fraunhofer ENAS und ZfM ein vierköpfiges Volleyball-Team für den Hallen Beach Cup 2013 in Chemnitz auf und belegte den 5. Platz.

### Kinderweihnachtsfeier

Für Kinder und Enkelkinder unserer Mitarbeiterinnen und Mitarbeiter veranstaltete das Fraunhofer ENAS am 13. Dezember 2013 eine Weihnachtsfeier. In der Back- und Bastelstube konnten kleine Geschenke vorbereitet werden. Über das Kinderpuppentheater der Umweltbühne Chemnitz und den Weihnachtsmann freuten sich die 24 Kinder im Alter von 1 bis 10 Jahren besonders.

# CONFERENCES

## Fraunhofer ENAS organized / co-organized the following conferences:

MicroCar International 2013	Leipzig, Germany	February 25 – 26, 2013
IHK NRW trifft Fraunhofer NRW, Industrie 4.0 – Intelligente Produkte für die Märkte von morgen	Paderborn, Germany	February 28, 2013
Smart Systems Integration Conference - Co-organizer	Amsterdam, The Netherlands	March 21 – 22, 2013
Conference "MicroClean 2013"	Lichtenwalde, Germany	May 13 – 15, 2013
Demoline LOPE-C 2013	Munich, Germany	June 11 – 13, 2013
iarigai 2013	Chemnitz, Germany	September 8 – 11, 2013
Printing Future Days 2013	Chemnitz, Germany	September 10 – 12, 2013
European Expert Workshop on Smart Systems Reliability EuWoRel	Berlin, Germany	September 16 – 17, 2013
THERMINIC – 19th International Workshop on Thermal Investigations of ICs and Systems	Berlin, Germany	September 25 – 27, 2013
International Semiconductor Conference Dresden Grenoble ISCDG 2013	Dresden, Germany	September 26 – 27, 2013
MEMUNITY Workshop - Co-organizer	Dresden, Germany	October 8 – 10, 2013
9th Fraunhofer Symposium	Sendai, Japan	October 31, 2013
MINAPIM 2013, "Smart Systems Solutions for a sustainable forest"	Manaus, Brazil	November 28 – 30, 2013

In 2013 the scientists of Fraunhofer ENAS presented their results at 62 conferences and exhibitions accompanying conferences. Thereby 17 keynotes and invited presentations have been given. At all organized and co-organized conferences research results and project results have been presented. A selection of additional conferences is included in the following table.

Micronarc Alpine Meeting 2013	Villars-sur-Ollon, Switzerland	January 14, 2013
SPIE Photonics West	San Francisco, USA	February 2 – 7, 2013
8th WORKSHOP ON THERMAL MANAGEMENT (8th European Advanced Technology Workshop on Micropackaging and Thermal Management)	La Rochelle, France	February 6 – 7, 2013
AmE 2013 - Automotive meets Electronics	Dortmund, Germany	February 19 – 20, 2013
Materials for Advanced Metallization MAM2013	Leuven, Belgium	March 10 – 20, 2013

# CONFERENCES

MEMS Engineering Forum	Tokyo, Japan	March 13 – 14, 2013
EuroSimE 2013	Wroclaw, Poland	April 15 – 17, 2013
ICMCTF	San Diego, USA	April 29 – May 3, 2013
Conference "MicroClean 2013"	Lichtenwalde, Germany	May 13 – 15, 2013
AMA Konferenz 2013	Nuremberg, Germany	May 16, 2013
63th ECTC	Las Vegas, USA	May 28 – 31, 2013
AVS: EIPBN 2013	Nashville, USA	May 28 – 31, 2013
17th IEEE International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS)	Barcelona, Spain	June 16 – 20, 2013
14th International Conference on the Science and Application of Nanotubes BT13	Espoo, Finland	June 24 – 28, 2013
European MEMSWave	Potsdam, Germany	July 1 – 3, 2013
2. Wireless Power Congress	Munich, Germany	July 2 – 3, 2013
CECAM 2013	Lausanne, Switzerland	July 8 – 10, 2013
ISFOE 13	Thessaloniki, Greece	July 8 – 11, 2013
InterPACK	Burlingame, USA	July 16 – 18, 2013
MWSCAS 2013	Columbus, USA	August 4 – 7, 2013
COMS 2013	Enschede, The Netherlands	August 25 – 28, 2013
Softcom 2013	Primošten, Croatia	September 18 – 20, 2013
BMT 2013	Graz, Austria	September 19 – 21, 2013
37th International Microelectronics and Packaging Conference IMAPS-CPMT	Krakow, Poland	September 22 – 25, 2013
Mikrosystemtechnik-Kongress	Aachen, Germany	October 14 – 16, 2013
IMAPS 2013	Munich, Germany	October 17 – 18, 2013
ILACOS, 7th International Laser and Coating Symposium	Hongkong, China	October 18, 2013
Advanced Metallization Conference AMC 2013	Albany, USA	October 21– 23, 2013
MicroTAS	Freiburg, Germany	October 27 – 31, 2013
ISMOT 2013	Kuala Lumpur, Malaysia	October 28 – 31, 2013
Airtech 2013 – International Congress 'Supply on the Wing'	Frankfurt/Main, Germany	November 5 – 7, 2013
TECHNOMER 2013 – 23. Fachtagung über Verarbeitung und Anwendung von Polymeren	Chemnitz, Germany	November 14 – 15, 2013
Swiss-@Print	Basel, Switzerland	November 21 – 22, 2013
15th Electronics Packaging Technology Conference EPTC 2013	Singapore	December 11 – 13, 2013

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# EXHIBITIONS AND TRADE FAIRS

nano tech 2013	Tokyo / Japan	Jan 30 – Feb 1, 2013
Smart Systems Integration 2013	Amsterdam, The Netherlands	March 13 – 14, 2013
SEMICON China 2013	Shanghai, China	March 19 – 21, 2013
HANNOVER MESSE 2013	Hannover, Germany	April 8 – 12, 2013
SENSOR + TEST 2013	Nuremberg, Germany	May 14 – 16, 2013
Sensors Expo and Conference 2013	Rosemont, USA	June 5 – 6, 2013
LOPE-C 2013	Munich, Germany	June 11 – 13, 2013
SIAE Paris Air Show 2013	Le Bourget, France	June 17 – 23, 2013
Silicon Saxony Day 2013	Dresden, Germany	June 24, 2013
nano micro biz 2013	Tokyo, Japan	July 3 – 5, 2013
SEMICON Europa 2013	Dresden, Germany	October 8 – 10, 2013
Mikrosystemtechnik-Kongress 2013	Aachen, Germany	October 14 – 16, 2013
MATERIALICA 2013	Munich, Germany	October 15 – 17, 2013
COMPAMED 2013	Düsseldorf, Germany	November 20 – 22, 2013

# PATENTS

Title: Sensormodul mit Weckeinrichtung	
Number: EP 11767769.0-1558	Date of application: April 12, 2013
Title: Flexibles mikrofluidisches System	
Number: HK 13105648.0	Date of application: May 13, 2013
Title: Fluidic actuator comprising deformable seal arrangement and long storability	
Number: US 13/901,109	Date of application: May 23, 2013
Title: Verfahren zur Fixierung einer beweglichen Komponente eines mikromechanischen Bauelementes	
Number: PCT/EP 2013/001543	Date of application: May 24, 2013
Title: Fluidischer Aktor mit verformbarer Membran und langer Lagerfähigkeit	
Number: EP 11782422.7	Date of application: June 6, 2013
Title: Fluidic actuator comprising deformable seal arrangement and long storability	
Number: ZA 2013/4611/KD	Date of application: June 21, 2013
Title: System zum Messen einer Axialkraft einer Schraubverbindung	
Number: DE 10 2013 107 671.8	Date of application: July 18, 2013
Title: Fluidic actuator comprising deformable seal arrangement and long storability	
Number: CN 201180065902.8	Date of application: July 24, 2013
Title: Permanent beschreibbares Photolumineszenz Quantum Dot Display	
Number: EP 11815614.0-1553	Date of application: July 26, 2013
Title: Functional Element Package and Fabrication Method therefor	
Number: JP 5330697	Date of grant: August 2, 2013
Title: Substrate having a coating comprising copper and method for the production thereof by means of atomic layer deposition	
Number: US 8507038 B2	Date of grant: August 13, 2013
Title: Mikrofluidisches System mit Temperierung	
Number: HK 13109481.2	Date of application: August 13, 2013
Title: Sensormodul mit Weckeinrichtung	
Number: DE 10 2010 060 906	Date of grant: September 2, 2013
Title: Verfahren zur Erzeugung integrierter und exotherm reagierender Systeme sowie deren Anwendung	
Number: DE 102013 109 879.7	Date of application: September 10, 2013
Title: Vorrichtungen zur Aussendung oder zum Empfang elektromagnetischer Strahlung und Verfahren zur Bereitstellung derselben	
Number: DE 102013221758.7	Date of application: October 25, 2013
Title: Abstimmbares Fabry-Pérot-Filter und Verfahren zu seiner Herstellung	
Number: DE 102010031206	Date of grant: November 12, 2013
Title: Electrostatically actuated micro-mechanical switching device	
Number: US 8610520 B2	Date of grant: December 17, 2013



# MEMBERSHIPS

## Memberships of Fraunhofer ENAS Scientists

acatech (Council of Technical Sciences of the Union of German Academies of Sciences)	Prof. T. Gessner	member
Academy of Sciences of Saxony, Leipzig, Germany	Prof. T. Gessner	member
Academy of Sciences, New York, USA	Prof. B. Michel	member
Advanced Metallization Conference AMC, Sematech, USA	Prof. S. E. Schulz	executive committee
Arnold Sommerfeld Gesellschaft zu Leipzig	Prof. B. Michel	scientific advisory board
Board of "KOWI", Service Partner for European R&D funding, Brussels, Belgium	Prof. T. Gessner	member
Deutscher Verband für Schweißen und verwandte Verfahren e. V.	Dr. M. Wiemer	chairman AG A2.6 „Waferbonden“
Digital Fabrication Conference (DF) of IS&T	Prof. R. R. Baumann	chair steering committee
Dresdner Fraunhofer Cluster Nanoanalytics	Prof. S. Rzepka	steering committee
Engineering and Physical Science Research Council, UK	Prof. B. Michel	referee
EPoSS (European Platform on Smart Systems Integration)	Prof. T. Gessner, Prof. T. Otto	steering group
European Center for Micro- and Nanoreliability (EUCEMAN)	Prof. B. Michel	president
European Center for Micro- and Nanoreliability (EUCEMAN)	Prof. S. Rzepka, Prof. B. Wunderle, J. Hussack	committee
EuroSimE, Bordeaux, France	Prof. B. Wunderle, Dr. R. Dudek	conference committee
German Science Foundation	Prof. T. Gessner	referee
Humboldt Foundation	Prof. B. Michel	referee
iarigai (The International Association of Research Organizations for the Information, Media and Graphic Arts Industries) 2013	Prof. R. R. Baumann	general chair
International Conference on R2R Printed Electronics (Asia)	Prof. R. R. Baumann	advisory committee
International Conference ICEPT, Shanghai, China	Dr. J. Auersperg	technical committee
International Conference IPTC, Singapore	Dr. J. Auersperg	technical committee
International Semiconductor Conference Dresden Grenoble, ISCDG	Prof. T. Gessner	conference chair
International Semiconductor Conference Dresden Grenoble, ISCDG	Prof. B. Michel, Prof. S. Schulz	technical committee
6th International Symposium on Flexible Organic Electronics (ISFOE)	Prof. R. R. Baumann	international scientific committee
5th International Symposium Technologies for Polymer Electronics TPE 2013	Prof. R. R. Baumann	international advisory committee
International Young Scientists Conference Printing Future Days	Prof. R. R. Baumann	general chair
IS&T – Society for Imaging Science & Technologies	Prof. R. R. Baumann	vice president
ITherm Conference	Prof. B. Wunderle	program committee
Large-area, Organic and Printed Electronics Convention, LOPE-C	Prof. R. R. Baumann	scientific board and advisory board
Materials for Advanced Metallization MAM	Prof. S. E. Schulz	scientific program committee
MEMS Industry Group, Executive Congress Europe 2013	Dr. M. Vogel	program committee

MEMUNITY	Dr. S. Kurth	executive committee
Microsystems Technology Journal	Prof. B. Michel	editor-in-chief
National Research Agency, France	Prof. B. Michel	referee
Nanotechnology Conferences, NSTI, USA	Prof. B. Michel	reliability track chairman
Organic Electronics Association (OE-A)	Prof. R. R. Baumann	member of the board
Senatsausschuss Evaluierung der Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL)	Prof. T. Gessner	member
SEMICON Europa	Prof. T. Gessner, Dr. M. Vogel	program committee of MEMS conference
Smart Systems Integration Conference	Prof. T. Gessner	conference chair
Smart Systems Integration Conference	Prof. T. Otto, Prof. B. Michel, Dr. C. Hedayat, Prof. K. Hiller, Prof. S. Rzepka	program committee
Therminic Workshop	Prof. B. Wunderle	conference chair

### Memberships of Fraunhofer ENAS

ALD Lab Dresden	Dresden, Germany
Cool Silicon e.V.	Dresden, Germany
Dresdner Fraunhofer-Cluster Nanoanalytik	Dresden, Germany
Elektronik-Forum OWL	Paderborn, Germany
European Center for Micro and Nanoreliability EUCEMAN	Berlin, Germany
European Platform on Smart Systems Integration EPOSS	Berlin, Germany
Fraunhofer-Allianz autoMOBILproduction	Germany
Fraunhofer-Allianz Nanotechnologie	Germany
Fraunhofer-Cluster 3D-Integration	Dresden and Chemnitz, Germany
Fraunhofer-Verbund Mikroelektronik	Germany
Industrieverein Sachsen 1828 e. V.	Chemnitz, Germany
innoZent OWL e.V.	Paderborn, Germany
It's OWL Intelligente technische Systeme Ostwestphalen/Lippe e.V.	Bielefeld, Germany
IVAM Microtechnology Network	Dortmund, Germany
MEMS Industry Group®	Pittsburgh, USA
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

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# PUBLICATIONS (SELECTION)

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## BOOKS

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Kurth, S.; Nowack, M.; Voigt, S.; Bertz, A.; Froemel, J.; Kaufmann, C.; Gessner, T.; Akiba, A.; Ikeda, K.: [Chapter Highly Reliable and Low Voltage Actuated Ohmic RF MEMS Switch with Wafer Level Packaging](#). ; in the book: RF MEMS Technologies: Recent Developments, ed. by Tayfun Akin, Alexander Muller, Dan Dascalu, Roberto Sorrentino (2013), pp 173-182, ISBN: 978-973-27-2311-1.

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## PAPERS

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Auersperg, J.; Dudek, R.; Rzepka, S.; Michel, B.: [Advantage and Current Limitations of Advanced Fracture Mechanics for 3D-Integration and BEoL under CPI Aspects \[Invited\]](#). 15th Electronics Packaging Technology Conference EPTC 2013, Singapore, 2013 Dec 11-13; Proceedings, IEEE Catalog Number: CFP13453-USB, ISBN: 978-1-4799-2833-0.

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Bargiel, S.; Gorecki, C.; Baranski, M.; Passilly, N.; Wiemer, M.; Jia, C.; Froemel, J.: [3D micro-optical lens scanner made by multi-wafer bonding technology](#). SPIE MOEMS and Miniaturized Systems XII, San Francisco, California (USA), 2013 Feb 2; Proceedings, DOI: 10.1117/12.2002422.

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Braeuer, J.; Besser, J.; Tomoscheit, E.; Klimm, D.; Anbumani, S.; Wiemer, M.; Gessner, T.: [Investigation of Different Nano Scale Energetic Material Systems for Reactive Wafer Bonding](#). PRiME 2012, 2012 Oct 7-12, Honolulu, HI (USA). ECS Transactions 2013, 50, 7 (2013), pp 241-251, DOI: 10.1149/05007.0241ecst, ISSN: 1938-5862 (print), 1938-6737 (online).

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Chen, J.; Chen, D.; Yuan, T.; Chen, X.; Zhu, J.; Morschhauser, A.; Nestler, J.; Otto, T.; Gessner, T.: [Microfluidic chips for cells capture using 3D hydrodynamic structure array](#). Microsystem Technologies, online, October 2013 (2013), DOI: 10.1007/s00542-013-1933-6.

Dimino, I.; Concilio, A.; Schueller, M.; Gratias, A.: [An adaptive control system for wing TE shape control](#). Proceedings of SPIE; Industrial and Commercial Applications of Smart Structures Technologies 2013, (part of SPIE Smart Structures/NDE 2013), San Diego, California (USA), 2013 Mar 10-14, Vol. 8690, ISBN: 978-0-8194-9473-3, DOI: 10.1117/12.2012187.

Dudek, R.; Auersperg, J.; Vogel, D.; Auerswald, E.; Rzepka, S.; Michel, B.: [Thermo-mechanical Reliability Assessment in 3D Integration with Focus on CPI](#). International Semiconductor Conference Dresden-Grenoble (ISCDG), Dresden (Germany), 2013 Sep 26-27.

Enderlein, T.; Helke, C.; Hiller, K.; Nestler, J.; Schueller, M.; Geidel, S.; Otto, T.; Gessner, T.: [Picosecond Laser Micromachining in the context of MEMS/NEMS applications](#). Smart Systems Integration Conference 2013 (SSI), Amsterdam (The Netherlands), 2013 Mar 13-14; Proceedings, ISBN: 978-3-8007-3490-0.

Euskirchen, J.; Büker, M.-J.: [SUPA – Die unsichtbare Revolution – Trends: Digitale Kultur, Wandel in der Arbeitswelt, Drahtlose Energieübertragung](#). 5. Ostwestfälischer Innovationskongress – OWIKon, Bielefeld (Germany), 2013 Oct 30.

Fiedler, H.; Toader, M.; Hermann, S.; Rodriguez, R.D.; Evgeniya, S.; Rennau, M.; Schulze, S.; Waechter, T.; Zahn, D.R.T.; Hietschold, M.; Schulz, S.E.; Gessner, T.: [Carbon nanotube based via interconnects: Performance estimation based on the resistance of individual carbon nanotubes](#). Microelectronic Engineering, online, 2013 Jul 23, <http://dx.doi.org/10.1016/j.mee.2013.07.007>.

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