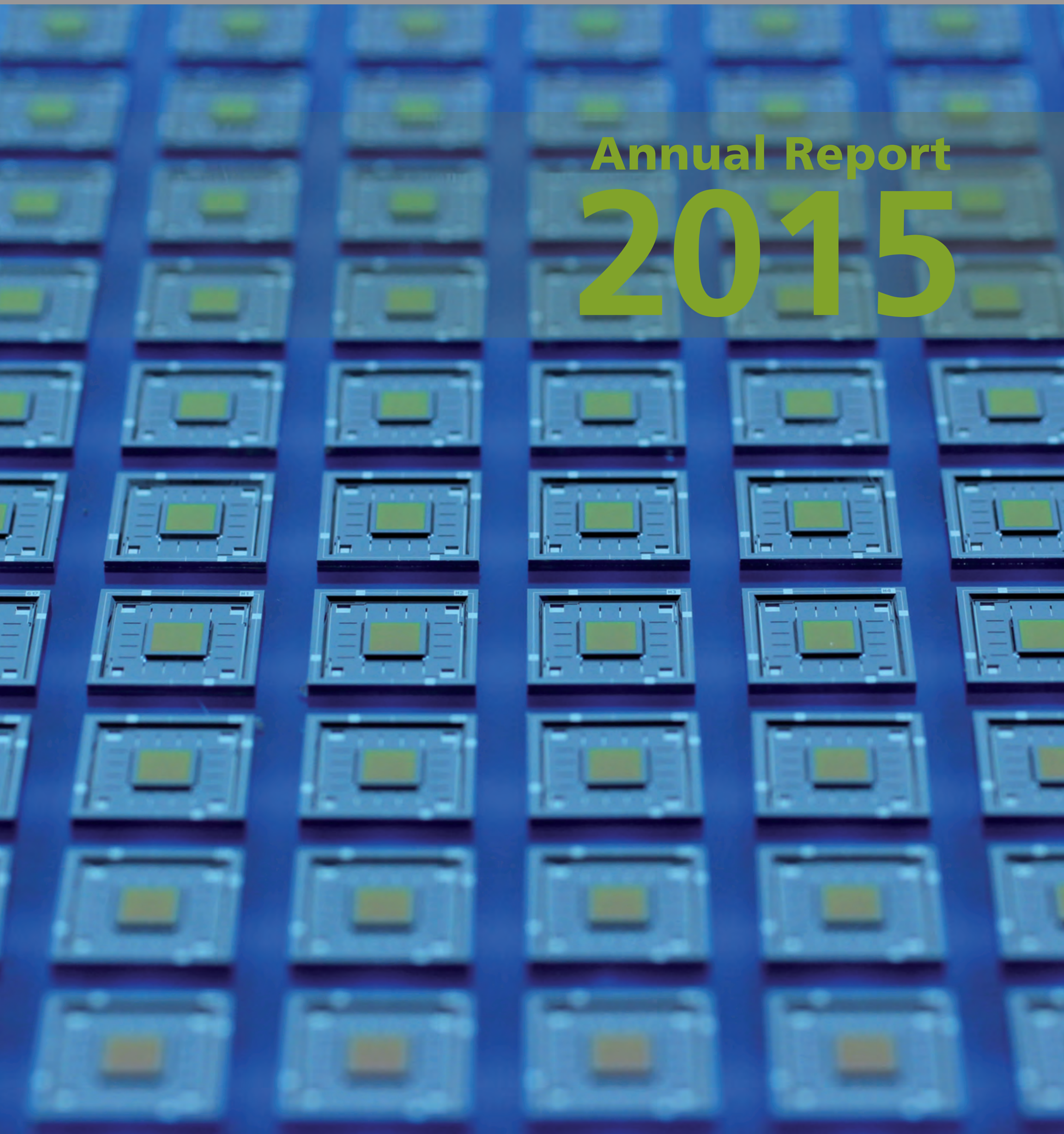
Fraunhofer ENAS

FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS



Annual Report 2015

The wavelength spectrum of infrared radiation and of visible light often reveals much more than senses can impart. Due to the specific reflection and absorption characteristics, most of the substances can be detected and analyzed quantitatively based on the wavelength spectrum. For many years, Fraunhofer ENAS together with partners is developing appropriate efficient and miniaturized spectral sensors such as the tunable infrared filter introduced on the cover page. They are fabricated at wafer-level just as other silicon devices. The image shows the silicon top level of the devices with the mechanically movable parts and ventilation holes for reducing the air friction damping. They carry special optical reflection and antireflection coatings in their central part. Together with the silicon bottom level that is not shown in the picture, a Fabry-Pérot resonator is established. Spectral sensors are built up by the combination with infrared detectors.

Die spektrale Zusammensetzung von Infrarotstrahlung und von sichtbarem Licht offenbart sehr oft viel mehr als das, was die Sinneseindrücke vermitteln. Die meisten Stoffe können aufgrund der von der chemischen Zusammensetzung abhängigen Reflexions- und Absorptionseigenschaften anhand der Spektren detektiert und quantitativ analysiert werden. An geeigneten leistungsfähigen und miniaturisierten Spektralsensoren arbeitet das Fraunhofer ENAS zusammen mit Partnern seit Jahren und entwickelte beispielsweise die im Bild gezeigten spektral abstimmbaren Infrarotfilter. Sie werden wie andere Siliziumbauelemente in großer Stückzahl in Wafern gefertigt. Im Bild ist die obere Ebene mit den mechanisch beweglichen und zur Reduzierung der Luftdämpfung geschlitzten Siliziumteilen zu erkennen, die in ihrem Zentrum spezielle optische Reflexions- und Antireflexionsschichten tragen. Sie bilden zusammen mit einer im Bild nicht erkennbaren unteren Siliziumebene einen Fabry-Pérot-Resonator. Durch die Kombination mit Infrarotdetektoren entstehen die Spektralsensoren.

ANNUAL REPORT 2015

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PREFACE

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

Smart systems for different areas of applications were the focus of our research and development activities in 2015. Our institute can once again look back at a successful year. A large portion of our research volume is generated by contract-based research, i.e. in the framework of direct orders from the industry and publicly funded projects. We maintained our high industrial revenue in 2015. At this point, we would like to thank our partners and customers for their trust and support.
In order to continue the positive results from 2015, we are continuously developing new topic areas. Our nanolithography has been fully functional since 2015. Initial applications allowed for the integration of carbon nanotubes for field effect transistors, the production of nanostructures for optical MEMS and masters for our nanoimprinting.
In order to promote scientific dialog and the exchange of knowledge between specialists from the industry and scientific fields, we organized and co-organized a number of international and national symposia in 2015. One of them, the international Smart Systems Integration Conference and Exhibition will celebrate its 10th anniversary this year. This highlights the significance of these self-sufficient, multi-functional technical systems or sub-systems, which combine sensors, actuators, data processing and data evaluation and communication interfaces. They are the hardware base in cyber-physical systems, the networked systems for the Internet of Things, Industry 4.0, smart homes and smart cities.
Our location, the Smart Systems Campus in Chemnitz, is also continuing to develop positively. In 2015, we were able to lay a foundation stone for the research facility MAIN (Center for Materials, Architecture and Integration of Nanomembranes) at the TU Chemnitz. Due to the increased number of employees, in 2015, we also started planning construction to expand Fraunhofer ENAS.
Since spring of 2015, we have been preparing this year's strategy audit for our institute. In this manner, we want to improve the performance capability of our institute.
In our 2015 annual review, we present selected projects at the institute. You will find a cross-section of a variety of activities at the institute which focus on smart systems. I invite you to ponder and think ahead. As an institute of the Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., research and development for industrial applications is also our central focus for 2016.

Director of the Fraunhofer Institute for Electronic Nano Systems ENAS

Prof. Dr. Thomas Gessner

VORWORT

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

Smart Systems für die verschiedenen Anwendungsbereiche standen auch 2015 im Mittelpunkt unserer Forschungs- und Entwicklungstätigkeit. Unser Institut blickt erneut auf ein erfolgreiches Jahr zurück. Ein Großteil unseres Forschungsvolumens wird durch Vertragsforschung, d.h. im Rahmen von Direktaufträgen der Industrie und durch öffentlich geförderte Projekte, generiert. Wir haben 2015 unseren hohen Industrieertrag gehalten. An dieser Stelle möchten wir unseren Partnern und Kunden für das Vertrauen und die Unterstützung danken.
Um das positive Ergebnis von 2015 in Zukunft fortzuschreiben, entwickeln und erschließen wir kontinuierlich neue Themenfelder. Seit Beginn des Jahres 2015 ist unsere Nanolithografie voll funktionsfähig. Erste Anwendungen ermöglichten die Integration von Kohlenstoffnanoröhren für Feldeffekttransistoren, die Herstellung von Nanostrukturen für optische MEMS sowie von Mastern für unser Nanoimprinting.
Um den wissenschaftlichen Dialog und den Austausch der Fachkollegen aus Industrie und Wissenschaft zu befördern, haben wir 2015 eine Reihe von internationalen und nationalen Tagungen organisiert bzw. co-organisiert. Eine davon, die internationale Smart Systems Integration Conference und Exhibition findet dieses Jahr bereits zum 10. Mal statt. Das unterstreicht die Bedeutung dieser autarken intelligenten multifunktionalen technischen Systeme oder Subsysteme, die Sensorik, Aktorik, Datenaufbereitung und Datenauswertung sowie Schnittstellen zur Kommunikation enthalten. Sind sie doch die Hardware der cyberphysikalischen Systeme – der vernetzten Systeme für das Internet der Dinge, Industrie 4.0, das intelligente Haus, die intelligente Stadt.
Unser Standort – der Smart Systems Campus Chemnitz – entwickelt sich positiv weiter. So konnten wir 2015 den Grundstein für den Forschungsbau MAIN (Zentrum für Materialien, Architekturen und Integration von Nanomembranen) der TU Chemnitz legen. Auf Grund der gestiegenen Mitarbeiterzahl begannen auch wir 2015 mit der Planung des Erweiterungsbaus des Fraunhofer ENAS.
Seit dem Frühjahr 2015 bereiten wir das diesjährige Strategieaudit unseres Institutes vor. Auf diese Art und Weise möchten wir die Leistungsfähigkeit unseres Instituts weiter verbessern.
In unserem Jahresrückblick 2015 zeigen wir Ihnen ausgewählte Projekte am Institut. Sie finden einen Querschnitt durch vielfältige Aktivitäten des Instituts, bei denen Smart Systems im Vordergrund stehen. Ich lade Sie zum Nach- und Vorausdenken ein. Als Einrichtung der Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. ist auch 2016 Forschung und Entwicklung für industrielle Anwendungen unser zentrales Anliegen.

Der Leiter des Fraunhofer-Instituts für Elektronische Nanosysteme

Prof. Dr. Thomas Geßner

FRAUNHOFER ENAS

Model of the planned annex next to Fraunhofer ENAS headquarters at the Smart Systems Campus Chemnitz.
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FRAUNHOFER ENAS

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The particular strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the development of smart integrated systems for different applications. Fraunhofer ENAS develops single components, technologies for their manufacturing as well as system concepts and system integration technologies and transfers them into production. The institute offers research and development services from the idea, via design and technology development or realization based on established technologies to tested prototypes.

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 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. Branches addressed are semiconductor industry, communication technology, medical engineering, biotechnology, industry automation, mechanical engineering, automotive industry, environmental engineering, power engineering, logistics as well as aeronautics.

The core competences are an indicator for the specific technological know-how of the institute. The excellence of Fraunhofer ENAS is based on a broad variety of technologies and methods for smart systems integration. These are 'Design and Test of Components and Systems', 'Silicon-Based Technologies for Micro and Nano Systems', 'Polymer-Based Technologies for Micro and Nano Systems', 'Printing Technologies for Functional Layers and Components', 'Nano Technologies for Components and Systems', 'Interconnect Technologies', 'System Packaging and 3D Integration Technologies', 'System Development and Integration' as well as 'Reliability of Components and Systems'.

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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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. Fraunhofer ENAS begleitet Kundenprojekte von der Idee über den Entwurf, die Technologieentwicklung oder Umsetzung anhand bestehender Technologien bis hin zum getesteten Prototyp.

Die Produkt- und Dienstleistungspalette von Fraunhofer ENAS reicht von hochgenauen Sensoren für die Industrie, Sensor- und Aktuatorsystemen 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 Kommunikationstechnik, die Luft- und Raumfahrt, der Automobilbau, die Biotechnologie, die Logistik, die Medizin- und Umwelttechnik sowie der Maschinenbau und Industrieautomatisierung.

Die Kernkompetenzen spiegeln das spezifische technologische Know-how des Instituts wider. Eine besondere Stärke des Fraunhofer ENAS liegt im breiten Spektrum an Technologien und Methoden für die Smart Systems Integration. Dazu gehören: Design and Test of Components and Systems, Silicon-Based Technologies for Micro and Nano Systems, Polymer-Based Technologies for Micro and Nano Systems, Printing Technologies for Functional Layers and Components, Nano Technologies for Components and Systems, Interconnect Technologies, System Packaging and 3D Integration Technologies sowie System Development and Integration und Reliability of Components and Systems.

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.

DEPARTMENT MULTI DEVICE INTEGRATION

Head of the department Multi Device Integration:

Prof. Dr. Thomas Otto
phone: +49 371 45001-231
e-mail: thomas.otto@enas.fraunhofer.de

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 nonsilicon materials (nanocomposites, ceramics, and polymers).

MEMS/NEMS design and development

Novel modeling and simulation techniques are essential for designing micro and nanoelectromechanical 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.

DEPARTMENT MICRO MATERIALS CENTER

Head of the department Micro Materials Center:

Prof. Dr. Sven Rzepka
phone: +49 371 45001-421
e-mail: sven.rzepka@enas.fraunhofer.de

Founded by professor Bernd Michel, the Micro Materials Center at today's Fraunhofer ENAS has some 20 years of experience 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 and robustly 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 complete applications
- Thermo-(electro-)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 fully electrical but also in hybride and ICE vehicles; reliability and safety of systems for autonomous driving
- Solder reliability for micro/nano interconnects
- Reliability for packaging in the micro/nano integration field
- Reliability for nanoelectronics and smart systems (3D integration, More-than-Moore)
- Physics of failure analysis, fatigue and creep analysis
- Accelerated stress testing strategies (e.g. combined tests: multiple loads simultaneously)
- 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.)

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 catalytic layers. These functionalities can improve and enhance the performance and the architecture of smart systems, e.g. by printed active devices, interconnects or printed power modules. In future, these products will have additional 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 everything.

In our understanding the term "Printed Functionality" goes far beyond color and we envision that the functionalities electrical conductivity, adapted dielectric properties, electrical semiconductivity, electric power, electro-luminescence/light emission, sensing environment, surface protection, intelligence via chip or even catalysis will be manufactured by employing presses 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 the 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 post-press treatment, we have installed a Novacentrix® PulseForge® and a HERAEUS NIR dryer in a web-fed system for additional functionality formation.

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

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

Head of the department Printed Functionalities:

Prof. Dr.
Reinhard R. Baumann
phone: +49 371 45001-234
e-mail: reinhard.baumann@enas.fraunhofer.de

DEPARTMENT BACK-END OF LINE

The department Back-End of Line focuses on

- Process development and integration
- Characterization techniques
- Modeling and simulation

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

The department has long standing expertise in the integration of low-k, porous ultra low-k materials, and airgaps into copper damascene interconnect systems.
Global demands such as the internet of things and industrial internet require holistic MEMS/NEMS - electronics integration concepts along with the development of novel sensors and devices. Thereby, we follow a wafer-level fabrication approach of miniaturized sensors and high frequency transistors. In particular, carbon nanotubes are under investigation for interconnect and nano systems. Furthermore, a new generation of highly sensitive XMR-based 2D/3D magnetic field sensors is developed.
A variety of sensors, electronics and further components are integrated into 3D smart systems. Therefore, vertical contacts (TSVs) are developed and combined with wafer bonding techniques which is done in cooperation with the department System Packaging.
All technologies are based on a comprehensive process portfolio from which individual process solutions are available for customer needs. Process development and integration are accompanied by characterization and modeling/simulation. Advanced simulation models and tools are used and developed for thin film deposition processes as well as for interconnect and nano systems.

Competences and research fields

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

- Atomic layer deposition of metals and metal oxides
- Carbon nanotubes for interconnects, transistors, and sensors
- Integration of low-k and ultra low-k (ULK) dielectrics and airgaps
- Magnetoresistive sensors based on spin-valve systems and magnetic tunnel junctions
- Metallization using CVD, ALD, PVD, and ECD
- Modeling and simulation of micro and nano devices, processes, and equipments
- Surface processing for interconnect systems and MEMS/NEMS (CMP, grinding, wet etching)

Head of the department Back-End of Line:

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

DEPARTMENT SYSTEM PACKAGING

The department System Packaging is working in the field of packaging technologies for MEMS and NEMS covering topics from zero-level packaging up to multi-level packaging. The potentials of packaging and system integration are manifold, ranging from hybrid integration of components on application-specific substrate carriers, over monolithic integration of electronics, to sensing and actuating components on substrate. In addition to the increasing functionality and reliability, the miniaturization and the smart systems integration are the greatest challenges for 'More-than-Moore' development.
Besides, conventional wafer bonding techniques such as silicon direct bonding, anodic, eutectic, adhesive, and glass frit bonding, new 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. Furthermore, the competence of the department involves dicing, chip and wire bonding as well as thin wafer handling. A new approach for the department is the medical use of packaged micro devices. Therefore, MEMS packaging techniques and thin film encapsulation technologies are investigated and characterized in terms of hermetical and biocompatible properties. 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 analyzes nanoscale intermediate layers and layer systems using PLD, PVD, and Aerosol-jet deposition for advanced MEMS packaging solutions. The aim of these new bond process investigations is to achieve a permanent and hermetic sealed joint between two wafers, using the lowest process temperature possible. Another application of nanostructures are micro energy storage systems. By combining nanostructured electrodes with ionic conductors, electric double-layers with large volumetric capacitance are realized resulting in autonomous microsystems such as smart sensor networks and medical implants.
Furthermore, the department is focusing on acoustic applications including capacitive micromachined ultrasonic transducers (CMUT), speakers, and microphones fabricated by using MEMS technologies. Using amorphous metals, free standing membranes with superior mechanical properties like high strength and elastic limit are realized using PVD technologies. In combination with printed magnets based on screen printing paste filled with magnetic particles and electrochemically deposited coils, electrodynamic actuators are realized.

Competences

- MEMS packaging, wafer-level packaging and 3D integration
- Nanoscale effects and imprinting
- Aerosol-jet and screen printing
- Medical and acoustic applications

Head of the department System Packaging:

Dr. Maik Wiemer
phone: +49 371 45001-233
e-mail: maik.wiemer@enas.fraunhofer.de

DEPARTMENT ADVANDCED SYSTEM ENGINEERING

The main research effort of the department Advanced System Engineering is focusing on designing robust micro and nanoelectronic systems by using efficient simulation methods and by measuring and characterizing precisely their performances. Especially, an expertise in the area of wireless sensor systems including Radio-Frequency and RFID technologies for harsh environments was developed and finds its application in specific industrial custom needs. Already in the early design stages, the constitution of these systems on both electronic and antenna sides takes all relevant disturbances like conducted or radiated parasitical electromagnetic effects into account. This approach allows to guarantee the electromagnetic compatibility (EMC), the signal integrity (SI), and the electromagnetic reliability (EMR) from the IC-level through packages up to the printed circuit board.
Beside wireless sensing and communicating systems, the department ASE has developed a strong know-how in the area of cordless energy transfer with high efficiency. For this, an optimized antenna array structure combined to a self-adaptive driving power electronics device was designed. This smart combination of antenna and electronics increases both the efficiency and the positioning freedom of the system by limiting drastically the produced electric smog, making the system applicable in close proximity to human beings.
In order to conduct such research, methods for the calculation of electromagnetic fields and circuits are applied at both analog and mixed-signal levels in order to analyze the transmission behavior (i.e. crosstalk, reflection, changes of the nominal signal waveform) in the time and frequency domain. Advanced and precise simulation models and algorithms like the event-driven approach enable the very fast simulation and characterization of mixed-signal systems, reducing drastically the needed design time, and thus the time to market gap. These methods are linked via well-defined interfaces with established software, such as Cadence/Spectre, SPICE or Matlab/Simulink, to enable efficient and robust top-down designs and bottom-up verifications.

Competences

- Wireless energy transmission
- Research and design of customer-specific electronic modules
- Development and optimization of RF antenna structures and circuits (RFID, WLAN, …)
- Mobile wireless and RFID smart sensor systems for harsh environments
- Advanced modeling and analysis of EMC and SI-effects
- System modeling and simulation
- Model-based development methods for custom specific heterogeneous systems
- Advanced 3D near-field scanning (high resolution up to 6 GHz)
- RF and EMC measurement on wafer-level up to 20 GHz
- Multiphysical modeling and simulation using CST µWave Studio, AnSys (HFSS), and Cadence (HSPICE/Spectra)

Head of the department Advanced System Engineering:

Dr. Christian Hedayat
phone: +49 5251 60-5630
e-mail: christian.hedayat@enas-pb.fraunhofer.de

ORGANIZATIONAL STRUCTURE

Director
Fraunhofer ENAS
Prof. Dr. Thomas Geßner
Phone: +49 371 45001-100
thomas.gessner@enas.fraunhofer.de

Deputy Director
Smart Systems/Microsystems
Prof. Dr. Thomas Otto
Phone: +49 371 45001-231
thomas.otto@enas.fraunhofer.de

Deputy Director
Micro and Nanoelectronics
Prof. Dr. Stefan E. Schulz
Phone: +49 371 45001-232
stefan.schulz@enas.fraunhofer.de

Departments

Multi Device Integration
Prof. Dr. Thomas Otto
Phone: +49 371 45001-231
thomas.otto@enas.fraunhofer.de

Micro Materials Center
Prof. Dr. Sven Rzepka
Phone: +49 371 45001-421
sven.rzepka@enas.fraunhofer.de

Printed Functionalities
Prof. Dr. Reinhard R. Baumann
Phone: +49 371 45001-234
reinhard.baumann@
enas.fraunhofer.de

Back-End of Line
Prof. Dr. Stefan E. Schulz
Phone: +49 371 45001-232
stefan.schulz@enas.fraunhofer.de

System Packaging
Dr. Maik Wiemer
Phone: +49 371 45001-233
maik.wiemer@enas.fraunhofer.de

Advanced System Engineering
Dr. Christian Hedayat
Phone: +49 5251 60-5630
christian.hedayat@
enas-pb.fraunhofer.de

Head of Administration
Gottfried Höppner
Phone: +49 371 45001-210
gottfried.hoeppner@enas.fraunhofer.de

Officer of the Director, Head of PR/Marketing
Dr. Martina Vogel
Phone: +49 371 45001-203
martina.vogel@enas.fraunhofer.de

International Offices

Fraunhofer Project Center NEMS/MEMS Devices and Manufacturing Technologies at Tohoku University, Japan

Prof. Masayoshi Esashi
Phone: + 81 22 305 2351
esashi@mems.mech.tohoku.ac.jp

Assoc. Prof. Jörg Frömel
Phone: +81 22 795 6937
joerg.froemel.e5@tohoku.ac.jp

Prof. Dr. Shuji Tanaka
Phone: +81 22 795 6934
tanaka@mems.mech.tohoku.ac.jp

Office Shanghai, China
SHI Min
Phone: +86 21 68758536 ext.1632
shi.min@sh.china.ahk.de

Office Manaus, Brazil
Hernan Valenzuela
Phone: +55 92 3182-4885
hernan@fraunhofer.org.br

Technische Universität Chemnitz

Center for Microtechnologies (ZfM)

President
Chair Microtechnology
Prof. Dr. Thomas Geßner
Phone: +49 371 531-33130
thomas.gessner@zfm.tu-chemnitz.de

Deputy
Prof. Dr. Karla Hiller
Phone: +49 371 531-33276
karla.hiller@zfm.tu-chemnitz.de

Department Lithography/Etch/Mask
Dr. Danny Reuter
Phone: +49 371 531-35041
danny.reuter@zfm.tu-chemnitz.de

Department Layer Deposition
Dr. Sven Zimmermann
Phone: +49 371 531-33671
sven.zimmermann@zfm.tu-chemnitz.de

Coordination of projects

MERGE
Martin Schüller
Phone: +49 371 45001-242
martin.schueller@enas.fraunhofer.de

Institute for Print and Media Technology

Chair Digital Printing and Imaging Technology
Prof. Dr. Reinhard R. Baumann
Phone: +49 371 531-35843
reinhard.baumann@mb.tu-chemnitz.de

University Paderborn

Chair Sensor Technology
Prof. Dr. Ulrich Hilleringmann
Phone: +49 5251 60-2225
hilleringmann@sensorik.upb.de

ADVISORY BOARD

The advisory board is an external advisory body attached to the institute. It 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.
Fraunhofer ENAS welcomes the new advisory board member Thomas Schmidt, the Saxon State Minister for Environment and Agriculture.

In 2015, 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 Sciene and Art
Jürgen Berger, Division Director Electronic and Micro Systems, VDI/VDE Innovation + Technik GmbH
Dr. Wolfgang Buchholtz, Manager Project Coordination, GLOBALFOUNDRIES
Prof. Dr. Maximilian Fleischer, Siemens AG
Dr. Christiane Gottschalk, Director Advanced Product Development, MKS Deutschland GmbH
Dr. Arbogast M. Grunau, Director Product Development, Schaeffler KG
MDirigin Barbara Meyer, Saxon State Ministry of Economy, Technology and Transportation
Thomas Schmidt, Saxon State Minister for Environment and Agriculture
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, Technische Universität Chemnitz
Helmut Warnecke, CEO, Infineon Technologies Dresden GmbH & Co. OHG

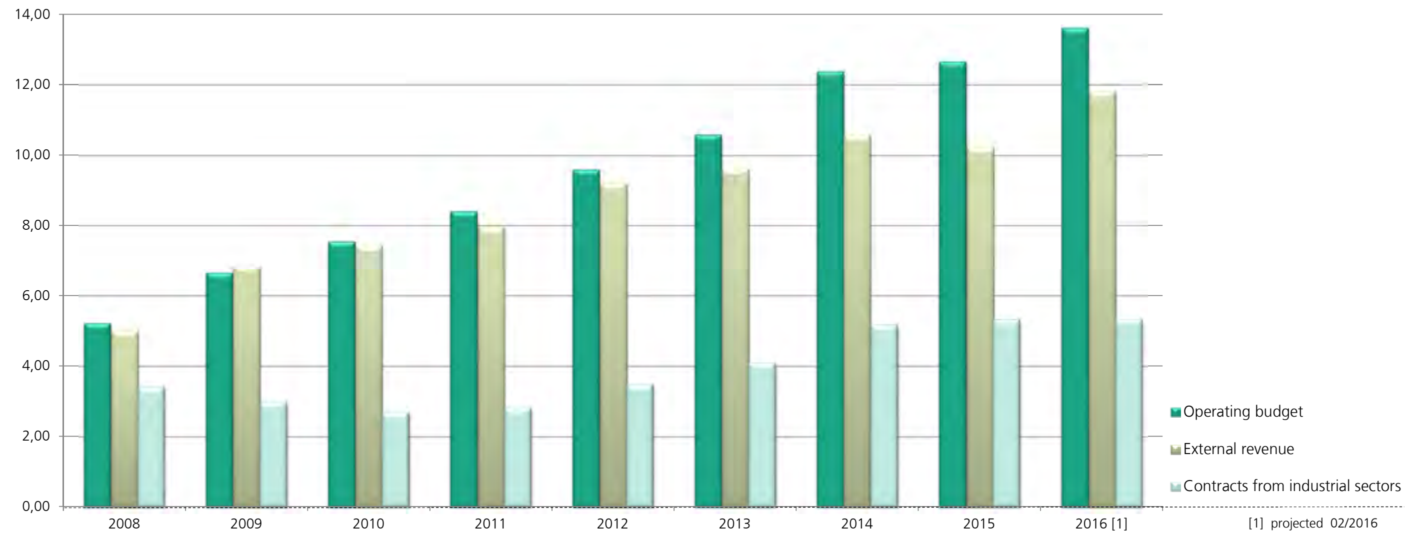
We thank all advisory board members and especially the chairman Prof. Dr. Udo Bechtloff and the deputy chairman Prof. Dr. Hans-Jörg Fecht for supporting our institute.

FACTS AND FIGURES

Development of the Fraunhofer ENAS / Entwicklung des Fraunhofer ENAS

	Year 2008	2009	2010	2011	2012	2013	2014	2015
Operating budget (in million euros) / Betriebshaushalt (in Mio. EUR)	5.2	6.7	7.6	8.4	9.6	10.6	12.4	12,6
Increasing of the budget (related to 2008) / Steigerung des Haushalts (bezogen auf 2008)	-	29 %	46 %	62 %	85 %	104 %	138 %	183 %
Industrial revenues (in million euros) / Wirtschaftsertrag (in Mio. EUR)	3.4	3	2.8	2.8	3.5	4.1	5.2	5.4
Investment (in million euros) / Investitionen (in Mio. EUR)	0.65	5.45	6.8	1.5	1.81	1.44	7.23	2.34
Staff / Mitarbeiterinnen und Mitarbeiter	63	73	91	102	104	125	129	127
Apprentices / Auszubildende	0	2	3	5	6	7	7	6
Students and student assistants / Studenten und Hilfskräfte	10	10	20	40	43	51	51	43
Publications and oral presentations / Publikationen und Vorträge	61	75	114	119	112	215	198	173
Patents / Patente	7	5	13	20	8	17	9	9
Dissertations / Promotionen	6	0	4	2	3	3	3	5
Academic lectures / Vorlesungen (Technische Universität Chemnitz)	17	17	23	27	24	24	24	24
Academic lectures / Vorlesungen (Universität Paderborn)	8	9	9	8	9	8	7	10
Academic lectures / Vorlesungen (Technische Universität Dresden)	0	0	2	2	2	1	0	0

FACTS AND FIGURES



Financial situation and investment

2015 was a year of stable growth for Fraunhofer ENAS. Not only the budget, which increased by 3.3 percent to 14.67 million euros, but also the continued, stable third-party funds highlight the solid development strategy of our institute. In 2015, Fraunhofer ENAS generated external earnings in the amount of 10.25 million euros. The revenue quota is at 82.5 percent. The orders from German and international industrial companies increased to 5.34 million euros which corresponds with an industrial share of 42.5 percent of the operating budget of 12.65 million euros.

The internal equipment investments and investments in furnishing/constructing the building in the last year were 1.72 million euros. The strategic investment in 2015 was 0.62 million euros.

Head of Administration:
Gottfried Höppner
phone: +49 371 45001-210
e-mail: gottfried.hoeppner@enas.fraunhofer.de

Personnel development

The success of any company and of any research institute relies on the minds of the employees, their knowledge about details and correlations, products, technologies, and processes. In 2015, six employees were hired so, at the end of the year, 127 people were employed by the Fraunhofer ENAS Chemnitz, Paderborn, and Berlin locations. Eight employees moved from Fraunhofer ENAS to the industrial sector or retired.

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

At the end of 2015, Fraunhofer ENAS employed 43 interns, graduate students/master's students and student aids. This employee base continues to prove itself an excellent source for young scientists and technicians.

Finanzielle Situation und Invest

Auch 2015 war für Fraunhofer ENAS ein von stabilem Wachstum geprägtes Jahr. Nicht nur das um 3,3 Prozent auf 14,67 Millionen Euro gestiegene Budget sondern auch die weiterhin stabilen Drittmittelerträge unterstreichen die solide Entwicklungsstrategie unseres Institutes. In 2015 erwirtschaftete Fraunhofer ENAS externe Erträge in Höhe von 10,37 Millionen Euro. Die Ertragsquote liegt bei 82,3 Prozent. Die Aufträge aus deutschen und internationalen Industrieunternehmen stiegen auf 5,38 Millionen Euro, was einem Industrieanteil von 42,5 Prozent am Betriebshaushalt von 12,65 Millionen Euro entspricht.

Die eigenen Geräteinvestitionen und Investitionen in die Ausstattung/Bau des Gebäudes im vergangenen Jahr betrugen 1,72 Millionen Euro. Der strategische Invest in 2015 betrug 0,62 Millionen Euro.

Verwaltungsleiter:
Gottfried Höppner
Telefon: +49 371 45001-210
E-Mail: gottfried.hoeppner@enas.fraunhofer.de

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. 2015 wurden sechs Mitarbeiterinnen und Mitarbeiter eingestellt, sodass zum Ende des Jahres 127 Personen an den Fraunhofer ENAS Standorten Chemnitz, Paderborn und Berlin beschäftigt waren. Acht Mitarbeiterinnen und Mitarbeiter wechselten von Fraunhofer ENAS entweder in die Industrie oder in den Ruhestand.

Drei Auszubildende schlossen 2015 erfolgreich ihre Ausbildung an unserem Institut ab und sind seitdem entweder bei Fraunhofer ENAS beschäftigt oder nahmen ein Studium auf. In Kooperation mit der TU Chemnitz und der Universität Paderborn haben Studentinnen und Studenten sowie junge Wissenschaftlerinnen und Wissenschaftler ihre Graduierungsarbeiten erfolgreich verteidigt.

Ende 2015 waren 43 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.

FRAUNHOFER ENAS – PARTNER FOR INNOVATION

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.

Interdisciplinary cooperation – key of success

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

Cooperation with industry

With the working field smart systems integration Fraunhofer ENAS is able to strongly support the research and development of many small and medium sized companies as well as large scale industry. By integration of smart systems in different applications Fraunhofer ENAS addresses the branches mentioned before. Our most common way of cooperation with industry is contract research for an individual partner. If the tasks to be solved are too complex, we offer pre-competitive research. In these cases, teaming up with companies and research institutes and public funding support is more effective than operating solo. In 2015 Fraunhofer ENAS has cooperated with more than 150 partners from industry worldwide. Fraunhofer ENAS carries out direct research and development orders as well as practical joint projects and pre-competitive research.

Cooperation within the Smart Systems Campus

Smart Systems Campus Chemnitz is an innovative network with expertise in micro and nanotechnologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close cooperation of science, applied research and industry is an everyday reality and reflects a strategy that is being fulfilled. Main Partners are the Technische Universität Chemnitz, the Fraunhofer ENAS, young companies within the start-up building, and companies within the business park.

Product and service portfolio

- High-precision sensors for industrial applications
- Sensor and actuator systems with control units and evaluation electronics
- Printed functionalities like antennas and batteries
- Material and reliability research for microelectronics and microsystem technology
- Development, design, and test of MEMS/NEMS
- Simulation and modeling of devices, processes, and equipment for micro and nano systems
- Integration of nanofunctionalities, such as carbon nanotubes, quantum dots
- Methods and technologies for MEMS/NEMS encapsulation and integration with electronics
- Metallization and interconnect systems for micro and nanoelectronics and 3D integration
- Reliability of components and systems
- Analytics for materials, processes, and devices

Application fields

- Semiconductor and semiconductor equipment and materials industries
- Communication sector
- Medical engineering
- Mechanical engineering
- Security sector
- Automotive industry
- Logistics
- Aeronautics

Cooperation with universities and research institutes

Fraunhofer ENAS has established a strategic network with research institutes and universities in Germany and worldwide.
Germany funds Excellence Initiatives for Cutting-Edge Research at Institutions of Higher Education. Fraunhofer ENAS works 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

In Asia, long-term cooperation exists with the Tohoku University in Sendai, the Fudan University Shanghai and the Shanghai Jiao Tong University.
A very strong cooperation exists with the Technische Universität Chemnitz. This cooperation ensures synergies between the basic research conducted at the TU Chemnitz and the more application-oriented research at the Fraunhofer ENAS. 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 especially in the field of electromagnetic reliability and compatibility as well as wireless energy and data transmission technology.

Main partners of basic research

- TU Chemnitz
- University Paderborn
- TU Dresden
- TU Berlin
- Tohoku University
- Fudan University
- Jiao Tong University

Cooperation within Fraunhofer-Gesellschaft

Fraunhofer ENAS belongs to the Fraunhofer Group for Microelectronics VμE since its foundation. Moreover, Fraunhofer ENAS is a member of 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 Heterogeneous Technologies Alliance, which is a novel approach to creating and developing microtechnologies, nanoelectronics and smart systems for next-generation products and solution together with CEA-Leti, CSEM, and VTT. Within the lighthouse project "Theranostic Implants" Fraunhofer ENAS is working together with 11 other Fraunhofer Institutes on strategic objectives.

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.

At present, the Fraunhofer-Gesellschaft maintains 67 institutes and research units. The majority of the nearly 24,000 staff are qualified scientists and engineers who work with an annual research budget of more than 2.1 billion euros. Of this sum, more than 1.8 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.

www.fraunhofer.de

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.

Die Fraunhofer-Gesellschaft betreibt in Deutschland derzeit 67 Institute und Forschungseinrichtungen. 24 000 Mitarbeiterinnen und Mitarbeiter, überwiegend mit natur- oder ingenieurwissenschaftlicher Ausbildung, erarbeiten das jährliche Forschungsvolumen von mehr als 2,1 Milliarden Euro. Davon fallen über 1,8 Milliarden Euro auf den Leistungsbereich Vertragsforschung. Mehr als 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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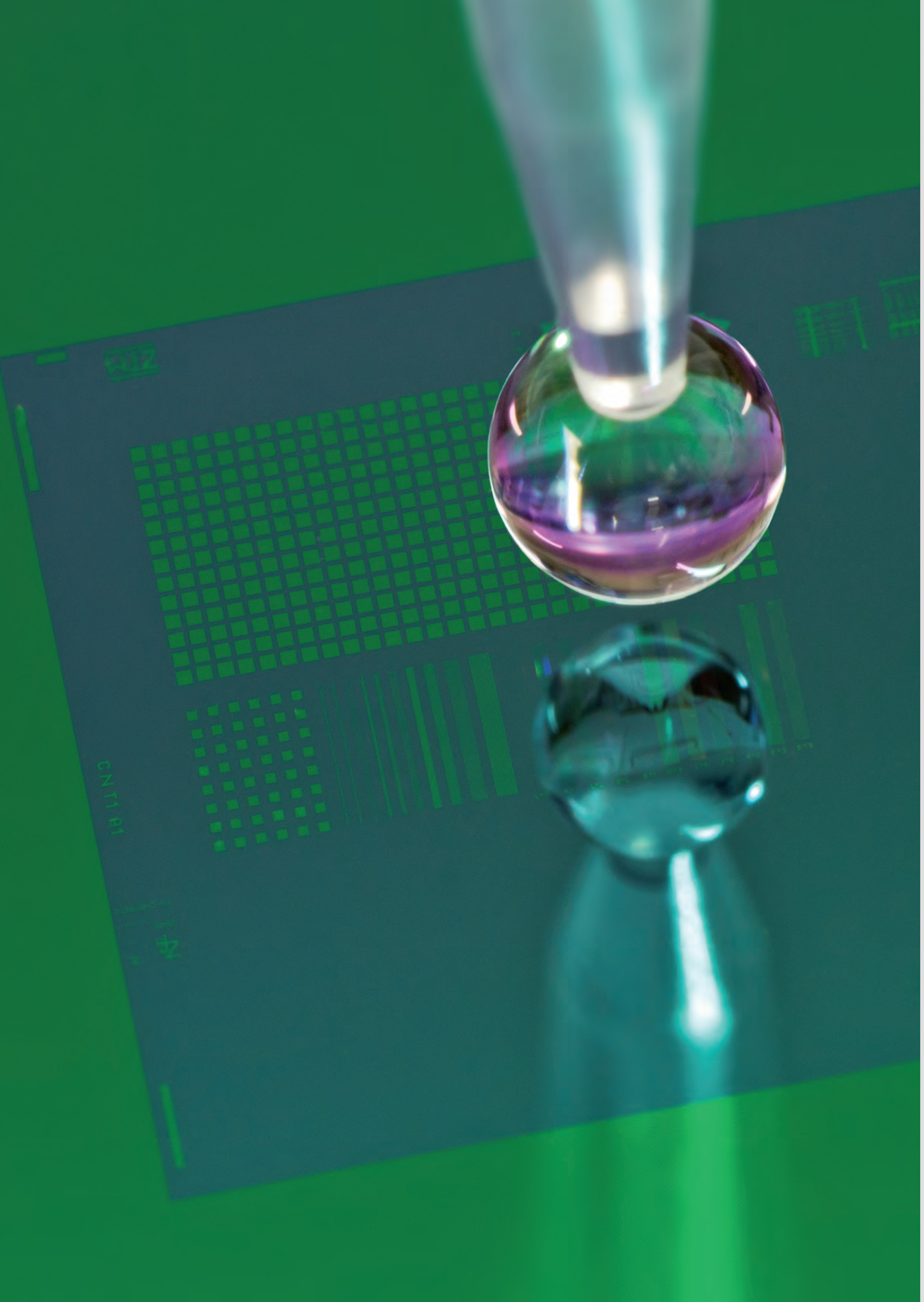
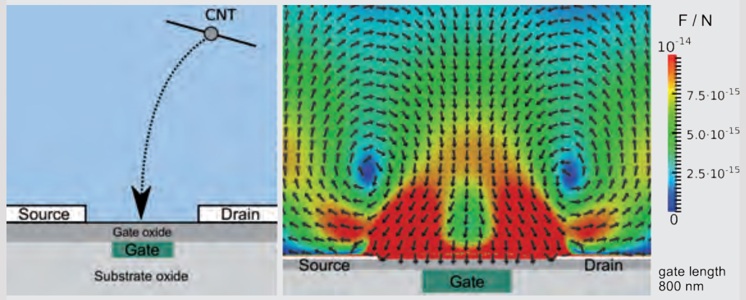


HIGHLIGHTS 2015

Integration of DNA origami in micro/nanostructured surfaces
Photo © Jürgen Lösel

R&D AND PROJECT HIGHLIGHTS



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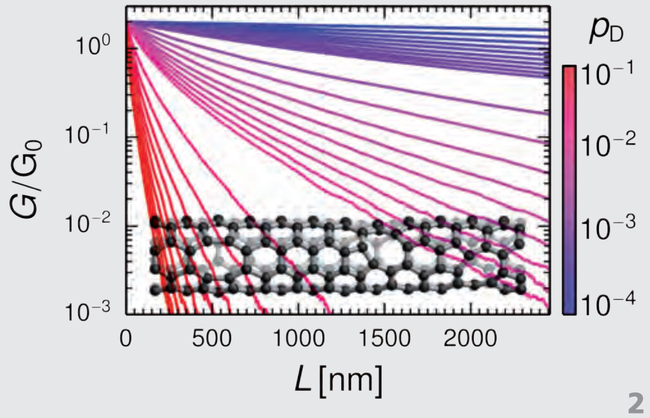

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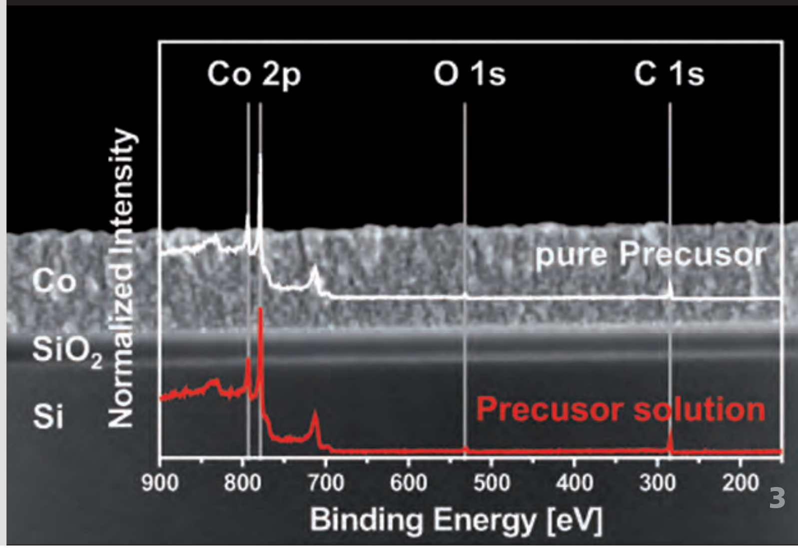

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Simulation of the dielectrophoretic deposition of carbon nanotubes

Dielectric particles experience a force when subjected to a nonuniform electric field. This effect, called dielectrophoresis (DEP), is currently exploited at Fraunhofer ENAS to deposit carbon nanotubes (CNTs) as channel material for future high-frequency CNT-based field effect transistors. However, during a DEP process, the forces acting on the CNTs strongly depend on the surrounding liquid medium, the electric properties of the CNTs, their size and shape as well as the frequency of the electric field.

To optimize the CNT deposition, a simulation workflow has been developed, which describes the motion of single CNTs during the process. The model includes the relevant physical effect that contribute to total force acting on the CNTs: the direct DEP force (which depends on the type of CNT and on the electric field frequency, and the gradient of the local electric field) and the drag effect due to the motion of CNT containing fluid (which is induced by temperature gradients due to local Joule heating of the fluid). These coupled effects are modeled and simulated for realistic 2D transistor geometries using a finite element solver. A subsequent time dependent simulation including the inherent Brownian motion of the CNTs tracks their individual trajectories and enables a systematic statistical analysis of the deposition of different CNT types for various process conditions and transistor geometries.

Conductance of carbon nanotubes with arbitrary defects

Based on an efficient quantum transport code, which was implemented at the Simulation group in the department BEOL, the current and the conductance of very large CNT devices in the µm range can be calculated. The use of recursive Green's function techniques yields linear scaling algorithms and allows to access the length-dependence with only a small extra effort. The underlying density-functional-based tight-binding model gives the accuracy of density functional theory while maintaining the simplicity and the fastness of the tight-binding approach. This transport code was used to determine the conductance of carbon nanotubes (CNTs) with structural defects and its dependence on the defect type and the defect probability as well as on structural parameters like CNT length and CNT diameter. The results of this comprehensive and computationally extremely expensive study were statistically analyzed and brought into a simple analytical model which describes the CNT conductance for an arbitrary number of arbitrarily mixed defects and arbitrary CNT diameters. Based thereon, conductance estimations can easily be performed, just by relating the conductance of a µm-long CNT with a huge amount of defects to material parameters of the single defects. This only requires a few transport calculations, whose computational costs are vanishingly small in comparison to the exact determination.
Paper: Teichert, F.; et al.: New Journal of Physics, 16 (2014), 123026.

1 *Sketch of transistor structure and CNT deposition .(left)*
Magnitude and direction of the total force acting on CNTs during the DEP process. (right)

Chemical Vapor Deposition of metals using precursor solutions

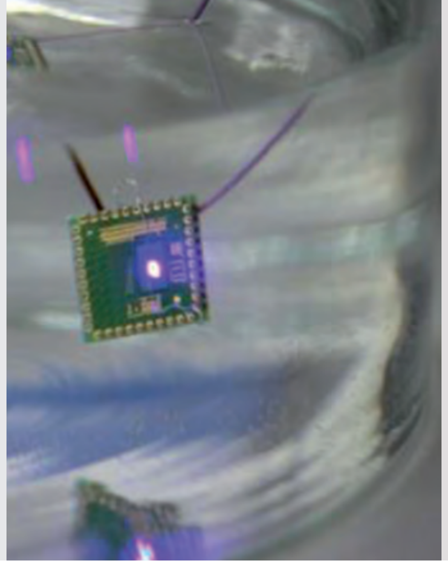
New metallic thin film materials have been introduced in the BEOL, especially in modern on-chip interconnect systems. For patterned substrates with high aspect ratio features gas phase deposition techniques such as CVD or ALD are able to deposit thin and homogenous layers in combination with a good step coverage. Therefore, metal precursors with specific properties such as high reactivity, long-term stability, high vapor pressure and economical consumption are necessary. Currently, a dicobaltatetrahedrane precursor is in the focus of research to deposit metallic Co layers. Due to the compounds being easily dissolvable in different organic solvents the use of this precursor solution during a CVD process has the benefit of better chemical handling and storing along with lower cost. It was found that the use of 20 % dicobaltatetrahedrane in n-hexane is most promising as precursor solution due to no influence of the solvent during the deposition process. This can be seen by comparing depositions without any coreactant using either the pure precursor or the precursor solution. XPS measurements of these films deposited at 250 °C show a similar layer composition. A series of CVD experiments at different deposition temperatures between 160 – 250 °C exhibit layer compositions which do not change significantly. By choosing the appropriate coreactant the carbon and oxygen impurities of the layers could be eliminated during the CVD process.

Plating process for Al conductor structures in PCB fabrication (AioLi)

Aluminum (Al) encountered in electrical engineering/electronics as plating and assembly material in various forms. The large area of printed circuit board technology is excluded from this. Copper (Cu) as the base metal, especially tin (Sn) and precious metals as plating materials dominate the PCB production. The increased manufacturing costs show a significant financial load for the industry by using these materials and technologies. Al is already represented in many areas, from the chip metallization in semiconductor devices up to connecting lines. Al is a suitable substitution material for Cu. Beside the good electrical, thermal and processing proper-

2 *Conductance of carbon nanotubes with structural defects in dependence on CNT length and defect probability.*

3 *SEM image and XPS measurements of cobalt layers deposited at 250 °C.*

4  

ties, Al offers the possibility for electrical contact by wire bonding. Therefore, the use of Al in various application fields up to the packaging promises an important economic and ecological effect. As a result, new applications in the automotive and industrial electronics, medical technology, or telecommunications are created. The major scientific and technical challenge is that the new approach should meet all requirements of the user industry. The aim of the project AioLi is the electrochemical deposition of Al layers from ionic liquids (IL) with variable thicknesses, a controlled deposition rate, a high uniformity, and a high layer quality. The project volume amounts 2.46 million euros (64 % share of funding by the BMBF) and is sponsored in main focus "SME-innovative".

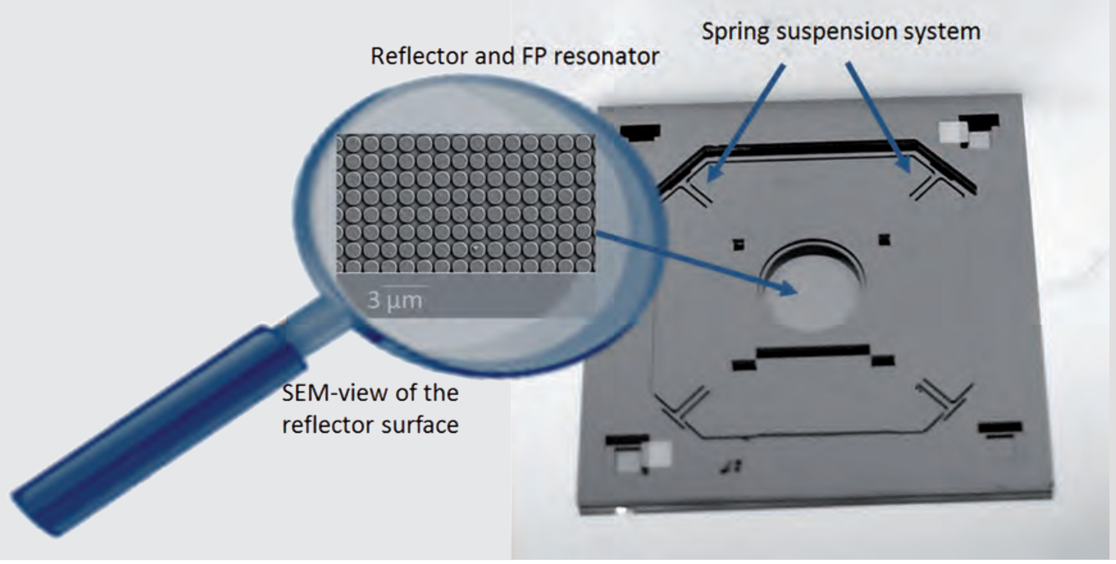
Parylene for encapsulation of medical devices

Following the miniaturization trend, new thin film encapsulation materials are required for medical implants to ensure the protection of the device from the body environment, and to protect the body against influence of the implant or parts of it. Parylene is a polymer, which combines a number of excellent properties and offers a wide potential for applications. The most important properties are biocompatibility and biostability, chemical inertness against all common acids, bases and solvents, electrical isolation, hydrophobicity, transparency, and a low permeability for gases and water. Hence, possible applications of parylene are the encapsulation of medical implants, MEMS and organic electronic devices as well as the usage of parylene as corrosion protection. Parylene coatings are produced by a CVD process within three steps: sublimation of dimer, pyrolysis and polymerization. In particular the deposition out of the gas phase at ambient temperature ensures highly conformal coatings without any internal stresses. At Fraunhofer ENAS competences for the deposition of different parylene types are established ensuring a high-quality level for its application in medical implants, MEMS and organic electronics.

4 Parylene Deposition Equipment Plasma Parylene LC 300 RW (Plasma Parylene Systems GmbH, Germany). (left); Functional LED on Board encapsulated and isolated by 3d conformal Parylene layer. (right)

Investigation of self-healing mechanisms for metallic materials

In the course of evolution, biological materials have developed to optimized systems with outstanding capabilities. One of their most impressive properties is the ability to regenerate. Human-made materials are far away from offering such opportunities. While there are few approaches of self-healing polymers and ceramics, the self-healing of metallic materials has been focused least in research until now.



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Within the Fraunhofer funded Discover project "healBOND" new approaches that can perspectively be the basis for self-healing metals are investigated. Both, a self-healing based on electroless metal deposition and on gallium-based alloying are addressed. In both parts the concept of a completely autonomous self-healing is pursued that takes place automatically inside the material in case of damage without any external activation. Self-healing of damages, e.g. micro-cracks, can enhance the reliability and lifetime of microsystems considerably. In applications like automotive, medical, aviation and space, reliability and lifetime of devices are of utmost importance. Typically, in such applications critical elements like heterogeneous material joints are designed with safety factors. In case of micro joints it basically means increasing the joint area and thus making the resulting device more expensive. With the ability of self-healing such joints can potentially be made smaller while still providing high lifetime and reliability.

Subwavelength structured reflectors for a tunable Fabry-Pérot filter

A novel tunable infrared filter with subwavelength gratings, which substitute the distributed Bragg reflectors in a former tunable Fabry-Pérot (FP) filter, was developed within a joint research project Nano3pt (BMBF funding). The FP resonator consists of a pair of parallel reflectors and of an air gap in between. Uniformly arranged disc resonators made of 100 nm thick aluminum at a 200 nm Si_3N_4 membrane carrier that stands freely after fabrication are building the reflector. The filter has an aperture of 2 mm. The upper reflector is movably suspended by a spring system and mechanically tuned by electrostatic forces with tuning voltages of up to 80 V. The currently fabricated filters can be tuned between 3 µm and 3.7 µm and show high peak transmittance between 55 % and 90 % and a wavelength bandwidth (FWHM) of 100 nm. Finite difference time domain analysis was applied for optimization of the dimensions of the subwavelength structures.
The fabrication of the disk resonator-based reflectors needs less effort in comparison to distributed Bragg reflectors. Since only two thin layers are used for each of the reflectors in comparison to multiple layers of higher thickness in case of DBR reflectors, less mechanical stress is introduced into the device. The planarity is enhanced and the roughness of the reflectors is reduced as a result. It opens the way toward tunable filters having large apertures with diameters of up to 10 mm.
Application perspectives are hyperspectral imaging, infrared spectral analysis and determination of concentration of substances in a great variety of fields in chemical engineering, energy and fuel production, and precision farming.

5 Microphotography of the FP filter chip and SEM view of a part of the reflector.

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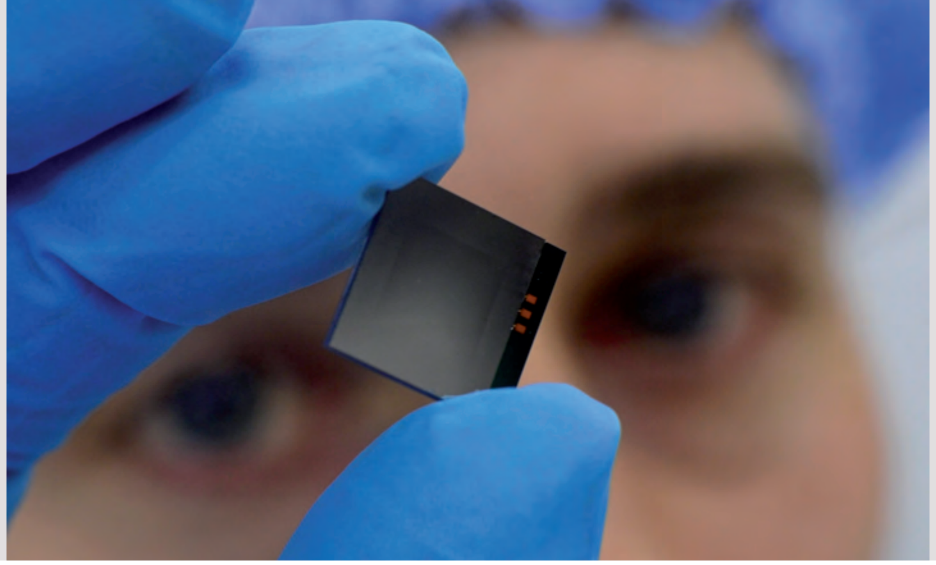

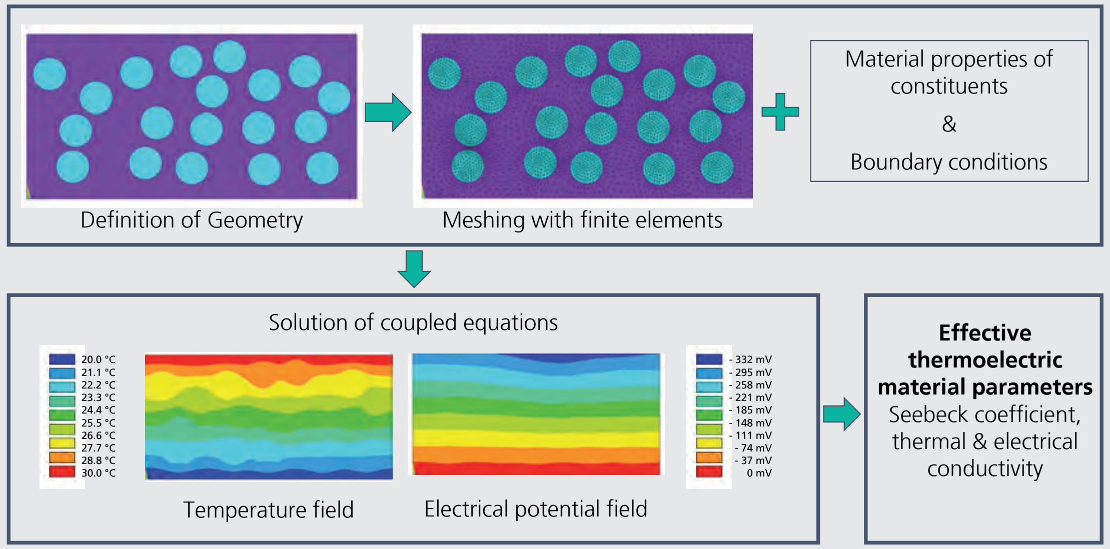

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Micro loudspeaker

The scientists at WPI-AIMR of Tohoku University Sendai and Fraunhofer ENAS in Chemnitz work together in the field of metallic glass. The scientists at Tohoku University have a deep knowledge of metallic glass which is the result of more than 20 years basic research in this field. The Gessner group at WPI-AIMR started to develop first MEMS-based on this knowledge.
As a result, Fraunhofer ENAS presented a MEMS loudspeaker with a membrane of metallic glass for the first time during the nanomicro biz 2015 from April 22 to 24 in Yokohama, Japan. The MEMS loudspeaker has the size of a fingernail and is manufactured in silicon microtechnology at wafer-level.
Nowadays, micro loudspeakers are part of all mobile electronic devices such as smart phones, tablets and laptops. This market is estimated to demand more than one billion microspeakers per year and is still growing. Analysts like IHS (iSupply) and Yole Developpément predict in their market studies that there are micro loudspeakers under development which will be on the market within the next years.
The loudspeaker can be manufactured in silicon-based MEMS technology. A thin layer of metallic glass is used as membrane of the MEMS speaker. Due to their amorphous micro structure, metallic glasses exhibit superior mechanical properties in comparison to crystalline materials. It can be deposited with standard microtechnology processes. In combination with dispensed magnetic paste and a micro coil, an electrodynamic actuator has been fabricated. The coil is manufactured in copper technology which has been developed by the Center for Microtechnologies of the TU Chemnitz.
A manufacturing of the speakers on silicon wafers can have distinctive advantages over conventional manufacturing, like high accuracy and reproducibility as well as low-cost batch processing and new packaging possibilities.

6 *The prototype of a MEMS loudspeaker is manufactured in silicon micro technology. It has a size of 12 x 12 x 0.8 mm.*
© Hendrik Schmidt

ENDOR – European network for the development of organic electric converters

The ENDOR project starting in 2013 aims to build up an interdisciplinary scientific network which targets the whole project development chain of organic and hybrid electric converters. Bringing scientists from material development, basic research, sensor design, and technology development together will lead the way to low-cost and flexible smart system solutions. Project partners from Sweden (Linköping University, ACREO AB), Poland (Lublin University, Warsaw University) and Germany (TU Chemnitz, Fraunhofer IWS, IAP and Rhine-Waal University of Applied Sciences) as well as associated partners from Cyprus and France focus mainly on thermoelectric and piezoelectric effects to develop self-sufficient sensors and systems for different applications in upcoming research projects.
International workshops and mobility periods of researchers enhance the strong interdisciplinary cooperation. Research associates from Chemnitz visited Linköping University working on the simulation of thermoelectric composites and the synthesis and experimental characterization of promising thermoelectric materials. A visiting scientist from Poland will further investigate these materials theoretically at Fraunhofer ENAS. The fruitful cooperation already resulted in the publication of first results on conferences and workshops. The network project is funded by the German Ministry of Education and Research (BMBF).

7 *Work flow – Calculation of effective thermoelectric material parameters of composites from finite element analysis (FEA).*

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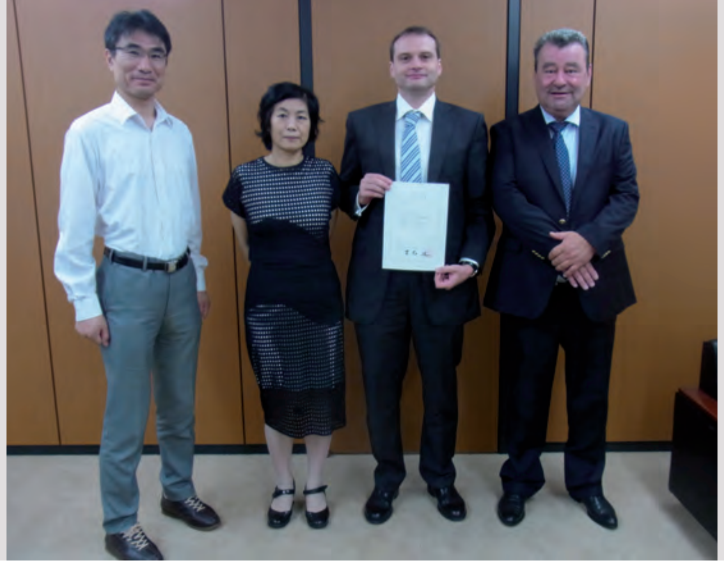

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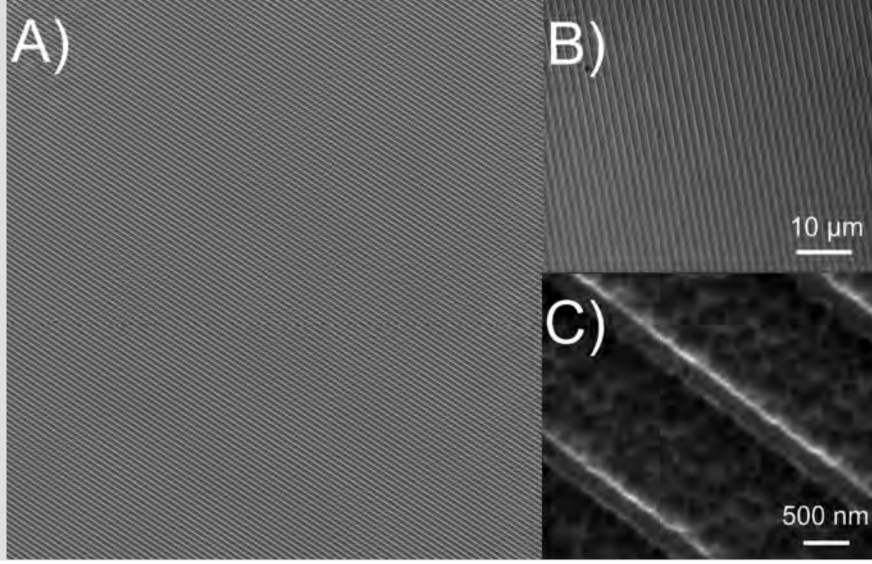


Successful cooperation of scientists of Fraunhofer ENAS and Center for Microtechnologies with the Tohoku University Sendai, Japan, in the field of micro-electromechanical systems

The Tohoku University in the megacity of Sendai belongs to the nine "World Premier International Research Centers" (WPI) chosen in Japan. The WPI is a project similar to the German Universities of Excellence program and it is supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology.
The World Premier International Research Center – Advanced Institute of Materials Research (WPI-AIMR) at the Tohoku University started to work accross faculties developing new materials and functional principles in October 2007. Professor Thomas Gessner, director of the Fraunhofer ENAS and of the Center for Microtechnologies at Technische Universität Chemnitz, is a principal investigator at the WPI-AIMR at Tohoku University. The Gessner group works in the field of NEMS/MEMS devices and micro/nano manufacturing technologies at the Tohoku University within the Shuji Tanaka-lab (the former Esashi-lab).
As from August 1, 2015, Dr. Jörg Frömel, former deputy head of the department System Packaging of Fraunhofer ENAS, was appointed Associate Professor at WPI-Advanced Institute for Materials Research of the Tohoku University Sendai, Japan. He received the certificate of appointment on August 4, 2015, from the hands of the director of WPI-AIMR, Professor Motoko Kotani.
The Gessner Laboratory is coexisting with the Fraunhofer Project Center "MEMS/NEMS Devices and Manufacturing Technologies at the Tohoku University". By order of Professor Gessner Assoc. Professor Frömel took over the local organization and direction of the Gessner group.
The main working fields of the Gessner group are:

- Acoustic micro actuators –- electromagnetically driven micro speakers that are cheaper and more energy-efficient than those produced by means of precision engineering
- Thermoelectric power generators – increase of efficiency by improving thermoelectric materials by exploiting nano effects
- Magnetic materials – deposition and structuring of magnetically hard and soft materials for use in MEMS

8 *Presentation of the certificate to Associate Professor Frömel (2nd from right) by Prof. Kotani (2nd from left) in the presence of Prof. Tanaka (left) and Prof. Gessner (right). (photograph: © Tohoku University)*

NEW EQUIPMENT

E-beam lithography

One of the key factors that drives semiconductor industries is the ability to fabricate more devices per area (wafer). In order to keep pace with current technology nodes and industry demands and to be able to do cutting-edge research, Fraunhofer ENAS established a Nanolithography group in 2014. The Nanolithography became operational in mid-2015 and comprises the following tools: a Vistec SB254 variable shaped electron beam lithography tool, a Jeol Scanning Electron Microscope (JSM-7800f) and a Sawatech semiautomatic resist track (spin coater, developer, hot and cool plate).

So far, the Nanolithography is working on projects from four different application fields related to micro and nano system technology: master fabrication for nanoimprint lithography, photonic structures, carbon nanotube integration and biological sensors. Due to the joint possibilities of the Nanolithography group and the process technologies available at Fraunhofer ENAS, we were able to attract new external project partners in Saxony and Europe. Initial results of the group were presented at the Electron Beam workshop at Fraunhofer ENAS as well as at the Fraunhofer Symposium in Sendai, Japan, both held in November 2015.

1 *SEM images of a nano imprint stamp patterned by electron beam lithography on a 6 inch wafer with a linewidth of 200 nm – A) overview; B) magnified by a factor of 2000; C) magnified by a factor of 40,000.*

Semiautomatic electrochemical deposition unit

The department System Packaging of Fraunhofer ENAS is working and researching in the field of MEMS packaging and wafer bonding in well-equipped laboratories and cleanrooms. The reactive bonding is already known as an innovative wafer bonding method. For the research and development of this bonding process, but also for the deposition of different functional or conductive and solder layers, the new equipment can be used and combines several functions. The primary functionality of the equipment is the deposition of nanoscale (multi-)layers onto different substrates of microsystems technology and microelectronics. The equipment can automatically electrochemically deposit metallic materials within the nanoscale from two aqueous solutions. To ensure future applications in nanotechnology, the equipment is able to deposit single layers but also multilayers with more than 200 single layers. The individual layers can be in situ deposited onto substrates up to 8 inch in diameter. Furthermore, the equipment includes two wet etching solutions baths for the patterning of metallic coatings.

2 *The semiautomatic electrochemical deposition unit. (photo on page 35)*

Advanced mechanical characterization on micro and nanoscale

As miniaturization and complexity of components increases, especially in the electronics sector, new localized mechanical characterization methods denote an increasing demand. Thanks to its very small probe dimension, nanoindenters are versatile tools for material and device characterization. In addition to well-established hardness and elastic modulus measurements, nanointender equipment offers various other test opportunities such as scratch and wear tests, miniaturized loading tests for device failure analysis as well as dynamic or continuous stiffness measurement. Surface profiles can be obtained by tactile measuring in order to accurately place the penetration tip on a complex component. Taking into account needs for testing at elevated temperatures, a highlight of our machine (Agilent G200) is its temperature stage (usable in the range: −40 to 160 °C) allowing us to determine elastic properties of materials as a function of temperatures. Moreover, a heating solution utilizing a laser to control the temperature of a specially designed indenter tip and the sample as well extends the temperature range up to 500 °C.
Dynamic stiffness measurement associated with the thermal chamber enables the determination of the temperature dependent storage and loss modulus of polymer films and thus their viscoelastic behavior. Combining measurements with finite element simulations of the indentation process, the access can be given to more complex material behavior, e.g. elastic-plastic material properties and parameters for damage mechanics can be evaluated.
In summary, the nanoindenter offers a broad range of material characterization methods allowing gaining material parameters especially when it is not possible to obtain them from macro samples.

3 *Cracked polysilicon test membrane after loading in the nanoindenter.*

DISSERTATIONS

Dissertations in 2015

February 6, 2015

PhD:	Mario Baum
Topic:	Strukturierungs- und Aufbautechnologien von 3-dimensional integrierten fluidischen Mikrosystemen
Institution:	Technische Universität Chemnitz

May 5, 2015

PhD:	Jörg Frömel
Topic:	Gallium-based Solid Liquid Interdiffusion Bonding of Semiconductor Substrates near room temperature
Institution:	Technische Universität Chemnitz

May 19, 2015

PhD:	Jinji Luo-Hofmann
Topic:	Investigation of Polymer Based Materials in Thermoelectric Applications
Institution:	Technische Universität Chemnitz

October 5, 2015

PhD:	Quan Wen
Topic:	A Novel Micro Fluid Kinetic Energy Harvester Based on the Vortex-Induced Vibration Principle and the Piezo Effect
Institution:	Technische Universität Chemnitz

December 21, 2015

PhD:	Patrick Matthes
Topic:	Magnetic and Magneto-Transport Properties of Hard Magnetic Thin Film Systems
Institution:	Technische Universität Chemnitz

AWARDS

IEEE Andrew S. Grove Award

The director of the Fraunhofer Project Center "NEMS/MEMS Devices and Manufacturing Technologies at Tohoku University", Principal Investigator of the World Premier International Research Center Advanced Institute for Materials Research (WPI-AIMR) and director of the Micro System Integration Center (µSIC) at Tohoku University – Professor Masayoshi Esashi – has been honored with the IEEE Andrew S. Grove Award in 2015. He received the medal at the 28th IEEE International Conference on Micro Electro Mechanical Systems in Estoril, Portugal, taking place January 18–22, 2015.

Silver Fraunhofer Needle

Appreciating the work of the chairman of the Fraunhofer ENAS Advisory Board Professor Udo Bechtloff, the president of the Fraunhofer-Gesellschaft Professor Reimund Neugebauer adorned him with the silver Fraunhofer needle.

1 Prof. Dr. Reimund Neugebauer (left), president of the Fraunhofer Gesellschaft, congratulated Prof. Dr. Udo Bechtloff (right) to the Silver Fraunhofer Needle. (photo © Fraunhofer Gesellschaft)

Fellow of IS&T

In 2015, Professor Baumann was awarded with the Fellow status of the Society for Imaging Science and Technology IS&T by Goeff J. Woolfe (Canon Information Systems Research Australia Pty Ltd.).

Research Award 2015 of Fraunhofer ENAS

Dr.-Ing. Roman Forke was honored with the Fraunhofer ENAS Research Award 2015. He received the award for his excellent scientific work in developing MEMS design and systems for high-precision inertial sensors. The director of Fraunhofer ENAS, Professor Thomas Gessner, awarded the prize. National and international guests as well as Fraunhofer ENAS staff took part in the ceremony in Chemnitz on December 17, 2015.

2 Prof. Dr. Thomas Geßner (left) awarded the Fraunhofer ENAS Research Award 2015 to Dr. Roman Forke (middle). The chair woman of the research award board, Prof. Dr. Karla Hiller (right), presented the ceremony.

Outstanding Paper Award of Emerald Literati Network

Every year Emerald Group Publishing awards excellent papers published. The 2015 outstanding paper award of the journal Soldering & Surface Mount Technology was handed over to Dr. Rainer Dudek for the paper "Reliability investigations for high temperature interconnects", published in volume 26. Co-authors are Andreas Fix, Joerg Trodler, Dr. Johann-Peter Sommer, Professor Bernd Michel and Professor Sven Rzepka. [Dudek, R.; Sommer, P.; Fix, A.; Trodler, J.; Rzepka, S.; Michel, B.: Reliability Investigations for High Temperature Interconnects. Soldering & Surface Mount Technology 26/1, 2014, pp 27-36]

Best Paper Award at Therminic

Mohamad Abo Ras got the best paper award for his paper "LaTIMA – an innovative test stand for thermal and electrical characterization of highly conductive metals, die attach, and substrate materials" at the 21st International Workshop on Thermal Investigation of ICs and Systems THERMINIC 2015 in Paris.

Best Paper of Conference Award at International Wafer-Level Packaging Conference 2015 in San Jose

The paper "3D wafer level packaging by using Cu-through silicon vias for thin MEMS accelerometer packages" has won the most prestigious best paper of conference award for the IWLPC 2015 in San Jose, USA. Lutz Hofmann, Dr. Danny Reuter, Ina Schubert, Dirk Wünsch, Michael Rennau, Dr. Ramona Ecke, Klaus Vogel, Dr. Knut Gottfried, Professor Stefan Schulz and Professor Thomas Gessner are authors of this paper.

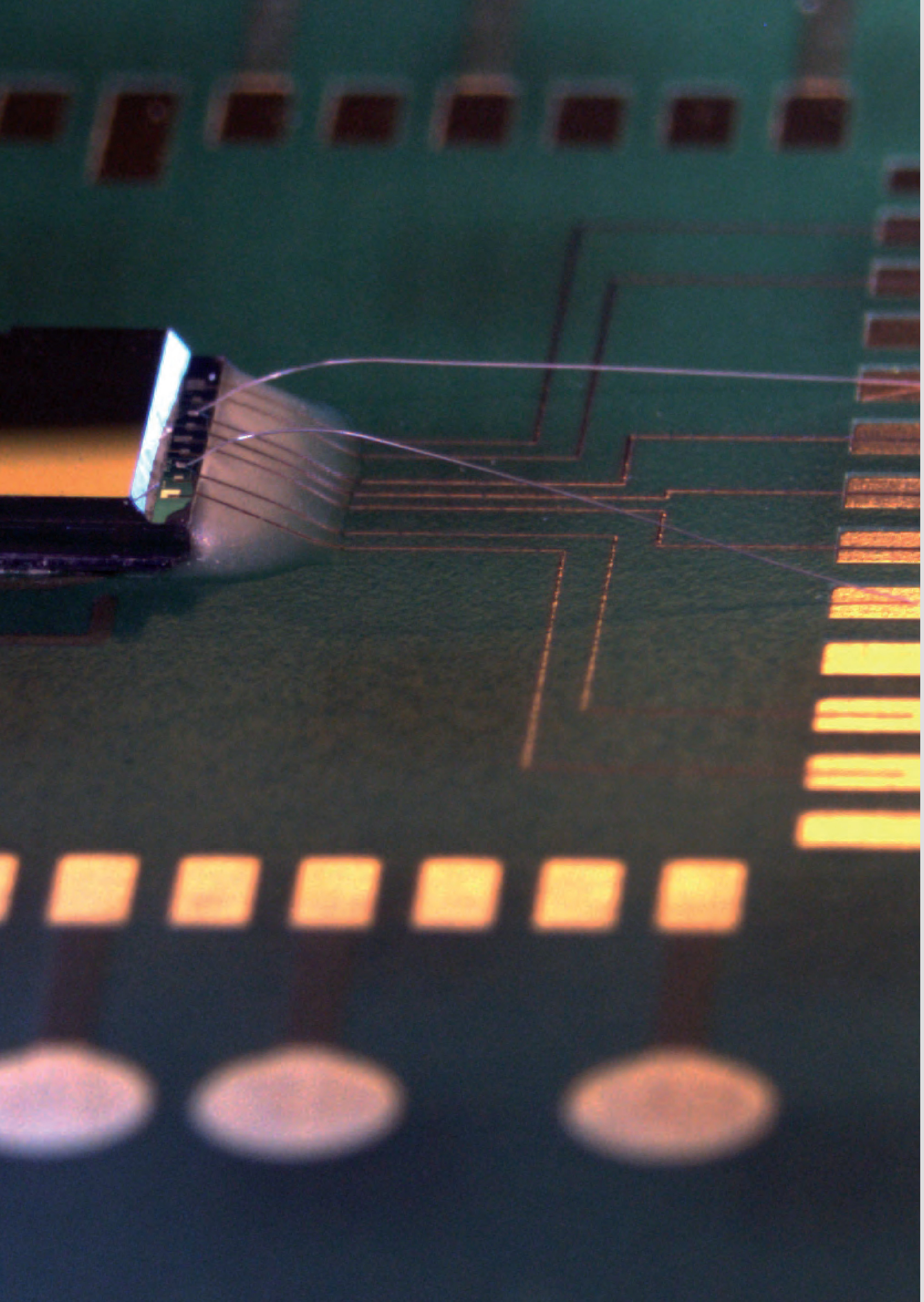
Leonore Dießner Prize

The Technische Universität Chemnitz awards the best female students in natural science and engineering science after finishing their master or diploma thesis. Nicole Köhler was honored with the Leonore Dießner Prize 2015. She did her master thesis at Fraunhofer ENAS and does now belong to our staff.

Best apprentice

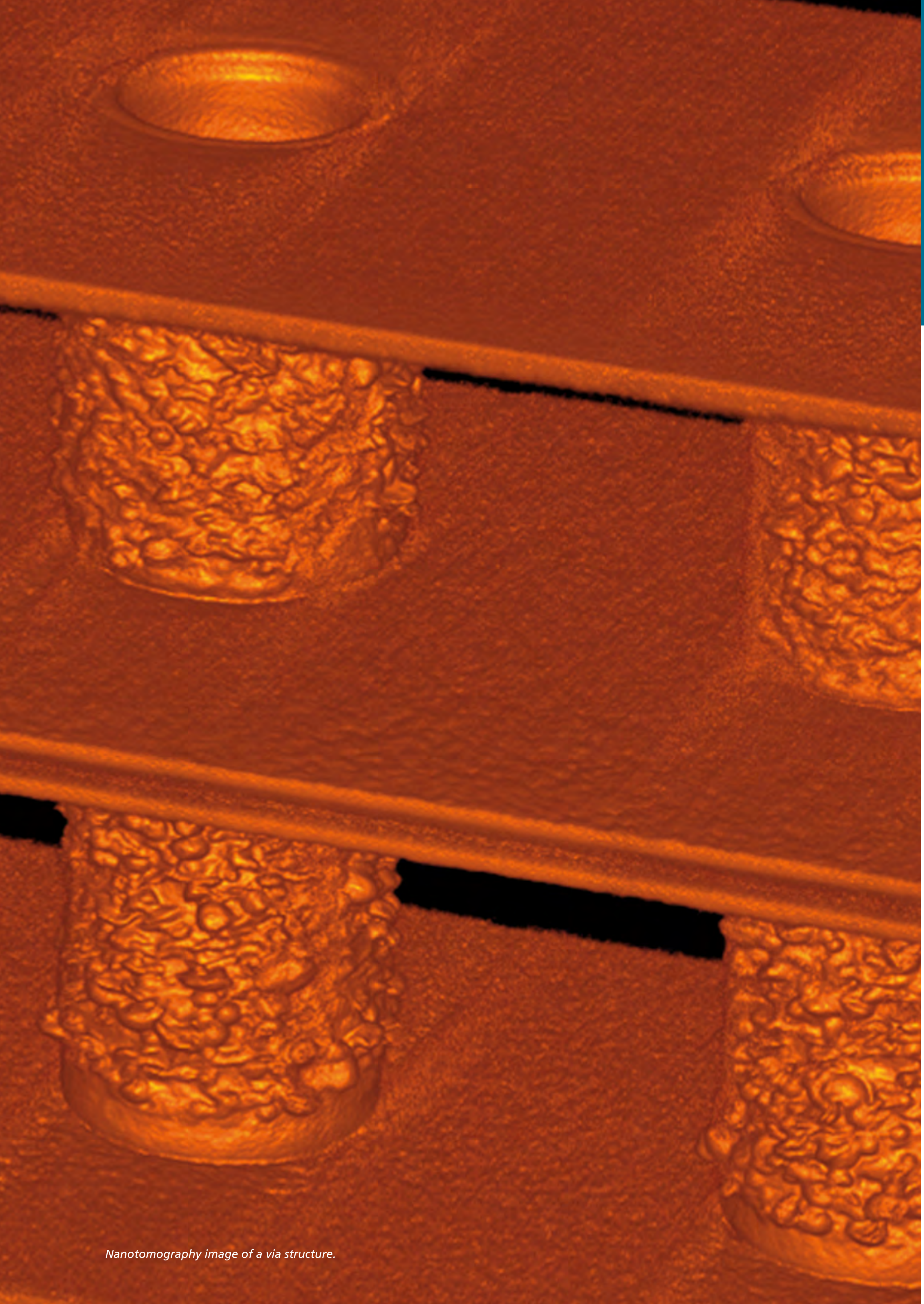
Every year the Fraunhofer-Gesellschaft awards the best apprentices. In 2015 Celina Kopiniok finished her vocational training not only within a shorter time but also with very good results. In November 2015 she was honored as one the best apprentices in the Fraunhofer-Gesellschaft.

3 Prof. Dr. Alexander Kurz (left), Executive Vice President Human Resources, Legal Affairs and IP Management honored Celina Kopiniok (middle) and her instructor Maik Reimann (right) as one of the best apprentices in the Fraunhofer-Gesellschaft. (photo © Fraunhofer-Gesellschaft)



RESEARCH REPORTS

The acceleration sensor mounted on top of the FR4 testboard was connected by aerosol jet technology and classic wire bonding. Wire bonding was chosen for two contacts as printed connections would cause short circuits due to cross contacts. Line widths for printed silver nano particle contacts was set at approx. 25 µm.



Nanotomography image of a via structure.

MICRO AND NANOELECTRONICS

Micro and nanoelectronics are still a key technology of the 21st century. It is not just about reducing the structural sizes, so-called downscaling, it is also about integrating additional functions (More-than-Moore) and new concepts in the framework of Beyond CMOS. Fraunhofer ENAS addresses the following topics:

- Materials, processes, technologies for micro and nanoelectronics
- 3D integration of electronics and sensors
- Modeling and simulation of technological processes and equipment, interconnect systems, field effect transistors, and mixed-signal systems
- Characterization and reliability evaluation of BEOL components through to chip-package interaction.

In the 2015 annual report, five topics are introduced in detail.

The first article is dedicated to the technological realization of field effect transistors on the basis of integrated carbon nanotubes for analog high-frequency applications. This work is driven forward in the cluster of excellence cfaed.

The second article is dedicated to the increasing requirement of smooth, homogeneous and extremely thin layers. It provides an overview of the simulation results on the reactor scale for process development and optimization of atomic layer deposition.

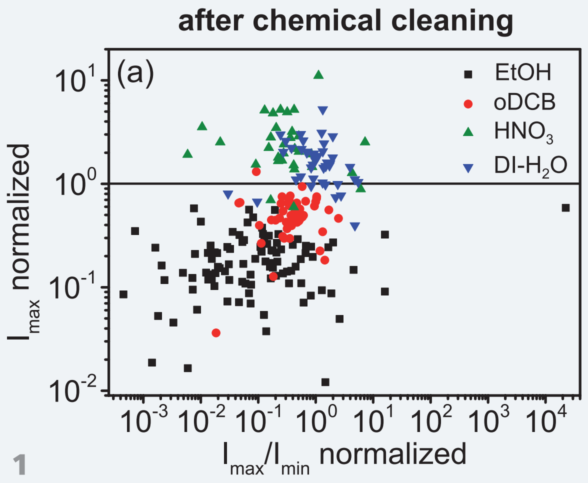
When packaging integrated circuits, efficient heat dissipation is significant. The third article includes results from the development of a sequential process flow for the generation of an underfiller capable of conduct high levels of heat.

The fourth and fifth articles focus on experimental procedures in the field of reliability evaluations of components and systems. A newly-developed optical measuring device is presented which allows a precise analysis of the deformation down to the nanometer range for temperatures between –80 °C to 400 °C. In addition, the results from the application of the FIB (Focused Ion Beam) for measuring intrinsic stress are illustrated.

Die Mikro- und Nanoelektronik ist nach wie vor eine der Schlüsseltechnologien des 21. Jahrhunderts. Dabei geht es nicht allein um die weitere Verringerung der Strukturgrößen, das sogenannte Downscaling, sondern auch um die Integration zusätzlicher Funktionalitäten (More-than-Moore) sowie neue Konzepte im Rahmen Beyond CMOS. Das Fraunhofer ENAS adressiert dabei folgende Themen:

- Materialien, Prozesse, Technologien für die Mikro- und Nanoelektronik
- 3D-Integration von Elektronik und Sensorik
- Modellierung und Simulation von technologischen Prozessen und Ausrüstungen, Interconnect-Systemen, Feldeffekttransistoren sowie Mixed-Signal-Systemen
- Charakterisierung und Zuverlässigkeitsbewertung von BEOL-Komponenten bis hin zur Chip-Package-Wechselwirkung.

Im Jahresbericht 2015 werden fünf Themen detailliert vorgestellt.
Der erste Artikel widmet sich der technologischen Realisierung von Feldeffekttransistoren auf Basis integrierter Kohlenstoffnanoröhren für analoge Hochfrequenzanwendungen. Diese Arbeiten werden im Exzellenzcluster cfaed vorangetrieben.
Der zweite Artikel trägt dem steigenden Bedarf an gleichmäßigen, homogenen und extrem dünnen Schichten Rechnung. Er veranschaulicht Simulationsergebnisse auf der Reaktorskala für die Prozessentwicklung und -optimierung der Atomlagenabscheidung.
Beim Packaging integrierter Schaltkreise ist die effiziente Wärmeabführung von Bedeutung. Der dritte Artikel enthält Ergebnisse der Entwicklung eines sequentiellen Prozessflusses für die Erzeugung eines hochwärmeleitfähigen Underfillers.
Der vierte und fünfte Artikel stellen experimentelle Verfahren im Bereich der Zuverlässigkeitsbewertung von Komponenten und Systemen in den Mittelpunkt. Vorgestellt wird eine neuentwickelte optische Messeinrichtung, die eine präzise Verformungsanalyse bis in den Nanometerbereich für Temperaturen zwischen –80 °C bis 400 °C ermöglicht. Darüber hinaus werden Ergebnisse der Anwendung des FIB (Focused Ion Beam) für die Messung intrinsischer Spannungen dargestellt.



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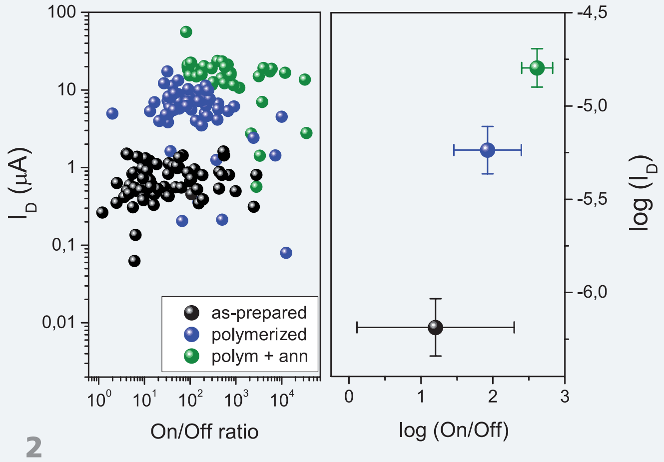

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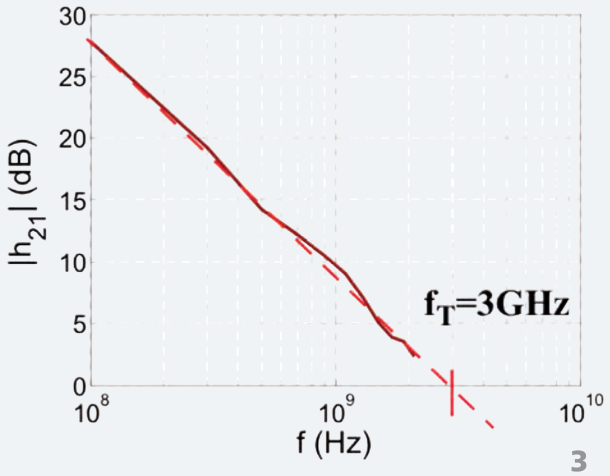

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TECHNOLOGY DEVELOPMENT FOR ANALOG HIGH-FREQUENCY CNT-FETS

Sascha Hermann, Martin Hartmann, Jana Tittmann-Otto, Marius Toader, Stefan E. Schulz

Within the Cluster of Excellence "Center for advancing electronics Dresden (cfaed)" the Carbon Nano Devices group at the Center for Microtechnologies and Fraunhofer ENAS develops the technology for analog field-effect transistors (FETs) based on carbon nanotubes (CNTs). Applying a dielectrophoretic approach, arrays with individually addressable FETs were prepared using standard silicon technology on 150 mm wafers, thus enabaling statistic evaluation of different aspects of CNT transistor fabrication.

Since dielectrophoresis is a liquid-based technique where surfactants are involved to maintain a stable dispersion, it is of crucial importance to examine their influence on electrical properties of FETs. Considering that surfactant molecules are potential charge-traps, four different approaches for cleaning of FETs were investigated by means of statistical studies on more than 600 CNT-FETs [1]. From combined XPS, Raman spectroscopy, and electrical studies it turned out that especially DI-H_2O and HNO_3 treatment appeared to be most effective for removal of surfactant residuals. Thereby, especially HNO_3 treatment significantly improved the on-current as well. Equally, there was a significant influence of a subsequent annealing treatment apparent which significantly affects hysteresis behavior and reduces the device-to-device variance.

Beside the presence of surfactants, CNTs can agglomerate into bundles during the assembly. This could lower the maximal current and reduce the transistor operation frequency. Therefore, alternative approaches toward enhancing the individualization of nanotubes by polymerization after integration were investigated and shall represent a milestone in improving the FET characteristics [2]. We used a styrene-sulfonic acid sodium salt (NaSS) in the so-called self-initiated photografting and photopolymerization (SIPGP) process. We report improved device-to-device consistency, lower variability in the threshold voltage (V_{th}), higher on/off ratios and drain currents (see Fig. 2). Moreover, subsequent vacuum annealing was found to induce ambipolar behavior, which could be conserved upon long-term storage under ambient conditions.

Contact:
Prof. Stefan E. Schulz
phone: +49 371 45001-232
e-mail: stefan.schulz@enas.fraunhofer.de

Dr. Sascha Hermann
phone: +49 371 45001-292
e-mail: sascha.hermann@enas.fraunhofer.de

Furthermore, FETs in a special high-frequency layout were fabricated on 6 inch wafers. To minimize parasitic capacitances a local and embedded bottom gate has been realized by damascene technology. A large amount of parallel aligned CNTs has been assembled on comb electrode structures to enable high transistor currents which are required at high-frequency operation. Extended electrical characterization [3] on the first HF-FET generations, which used 50 nm SiO_2 gate dielectric and 0.8 µm channel length, operated already at a transit frequency of up to 3 GHz (Fig. 3). Ongoing work is focusing on higher device performance by shrinkage of device dimensions, integration of high-k gate dielectrics and technology optimization.

References

[1] Tittmann-Otto, J.; Hermann, S.; Kalbacova, J.; et al.: Effect of cleaning procedures on the electrical properties of carbon nanotube transistors – a statistical study. J. Appl. Phys. (submitted)

[2] Toader, M.; Hermann, S.; Schubel, R.; Hartmann, M.; et al.: Enhanced performance in SWCNT-based FETs via direct synthesis of poly (sodium 4-styrenesulfonate) in the FET channel. Appl. Phys. Lett. (submitted)

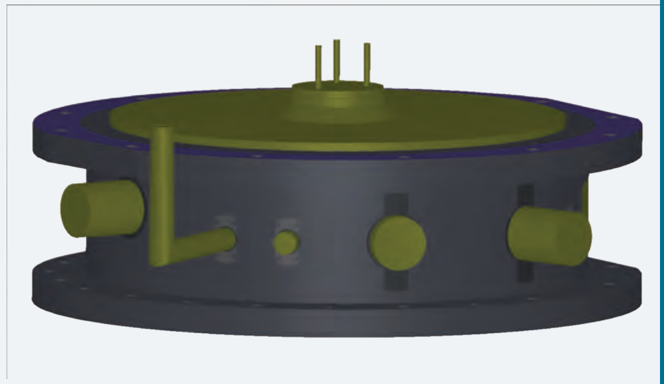
[3] Haferlach, M.; Claus, M.; Pacheco, A.; et al.: Electrical characterization of emerging transistor technologies: issues and challenges. IEEE Trans. on Nanotechnology, 2016. (submitted)

Als Projektpartner im Exzellenz-Cluster cfaed ist die Gruppe „Carbon Nano Devices" mit der technologischen Realisierung von Feldeffekt-Transistoren mit integrierten Kohlenstoffnanoröhren für analoge Hochfrequenzanwendungen betraut. Unter Nutzung von mikrotechnologischen Prozessen und des in der Gruppe weiterentwickelten Dielektrophorese-Verfahrens, wurden systematische Studien zum Einfluss verschiedener Prozessparameter bei der Fertigung von CNT-Transistoren auf Waferebene durchgeführt. So zeigte zum Beispiel ein systematischer Vergleich verschiedener Nachbehandlungsprozeduren, dass eine HNO_3-Behandlung entscheidende FET-Eigenschaften verbessert. Darüber hinaus wird das Problem der CNT-Bündelbildung in FET-Kanälen adressiert. In Zusammenarbeit mit cfaed-Partnern an der TU Dresden wurde ein neuartiges Nachbehandlungsverfahren auf Basis der Photopolymerisation untersucht. Es zeigte sich eine signifikante Verbesserung des Schaltverhaltens der FETs. Auch bei der Fertigung von Hochfrequenztransistoren konnte ein großer Fortschritt erzielt und eine Transitfrequenz von bis zu 3 GHz demonstriert werden.

1 *Comparison of the normalized maximum current and normalized maximum/minimum current ratio after different cleaning procedures. Data were normalized by dividing the values after treatment by the values of the preceding state. Approx. 150 transfer characteristics per cleaning procedure were evaluated.*

2 *The measured (left) and representative values (right) for the on/off ratio and I_D obtained for multiple (approx. 70) devices.*

3 *Current gain over frequency for V_{DS} = 4 V.*



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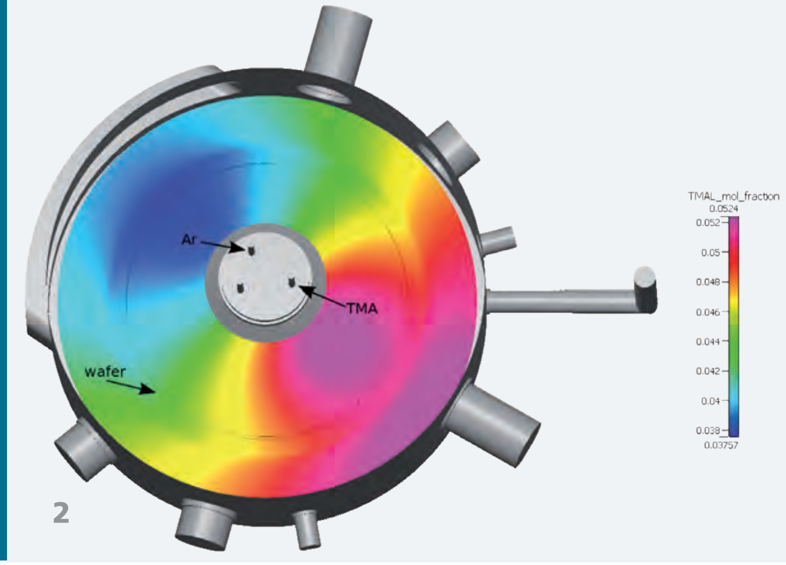

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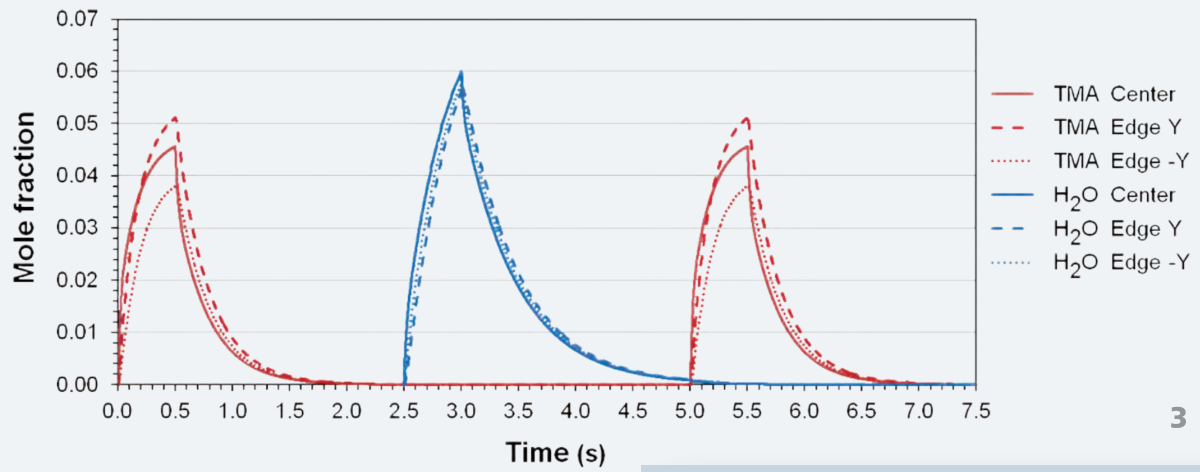

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REACTOR SCALE SIMULATION OF ALD PROCESSES

Linda Jäckel, Hermann Wolf

The progressive downscaling of microelectronic devices leads to an increasing demand for deposition technologies which can produce uniform, homogenous and ultrathin layers. Atomic layer deposition (ALD) has the capabilities to produce such layers even in features with high aspect ratio. The quality of the resulting layers from ALD processes depends strongly on the used process parameters. Important parameters are surface temperature, process pressure, inflow conditions, dosing, and purging times. At the Fraunhofer ENAS we use computational fluid dynamics which simulate the ALD process on the reactor scale to analyze and optimize the parameter influence.

Capabilities of reactor scale simulation

Reactor scale simulations are based on solving conservation equations for mass, momentum, energy, and species. To solve the resulting system of equations it is necessary to supply initial and boundary conditions. Furthermore, information about reactor geometry, flow physics, thermodynamic and transport properties of all fluid species and surface reactions are required. The flow physics in a reactor is complex, therefore a fine discretization in space and time is required. Since the resulting number of cells can become very large, reactor scale simulations are often computationally expensive. Therefore, parallel simulations are performed using high-performance clusters.

Results from reactor scale simulations contain information about flow field, pressure, temperature, and precursor distribution. Transient simulations reveal how the precursor gets distributed in the reactor over time. This helps us to identify regions or corners where the precursor gas gets stuck due to recirculation or to judge whether or not a shower head is configured correctly. Transient simulations also yield information about time scales. This shows us how fast a precursor is distributed and purged and allows us to define minimal process times for dosing and purging steps.

Contact:
Prof. Stefan E. Schulz
phone: +49 371 45001-232
e-mail: stefan.schulz@enas.fraunhofer.de

Dr. Jörg Schuster
phone: +49 371 45001-286
e-mail: joerg.schuster@enas.fraunhofer.de

Application of reactor scale simulation - AL_2O_3 ALD

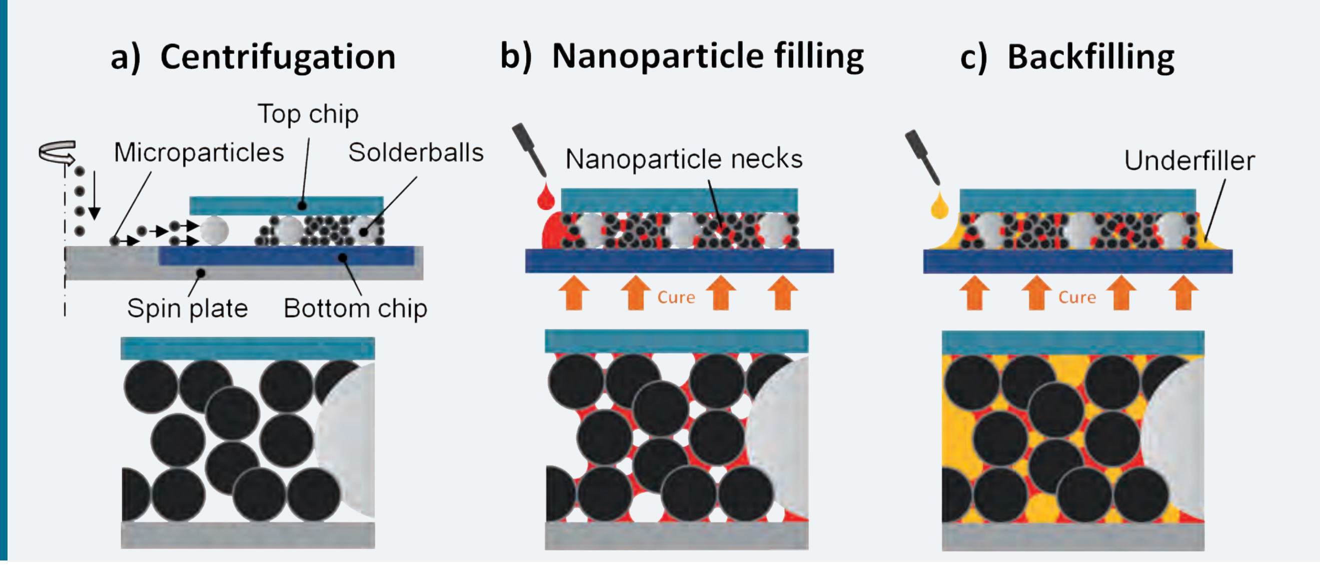
We investigated an Al_2O_3 ALD process using trimethylaluminum (TMA) and water. Experiments showed nonuniform Al_2O_3 deposition for this process. Therefor we used a reactor scale simulation to evaluate the purge time efficiency. In this investigation surface reactions were omitted as the reactor fluid dynamics was the key interest. A single wafer reactor was used (Fig. 1). The precursor and co-reactant inlets are arranged in an eccentric fashion at the top of the reactor. This leads to a nonuniform precursor distribution in the ALD reactor (Fig. 2). To evaluate the efficiency of the purging steps a transient analysis was conducted. The transient analysis of this ALD process showed that the chosen purging times of 2 s are sufficient (Fig. 3). As a result we concluded that the chosen purging times are not the reason for the nonuniform ALD process.

Reactor scale simulations are a useful instrument in understanding ALD reactor flow. Simulation results help us to understand the complex gas flow much better than experimental observations could. Reactor scale simulations show regions where optimization is possible and can also explain nonoptimal ALD results like nonuniform deposition or a low growth per cycle. Especially in developing new ALD processes reactor scale simulations are a key tool.

Die fortschreitende Miniaturisierung mikroelektronischer Bauteile führt zu einer steigenden Nachfrage nach Abscheideverfahren zur Erzeugung von gleichmäßigen, homogenen und extrem dünnen Schichten. Die Atomlagenabscheidung (ALD) besitzt die Fähigkeit zur Abscheidung dieser Schichten. Die Qualität der resultierenden Schichten hängt stark von den gewählten Prozessparametern wie Oberflächentemperatur, Prozessdruck, Einströmungsparameter der Gase, Dosierungs- und Spülzeiten ab. Der Einfluss dieser Parameter kann mithilfe von numerischer Strömungssimulation auf der Reaktorskala theoretisch untersucht werden.

Simulationen auf der Reaktorskala sind ein wertvolles Werkzeug zur Analyse von ALD-Prozessen. Als Ergebnis liefern diese Simulationen Informationen zum sich einstellenden Strömungsfeld, dem Druck und der Precursorverteilung im Reaktor. Anhand der Simulationsergebnisse ist es möglich, Optimierungsmöglichkeiten aufzuzeigen. Instationäre Simulationen erlauben darüber hinaus die Bewertung der Effizienz der Dosier- und Spülschritte. Besonders in der ALD-Prozessentwicklung spielen Simulationen auf der Reaktorskala eine wichtige Rolle und können die experimentelle Entwicklung unterstützen.

1 *Investigated ALD reactor geometry.*
2 *Precursor concentration above the wafer surface after the 0.5 s TMA dosing step shows nonuniform precursor distribution due to eccentric inlet position.*
3 *Precursor concentrations over one ALD cycle above the wafer surface.*



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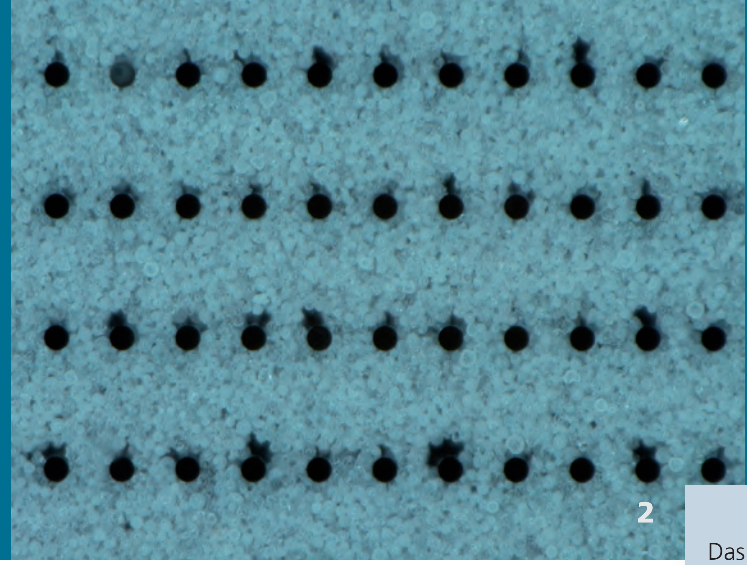

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HYPERCONNECT: SELF-ASSEMBLY OF MICRO AND NANOPARTICLES BY CENTRIFUGAL FORCES AND CAPILLARY BRIDGING FOR 3D THERMAL INTERCONNECTS

Christian Hofmann, Mario Baum, Wei-Shan Wang, Maik Wiemer

Efficient heat dissipation is of major importance in advanced packages of high-performance integrated circuits (ICs). To ensure and extend the integration density, 3D chip stacking with multiple silicon dies vertically arranged on each other is indispensable. However, these packages require an enhanced thermal management in order to dissipate the heat from each stacked die to the heat sink. Therefore, a highly thermal conductive underfill material is essential to affect the thermal resistance of the entire chip stack significantly. Due to the average thermal conductivities of commercially available capillary underfills of ≤ 0.8 $Wm^{-1}K^{-1}$, traditionally used to relieve mechanical stress from solder balls in flip-chip packages, they are not sufficient for high-performance 3D chip stacks.

The HyperConnect project was a 36 months EU cooperative research project finished in 2015, funded by the European Commission under the 7th Framework Programme (FP7) in the area of nanosciences, nanotechnologies, materials, and new production technologies (NMP) under Grant Agreement no. FP7-NMP-310420. At least 10 partners from Europe were contributing to that project (among others: IBM Research GmbH, Switzerland; Stiftelsen Sintef, Norway; Fraunhofer ENAS, Germany; Technische Universität Chemnitz, Germany).

The goal of the research work was to develop a sequential process flow for an advanced concept of percolating thermal underfill (PTU) using the self-assembly of micro and nanoparticles. Due to the connection of the contact points in a micron-sized particle bed by using nano-sized compound material, a highly percolated network with increased thermal conductive paths was investigated. It was already demonstrated, that the resulting composite material allows thermal conductivities up to 3.8 $Wm^{-1}K^{-1}$ [1].

The research work of Fraunhofer ENAS was focused on three main process steps, the centrifugal filling of microparticles into a defined silicon cavity and under a chip-on-board sample to form a percolating particle bed, the self-assembly of nanoparticles around the spherical contact surfaces by capillary bridging (so-called neck formation) and the backfilling of the formed particle network with an unfilled capillary epoxy. Figure 1 shows the process flow.

Contact:

Dr. Maik Wiemer

phone: +49 371 45001-233

e-mail: maik.wiemer@enas.fraunhofer.de

Dr. Mario Baum

phone: +49 371 45001-261

e-mail: mario.baum@enas.fraunhofer.de

For the centrifugal filling silica and alumina spheres with diameters ranging from 27 to 30 µm resp. 25 to 36 µm, dispensed into a rotating filling disk, were investigated. As a replacement of the solder ball contacts within a chip stack, fabricated silicon dies with different pillar layouts were filled with microparticles. The fill fraction, fill front, packing structure, and occurred defects dependent on the rotational speed were studied. Especially, an empty space in the particle bed behind the pillars in fill direction (referred to as "shadowing") appeared as a defect (Fig. 2) [2].

It could be shown how processing aspects did influence the neck formation by capillary bridges between the microparticles. For the initial experiments, metal-based nanoparticle inks were assembled into the contact points of the micron-sized spheres, directed by capillary force during drying. The concentration of the nanoparticle suspension as well as drying and sintering temperatures and times were tested experimentally. In addition, further defects in terms of microparticle rearrangements, voids and air inclusions were examined for different solvents und nanoparticle inks. Finally, the formed particle network is stabilized with a two-component epoxy system (Fig. 3).

The authors would like to thank the colleagues of IBM Research GMBH, Switzerland for their valuable support in experiments, fabrication and characterization. In addition, we would like to thank Kerry Yu from Intrinsiq Materials Inc. for providing the copper nanoparticle ink as well as Albert Aachen from Lord GmbH for the formulation and modification of epoxy matrix material with a low viscosity.

Das Projekt HyperConnect war ein 36-monatiges europäisches Verbundprojekt, das Ende 2015 erfolgreich abgeschlossen wurde. Es wurde von der Europäischen Kommission im 7. Rahmenprogramm im Bereich der Nanowissenschaften, Nanotechnologien, Materialien und Fertigungstechnologien unter der Vertragsnummer FP7-NMP-310420 gefördert. Mit insgesamt 10 Partnern wurde intensiv an neuen Materialien, Prinzipien und Technologien für weiterentwickelte kapillare Underfiller geforscht.

Das Ziel des Forschungsprojektes war es, einen sequenziellen Prozessfluss für die Erzeugung eines hochwärmeleitfähigen Underfillers zu entwickeln. Die wesentliche Forschungsarbeit des Fraunhofer ENAS fokussierte sich dabei auf drei Hauptprozessschritte, beginnend mit dem Füllen von Mikropartikeln in eine definierte Siliziumkavität zwischen Chip und Substrat, welches mit Hilfe einer Zentrifuge erreicht werden konnte. Weiterhin konnte mittels Nanopartikel-Tinten und kapillarer Brückenbildung eine Ausbildung von „Hälsen" zwischen den Mikropartikeln erzeugt werden. Abschließend wurde eine speziell entwickelte Underfill-Matrix kapillarisch in das bereits bestehende Netzwerk aus Mikro- und Nanopartikeln gefüllt. Nach Beendigung des Projektes konnte eine fünffache Verbesserung der Wärmeleitfähigkeit gegenüber handelsüblichen thermischen Underfills gezeigt werden.

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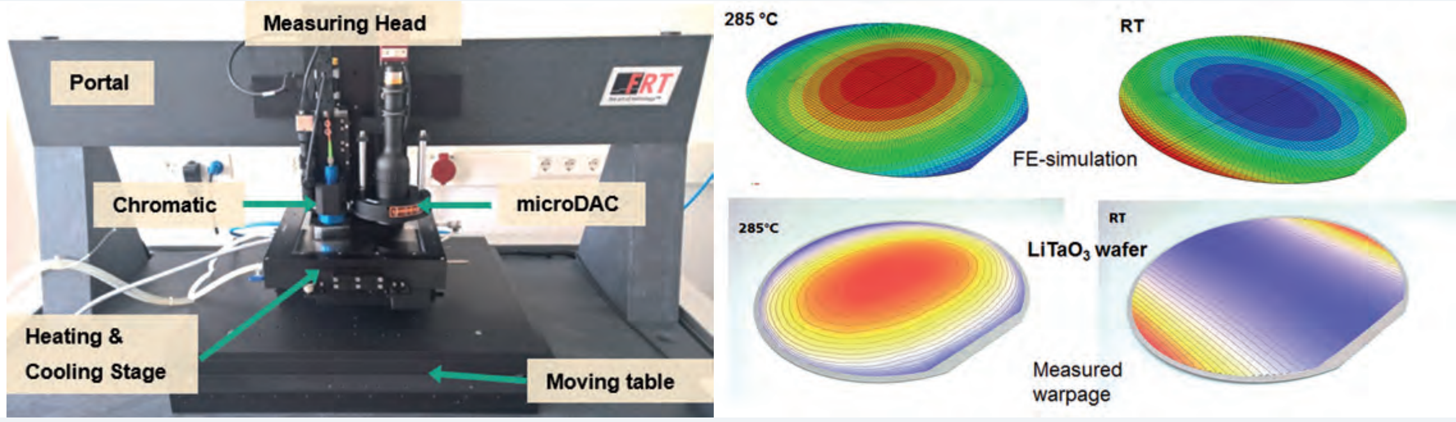
1 *Main process steps to achieve the percolating thermal underfill (PTU).*

2 *Microscope image of a filled chip cavity with Al_2O_3 particles in the size range of 25 to 36 µm with the shadowing effect behind the silicon pillars.*

3 *SEM images of the particle network and necks formed by capillary-bridging.*



1

HIGH-PRECISION DEFORMATION MEASUREMENTS IN MULTI-SCALE APPLICATIONS – A VERIFICATION METHODOLOGY FOR SIMULATION-BASED RELIABILITY PREDICTIONS

Rainer Dudek, Marcus Hildebrandt, Ellen Auerswald, Sven Rzepka

Electronics reliability and robustness remain in the focus of research

Highly integrated smart systems use in harsh environments remains one of the major trends. Many added functionalities require power and high-power features (e-mobility, direct machine control, energy generation and distribution,…). Hence, the thermo-electromechanical reliability risks will be increased further as compared to the level of today's smart systems. Another trend is to increase the level of heterogeneity in smart systems integration.

Increased system complexity requires sophisticated modeling

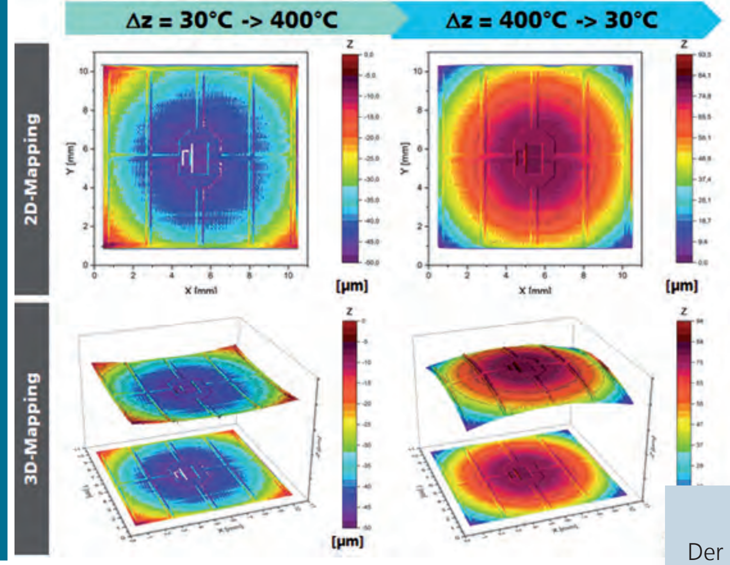
In consequence, the necessity of guaranteeing full dependability and good reliability of the new systems requires systematic research. Thermally induced stress due to thermal mismatch between the heterogeneous systems is generally the source for thermo-mechanical failure. In the field of smart systems addressing the issue of reliability, the physics of failure approach is followed. Efficient virtual design strategies and architectural product features capable of prognostic health monitoring are applied.

Experimental verification of modeling input and output is the key for precise failure prediction

As the levels of packaging integration, material diversity, and system complexity are increased, verification of simulation by experimental means are more important than ever. In particular, highly miniaturized materials used down to the nanometer range imply changes and process dependence of materials behavior, which is hardly to be handled without very special, problem dependent experimental techniques. This is even more important as the increase in integration level may lead to more interlinking and interaction between the different materials.

Contact:
Prof. Sven Rzepka
phone: +49 371 45001-421
e-mail: sven.rzepka@enas.fraunhofer.de

Dr. Rainer Dudek
phone: +49 371 45001-416
e-mail: rainer.dudek@enas.fraunhofer.de



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Der Einsatz hochintegrierter Smart Systems in rauen Umgebungen bleibt nach wie vor einer der wichtigsten Trends. Daher werden sich die thermo-mechanischen Zuverlässigkeitsrisiken weiter erhöhen. Thermisch induzierte Spannung aufgrund der thermischen Fehlanpassung zwischen den heterogenen Systemen ist häufig die Quelle für thermo-mechanisches Versagen. Auch auf dem Gebiet der Smart Systems ist daher die Frage der Zuverlässigkeit, die mittels FE-Simulation adressiert wird, eng mit den thermischen Verspannungen verknüpft. Stark miniaturisierte Materialien zu verwenden, bedeutet Änderungen und Prozessabhängigkeit des Materialverhaltens, dass kaum ohne ganz besondere problemabhängige experimentelle Techniken verifiziert werden kann. Eine dafür neuentwickelte optische Messeinrichtung ermöglicht die präzise Verformungsanalyse in einem breiten Temperaturspektrum von –80 °C bis 400 °C bis in den Nanometerbereich. Feldmessungsfunktionen basieren auf unterschiedlichen Messprinzipien für in-plane und out-of-plane Verschiebungsmessungen. Die Kombination dieses Messsystems mit der Finite-Elemente-Modellierung ermöglicht eine hervorragende Analyse des realen Systems.

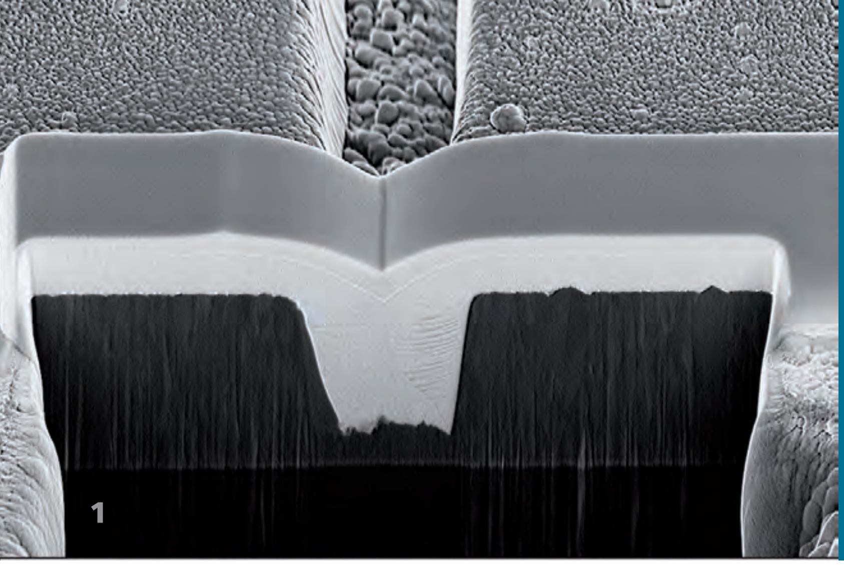
New optical metrology device allows for precise deformation analysis down to nanometer range in a wide temperature spectrum

The development of a new measuring system for both in-plane and out-of-plane deformations based on a long standing experience in optical measurements for microsystem applications at the department MMC closely interacting with the company "Chemnitzer Werkstoffmechanik GmbH (CWM)". The need for the development of a new measuring system became apparent after detailed market studies revealed that there is no device in the market which allows for measuring parameters that were targeted for the application spectrum.

The parameters now realized are really impressive: an out-of-plane measuring resolution of 30 nm and an in-plane resolution of 50 nm in a temperature range between –80 °C up to 400 °C! Obviously, the measuring precision makes sense only in conjunction with a high-temperature stability which is extraordinary as well: 0.01 K controlled by four temperature sensors in the temperature chamber. Field measurements capabilities base upon different measuring principles for in-plane and out-of-plane displacement measurements which are realized as two different measuring heads mounted in such a way as they are able to investigate the same object at a certain temperature. The pointwise measurement of the out-of-plane component is performed by chromatic sensor with a high-precision moving table, both designed by FRT (Fries Research & Technology GmbH) measuring devices. A high-resolution camera delivers the signals for in-plane field measurement of the object deformations. Object deformation at different states is calculated by digital image correlation software VEDDAC which also allows for picture stacking and thereby a limited evaluation of the deformation in the third dimension. An advantage of the measuring system is that measuring precision can be verified by combining the two approaches for the same object. These cases can be used as calibration cases for various objects, starting from the chips or MEMS-level up to the system-level. No doubt that the combination of these measuring system with finite element modeling allows for excellent reflection of the real system.

1 *New optical metrology device (left) and simulated vs. measured warpage of a coated Lithiumtantalat wafer for sensing applications (right).*

2 *Temperature dependent warpage of an IGBT chip.*



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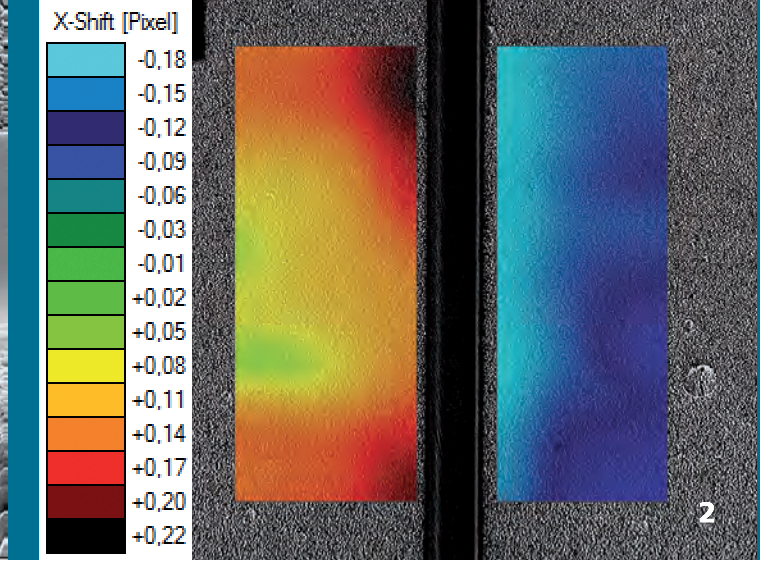
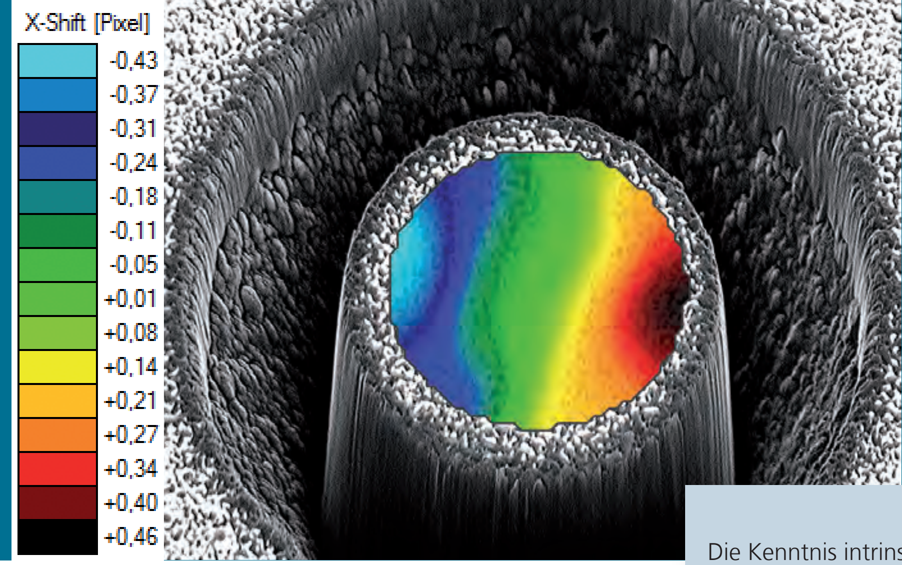




3

MEASUREMENT OF INTRINSIC STRESSES USING FIB EQUIPMENT BECOMES A METHOD OF REGULAR INDUSTRIAL PRACTICE

Dietmar Vogel, Ellen Auerswald, Sven Rzepka

Intrinsic stresses in semiconductor and MEMS devices significantly affect functional behavior and reliability. Trusted knowledge on stress amount and sign is a basic need developing new products. Electronics and MEMS devices often demand an extremely high spatial resolution of stress states. Only a few methods like X-ray/electron diffraction, microRaman spectroscopy, and TEM-based methods have been established as indirect stress measurement tools. Even finite element simulation reaches its limits to predict reliably mechanical stresses, if systems and manufacturing processes are rather complex and material laws are insufficiently known. Stress measurement by means of FIB-based ion milling and subsequent quantification of stress relief deformation is a new promising approach. First papers were published 10 years ago, among them Fraunhofer initial research. Up to now, the method has been utilized and strengthened by several European research labs. Currently, an extensive research program within the European FP7 framework project ISTRESS “Pre-standardisation of incremental FIB micro-milling for intrinsic stress evaluation at the sub-micron scale” is rendered. Its main objective is a commercialization and availability under industrial conditions. Fraunhofer ENAS is one of the consortium partners triggering and executing this program.

The method, often termed FIB-DIC or fibDAC, uses milling in standard Focused Ion Beam (FIB) equipment to release stresses very locally. Utilizing Digital Image Correlation (DIC) algorithms on high-resolution SEM micrographs captured before and after ion milling, the relief deformation field around the milling pattern is determined. Stresses prior to ion milling are found from measured relaxation strains assuming linear elastic material behavior. Various milling pattern have been deployed in the past, in dependence on the desired stress components and striven for spatial resolution. Some of them are depicted in the Figures 1–3. Typically obtained stress resolution ranges from 1 to some 10 MPa, in dependence on the elastic material properties of studied objects. The method reveals an excellent spatial resolution of 10 nm laterally on patterned surfaces and of 50 nm in depth measurements. Because the method does not require crystalline materials as for established diffraction methods, it can be applied to a much wider group of materials, like nanocrystalline or amorphous materials. The mentioned capabilities make it a favored candidate for local stress measurements on MEMS and electronics products.

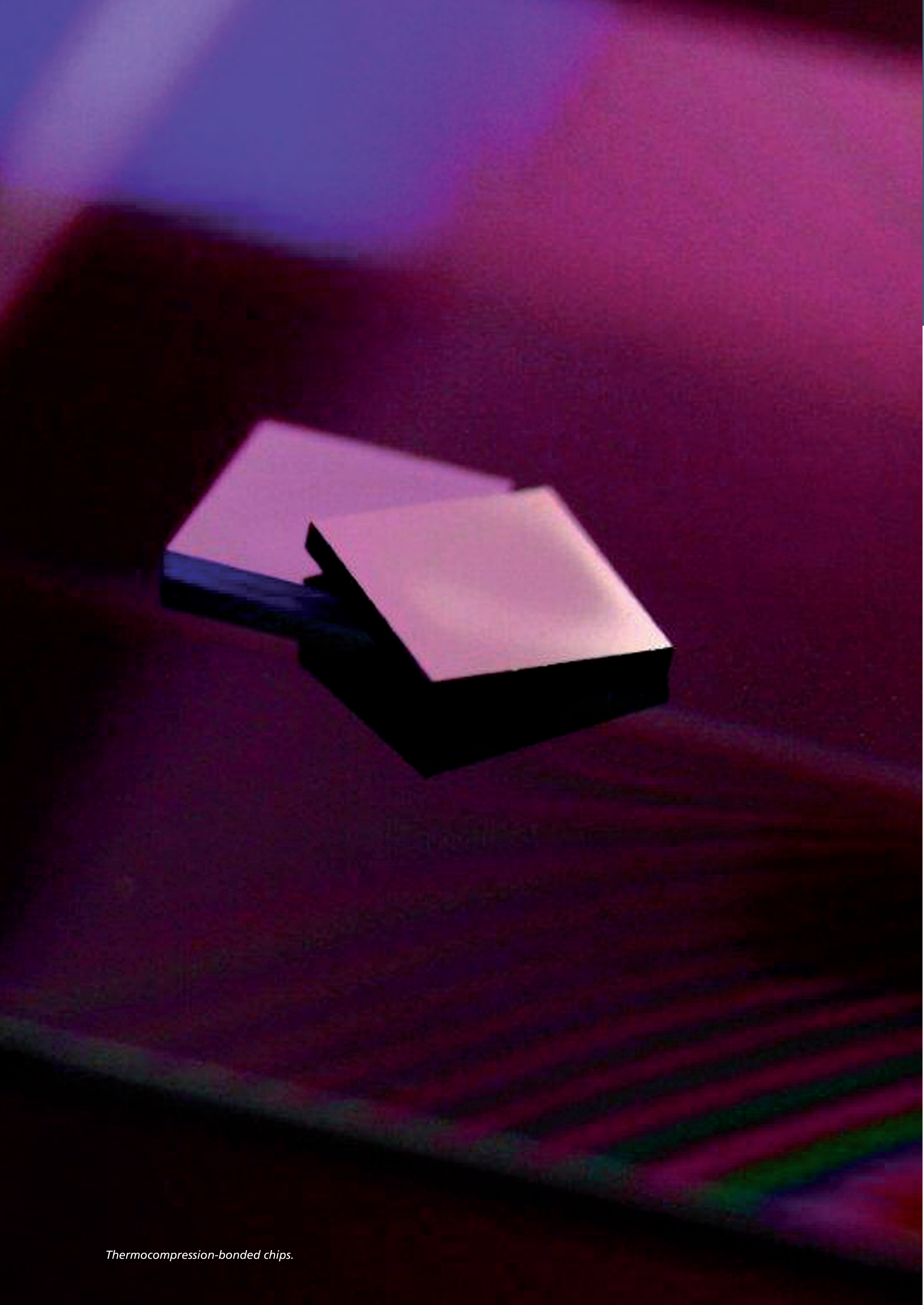
Contact:
Prof. Sven Rzepka
phone: +49 371 45001-421
e-mail: sven.rzepka@enas.fraunhofer.de

Dr. Dietmar Vogel
phone: +49 371 45001-412
e-mail: dietmar.vogel@enas.fraunhofer.de

In a research lab version, the FIB-DIC approach was applied and tested at Fraunhofer IZM and Fraunhofer ENAS by contributing to different reliability analyses for industrial customers. Nevertheless, the method could not be considered a method for regular industrial use. The mentioned above project ISTRESS tackled this drawback. A designated objective is the automation of the whole measurement process in order to obtain stress results at least within a few hours. Another goal addressed is the creation of a measurement tool which allows cost efficient measurements performed on FIB operator skills. A major European FIB manufacturer (Tescan) joined the ISTRESS project and is looking for implementation opportunities into a commercial FIB system. Beside these activities, the consortium made essential effort to validate the FIB-DIC method aiming at its pre-standardization to reach a wider level of acceptance by industrial users. December 2016, at the end of the project a Best Practice Guidebook will be delivered by the consortium, significantly simplifying access to the tools for new customers as well as giving support for decision makers. The FIB-DIC stress measurement method is not limited to MEMS and electronics devices but addresses many industrial research and development domains faced with stress issues, e.g. for products like wear resistance layers, cutting tools, and high-strength materials for aircraft and power plant engines.

Die Kenntnis intrinsischer Spannungen in Halbleiter- und MEMS-Produkten ist von großer Bedeutung, da letztere entscheidenden Einfluß auf funktionelles Verhalten wie auf die thermo-mechanische Zuverlässigkeit von Produkten haben. Ein neues Meßverfahren zur Messung lokaler Spannungen nutzt Ion-Milling in kommerziellen FIB-Geräten, um räumlich begrenzte Relaxationsdeformation an Materialien zu erzeugen. Bildverarbeitung an SEM-Bildern, vor und nach dem Milling aufgenommen, gestatten diese Deformationen zu messen und daraus die ursprüngliche Spannung zu ermitteln. Das Verfahren besitzt eine exzellente Ortsauflösung (10 nm lateral, 50 nm in Objekttiefe) bei gleichzeitiger Messgenauigkeit der Spannungen zwischen 1 und einigen 10 MPa. Ein FP7-Projekt gefördert durch die EU verfolgt die Zielstellung, das unter Laborbedingungen bereits eingesetzte Messverfahren in ein industrietaugliches umzuwandeln. Wesentliche Zielstellungen sind dabei Messprozess-Automatisierung, Kosteneffizienz des Messprozesses und Pre-Standardisierung des Verfahrens sowie Implementierung in ein kommerzielles FIB-Gerät. Ein Best-Practice-Guide soll einen effizienten Einstieg neuer industrieller Nutzer unterstützen

1 – 3 *Ion milling of trenches (Fig. 1 / Fig. 2) and circular pillars (Fig. 3) used to cause stress relief. Relaxation displacements (colored isoline plots, pixel units) are used to compute stresses.*



Thermocompression-bonded chips.

SENSOR AND ACTUATOR SYSTEMS

Highly precise micro-electromechanical and nano-electromechanical systems belong to the unique products of Fraunhofer ENAS within the Fraunhofer-Gesellschaft. In order to reinforce this competence long-term, Fraunhofer ENAS works on the further development of micro and nano-technologies. In addition, nano-based sensors, sensors and actuators with low energy consumption, and polymer-based sensors are also developed.

The first two articles address 3D integration of sensors and electronics. Processes such as thinning wafers, handling the thin wafers using temporary wafer bonding and implementing through-silicon via technologies (TSV) play a significant role. The first article describes a Via Last technology for MEMS based on Cu-TSVs. The second article is dedicated to temporary wafer bonding.

In the European project UNSETH, the consortium is developing a new generation of anti-tamper protection for electronic circuits. Existing solutions on the chip level are supplemented by assembly and packaging solutions. The third article presents the 3D integration based on printed multilayers and through-polymer vias and reliability analyses by Fraunhofer ENAS in this project.

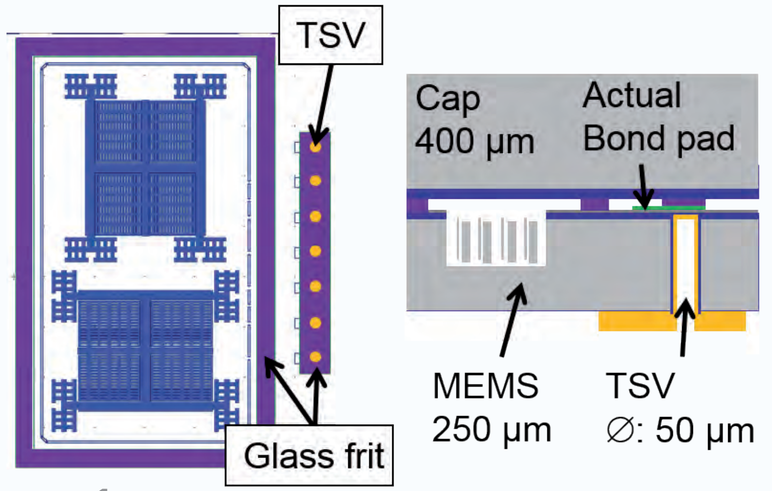
The last two articles describe sensor developments on flexible substrates. These can be integrated into any plastic component, including lightweight structure components, and functionalize them cost effectively. Thus, sensors based on printed resonators have been developed in the framework of the work in the cluster of excellence MERGE. The fifth article is dedicated to light-emitting diodes based on semiconductor nanocrystals (quantum dots).

Hochpräzise mikroelektromechanische und nanoelektromechanische Systeme gehören zu den Alleinstellungsmerkmalen des Fraunhofer ENAS innerhalb der Fraunhofer-Gesellschaft. Um diese Kompetenz langfristig zu stärken, arbeitet Fraunhofer ENAS an der Weiterentwicklung von Mikro- und Nanotechnologien. Darüber hinaus werden nanobasierte Sensoren, Sensoren und Aktuatoren mit geringem Energiebedarf sowie polymerbasierte Sensoren entwickelt.

Die ersten beiden Artikel adressieren die 3D-Integration von Sensorik und Elektronik. Dabei spielen Prozesse wie das Abdünnen von Wafern, das Handling der dünnen Wafer mittels temporärem Waferbonden sowie die Implementierung von Through-Silicon-Via-Technologien (TSV) eine wesentliche Rolle. Der erste Artikel beschreibt eine Via-Last-Technologie für MEMS-basierend auf Cu-TSVs. Der zweite Artikel widmet sich dem temporären Waferbonden.

Im Europäischen Projekt UNSETH entwickelt das Konsortium eine neue Generation von Schutzmaßnahmen für elektronische Schaltungen. Vorhandene Lösungen auf Chiplevel werden durch Packaging- und AVT-Lösungen ergänzt. Der dritte Artikel präsentiert die 3D-Integration basierend auf gedruckten Multilagen und Through-Polymer-Vias sowie Zuverlässigkeitsanalysen von Fraunhofer ENAS in diesem Projekt.

Die beiden letzten Artikel beschreiben Sensorentwicklungen auf flexiblen Substraten. Diese können in beliebigen Kunststoffbauteilen unter anderem in Strukturleichtbauteile integriert werden und diese kosteneffektiv funktionalisieren. So sind im Rahmen der Arbeiten im Exzellenzcluster MERGE Sensoren basierend auf gedruckten Resonatoren entwickelt worden. Der fünfte Artikel widmet sich lichtemittierenden Dioden auf Basis von Halbleiter-Nanokristallen (Quantum Dots).



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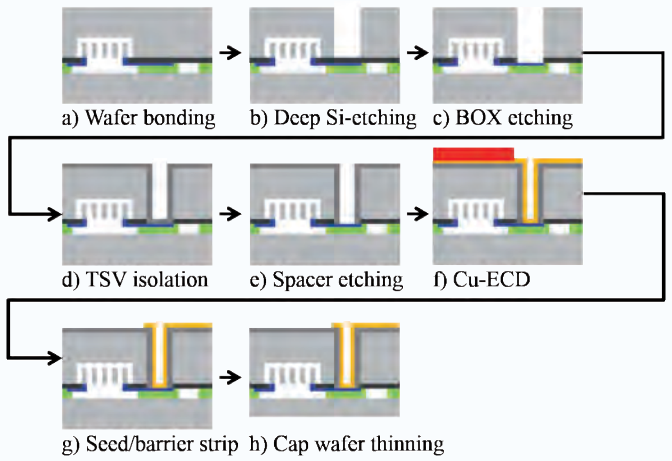

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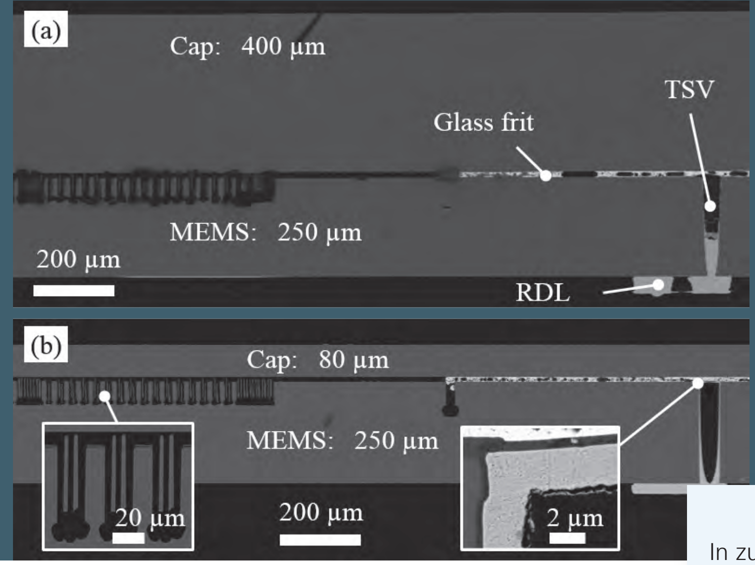

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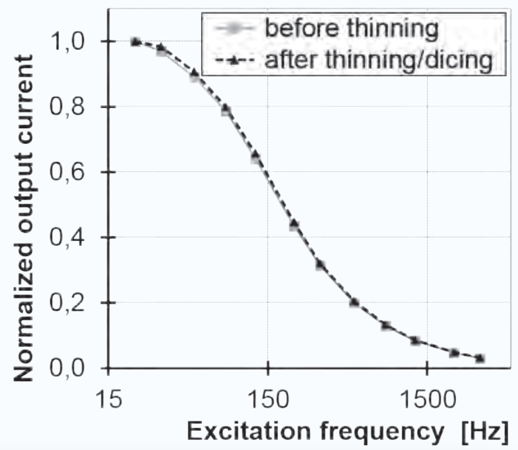

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In zukünftigen mobilen Geräten wie tragbarer Elektronik oder Smartcards werden perspektivisch immer mehr Funktionalitäten bei reduziertem Platzbedarf integriert. Dies verlangt nach speziellen Technologien für die Herstellung und Verkapselung der Einzelkomponenten (z.B. MEMS) und umfasst Technologien der 3D-Integration wie die Implementierung von TSVs. Im Rahmen dieser Arbeit erfolgte die Erarbeitung einer Via-Last-Technologie für MEMS basierend auf Cu-TSVs. Die Machbarkeit konnte anhand eines zweiachsigen Beschleunigungssensors demonstriert werden.

CU-TSV FOR MEMS BASED ON A VIA LAST APPROACH

Lutz Hofmann, Danny Reuter, Ina Schubert, Michael Rennau, Ramona Ecke, Knut Gottfried, Stefan E. Schulz

Introduction

Future applications such as mobile devices, wearable electronics, or smart cards have the need to integrate more and more functionality on ever decreasing space [1]. This puts major challenges on the fabrication technology of the implemented devices such as micro-electromechanical systems (MEMS) and their packaging [2]. Here, one widely emerging technique is the three-dimensional (3D) integration based on through-silicon vias (TSVs) and device stacking [3].
A Via Last approach (i.e. TSVs after wafer bonding) could be applied to the cap of a MEMS device or to its active part. Advantageously, the latter method tolerates intermediate layers (e.g. glass frit bonding). The major challenge is the fabrication of high aspect ratio (HAR) TSVs which results from the MEMS wafer thickness that is necessary to preserve the MEMS integrity and hence, its functionality. This report summarizes the fabrication of a demonstrator based on a two-axis MEMS accelerometer in the so-called AIM (Air Gap Insulated Microstructure) technology [4] as shown in Fig. 1.

Contact:
Prof. Stefan E. Schulz
phone: +49 371 45001-232
e-mail: stefan.schulz@enas.fraunhofer.de

Dr. Knut Gottfried
phone: +49 371 45001-299
e-mail: knut.gottfried@enas.fraunhofer.de

TSV technology

The principle TSV process flow (Fig. 2) starts with glass frit bonding (a). In the first TSV process step (b), deep reactive ion etching (DRIE) is utilized to form HAR TSVs with a depth of 250 µm. An LF bias is used to minimize lateral etching at the isolator interface. The buried oxide (BOX) film has to be removed in order to reveal the sensor metallization (c) which is accomplished by a RIE process. As isolation between the TSVs and the bulk-Si (d), a conformal SiO_2 liner is deposited by means of a SACVD-based process. This liner needs to be re-opened at the TSV bottom (e). It is realized by a highly anisotropic process that prevents any lateral etching of the sidewall isolation liner and is based on a low chamber pressure for a higher directional ion bombardment.
The metallization (f) starts with the deposition of the TiN barrier/adhesion layers and a Cu-seed layer by a MOCVD process. A photo resist mask is applied and serves as mould for the subsequent conformal electrochemical deposition (ECD) of 3 ... 10 µm Cu. Beside the TSV metallization, the redistribution layer (RDL) is deposited at the same time. After the ECD process the photo resist, Cu seed layer as well as the TiN barrier/adhesion layer are removed (g) by wet chemical etching. Finally, the cap wafer is thinned down from the initial 400 µm to 100 µm by a grinding process followed by a stress release etching in a RIE process.

Results and discussion

Figure 3 shows SEM images of the MEMS accelerometer with Cu-TSVs before and after thinning to a final device thickness of approx. 350 µm. No grinding or dicing induced defects such as cracks in the cap wafer or in the micromechanical structures could be identified in the SEM images of the thinned MEMS. For the functional characterization of the MEMS accelerometer an electrostatic excitation (sinus with $V_{pp} = 2$ V) was applied (Fig. 4). No obvious deviation could be observed between the curves before and after thinning which confirms the functionality of the accelerometer even after the harsh processes of wafer thinning and dicing.

Conclusion

The implementation of Cu-TSVs in an existing two-axis MEMS accelerometer was demonstrated. In the first run, the final thickness of the MEMS yields a value of approx. 350 µm. Further miniaturization in lateral size is possible by adapting the MEMS design to the TSV implementation and further height reduction is currently being addressed by developing a cap wafer TSV technology. Reliability tests will be performed in order to proof the mechanical strength of the complete device and the integrity of the MEMS.

Acknowledgement

The authors like to thank the team of the Fraunhofer ENAS and Center for Microtechnologies (Technische Universität Chemnitz) for carrying out unit processes, cross sectional polishing, and SEM imaging.

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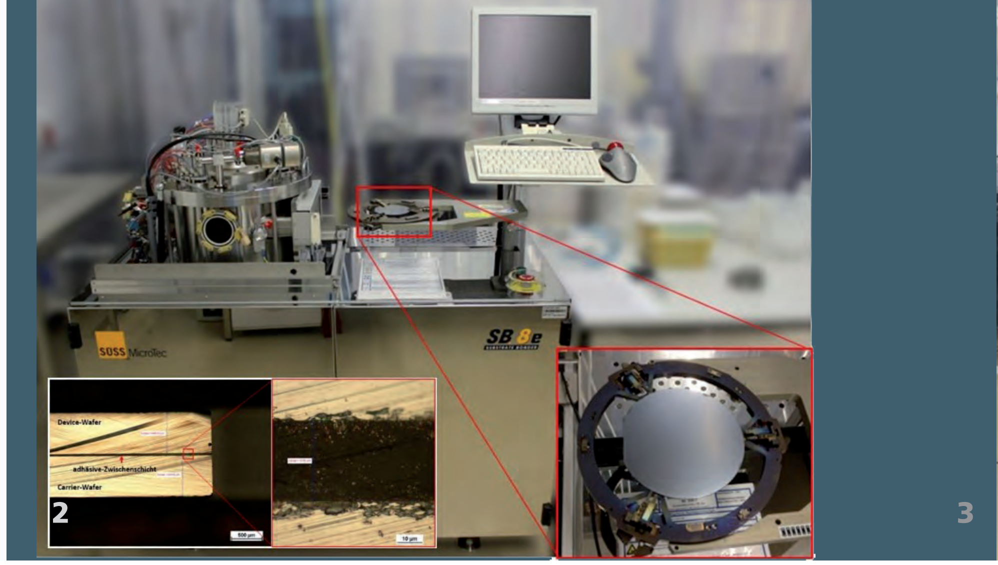
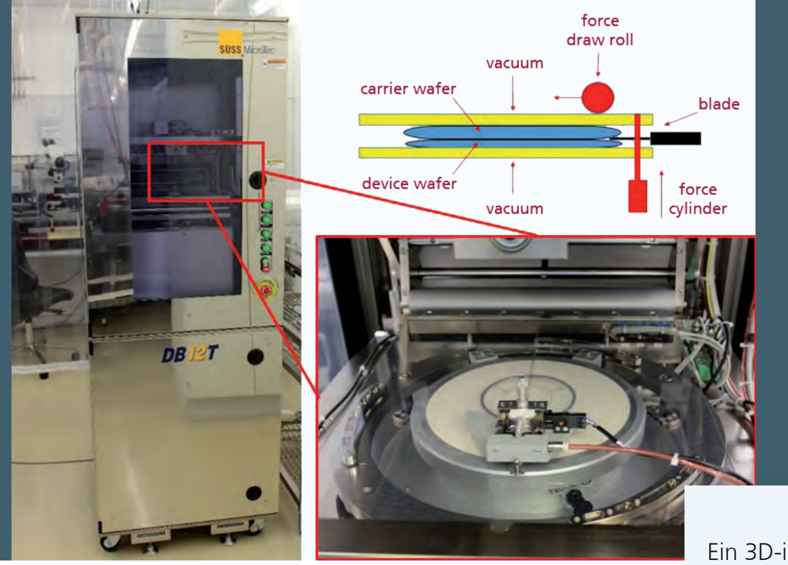
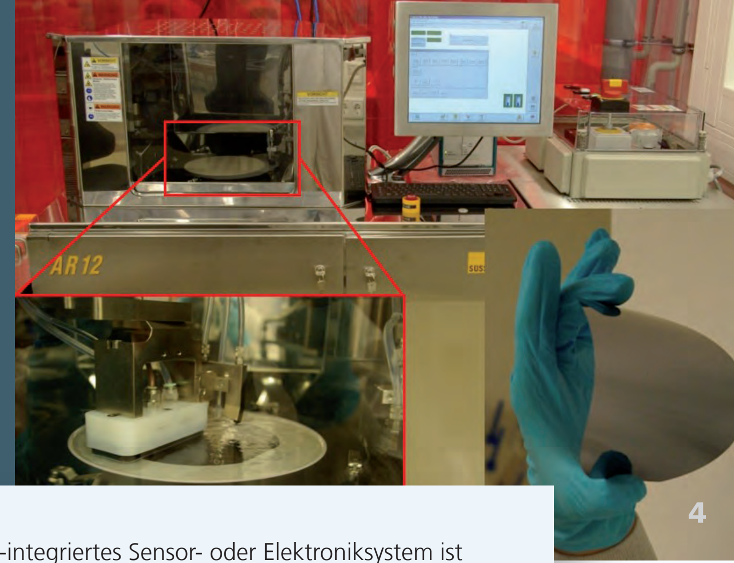
1 *Demonstrator layout with adapted glass frit pattern and corresponding cross section.*
2 *Principle TSV technology flow.*
3 *MEMS with Cu-TSVs before (a) and after (b) wafer thinning.*
4 *Response curve of the MEMS accelerometer before and after thinning upon electrostatic excitation.*







TEMPORARY WAFER BONDING FOR MEMS DEVICES

Dirk Wünsch, Maik Wiemer
Stefan Lutter, Markus Gabriel (SUSS MicroTec Lithography GmbH)

3D integrated sensors or electronic systems consist of individual components which are vertically stacked and have electrical connections. Therefore, new technologies and the development of new processes are essential. One key technology is the back thinning after temporary wafer bonding. The 3D integration requires the wafer thinning of both MEMS and CMOS devices. Ultrathin silicon wafers up to 100 µm have low stability, low bending stiffness, and are fragile. In order to enable the fabrication of thin Si substrates or to stabilize them during the mechanical processing, it is necessary to temporarily attach a device wafer to a carrier wafer [1]. Different processes have been established recently. One method for temporary wafer bonding is provided by Brewer Science, which is called zone bonding. This method involves the spin coating of a device wafer with an adhesive. The carrier is coated with another adhesive at the wafer edge. The remaining area in the center of the carrier wafer is with an anti-sticking layer. The spin coating of the device and the carrier wafers is carried on the semiautomatic RCD8 spin coater from SUSS MicroTec. The device wafer is prepared by the deposition of a layer thickness of 15 – 30 µm of an adhesive (ZoneBOND® 5150-30). The first step of the carrier wafer fabrication on the RCD8 is the formation of a zone on the wafer edge with the adhesive ZoneBOND® EM 2320-15. An exact centering of the carrier wafer on the vacuum chuck is important for the wafer edge zone to get uniform coating. The thickness of the layer is in the range of 0.5 – 3 µm. After baking at 220 °C, an anti-stick layer (ZoneBOND® Z1 3500-02) is dispensed on the center of the carrier wafer. Figure 1 shows the coating system with a fabricated carrier wafer by using the ZoneBOND® method.

The subsequent adhesive wafer bonding is realized by using a SUSS MicroTec SB8 wafer bonder. The adhesive wafer bonding is carried out under vacuum (process pressure < 5 mbar) with a 170 kN/m² bonding pressure. During the bonding process, two zones are formed. In the middle of the wafer is a fragile adhesive region (zone 1). In contrast to the zone 1, there is a strong adhesive area on the wafer edge (zone 2). Figure 2 shows a wafer stack on a 6 inch fixture before bonding in the SB8e and the formed intermediate layer after the adhesive wafer bonding. After chemical, mechanical and thermal processes (T < 250 °C), the edge zone of the strong adhesive area is released with limonene or mesitylene. Then, the wafer stack with the device wafer face down is mounted on a tape frame and placed in a debonding system (DB12T from SUSS MicroTec).

Contact:
Dr. Maik Wiemer
phone: +49 371 45001-233
e-mail: maik.wiemer@enas.fraunhofer.de

Dirk Wünsch
phone: +49 371 45001-262
e-mail: dirk.wuensch@enas.fraunhofer.de

In the DB12T debonder, the mounted wafer stack is fixed on both sides by vacuum. The mechanical separation of device and carrier wafers is done by a blade over the C-cut at the wafer edge. The carrier wafer is clamped over the blade and vertically moved on a flex plate over power cylinder at room temperature (see Fig. 3). In the final step, the device wafer on the mounted tape frame and the carrier wafer are cleaned. Similar to the edge release process, the cleaning is performed in the SUSS MicroTec AR12 module with limonene or mesitylene. With this process flow, a thinned wafer (150 mm diameter) down to 50 µm can be fabricated (see Fig. 4). In parallel, Brewer Science presented a new temporary wafer bonding method, called BrewerBOND® process. The process flow, particularly, the preparation of carrier wafer is significantly simplified for the BrewerBOND® method. Compared to ZoneBOND®, the anti-sticking layer is coated on the complete carrier wafer. As a result, wet chemical edge release before debonding is not required. The focus of different projects in cooperation with SUSS MicroTec is to clarify suitable process parameters for wafer coating using a new adhesive (e.g. BrewerBOND® 305) for the device wafer as well as a new anti-sticking layer (e.g. BrewerBOND® 510) for the carrier wafer. Preliminary investigations show that the bond strength is sufficient in terms of mechanical, thermal and chemical stress.

Ein 3D-integriertes Sensor- oder Elektroniksystem ist aus mehreren Einzelchips zusammengesetzt, vertikal übereinander gestapelt und elektrisch miteinander verbunden. Dafür sind neue Technologien sowie die Entwicklung neuer Prozesse notwendig geworden. Eine Schlüsseltechnologie stellt dabei das Rückdünnen über temporäres Waferbonden dar. Sehr dünne Siliziumwafer unterhalb von 100 µm Dicke besitzen eine minimale Stabilität, geringe Biegesteifigkeit und sind daher leicht zerbrechlich. Um die Herstellung solch dünner Si-Substrate überhaupt zu ermöglichen bzw. diese während der Bearbeitung mechanisch zu stabilisieren, ist es notwendig, die Device-Wafer vorübergehend (temporär) auf einen Träger-Wafer aufzubringen [1]. Dazu wurden in der jüngsten Vergangenheit verschiedene Verfahren etabliert. Ein Verfahren zum temporären Waferbonden ist das von Brewer Science bereitgestellte und bekannte ZoneBOND®-Verfahren. Parallel wurde von Brewer Science ein neues temporäres Waferbondverfahren, das sogenannte BrewerBOND®-Verfahren, vorgestellt. Bei beiden Verfahren sind die Präparation des Device-Wafers, das adhäsive Waferbonden und das Waferdebonden nahezu identisch. Lediglich die Präparation des Carrier-Wafers wird entscheidend vereinfacht.

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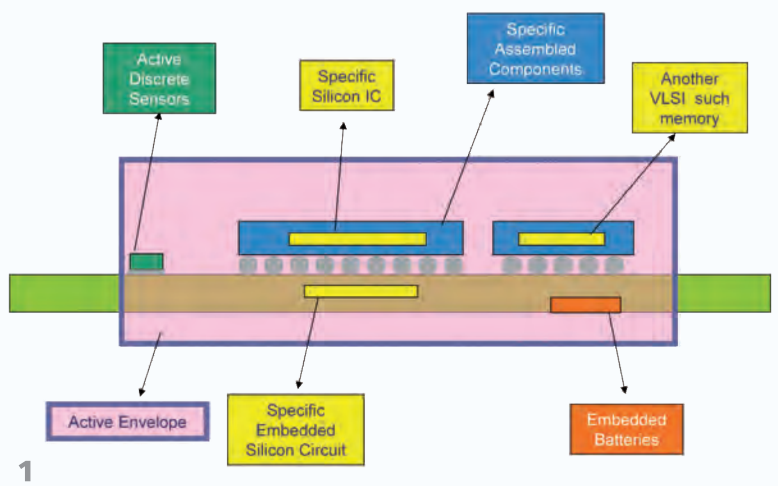
1 SUSS RCD 8 coating system with fabricated carrier wafer.
2 Adhesive wafer bonding on SUSS SB8e bonder with formed intermediate layer.
3 Debonding with DB 12T.
4 Cleaning with AR12 and 50 µm device wafer after final preparation.



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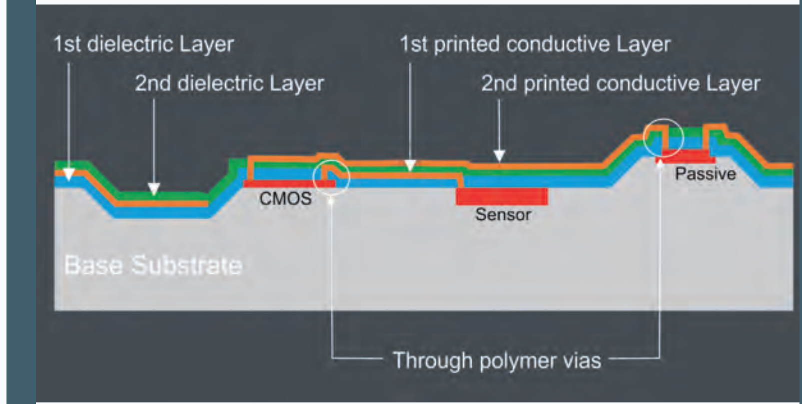

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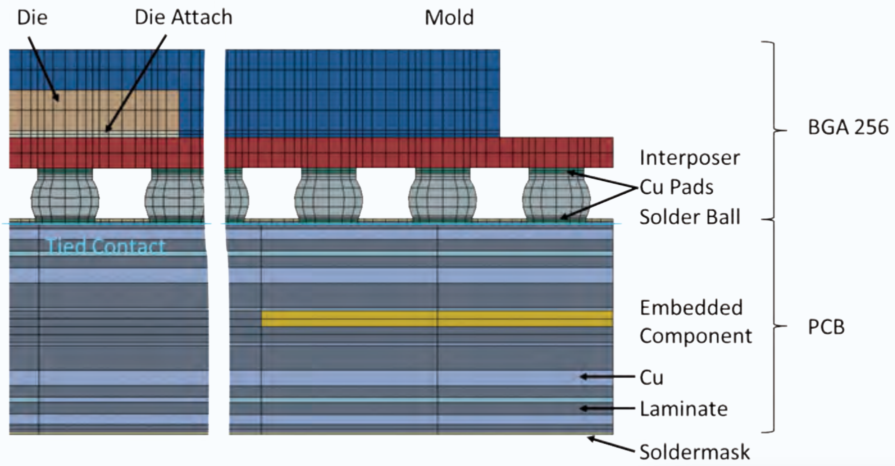


3

UNSETH: PROCESS AND RELIABILITY ASSESSMENTS OF INTEGRATION AND PACKAGING TECHNOLOGIES PROVIDING HARDWARE-BASED SECURITY

Eberhard Kaulfersch, Frank Roscher, Jan Albrecht, Nooshin Saeidi

Security has become a vital part of European electronic equipments as they handle sensitive data in uncontrolled environments and increasingly face content protection issues and counterfeiting. Tamper protection and high security, compatible with mass production cost and robust secure protection for high-end products, are focused on within the EU project UNSETH (FP7-SEC GA N°312701). It adds new tamper detection features and higher tamper resistance for electronic assembly and packaging to yet available chip level solutions and proposes a generic protection profile up to the highest possible assurance level.

By introducing new nanomaterials printed envelope, 3D devices and mesh embedded into PCB and SiP with active anti-tamper sensors or combination of all, testing and reliability evaluation, UNSETH provides advanced secure systems. Both, the electronic modules themselves and manufacturing processes are under development including aerosol jetting of nanoparticle inks at Fraunhofer ENAS, components embedding in PCB at AT&S and eWLP and SiP assembly at Nanium. Thales checks manufacturability of the technologies and brings in security applications for which Epoche & Espri proposes the protection profiles.

Two complementary technologies set up tool boxes for security:

- 1st level of anti-tamper protection by embedding protectable secure microcontroller in PCB as highly integrated part of the electronic system
- 2nd level of anti-tamper envelope by a secure sensor printed in a casing above the electronic module

At Fraunhofer ENAS, a new 3D integration approach based on printed multilayers and through-polymer vias was developed for the secure envelope and to enable vertical and horizontal integration of components, different in shape, size, material, process and function combining multifunctionalities in one package and miniaturizing smart systems. A parylene thin film is insulating conductive multilayers with interconnect vias opened by a fine-tuned laser ablation process. For conductive multilayer fabrication entirely basing on aerosol-jet printing (AJP) technique, Fraunhofer ENAS explored the printing of a commercially available silver nanoparticle ink on a CVD parylene dielectric coating and via filling. AJP enables < 20 µm fine line deposition of metal particle inks strongly depending on used ink, substrate materials and pre-treatment. Highly conformal homogeneous void free coatings with good insulation properties even on 3D substrates achieved by the CVD process in vacuum close to RT, pre-treatment procedures, AJP of Ag ink and opening vias in parylene by laser ablation without damaging the layers underneath demonstrate a new approach for multilayer redistributions on substrates with some level of 3D form factor.

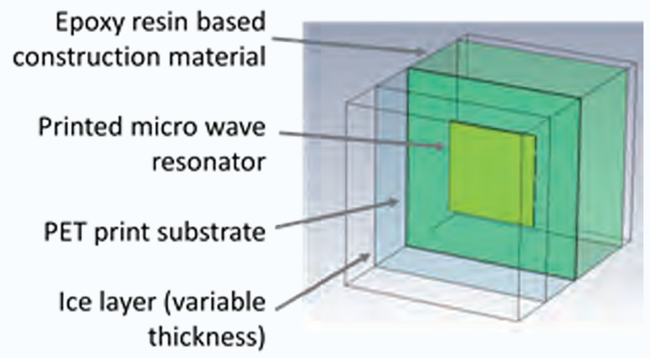
Contact:
Prof. Sven Rzepka
phone: +49 371 45001-421
e-mail: sven.rzepka@enas.fraunhofer.de

Dr. Eberhard Kaulfersch
phone: +49 371 45001-422
e-mail: eberhard.kaulfersch@enas.fraunhofer.de

Reliability assessments of smart secure PCB in presence of both, embedded components as well as large SMD, used FE models to evaluate thermo-mechanical stresses and strains numerically. Simulations of process and test steps and related experiments located and monitored stresses, plastic and creep strains evolving in the embedded dies and interconnects, primarily induced by CTE mismatches between PCB and components. Temperature cycles, vibrations, shocks, etc. pose risks for modules within systems of high security relevance. Detailed local 3D models thus replicated corresponding physical effects, always calibrated experimentally in reliability tests for evidence of failure mechanisms, locations and probability. To evaluate solder joint degradation as well as delaminations and cracks between the PCB and embedded components in detail, a global/local modeling strategy was followed for identifying loading conditions mainly contributing to degradation and for minimizing excessive stressing of the device.

Das Projekt UNSETH (FP7-SEC GA N°312701) entwickelt unter Leitung von Thales TCS/TGS und Mitarbeit von Fraunhofer ENAS, Nanium und Epoche & Espri eine neue Generation von Schutzmaßnahmen für elektronische Schaltungen. Vorhandene Lösungen auf Chiplevel werden durch Packaging- und AVT-Lösungen ergänzt, die sowohl die Einbettung aktiver Komponenten wie Mikrocontroller und Waferlevel-Packages sowie Lagen mit Netzstruktur als auch in Aerosoldruck von silbernanopartikelhaltigen Tinten hergestellten Abdeckungen für sichere Leiterplattenbereiche umfassen. Zur Realisierung der Sensorstruktur in der aktiven Kappe als auch als Umverdrahtung für die 3D-Integration wurde am Fraunhofer ENAS ein Multilagenaufbau entwickelt, bei dem ein Parylen-Dielektrikum die leitenden Silberstrukturen trennt und Durchkontaktierungen durch Laserablation hergestellt werden.
Die Prozessentwicklung beinhaltet die Optimierung des Druck- und Sinterprozesses, der Vorbehandlungsschritte, des Laserbohrens und des Viafills. Um den Anforderungen an die Robustheit der sicheren Elektronik genügen zu können, werden die Entwicklungen von umfangreichen numerischen und experimentellen Zuverlässigkeitsuntersuchungen begleitet.

1 Secure envelope building blocks.
2 Schematics of 3D integration based on printed multilayers and through-polymer vias.
3 Detailed simulation model of PCB with embedded components.



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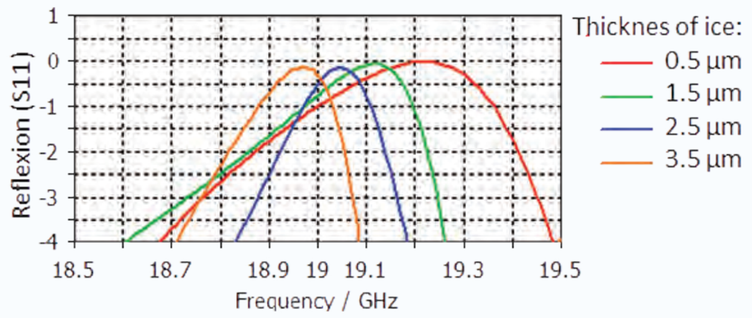

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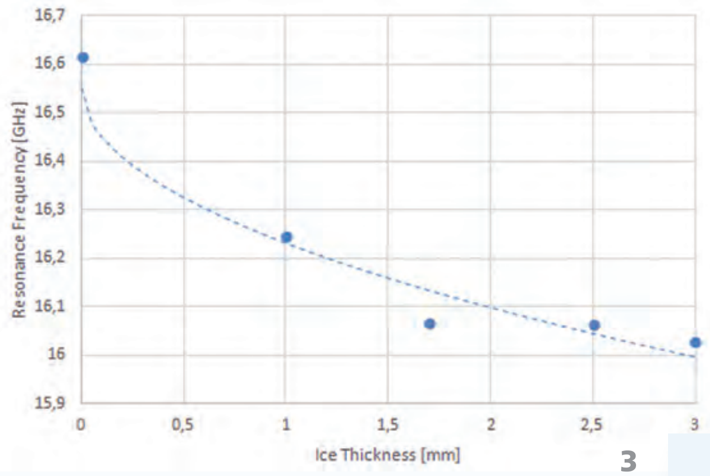

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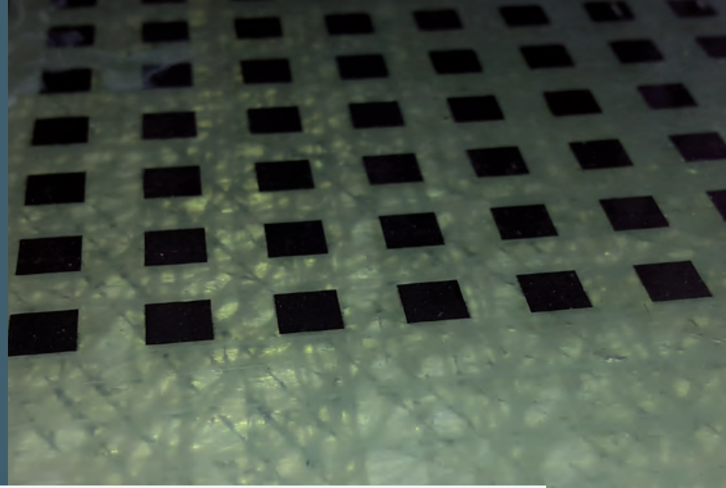


4

REMOTE ICE DETECTION BY PRINTED RESONATOR ARRAYS FOR ROTOR BLADES OF WIND POWER PLANTS

Toni Großmann, Steffen Kurth

Remotely accessible ice detectors applied in rotor blades of wind power plants can help to reduce downtime, especially in cold regions or in cold winter months. If ice accretion occurs, the wind power plant has to be shutdown to avoid ice throw, operational hazards and to prevent noise. Currently, precautionary shutting down the wind power plant is controlled by weather stations on the towers, if conditions let assume ice accretion. It may also occur in situations without real ice accretion and reduces the operator's profit. Therefore, sensor systems detecting ice accretion directly on the blades are highly desirable. Current sensor concepts comprise active sensors that require wiring for power or data transfer. Cables as well as their connections must be integrated into the blades. A passive sensor with remote read-out reduces the integration efforts significantly leading to further proliferation of ice detectors and wind power plants and hence, increases global power output.

The sensor approach for ice accretion recognition on rotor blades comprises of a periodical two-dimensional grid of passive resonators made of planar conductors. They are integrated into the blade (a fiber-reinforced structure) close to the surface to provide the sensor functionality. The resonance frequency and the quality factor of the resonators depend on the permittivity of the materials wherein the electromagnetic fields extend. Numerical 3D full-wave simulations using CST Microwave Studio have shown that an ice capping on the resonator causes a shift of the resonance frequency toward lower values. Ice has much higher permittivity than the air that flows over the blades usually. The resonators are able to detect the difference, even when they are located a few millimeters below the blade's surface. Applying reflection measurement using microwaves to determine detuning of the resonator enables remote operation.

For the fabrication of the sensor, technologies are used that can be easily adopted by the common fabrication processes of the blades. The first step in sensor fabrication is realizing the conductive patterns of the resonators. Gravure printing with silver ink on large rolls of coated PET foils is applied to achieve low-cost and large-scale production. After printing the resonators, sintering is necessary to get conductive surfaces. In the second step the printed resonators are integrated into the fiber-reinforced plastic using vacuum infusion technique. Cross-bonded glass fiber layers are placed on the printed foil and get impregnated with epoxy resin. After a drying period of 24 hours (under vacuum), a compact piece of glass fiber-reinforced plastic with the integrated sensor is available.

Contact:
Prof. Dr. Thomas Otto
phone: +49 371 45001-231
e-mail: thomas.otto@enas.fraunhofer.de

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

The passive sensor demonstrated the detection of ice accretion in first experiments. Wherein, ice layers with increasing thickness were generated. The necessary lab-equipment comprises two horn antennas connected to a network analyzer. The antennas point both to the resonators; one stimulates the resonators the other collects the reflected signal. The network analyzer displays the variations of the reflection behavior in case of increasing ice accretion.

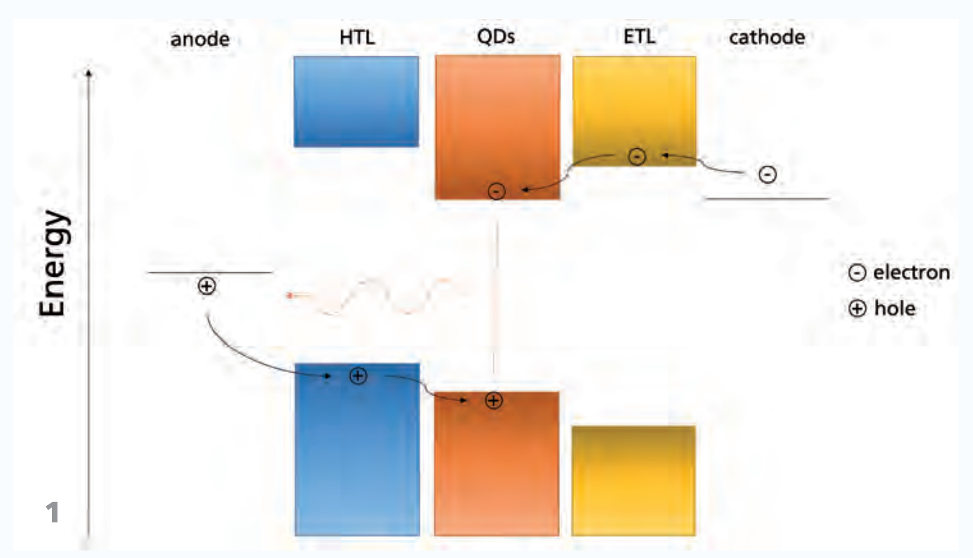
The performed measurements show a shift of the resonance peak with strong correlation to ice accretion. Therefore, the presented sensor approach including its fabrication shows the generation of sensitive functions. This enables the fabrication of smart lightweight structures with integrated sensor functionalities without using sensitive electronic components and wiring within the lightweight structures of a rotor blade.

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.

Also a special thanks is due to the employees of the Center for Microtechnologies (ZfM), the Institute for Printing and Media Technology and the Institute of Lightweight Structures of TU Chemnitz for their efforts and their support

Gedruckte passive Sensoren können dazu beitragen, die Stillstandzeit von Windkraftanlagen in kalten Jahreszeiten und Regionen zu verkürzen. Wegen der Gefahr von Eisansatz an den Rotorblättern wird der Betrieb bei bestimmten Wetterbedingungen vorsorglich eingestellt. Das ist nicht nötig. Mit Eisdetektoren versucht man das Abschalten erst dann vorzunehmen, wenn Eisansatz tatsächlich vorliegt. Bestehende Sensoren benötigen Anschlüsse und Zuleitungen für die Energie- und Datenübertragung, die mit viel Aufwand in die Blätter integriert werden müssen. Für passive Sensoren ist keine Verkabelung notwendig, wodurch sich der Integrationsaufwand erheblich reduziert. Dadurch ergeben sich Vorteile hinsichtlich der Einsparung von Kosten und eine Steigerung des Energieertrags.
Der Sensor für die Eiserkennung basiert auf gedruckten, leitfähigen Resonatoren, die in das Rotorblatt integriert werden. Sie verändern ihre Resonanzfrequenz und ihre Güte bei Eisansatz, was über eine Reflexionsmessung drahtlos erfasst wird. Das passive Funktionsprinzip des Sensors und die Ausnutzung großserientauglicher Produktion ermöglichen die (kosten-)effektive Funktionalisierung von Leichtbaustrukturen.

1 *Simulation model.*
2 *Simulation result showing the reflected signal at different ice thicknesses.*
3 *Measurements from first experiments of the passive sensor (left).*
4 *Photograph of the fabricated and integrated resonator array.*



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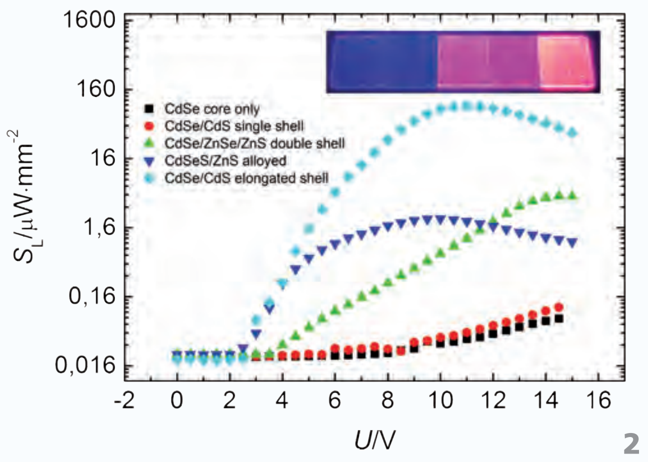

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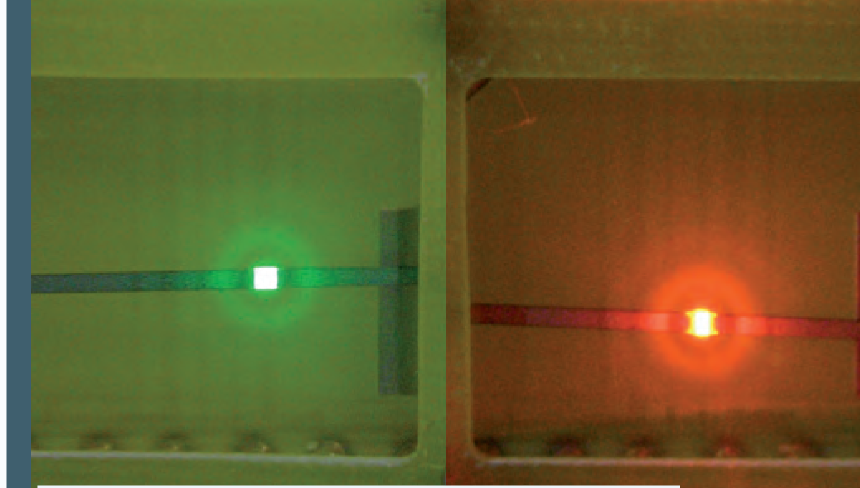
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LIGHT-EMITTING DIODES BASED ON QUANTUM DOTS FOR INTEGRATION IN PLASTIC MATERIAL

Jörn Langenickel, Alexander Weiß

In recent years, colloidal quantum dots (QDs) have strongly attracted attention in the field of lighting and display technologies [1]. These are crystals from inorganic semiconductors in the size of a few nanometers which leads to quantum effects which dictate their optical and electronical behavior. The smaller these crystals get, the more confined are the charge carriers which increases the gap between the energy bands of the QDs. This means the wavelength of the emitted light of the QDs can be tuned by their size. Other advantages are the high quantum efficiency, small full width at half maximum (FWHM), chemical stability, and the possibility to process from a solution.

These advantages are used in light-emitting diodes based on QDs (QD-LEDs) which give them a few benefits over their organic counterparts. It is possible to produce QD-LEDs in nearly every wavelength of the visible light with the same material by using different sized QDs as the emitting layer and the FWHM is much smaller (30–40 nm for QD-LEDs and 60–120 nm for organic emitters). Furthermore, the progress of QD-LEDs has been enormous in the past 15 years and external quantum efficiency (EQE) values of over 20 % [2] were reached. Because of these special properties of the light, QD-LEDs are interesting for use in different fields as lightning, as for example spectroscopically sensors.

The typical setup of a QD-LED is a layer of QDs sandwiched between a hole transport layer (HTL) and an electron transport layer, as well as the electrodes (Fig.1). The highest efficiencies were reached using an organic HTL and an inorganic ETL. For deposition of these layers, the Fraunhofer ENAS provides different opportunities, both vapor deposition techniques (e.g. sputtering, thermal evaporation or molecular beam) and solution-based techniques (e.g. inkjet printing or spin coating). With these possibilities the QD-LEDs can be processed with low costs on large-area and flexible substrates. To provide degradation of the materials, especially the organic ones, all the depositions can be processed under inert gas atmosphere.

Contact:
Prof. Dr. Thomas Otto
phone:+49 371 45001-231
e-mail: thomas.otto@enas.fraunhofer.de

Dr. Alexander Weiß
phone:+49 371 45001-246
e-mail: alexander.weiss@enas.fraunhofer.de

Figure 2 shows the density of the illumination power as a function of the voltage for different QD-LED setups. These setups are produced in the same way, except for the QD-layer. These layers distinguish in the material of the shells of the QDs. The shells are epitaxial grown semiconductors around the QDs which passivate and confine the charge carriers in them. With this approach, the suitability of the different shells were investigated electrically and optically. It was shown that it is important to choose the right material of the shells as well as the right shape. Present results were obtained within the project "Quaspink" (Sächsische Aufbaubank, SAB No: 100111575).

Within a project of the cluster of excellence "Merge Technologies for Multifunctional Lightweight Structures – MERGE" we participated to develop a method to integrate QD-LEDs on PET foils in lightweight structures. This could lead to two improvements. On the one hand, it could be possible to integrate luminous elements in every shape or color directly into lightweight structures during the production process. On the other hand, one of the biggest problems, the degradation of these QD-LEDs by external influences like water or oxygen, can be reduced. This would be a new approach for encapsulation and for the integration of such functionalities.

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Durch ihre speziellen optischen und elektrischen Eigenschaften haben Halbleiter-Nanokristalle (engl. Quantum Dots, QDs) eine große Aufmerksamkeit im Bereich der Beleuchtungstechnik. Besonders die lichtemittierenden Dioden auf Basis dieser QDs (QD-LEDs) besitzen ein großes Potenzial, da sie in nahezu allen sichtbaren Farben hergestellt werden können und eine geringe Halbwertsbreite des emittierten Spektrums aufweisen. Dadurch sind sie auch interessant für spezielle Bereiche außerhalb der normalen Beleuchtung, wie z.B. spektroskopische Sensoren. Diese QD-LEDs sind Schichtstapel aus organischen und anorganischen Halbleitern, mit einer Schicht Halbleiter-Nanokristalle als emittierende Schicht dazwischen. Zum Aufbringen dieser Schichten bietet das Fraunhofer ENAS diverse lösemittel- als auch gasphasenbasierte Techniken an, mit denen diese QD-LEDs auch auf flexiblen Substraten wie Folien aufgebracht werden können. Derzeitig wird daran gearbeitet, solche beschichteten Folien in Leichtbaustrukturen zu integrieren. Das hat zum Vorteil, dass während der Produktion Leuchtelemente in Leichtbaustrukturen integriert werden können und die Degradation der QD-LEDs durch Wasser und Sauerstoff gebremst wird.

1 *Band structure of a typical setup of a QD-LED. It shows the injection of the charge carriers through the HTL and ETL.*

2 *Illumination power as a function of the voltage for different QD-LEDs with different materials for their shell. In the upper right corner the photoluminescence of the different QDs are shown.*

3 *QD-LEDs with peak emission of 525 nm (left) and 620 nm (right).*

Close up of channel structures in the transparent injection moulded first generation microfluidic cartridge.

SMART MEDICAL SYSTEMS

In the field of smart medical systems, Fraunhofer ENAS addresses the following topics:

- Diagnostics and monitoring, etc.
  - Highly-integrated lab-on-a-chip solutions for point-of-care diagnostics
  - Fabry-Pérot interferometer (FPI), NIR/MIR micromirror spectrometer
  - Printed batteries for low-cost disposables
- Implants
  - Miniaturized sensors for medical applications
  - Biocompatible packaging technology, including surface modification, nano-imprinting for medical applications
  - Wireless energy supply
- Reliability of intelligent systems for medical technology including material characterization.

We selected three projects for the 2015 annual report.

The first article presents results from the European project PBSA "Photonic Biosensor for Space Application". The focus of the content is the suitability of a combination of an optical sensor, microfluid and protein verification for the miniaturization into a mobile system.

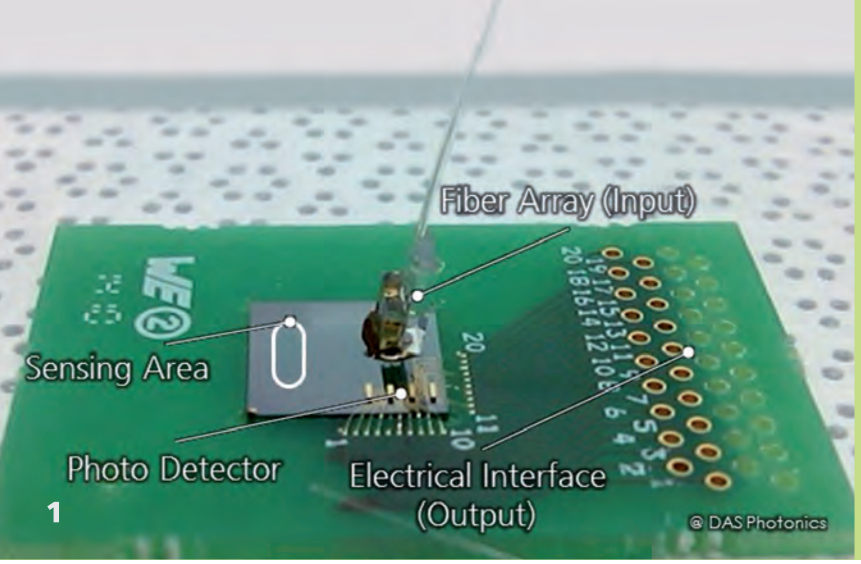
The second article presents results from the European project DeNeCor. The German consortium PolyDiagnost GmbH, MR:comp GmbH and Fraunhofer ENAS developed an MRI-safe microendoscope. The entire project places the focus of the work on the development of effective therapeutic and diagnostic technologies without erroneous interference with the other respective technology.

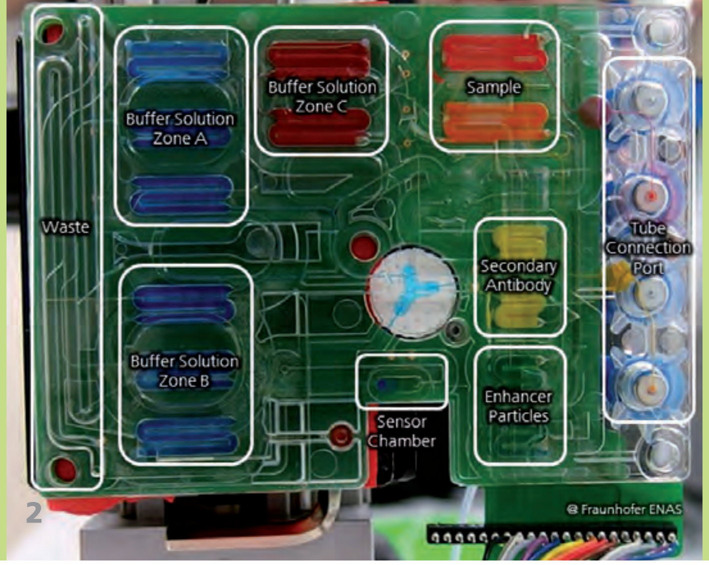
In the field of cardiovascular diseases, patients currently receive pacemakers and defibrillator implants. These require energy to function, usually in the form of batteries which have to be replaced from time to time. The third articles presents another approach based on a wireless energy supply for implants.

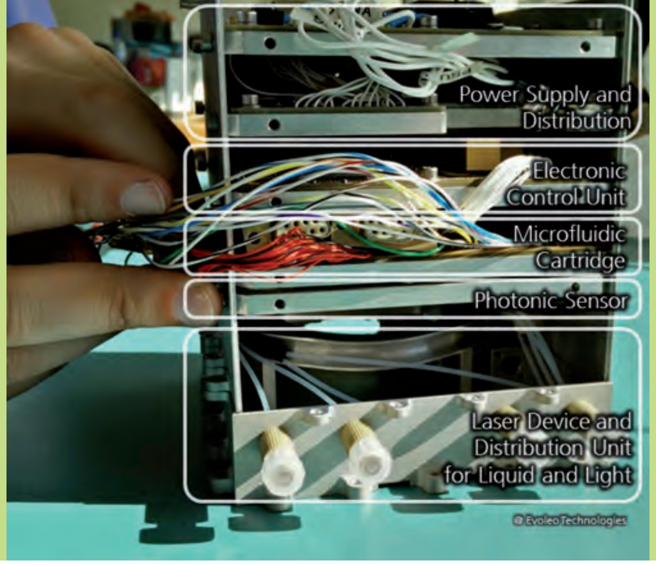
In der Medizintechnik adressiert Fraunhofer ENAS Themen aus den Bereichen:

- Diagnostik und Monitoring, u.a.
  - hochintegrierte Lab-on-a-Chip-Lösungen für die Point-of-Care-Diagnostik
  - Fabry-Pérot-Interferometer (FPI), NIR/MIR-Mikrospiegel-Spektrometer
  - Gedruckte Batterien für preiswerte Einwegartikel
- Implantate
  - Miniaturisierte Sensoren für medizintechnische Anwendungen
  - Biokompatible Aufbau- und Verbindungstechnik, einschließlich Oberflächenmodifikation, Nanoimprinting für medizinische Anwendungen
  - Drahtlose Energieversorgung
- Zuverlässigkeit von intelligenten Systemen für die Medizintechnik inklusive Werkstoffcharakterisierung.

Für den Jahresbericht 2015 haben wir drei Projekte ausgewählt.
Der erste Artikel zeigt Ergebnisse aus dem Europäischen Projekt PBSA „Photonic Biosensor for Space Application". Inhaltlich steht die Eignung einer Kombination aus optischem Sensor, Mikrofluidik und Proteinnachweis für die Miniaturisierung zu einem mobilen System im Mittelpunkt der Untersuchungen.
Der zweite Artikel präsentiert Ergebnisse des Europäischen Projektes DeNeCor. Das deutsche Konsortium PolyDiagnost GmbH, MR:comp GmbH und Fraunhofer ENAS entwickelte ein MRT-sicheres Mikroendoskop. Das Gesamtprojekt stellt die Entwicklung von wirksamen therapeutischen und diagnostischen Techniken ohne fehlerhafte Beeinflussung der jeweils anderen Technik in den Mittelpunkt der Arbeiten.
Im Bereich der Herz-Kreislauf-Erkrankungen werden heutzutage den Patienten Herzschrittmacher und Defibrillatoren implantiert. Diese benötigen für ihre Funktionsfähigkeit Energie, meist in Form von Batterien, die von Zeit zu Zeit gewechselt werden müssen. Der dritte Artikel zeigt einen anderen Ansatz basierend auf der drahtlosen Energieversorgung von Implantaten.







DEVELOPMENT OF A MOBILE DIAGNOSTIC PLATFORM FOR THE USE ON SELF-CONTAINED, EXPLORATION ROVERS WITHIN HARSH ENVIRONMENTS

Sascha Geidel, Jörg Nestler, Thomas Otto

Missions within terrestrial or space environments delivering risks to human encounter need to be analyzed by self-contained, exploration rovers. Beside imaging tasks, biochemical analyses are one major goal. Where the retrieval of the robot is not possible or desirable, the analyses have to be done on the spot. This leads to the demand of automation of biochemical analyses within a smart, mobile system which is capable of driving the analysis process and analyzing the recorded data.

Sensitivity through photonic sensing

The system is built around a photonic-based biosensor with an array of sensing elements for the detection of multiple analytes (DAS Photonics SL, Spain). The photonic biosensor uses a laser source which couples light into the chip through an optical fiber. The light is transmitted through the chip and split up onto a number of sensing elements. Due to biochemical coupling processes the photonic signal changes. The integrated photo detector array transfers the optical signal to an electrical signal which can easily be amplified and evaluated.

The characteristics of the photonic sensor were enabled by the functionalization of the sensing elements (INTA, Spain). This allows for example the selective and highly sensitive detection of a set of target analytes for life detection tasks on extraterrestrial exploration missions (Fig. 1).

Mobility through microfluidic integration

Since biosensors can be highly miniaturized and necessary reagent volumes are within the microliter range, tubes, valves, and actuators are in the focus of miniaturization. The integrable electrolysis actuation method developed by Fraunhofer allows the desired integrated, automated assay processing (Fig. 2). [1,2] Within the project a new cartridge was developed which is specialized to the needs of the assay (number and volume of reagents), remote sample filling, photonic sensor mounting, and automated assay processing.

Contact:
Prof. Dr. Thomas Otto
phone: +49 371 45001-231
e-mail: thomas.otto@enas.fraunhofer.de

Dr. Jörg Nestler
phone: +49 371 45001-240
e-mail: joerg.nestler@enas.fraunhofer.de

Independency through system-level integration

Both subsystems, the biosensor and the microfluidic one, need an electronic infrastructure to perform. In cooperation with Evoleo Technologies Lda (Portugal) power supplies, photonic and microfluidic driving electronics and signal amplification were miniaturized. The hardware can be remotely controlled through an on-board operating system (Fig. 3).

Results

The newly developed subsystems were technologically evaluated in combination and separately. Even radiation tests with gamma and proton exposure were done to prove the capability to last under harsh environmental conditions. Eventually, the system was successfully applied to a biochemical assay under the use of different target analytes with no human interaction needed at all.

Conclusion

A multidisciplinary approach was shown, where highly integrated microfluidics were combined with a sophisticated photonic sensor suitable to allow protein measurements with an one-step analytic device. The project miniaturized the necessary electronic equipment (like laser systems and power distribution units) and combined it with a microfluidic cartridge and a biosensor into a small package.

Acknowledgement

The authors would like to thank the European Union for their funding of the project PBSA "Photonic Biosensor for Space Application" within the FP7-program (FP7 program Grant Agreement No. 312942-PBSA; http://www.pbsa-fp7.eu/).

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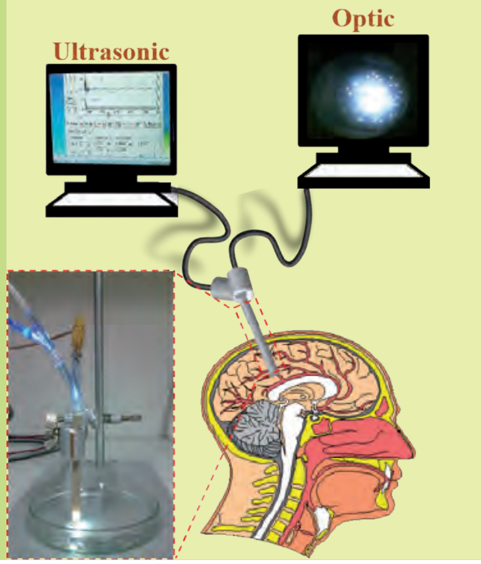
Autonome Robotersysteme werden zukünftig verstärkt zu Aufklärungszwecken unter rauen Bedingungen eingesetzt werden. Neben der Bildaufzeichnung verstärkt sich die Forderung, biochemische Analysen durchführen zu können. Die Nachfrage nach smarten, mobilen Systemen für ferngesteuerte Probenverarbeitung und -auswertung wächst.

Das Fraunhofer ENAS erforschte in Kooperation mit mehreren europäischen Partnern die Eignung einer Kombination aus Sensor, Mikrofluidik und Proteinnachweis für die Miniaturisierung zu einem mobilen System. Die Kombination eines hochsensitiven photonischen Sensors mit einer selektiven biochemischen Funktionalisierung erlaubte den Einsatz als omnipotentes Analysepanel (Abb. 1). Angepasst darauf wurde eine mikrofluidische Kartusche entwickelt, die aufgrund ihres einmaligen Flüssigkeitshandlings, auch komplexe biochemische Nachweise ohne menschliche Interaktion durchführen kann (Abb. 2). Durch die konsequente Miniaturisierung konnte die notwendige Laborelektronik mit Sensor und Kartusche zu einem handlichen System kombiniert werden, dessen Funktionsnachweis auch schon Repräsentanten der EU demonstriert werden konnte (Abb. 3).

1 *Photonic integrated circuit for bio-sensing applications.*

2 *Microfluidic cartridge for photonic sensor mounting with integrated actuation.*

3 *The final system fits into a small package including the microfluidic cartridge, the entire electronics, and the laser equipment.*



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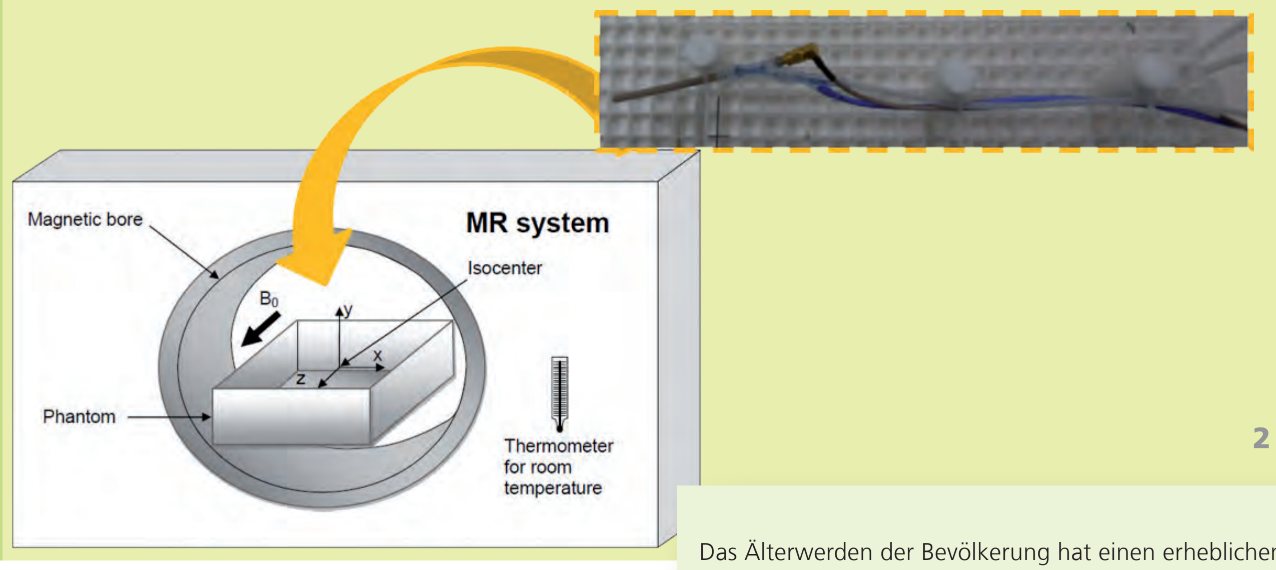

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DENECOR: DEVICES FOR NEUROCONTROL AND NEUROREHABILITATION

Nooshin Saeidi, Mario Baum, Robert Kinner, Maik Wiemer

Population ageing is a challenge for the future of healthcare systems. Often, an elderly individual may suffer from more than one disease or medical condition (e.g. neurological disorders such as Alzheimer, Parkinson, or chronic pain), while the diagnostic and therapeutic techniques for one may be incompatible with those of the others. The fact that more people with multiple chronic conditions will require health services clearly demands for the compatibility of therapy and diagnosis. On the other hand, active devices can offer new and effective solutions for health check and treatment. Therefore, many patients will be wearing such implants in their bodies for short or lifetime periods. These devices are not always compatible with key diagnostic tools, one of them being Magnetic Resonance Imaging (MRI), a very accurate disease detection technique.

Finding a solution for this situation will not only help patients to benefit from a broader range of medical advancements but also contribute to the development of more effective "combined" therapeutic and diagnostic techniques. The DeNeCor project with a consortium of over 20 research and industrial partners from 7 European countries funded within the ENIAC framework, a major scheme of the European Commission, is going to demonstrate the coexistence of therapeutic devices and diagnostic systems.

As part of this project the System Packaging department of Fraunhofer ENAS has developed a MRI safe endoscopic probe demonstrator for brain surgery. The so-called "µendoscope" integrates ultrasonic and optic components into a single device for use in intraoperative procedures (Fig. 1).

The optical functionality (light and image fibers) is used to guide the µendoscope's tip and locate the tumour tissue. Once temporarily implanted, the µendoscope is fixed in the desired position for the duration of examination. Ultrasound functionality of the µendoscope is then employed to obtain high-resolution and depth scans of the target and identify tiny areas of the brain tissue. This approach also allows for a therapeutic application of the µendoscope, so that by delivering sufficient amount of acoustic energy the tumour cell destruction can be achieved. As illustrated in Figure 1, two workstations are employed to acquire the ultrasound signals obtained from the µendoscope's transducer and viewing the image captured by the µendoscope's image fiber. The diameter of the current probe is 5 mm. Further miniaturization will enable positioning the tip much closer to the affected tissue and detect much smaller lesions.

Contact:
Dr. Maik Wiemer
phone: +49 371 45001-233
e-mail: maik.wiemer@enas.fraunhofer.de

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

As MR safety considerations have been taken into account in the design and operation procedure of the µendoscope, MRI can be performed while the µendoscope is inserted into the brain. This way, these two powerful modalities complement each other and increase the accuracy of diagnosis and therapy. The µendoscope has been successfully tested for functionality under MR environment.

Highlights:

- Combination of ultrasonic and optic functionalities
- Diagnosis and therapy application
- MR safe

Main specifications:

- Ultrasound
  - Transducer: PZT-based with quartz lens
  - Focal length: 3.8 to 4 mm
  - Lateral resolution: 0.2 mm
  - Frequency range: 15–20 MHz
- Optic
  - Light fiber to deliver light from a source to the target tissue and bundles of fiber optics (10,000 ± 1,000 pixels) to transmit the image to a viewer system
- Housing
  - PEEK

Das Älterwerden der Bevölkerung hat einen erheblichen Einfluss auf das Auftreten neurologischer Krankheiten wie Alzheimer, Parkinson, Gehirnschlag und chronischen Schmerz. Nicht selten leidet ein Patient an mehr als einer Krankheit. Diagnostische und therapeutische Maßnahmen für eine Krankheit können unverträglich sein mit Maßnahmen, die eine weitere Krankheit des Patienten erfordern. Das DeNeCor-Projekt, bestehend aus einem Konsortium von über 20 Partnern aus Forschung und Industrie, widmet sich dieser Problematik und erforscht die Koexistenz von therapeutischen und diagnostischen Techniken. Als Teilnehmer dieses Projektes hat die Abteilung System Packaging des Fraunhofer ENAS eine endoskopische Sonde für die Hirnchirurgie entwickelt. Das sogenannte „µEndoskop" vereinigt Ultraschall und optische Komponenten in einem Instrument für den chirurgischen Einsatz. Die optische Funktionalität dient zur Orientierung und zur Lokalisierung des Zielgewebes. Ultraschall wird dann dazu benutzt, einen hochauflösenden Tiefenscan des Gewebes zu erhalten. Zudem ermöglicht diese Vorgehensweise den Einsatz des µEndoskops als therapeutisches Instrument, indem das µEndoskop akustische Energie abgibt, um Tumorgewebe lokal zu zerstören. Da MR-Sicherheitshinweise beachtet wurden, kann MRI ausgeführt werden, während sich das µEndoskop im Gehirn befindet. Auf diese Weise ergänzen sich die beiden leistungsfähigen Betriebsmodi und erhöhen die Genauigkeit in Diagnose und Therapie.

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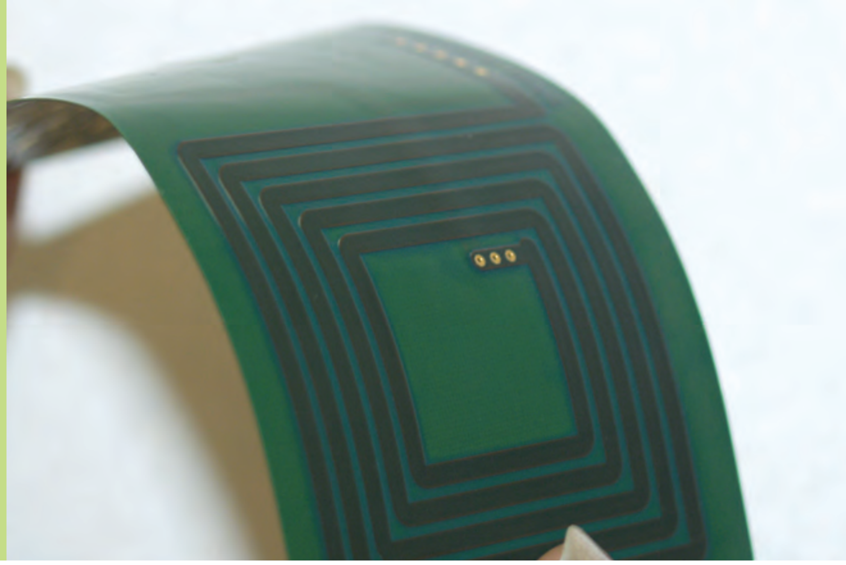
1 *The µendoscope with combined optical and ultrasound capabilities.*

2 *The test setup to evaluate the functionality during MR exposure.*



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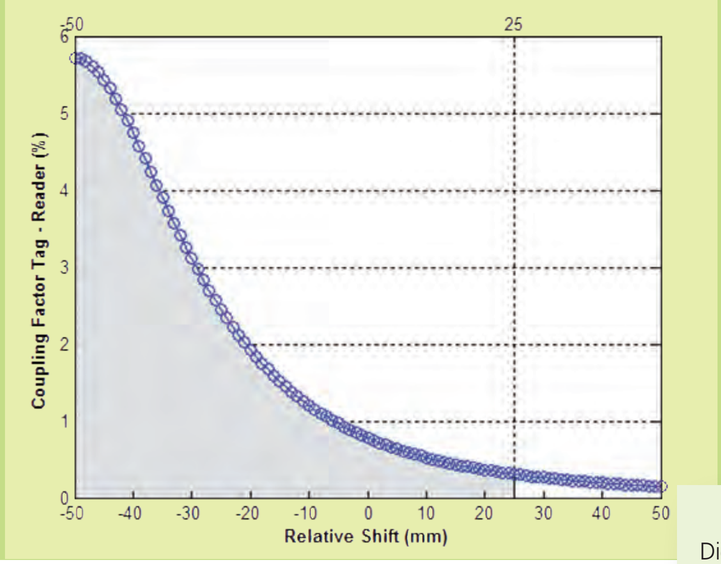


2

WIRAPLANT: WIRELESS ACTIVE IMPLANTS

Maik-Julian Büker, Christian Hedayat, Ulrich Hilleringmann

Motivation

Wirelessly transferred energy for mobile devices, systems, and sensors provides a huge number of advantages which find a direct application in all areas where connecting cables represent a development bottleneck or a mechanical, electrical and biological difficulty. In the domain of medical and biological equipment, the wireless energy transmission can be implemented in any kind of mobile devices which must be regularly charged like portable scanners, diagnostic tools and especially implants. It is particularly useful for systems with actuators or telemetry and monitoring functions worn close to the body or inside it. In the case of wearable electronics, it can be incorporated into jackets, vests or undergarments and be used for health analyses.

When considering the domain of implants (e.g. pacemaker, defibrillator, hydrocephalus implant, retina implant…) supplying these systems inside the body is a challenging issue, since connecting them with cables and a galvanic plugging interface through the skin constitutes an ideal housing for pathogenic agents and opens the door for infections and is uncomfortable for the patient. Moreover, when implanting energy consuming actuators like pumps or defibrillators, battery-based solutions are limited in terms of operating time and need thus to be regularly replaced with heavy and risky surgical interventions. The wireless energy transmission allows to overcome this major issue by supplying the accumulators of the implanted device periodically without cables and thus without physical intervention. In that way, long-term ambulant therapies involving energy consuming devices are made possible by guaranteeing the comfort and the mobility of the patients.

WIRAplant based on the WiTech-Technology

The wireless energy transmission system developed at the Fraunhofer ENAS department ASE called WiTech allows to transmit wirelessly both data and power up to 50 W. It is built on conventional low-cost printed circuit board (PCB) which has the powerful advantages to be highly miniaturizable, flexible, easily integrable in existing devices (and their housings), and combinable with other electronic PCB modules. The transmission area is not restricted and offers the greatest possible lateral freedom. It can cover large surfaces like a bed, an operation table or a diagnostic plane in medical centers but also at home. In order to limit the transmission area to the geometrical location of the receiving device, an array of switched coils are implemented on the transmitting PCB area. These coils detect the presence of an authorized receiver and are driven only at positions where the energy transmission is needed, optimizing and restricting dynamically the transmission pattern. In this way the magnetic fields are generated only at focused areas without spreading out over the whole transmitting area. This smart energy transmission system contributes to improve the system's efficiency simultaneously and to reduce drastically the radiated field by focusing it at requested positions.

Contact:
Dr. Christian Hedayat
phone: +49 5251 60-5630
e-mail: christian.hedayat@
enas-pb.fraunhofer.de

Technical data

The WiTech technology involved in the WIRAplant project is based on the inductive energy transmission. The involved frequencies are in the domain of some MHz, which are non-aggressive and have the advantage of offering useful ranges with a good efficiency by limiting unwanted side effects such as heating metallic foreign bodies. The system is able to transmit up to 50 W and current investigations are carried out in order to reach higher powers up to 80 W or even 100 W. The maximum operating distance is about 10 cm with an efficiency up to 70 %. However, extended transmission ranges can be achieved by using larger coils or by reducing the acceptable level of efficiency.

Die drahtlose Energieübertragung für mobile Systeme bietet eine Vielzahl von Vorteilen und Anwendungsmöglichkeiten in allen Bereichen, in denen Anschlussleitungen einen mechanischen, elektrischen oder biologischen Engpass bedeuten. Im Bereich der medizinischen und biologischen Geräte ist die kabellose Energieversorgung von tragbaren Geräten, die regelmäßig aufgeladen werden müssen (wie Diagnosewerkzeuge und Implantate), eine vielversprechende Lösung. Für Implantate ist die Kabelverbindung in das Körperinnere eine besonders große Herausforderung, da die Zuleitung durch die Hautschnittstelle eine bevorzugte Eingangstür für Krankheitserreger darstellt. Darüber hinaus beschränken diese kabelgebundenen Systeme die Mobilität und den Komfort des Patienten drastisch.

Die am Fraunhofer ENAS entwickelte Technologie WiTech erlaubt es, Systeme kabellos mit Daten und Strom (bis 50 W) zu versorgen. WiTech basiert auf herkömmlichen kosteneffektiven Leiterplattentechnologien und ist in allen Arten von Endgeräten einfach integrierbar. Diese PCB-Fähigkeit bedeutet ein hohes und flexibles Miniaturisierungspotenzial und erleichtert die Kombination mit bestehenden Geräten (und deren Gehäuse).

1 *The WIRAplant approach bases on flexible PCBs that allow an excellent integrability.*
2 *Effect of the relative shift on the coupling factor.*

SMART MOBILITY

In the field of smart mobility, Fraunhofer ENAS addresses smart systems for applications in the following sectors:

- Automotive
- Railways
- Aeronautics.

Internationally, Fraunhofer ENAS particpates in the Clean Sky Joint Technology Initiative (JTI) – the largest EU project for sustainability and competitiveness of aeronautics in Europe. Cross-departmentally, the competences are utilized in the fields of reliability tests and service life projections, accelerated test methods for projecting fatigue of fiber-reinforced polymers, actuator technologies for active flow control (AFC) as well as sensor and communication technologies for aeronautics. Current developments were introduced in the last two annual reports.

In the 2015 annual report, two additional topics are presented in detail.

The first article addresses electronic mobility. In the framework of the EU project COSIVU, in cooperation with partners, a new drive concept for electrical vehicles was developed with a focus on utility vehicles.

Systems that function reliably at temperatures of up to 300 °C are required in automobiles and for other applications. In the framework of the Fraunhofer internal preliminary research, comprehensive process and material developments for a technology platform for temperature-stable microsystem and electronics components were performed. The results are presented in the second article.

Im Bereich Smart Mobility adressiert Fraunhofer ENAS intelligente Systeme für Anwendung in den Bereichen:

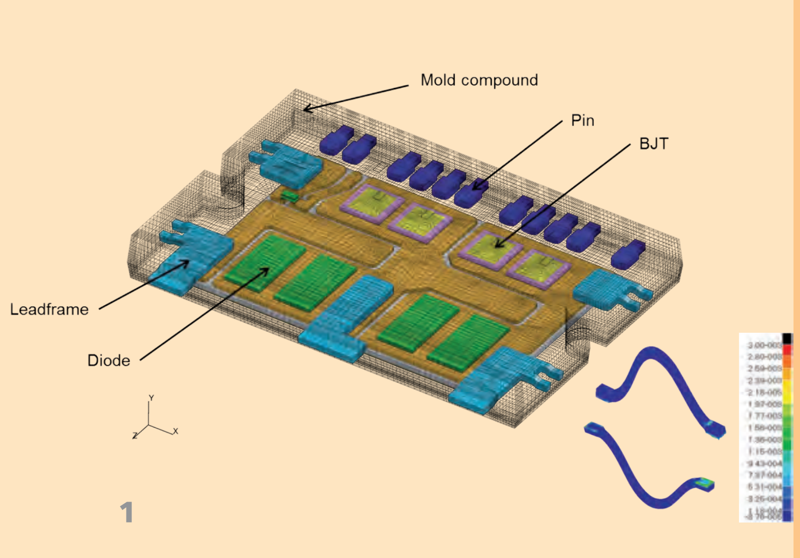
- Automobil
- Bahn
- Luftfahrt.

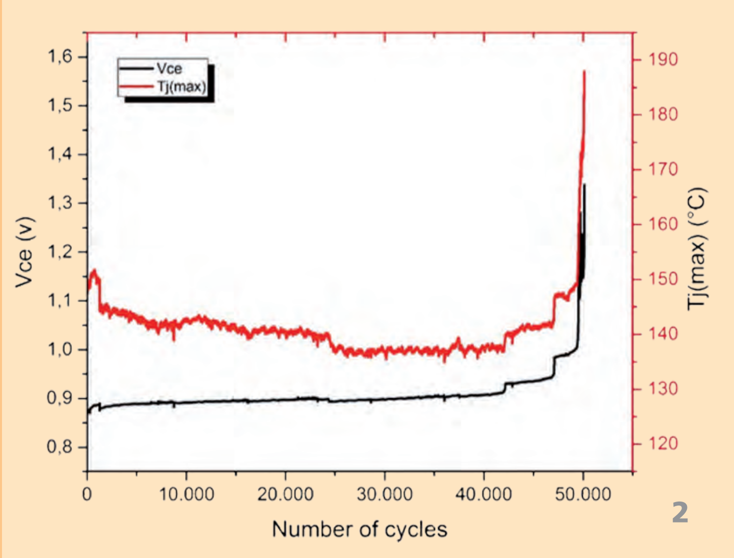
International arbeitet Fraunhofer ENAS in der Clean Sky Joint Technology Initiative (JTI) - dem größte EU-Projekt für Nachhaltigkeit und Wettbewerbsfähigkeit der Luftfahrt in Europa mit. Abteilungsübergreifend werden die Kompetenzen auf den Gebieten Zuverlässigkeitstests und Lebensdauervorhersagen, beschleunigte Testmethoden für die Vorhersage der Ermüdung faserverstärkte Polymere, Aktortechnologien zur aktiven Strömungsbeeinflussung (AFC) sowie Sensor- und Kommunikationstechnologien für die Luftfahrt eingebracht. Aktuelle Entwicklungen sind in den letzten beiden Jahresberichten vorgestellt worden.

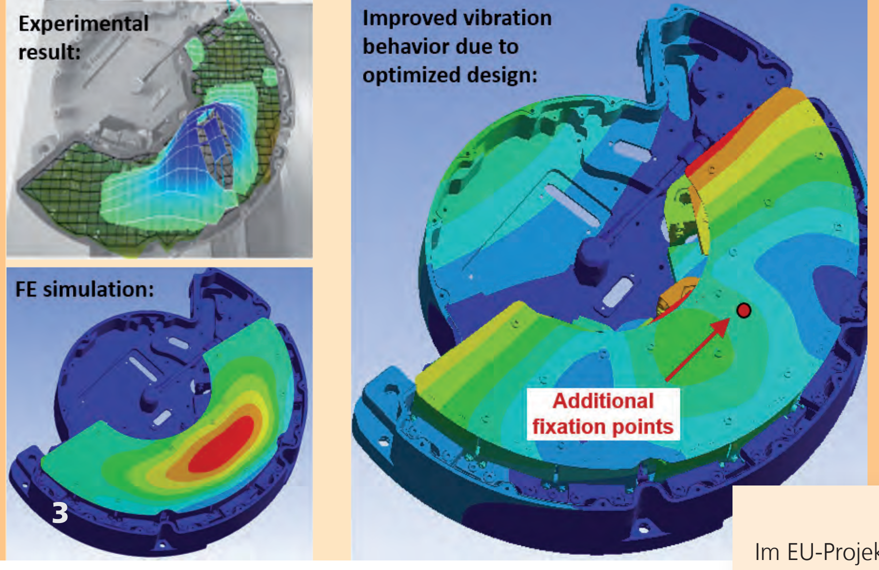
Im Jahresbericht 2015 werden zwei weitere Themen vertieft.

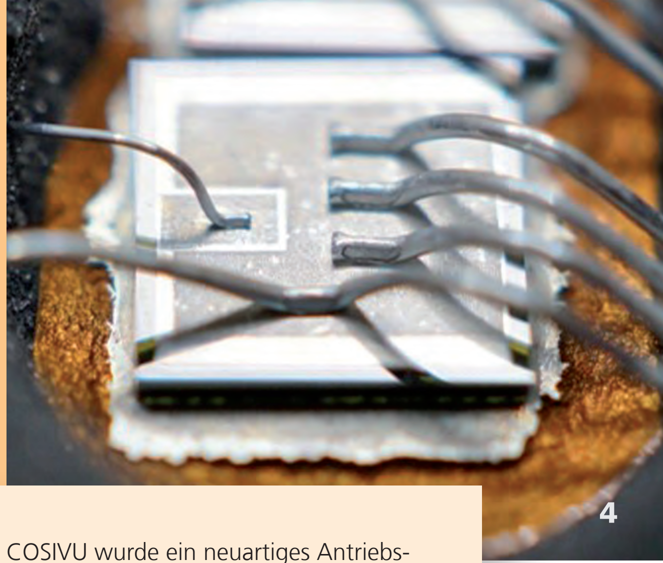
Der erste Artikel adressiert die Elektromobilität. Im EU-Projekt COSIVU wurde mit Partnern ein neuartiges Antriebskonzepts für Elektrofahrzeuge mit Schwerpunkt auf Nutzfahrzeuge entwickelt.

In Automobilen aber auch anderen Anwendungen werden Systeme, die bei Temperaturen bis 300x°C zuverlässig funktionieren, benötigt. Im Rahmen der Fraunhofer-internen Vorlaufforschung sind umfangreiche Prozess- und Materialentwicklungen für eine Technologieplattform temperaturstabiler Mikrosystem- und Elektronikkomponenten durchgeführt worden. Ergebnisse werden im zweiten Artikel präsentiert.









RELIABILITY ASSESSMENT AND OPTIMIZATION OF A SMART DRIVE UNIT

Alexander Otto, Eberhard Kaulfersch, Sven Rzepka

The requirements for commercial vehicles as well as for construction machines in terms of performance, efficiency and reliability (uptime) are constantly growing. These challenges have been addressed within the European project COSIVU (grant agreement no. 313980) by developing a novel electric drive-train architecture for construction vehicles as well as for passenger cars [1], [2]. The main features of the developed system are high modularity, compactness and efficiency (up to 50 % less power losses than in conventional systems). They have been achieved by a highly sophisticated mechatronic integration of electric motor, power electronics (featuring full SiC bipolar junction transistors and diodes), cooling system, and control electronics. Furthermore, health monitoring features such as thermal impedance monitoring for the SiC power modules as well as structure-borne sound analysis for the e-motor and gearbox have been implemented.

In order to enable subsequent commercialization of the developed systems after the course of the project, reliability investigations have been carried out along the development process. The focus has been set on two topics which have been identified as being potentially critical and which will be described in the following.

Contact:
Prof. Sven Rzepka
phone: +49 371 45001-421
e-mail: sven.rzepka@enas.fraunhofer.de

Dr. Eberhard Kaulfersch
phone: +49 371 45001-422
e-mail: eberhard.kaulfersch@enas.fraunhofer.de

Reliability investigations on SiC BJT power modules

Main subject of investigation was the newly developed SiC bipolar junction transistor (BJT) power module [3]. In order to identify potential weak points and to assess the reliability of the new technology, thermo-mechanical FE simulations in combination with warpage measurements and thermal analyses (for calibration purposes) have been performed (Fig. 1). In parallel, power cycling tests on the new SiC BT power modules have been carried out. The test results confirm the simulation findings that end-of-life is mainly determined by wire-bond lift-off (Fig. 2).

Mechanical robustness analysis of inverter system

A further topic was the investigation of the mechanical robustness of the developed inverter. This was motivated by the fact that due to the direct attachment on the electric motor, high mechanical and vibrational loads are expected throughout the lifetime, in particular for the targeted construction equipment applications. For this reason, virtual prototyping was done by building up a simulation model of the complete inverter system in order to investigate its response with respect to different mechanical loadings. For calibration and verification of the simulation model, experimental modal analyses have been performed. The results show that the first three resonance frequencies of the large control PCB board are located in the maxima of the loading spectrum of the targeted construction vehicle. With this knowledge, design optimization guidelines, i.e. additional fixation points for the control PCB, could be defined in order to drastically reduce the maxima and hence, finally to improve the robustness of the overall system, as simulation results for the improved inverter model have confirmed (Fig. 3).

Im EU-Projekt COSIVU wurde ein neuartiges Antriebskonzepts für Elektrofahrzeuge mit Schwerpunkt auf Nutzfahrzeugen entwickelt. Hauptmerkmale sind die hohe Modularität, Kompaktheit und Effizienz (bis zu 50 % weniger Verluste als in herkömmlichen Antriebssystemen). Letzteres wurde dabei durch eine auf Siliciumcarbid-Bipolartransistoren basierenden Leistungselektronik erreicht. Zusätzlich wurden neuartige Gesundheitszustandsüberwachungskonzepte für die mechanischen (Körperschallanalyse) sowie die leistungselektronischen Komponenten (thermische Impedanzspektroskopie) implementiert. Die Aufgabe des Fraunhofer ENAS bestand in der Zuverlässigkeitsbewertung und -optimierung der Leistungselektronik sowie des mechanischen Gesamtaufbaus (Inverter).

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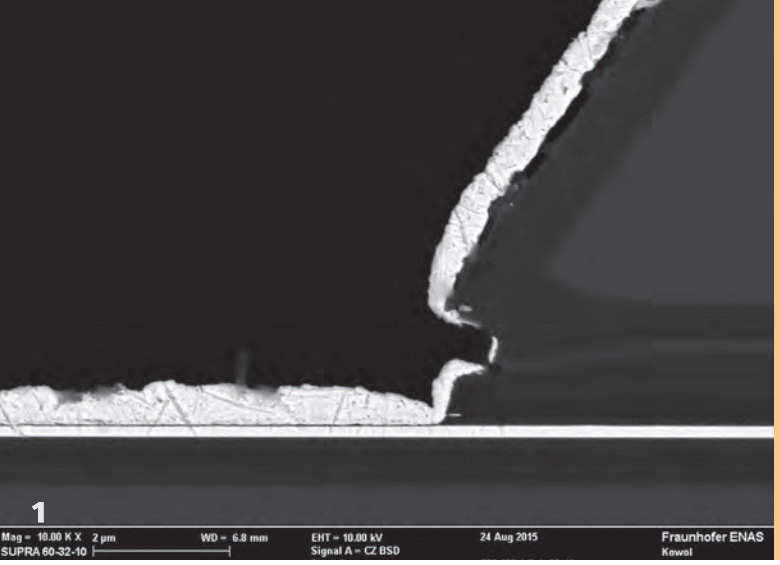
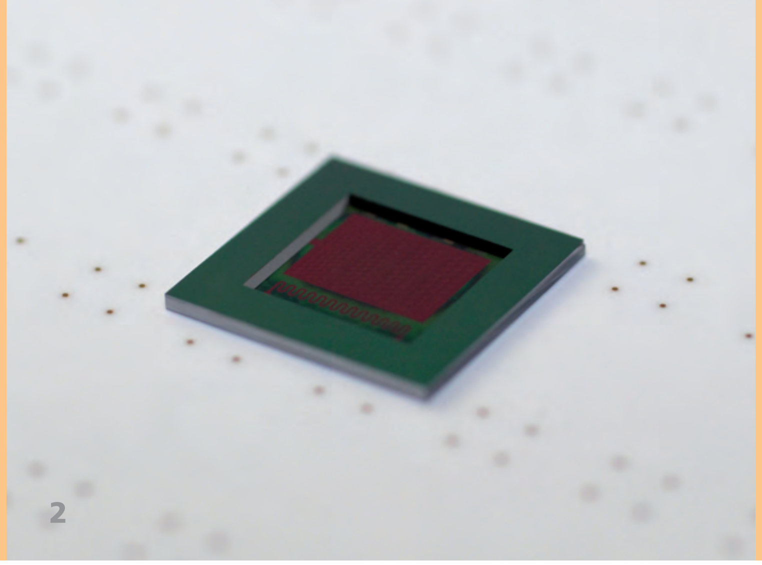
1 *FE model of SiC BJT power module (left) and equivalent plastic strain increment accumulated in the bond-wire during one power cycle (right).*

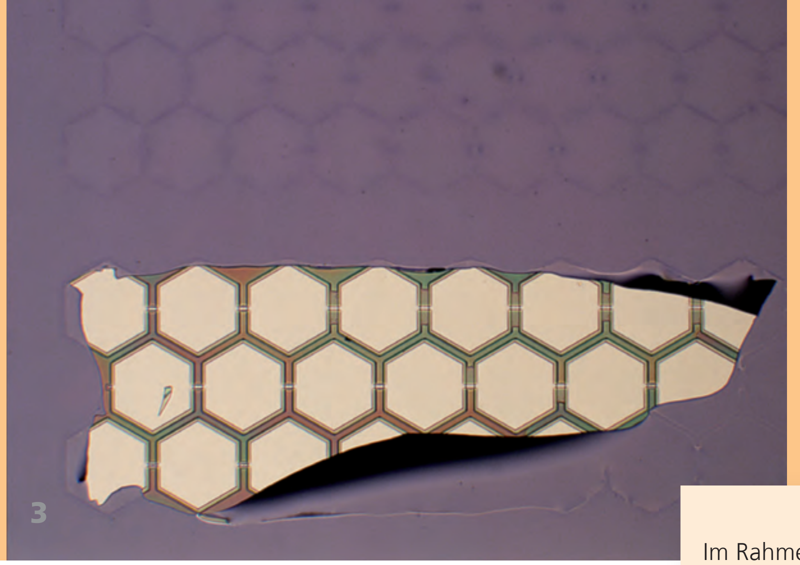
2 *Evolution of $T_{j,max}$ and V_{ce} during power cycling until end-of-life.*

3 *Investigation and optimization of mechanical robustness of inverter by means of virtual prototyping in combination with experimental modal analysis.*

4 *Photographic image of investigated SiC BJT device.*







MATERIALS AND TECHNOLOGIES TO ENABLE HIGH-TEMPERATURE STABLE MEMS AND ELECTRONICS

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. Within the joint project MAVO HOT-300, various Fraunhofer Institutes worked on extending the operating range of smart systems containing MEMS and electronics up to 300 °C.

Contact:
Dr. Maik Wiemer
phone: +49 371 45001-233
e-mail: maik.wiemer@enas.fraunhofer.de

Prof. Sven Rzepka
phone: +49 371 45001-421
e-mail: sven.rzepka@enas.fraunhofer.de

Wafer-level packaged multifunctional MEMS with ceramic interposer

Ultrasonic transducers based on piezoelectric effect are often limited in terms of operating temperature. In this project, we have developed a 1 MHz capacitive micromachined ultrasonic transducer (CMUT) with platinum metallization and integrated temperature sensor on a ceramic interposer. Depending on their size, the ultrasonic cells are also applicable for pressure sensing. A temperature stable composite membrane consisting of thermal SiO_2, LP-CVD Si_3N_4, Ti/Pt and PE-CVD SiO_2 has been defined by a combination of sequential temperature-dependent measurements (e.g. layer stress) on the deposited layers together with extensive numerical simulations. This approach leads to temperature-dependent models based on the actual mechanical properties of the deposited layers. The MEMS component is fabricated on two separate wafers, which are assembled by direct bonding of PE-CVD SiO_2 layers. To reduce stress inside the package, through-silicon vias (TSV) with thin sidewall metallization between 500 nm and 2 µm instead of completely filled vias are used.

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 LTCC has been investigated. Micro Chevron test was used to determine the bonding strength of the silicon-ceramic interface as a function of bonding temperature, plasma surface activation and testing temperature. To realize electrical interconnections between the silicon and LTCC wafers, thin metal layers are simultaneously thermocompression-bonded during the anodic bonding process.

Reliability and lifetime

High operating temperatures result in new temperature driven mechanisms of degradation and material interactions which are only marginally covered until now. Therefore, the determination of reliability risks and mechanisms as well as their allocation to specific construction situations is an essential part of the research. An 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. The determination of temperature shock strength of electronic components even at high temperatures requires the adaptation of the available equipment. A two-oven system has been developed in which a temperature range from −70 °C to 450 °C can be covered by using a robotic handling system. The full electric in situ monitoring capability of the samples during the measurement is ensured. Also vibration and humidity can be included in the testing setup within a combined test. With the acquired data, reliability models can be generated and validated which allow reliable predictions and risk evaluations for the new requirements. With combined usage of advanced simulative and experimental methods, it is possible to identify potential weak spots in the overall system. These are, for instance possible interface delamination, determination of fracture and crack risks, ensuring the functionality under changing boundary conditions, evaluation of long-term stability and determination of acceleration factors.

Acknowledgement

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Im Rahmen des Projektes MAVO HOT-300 wurden durch die Fraunhofer-Institute ENAS, IKTS, IMS, IMWS sowie IZM umfangreiche Prozess- und Materialentwicklungen für eine Technologieplattform temperaturstabiler Mikrosystem- und Elektronikkomponenten durchgeführt. Mehrere keramikbasierte Packages (z.B. Lead-frame, WLP) wurden aufgebaut und umfangreich hinsichtlich Ihrer Zuverlässigkeit bis 300 °C Betriebstemperatur untersucht. Weiterhin wurden temperaturstabile Einzelkomponenten wie Multifunktions-MEMS, Trench-Kondensatoren sowie CMOS-Schaltungen entwickelt und hergestellt. Ein wichtiger Schwerpunkt bei der Entwicklung der temperaturstabilen, multifunktionalen MEMS-Komponenten waren die Aufbau- und Verbindungstechniken, insbesondere die Fügeverfahren zum Herstellen der Membranstruktur sowie zum Verbinden von Siliziumsubstraten mit LTCC-Keramik auf Waferebene. Hierfür wurde ein hybrides Waferbonden entwickelt, welches einerseits die mechanische Verbindung zwischen der Keramik und dem Silizium über ein anodisches Verfahren erlaubte und andererseits die vertikale elektrische Kontaktierung der beiden Substrate über ein Thermokompressionsverfahren realisierte. Begleitend dazu wurden Materialparameter ermittelt, Simulationsmodelle erarbeitet sowie Testmethoden weiterentwickelt.

1 *Identification of technology bottlenecks by cross-sectional SEM analysis of TSV metallization.*
2 *Fabricated multifunctional MEMS on a ceramic interposer with vertical interconnects.*
3 *Manually exposed ultrasonic cell electrodes.*

SMART PRODUCTION

Smart production addresses the development of system solutions in the field of Industry 4.0. In addition to plug and play sensors in real production environments, core topics include status or environment monitoring based on microsystems including optimized data analysis and communication of the data.

Fraunhofer ENAS focuses on:

- Status monitoring of consumables and systems in machine construction
- Sensor integration in system components
- Monitoring in logistics (transport monitoring, monitoring in the warehouse, etc.)
- Production of flexible printed systems
- Plagiarism protection
- Reliability analyses, fracture mechanics.

The following three articles present different topics.

The first article addresses the monitoring of the thermal stress on drive units in conveyor systems. Based on intelligent processing of the sensor signals, it is possible to create long-term load profiles or an early warning of wear and tear-related failures.

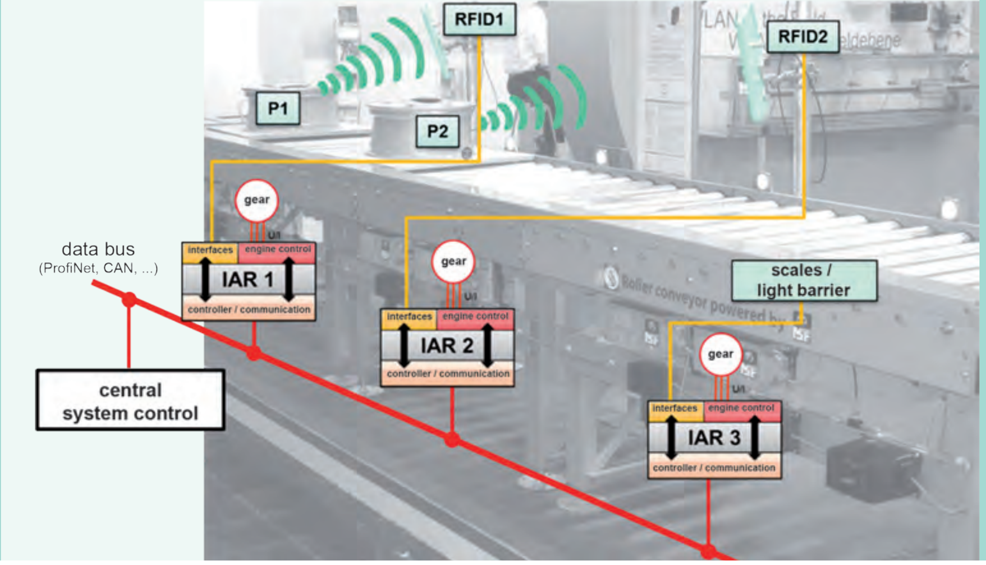
The second article is dedicated to monitoring ambient air or other gases. In the framework of the ENIAC project ESEE (Environmental Sensors for Energy Efficiency), a spectrometric measurement procedure for the oxygen concentration in gases was developed and tested in cooperation with the partners from Infineon, Airbus and the Friedrich-Alexander University of Erlangen-Nürnberg.

Fraunhofer ENAS conducts comprehensive research and development in order to manufacture components for printed intelligent systems. The third article includes the digital roll-to-product production of flexible, printed smart systems.

Smart Production adressiert die Entwicklung von Systemlösungen im Bereich der Industrie 4.0. Kernthemen sind neben der Integration von Sensoren mittels Plug and Play in realen Produktionsumgebungen das Zustands- oder Umweltmonitoring basierend auf Mikrosystemen einschließlich optimierter Datenanalyse und Kommunikation der Daten.
Fraunhofer ENAS arbeitet in den Schwerpunkten:

- Zustandsmonitoring von Verbrauchsmitteln und Anlagen im Maschinenbau
- Sensorintegration in Anlagenkomponenten
- Monitoring in der Logistik (Transportmonitoring, Monitoring im Lager, ...)
- Herstellung flexibler gedruckter Systeme
- Plagiatschutz
- Zuverlässigkeitsanalysen, Bruchmechanik.

Die drei nachfolgenden Artikel stellen unterschiedliche Themen vor.
Der erste Artikel adressiert die Überwachung der thermischen Belastung von Antriebseinheiten in Förderanlagen. Basierend auf einer intelligenten Aufbereitung der Sensorsignale ist die Erstellung langfristiger Lastprofile bzw. eine frühzeitige Warnung vor verschleißbedingten Ausfällen möglich.
Der zweite Artikel widmet sich der Überwachung von Raumluft oder anderen Gasen. Im Rahmen des ENIAC-Projekt ESEE (Environmental Sensors for Energy Efficiency) ist zusammen mit den Partnern von Infineon, Airbus und der Friedrich-Alexander Universität Erlangen-Nürnberg ein spektrometrisches Messverfahren für die Sauerstoffkonzentration in Gasen entwickelt und erprobt worden.
Fraunhofer ENAS führt umfangreiche Forschungs- und Entwicklungsleistungen durch, um Komponenten für gedruckte intelligente Systeme herzustellen. Der dritte Artikel beinhaltet die digitale Rolle-zu-Produkt-Herstellung von flexiblen gedruckten Smart Systems.



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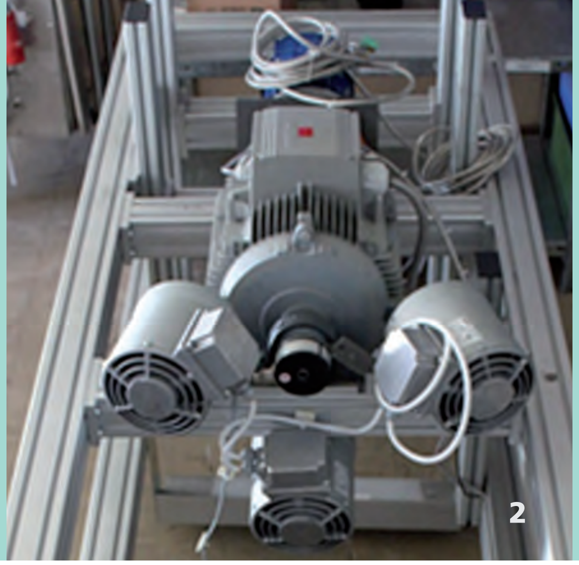

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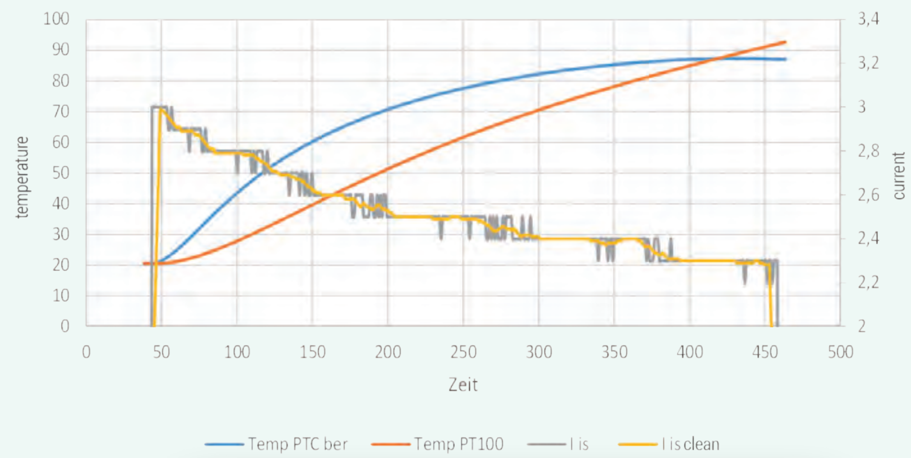

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INTELLIGENT INDUSTRIAL DRIVE AND FLEXIBLE MANUFACTURING BASED ON WORKPIECE DATA AND SENSOR INFORMATION

Volker Geneiß, Marc Ebmeyer, Christian Hedayat

Introduction

In many areas of industrial manufacturing and transportation processes, an increasing heterogeneity of the distribution of goods up to a one piece-workflow is observed. The action of driving and lifting these goods within the production chain plays a central role in optimizing the automated processes and logistics.

Traditional drive and lifting elements are usually designed for the maximum load or the worst case without considering the possibility of a dynamic operation adjustment as a function of the processed good which may have different physical parameters such as dimension, weight, and material. Indeed, a decentralized, adaptive adjustment of the control drive systems makes it possible to optimize the production and/or logistic line in terms of energy consumption, downtime, wearout and cycle times while allowing the processing status to be tracked and estimated in real time. This is one major aspect of the so called industrial revolution 4.0.

Adaptable analog and digital interfaces are integrated in the actuator modules enabling a cost-effective detection of product parameters based on sensors that already exist in the system or that can be integrated easily. Figure 1 shows such an approach, in which the different products (P1, P2) can communicate directly via a bidirectional wireless communication with the intelligent drive units (IAR1, IAR2). Similarly, plant-based information supplied by weighing machines and photocells are covered (IAR3). By transmitting product data and parameters between the workpiece and the drive unit, the developed model-based optimization, control and diagnostic algorithms of the actuators can be easily re-parameterized on-the-fly.

Condition monitoring of drive units

Drive units in conveyors are subjected to high loads and an associated wearout. In order to avoid production downtimes due to sudden and unforeseen defects, the thermal load of these components should be continuously monitored. The nonlinear PTC thermistors implemented in drive units actually only allow emergency detection of a critical operating temperature. Thus, an intelligent processing of the sensor signals for the continuous load monitoring is essential, creating long-term load profiles or generating an early warning information. Thus, the motor itself becomes a sensor of the system.

Contact:
Dr. Christian Hedayat
phone: +49 5251 60-5630
e-mail: christian.hedayat@enas-pb.fraunhofer.de

The recorded PTC curves show relatively similar variations of the PTC resistance versus temperature for all sensors. However, a significant offset shift of up to 20 Ω can be seen at room temperature. Without correction, this corresponds to an equivalent uncertainty of about 20 K.

For further investigations, the industrial partner MSF Vathauer provided a test motor with an associated frequency converter. Based on this test rig, several experiments were made to assess the temperature behavior of various sensors. The evaluation of the sensed parameters happened via a serial interface to the frequency converter as well as by the use of external laboratory measuring devices.

All data have been merged into a specially written measurement software and a measuring concept was developed including the coil resistance of the motor winding as a calibration reference. Thus, an auto calibrated measurement system could be designed that trains the individual calibration curve of an unknown motor sensor during normal operation. Due to the new possibility of precise monitoring of engine temperature without implementing additional sensors in the drives, the partner MSF Vathauer can offer its clients an enormous added value in the field of condition monitoring of equipment with minimal additional cost.

Antriebseinheiten in Förderanlagen sind hohen Belastungen und einem damit verbundenen Verschleiß ausgesetzt. Um Produktionsausfälle durch unvorhergesehene Defekte zu vermeiden, müssen die thermische Belastung dieser Komponenten kontinuierlich überwacht werden. Die im Antrieb implementierten nichtlinearen PTC-Thermistoren erlauben derzeit nur eine Notfalldetektion einer kritischen Betriebstemperatur. Im Sinne der industriellen Revolution 4.0 ist daher eine intelligente Aufbereitung der Sensorsignale zur kontinuierlichen Lastüberwachung in einem möglichst breiten Einsatzbereich von hoher Relevanz. Damit wird die Erstellung langfristiger Lastprofile bzw. eine frühzeitige Warnung vor verschleißbedingten Ausfällen ermöglicht. Der Motor wird so zum Sensor in der Anlage.

References

[1] Regtien, P. P. L.: Sensors for Mechatronics. Elsevier, 2012.
[2] Meyer zu Hoberge, S.; Hilleringmann, U.; Jochheim, C.; Liebich, M.: Piezoelectric Sensor Array with Evaluation Electronic for Counting Grains in Seed Drills. Africon 2011. ISSN: 2153-0025

1 *Schematic diagram of an internal logistics process using the example of a rim production with intelligent drive control (IAR).*

2 *Typical drive unit.*

3 *Temperature and current within the electrical drive.*

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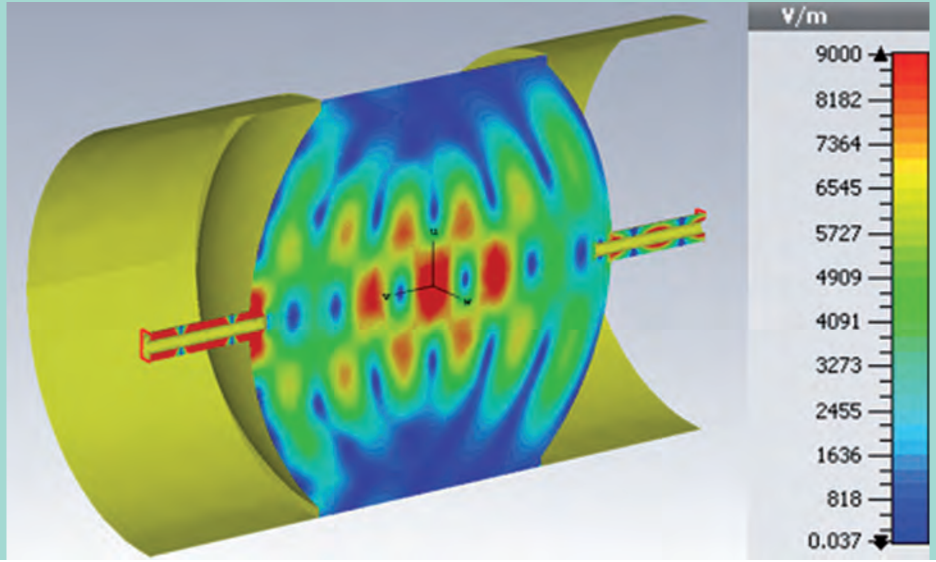

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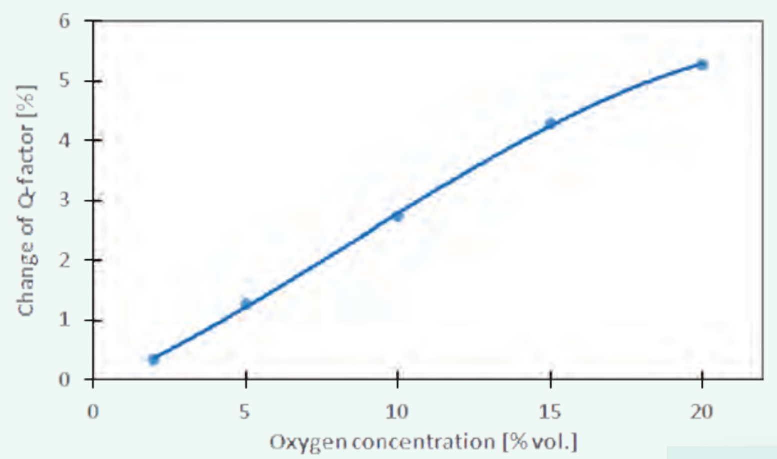

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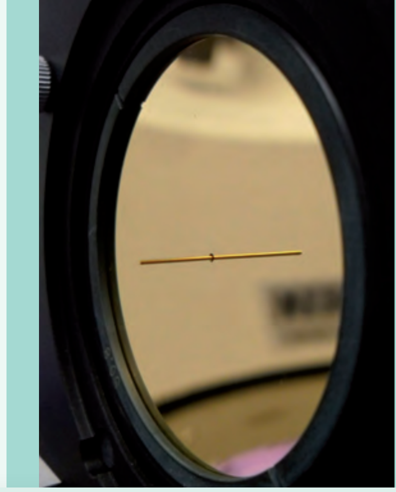

OXYGEN MEASUREMENT BY CAVITY-ENHANCED MM-WAVE SPECTROSCOPY

Julia Wecker, Markus Gaitzsch, Steffen Kurth

A cavity enhanced millimeter-wave absorption spectrometer for oxygen concentration measurement was developed in the framework of the ENIAC project ESEE (Environmental Sensors for Energy Efficiency) together with partners from Airbus, Infineon and the Friedrich-Alexander University Erlangen-Nürnberg. The application background is the analysis and control of the air quality in buildings and vehicles and an energy efficient air conditioning.

The oxygen measurement system consists of a resonator of the Fabry-Pérot type that is used as a sample cell, of an integrated mm-wave micro transceiver, and of coupling means to connect the resonator to the transceiver. The air in the sample cell is influencing the quality factor of the resonances at oxygen specific frequencies by the content of oxygen. Oxygen shows a significant absorption peak at frequencies around 60.6 GHz and leads to a concentration dependent damping of the resonator which is used as a measure for the oxygen concentration. To achieve a compact sensor system, the concept envisages two integrated transceiver circuits.

In order to achieve a practically relevant sensitivity, the resonator is designed to virtually increase the absorption path by its quality factor. Therefore, a high quality factor is desired. The Fabry-Pérot resonator operates at high-order resonant modes to cover the wavelength range between 50 GHz and 70 GHz by multiple resonances with a peak density of approximately 1.33 GHz. It consists of two metal mirrors with a diameter of 50 mm. The quality factor is influenced by the mirror size, by the roughness and the surface conductance of the mirror surface, and by the damping caused by the coupling to the transceiver ports. In contrast to former work, which uses coupling foils in between the both mirrors of the Fabry-Pérot resonator and external antennas, a coaxial coupling principle is used here. Two stubs, connected to the signal input and output ports of the transceiver, are located in the center of each of the mirrors respectively. They are directly connected to the coaxial ports of the transceiver. The penetration length of the stubs inside the Fabry-Pérot resonator influences the coupling strength and the damping of the resonator as well.

The stubs have a 0.6 mm diameter and are mechanically supported either by flange launchers which are fixed at the back side of the mirrors or by interposers made of high-frequency PCB substrate.

Contact:
Prof. Dr. Thomas Otto
phone: +49 371 45001-231
e-mail: thomas.otto@enas.fraunhofer.de

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

The integrated SiGe frontends of the transceiver address a frequency band from 50 GHz to 70 GHz. They are realized as heterodyne structures with integrated directional couplers, thus it is possible to measure the same parameters as with a commercial Vector Network Analyzer. The transceiver performs a frequency sweep over the desired range and allows the normalization of the amplitudes and limits the risk of cross sensitivity to other components in the air.

Testing the system, a first resonator sample was coupled to a commercial vector network analyzer for transmission measurements. The resonance peaks have a magnitude between –20 dBm and –40 dBm. Different oxygen concentrations were measured in a concentration range of 0 % … 20 %, resulting in a decrease of amplitude and bandwidth of the resonant peaks at higher oxygen concentration.

Due to the sensor principle without hot parts, an application within sensitive areas, e.g. inside of fuel tanks is possible. The sensor may also be used for detection of other gases with high absorption coefficients in the millimeter wave range (ammonia, sulfur dioxide).

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Ein spektrometrisches Messverfahren für die Sauerstoffkonzentration in Gasen wurde im ENIAC-Projekt ESEE (Environmental Sensors for Energy Efficiency) zusammen mit Partnern von Infineon, Airbus und der Friedrich-Alexander Universität Erlangen-Nürnberg entwickelt und erprobt. Es arbeitet auf der Basis eines mit dem zu messenden Gas gefüllten Fabry-Pérot-Resonators im Frequenzbereich 50 GHz … 70 GHz. Der Resonator vergrößert virtuell die Absorptionsweglänge des Spektrometers um den Wert seines Gütefaktors, so dass eine praktisch verwertbare Empfindlichkeit erreicht wird. Zwei integrierte Transceiver sind direkt an den Fabry-Pérot-Resonator angekoppelt. Im Gegensatz zu bisher publizierten Arbeiten wird hier anstelle von Koppelfolien und Antennen mit einer axialen Kopplung durch zwei Stubs im Zentrum der Reflektoren des Resonators gearbeitet, wodurch eine wesentliche Verkleinerung des Bauraumes zustande kommt. Erste Messungen mit einem kommerziell verfügbaren Netzwerkanalysator am Resonator zeigen, dass die Sensitivität für die Detektion von Sauerstoff im Konzentrationsbereich 2 % … 20 % ausreichend hoch ist. Anwendungsmöglichkeiten werden neben dem Raumluftmonitoring in Fahrzeugen und Gebäuden vor allem zur Messung der Sauerstoffkonzentration in Treibstofftanks gesehen, da das hier eingesetzte Verfahren im Gegensatz zu den meisten Sauerstoffsensoren keine beheizten Bauteile benötigt. In anderen Frequenzbereichen würde mit dem gleichem Prinzip auch Ammoniak oder Schwefeldioxid detektierbar sein.

1 *Model of the FP resonator and distribution of the E-field in the resonator.*

2 *Measured change of the quality factor at different oxygen concentrations.*

3 *Photography of one of the reflectors with the axial coupling stub.*

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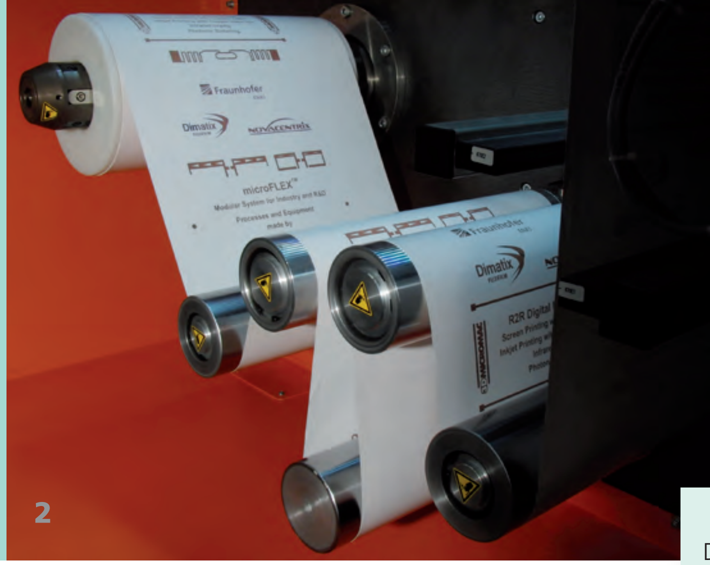

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DIGITAL ROLL-TO-PRODUCT MANUFACTURING OF FLEXIBLE PRINTED SMART SYSTEMS

Andreas Willert, Ralf Zichner, Reinhard R. Baumann

The digital roll-to-product manufacturing of flexible printed smart systems requires comprehensive know-how, technology expertise and a suitable production line with all the appropriate manufacturing techniques. In this respect, Fraunhofer ENAS carries out extensive research and development to demonstrate for the industry a top-notch technology concept based on an approved pilot production line for the manufacturing of components of printed smart systems: printed conductive paths, antenna systems, and sensors. Particular attention is paid to the combination of digital, material-efficient printing processes and high speed sintering techniques.

The installed pilot line microFLEX™ (Fig. 1) consists (from left to right) of an unwinder, a screen printing unit (spgprints®), a digital inkjet module (Fujifilm Dimatix SAMBA™ head technology), a UV-LED array, an IR curing unit (Heraeus), a digital intense pulsed light (IPL) photonic sintering device (Novacentrix® Ltd.) and a rewinder.

One of the major competences of the department Printed Functionalities is the processing (printing and sintering) of functional inks (e.g. based on metal particles and polymers). These inks require a special, often technologically complex treatment after printing to achieve the desired functionality like electrical conductivity, semi-conductivity, or insulation.

High-speed functionalization/sintering of inks

Functional inks consist of several ingredients: e.g. metal nano particles to generate conductivity, additives (e.g. polymers) to stabilize the ink, and solvent mixtures to tune the viscosity to the chosen printing technology. For the targeted functionality of electrical conductivity the metal nanoparticles are essential, while all other ingredients are solely determined by the printing process itself but they usually decrease or even prevent the conductivity. Therefore, these ingredients have to be removed from the printed layer. Thermal or IR treatment can eliminate most of the solvents. To get rid of the remaining polymers more sophisticated technologies like IPL are necessary. These technologies help to fuse the isolated nanoparticles to solid metal layers by sintering which are electrically conductive.

Contact:
Prof. Dr. Reinhard R. Baumann
phone: +49 371 45001-234
e-mail: reinhard.baumann@enas.fraunhofer.de

Dr. Andreas Willert
phone: +49 371 45001-441
e-mail: andreas.willert@enas.fraunhofer.de

Our solution is the combination of near infrared (NIR) and intense pulsed light (IPL) photonic sintering technology in one roll-to-product manufacturing line to interlink the isolated metal nanoparticles. By this combination of sintering technologies a defined energy is applied to the printed pattern on a micro to millisecond timescale. This ensures a heat up and melting of particles generating a conductive pattern.

The short time scale for this sintering process allows a high-speed production of flexible printed smart systems with a throughput of 1 m²/min.

Ongoing research and development

Driven by our customer needs, research and development is focused on:

- Smart systems applications on flexible and temperature sensitive substrates like polyethylene terephthalate – PET: The challenge is the PET substrate temperature limitation of only 110 °C which requires new methods for sintering of printed patterns which must be done at temperatures of up to 1000 °C (functional ink dependent).
- The printability of new functional inks: The challenge is the adjustment of printing process parameters in respect of ink parameters like viscosity, particle sizes, binders as well as the adhesion on the substrate.
- Sintering techniques for new functional inks and different kinds of flexible substrates: The challenge is to obtain specified functional layers with reliable adhesion to the substrate.

Die digitale Rolle-zu-Produkt-Herstellung von flexiblen gedruckten Smart Systems erfordert umfassendes Know-how, Technologiekompetenz sowie eine geeignete Produktionslinie, die alle geeigneten Herstellungstechniken beinhaltet. In dieser Hinsicht führt Fraunhofer ENAS umfangreiche Forschungs- und Entwicklungsleistungen durch, um Komponenten für gedruckte intelligente Systeme herzustellen. Hierzu zählen gedruckte Leiterbahnen, Antennensysteme und Sensoren (Abb. 2). Besondere Aufmerksamkeit wird dabei auf die Kombination von digitalen, materialsparenden Druckverfahren und Hochgeschwindigkeitssintertechniken gelegt.

Die dafür installierte Pilotlinie microFLEX™ (Abb. 1) besteht aus (von links nach rechts): einem Abwickler, einer Siebdruckeinheit (spgprints®), einem digitalen Inkjet-Modul (Fujifilm Dimatix SAMBA™), einem UV-LED-Array, einer IR-Einheit (Heraeus), einer digitalen Intense Pulsed Light (IPL) photonischen Sintereinheit (Novacentrix® Ltd.) und einem Aufwickler.

Eine der wichtigsten Kompetenzen der Abteilung Printed Functionalities ist die Verarbeitung (Drucken und Sintern) von funktionellen Tinten (z. B. auf Basis von Metallpartikeln oder Polymeren). Diese Tinten erfordern eine spezielle, oft technologisch komplexe Behandlung nach dem Druckverfahren, um die gewünschte Funktionalität wie die elektrische Leitfähigkeit, Halbleitfähigkeit oder Isolation zu erzielen.

1 *Fraunhofer ENAS pilot line microFLEX™.*
2 *Printed, electrical conductive patterns for smart systems.*


85 MEMBERSHIPS
173 PUBLICATIONS
76 CONFERENCES
34 LECTURES
5 DISSERTATIONS
9 PATENTS
17 EXHIBITIONS AND TRADE FAIRS
24 PRESS INFORMATION

ATTACHMENT

EVENTS

Chemnitz workshops on Nanotechnology, Nanomaterials and Nanoreliability

The Chemnitz workshop series on Nanotechnology, Nanomaterials and Nanoreliability have been successfully continued in 2015. The first one was the workshop "Medical Engineering – miniaturized analytics and diagnostics" on March 25, which has been commonly organized with Silicon Saxony, biosaxony and GWT. The department System Packaging invited to the workshop "System Integration Technologies" on June 23 and 24, 2015. Fraunhofer researchers and guests discussed about current research and development results on wafer bonding and packaging technologies. On September 28, 2015, the department Micro Materials Center organized a workshop on reliability research for smart systems.

International conferences and workshops

At the 9th Smart Smart Systems Integration Conference and Exhibition, 271 attendees discussed about smart systems, manufacturing technologies, integration technologies, and applications. The annual Micromachine Summit has been organized by the German chief delegate Professor Thomas Gessner. 70 delegates from 18 countries and regions met in Berlin in May 2015, in order to discuss about current developments in their countries/regions, the internet of things and especially smart systems for manufacturing and factory automation.
For the first time ISMOT 2015 – International Symposium on Microwave and Optical Technology took place in Germany. Scientists from 15 nations attended the conference in Dresden from June 29 to July 1.
For the 6th time, Fraunhofer ENAS organized the Minapim in Manaus, Brazil. The topic was smart monitoring for agriculture, industrial, environmental, and health applications.
The 11th Fraunhofer Symposium in Sendai was held on November 27, 2015. The Fraunhofer Symposium addresses especially nanotechnologies as well as the cooperation with Fraunhofer-Gesellschaft.

Chemnitzer Seminare

Die Chemnitzer Seminarreihe „Chemnitzer Seminare – Nanotechnology, Nanomaterials and Nanoreliability" wurde 2015 erfolgreich weitergeführt. Sie startete mit dem gemeinsamen Workshop seitens Silicon Saxony, biosaxony und GWT zum Thema „Medizintechnik – Miniaturisierte Analytik und Diagnostik" am 25. März 2015. Fortgesetzt wurde die Reihe am 23. und 24. Juni durch die Abteilung System Packaging mit dem Thema „System Integration Technologies". Auf der Ganztagesveranstaltung stellten Fraunhofer-Wissenschaftler und Gäste aktuelle Forschungs- und Entwicklungsergebnisse zu Waferbondverfahren und Packaging-Technologien vor. Den Abschluss bildete am 28. September 2015 das seitens Micro Materials Center organisierte Seminar zur Zuverlässigkeitforschung für Smart Systems.

Internationale Konferenzen und Workshops

Die neunte Smart Systems Integration Konferenz fand im März 2015 in Kopenhagen, Dänemark statt. 271 Teilnehmer aus 21 Ländern diskutierten über intelligente Systeme, Herstellungstechnologien, Integration und Anwendungen. Das jährliche Treffen der weltweiten Experten im Bereich Mikrosystemtechnik, das Micromachine Summit wurde 2015 vom Chefdelegierten der deutschen Delegation, Prof. Thomas Gessner, organisiert und veranstaltet. 70 Delegierte aus 18 Länder und Regionen trafen sich im Mai 2015 in Berlin, um über die Entwicklungen in den Ländern und Regionen, das Internet der Dinge und speziell Smart Systems for Manufacturing and Factory Automation zu diskutieren. Erstmalig in Deutschland fand vom 29. Juni bis 1. Juli 2015 die ISMOT 2015 – International Symposium on Microwave and Optical Technology – in Dresden statt. Der Einladung folgten Teilnehmer aus 15 Nationen. Bereits zum sechsten Mal organisierte Fraunhofer ENAS die Minapim in Manaus Brasilien. 2015 stand sie unter dem Motto "Smart Monitoring for Agriculture, Industrial, Environmental and Health Applications". Zum elften Mal wurde unter Chemnitzer Federführung das Fraunhofer-Symposium in Sendai am 27. November 2015 organisiert. Es stand unter dem Thema Nanotechnologien und Kooperation mit der Fraunhofer-Gesellschaft.

Science meets Arts

Fraunhofer ENAS published the book "Science meets Arts" about its art exhibition series after the 10th exhibition. It shows a selection of the artworks, graphics, paintings, and sculptures we showed in the exhibitions at Fraunhofer ENAS since 2010.
The 11th show was the first exhibition of a photographer. Dirk Hanus presented people and rooms as main theme within his artwork. In fall we remembered Heinz Tetzner, a famous graphic artist and painter who died in 2007. His daughter and the Neue Sächsische Galerie in Chemnitz supported the show with artworks. In November we invited to a gallery talk with people who accompanied his life. Our curator Georg Felsmann talked to Brigitta Milde from the Kunstsammlungen Chemnitz and the painters Klaus Hirsch and Siegfried Otto-Hüttengrund about the work of Heinz Tetzner as a part in contemporary history.

Fraunhofer ENAS introduced the Science meets Art series also in a public exhibition. With the theme "Arbeit – Wohlstand – Schönheit" projects of arts, sports, and education were presented to the public in a shopping mall in downtown Chemnitz.

Chemnitz City Run

A team of 24 employees of Fraunhofer ENAS and the Center for Microtechnologies of TU Chemnitz started at the Chemnitz City Run 2015. Our team consisted of four women and 20 men reaching the finish among 6007 runners. Our best male starter finished as 86th and our best female as 267th. Our best team of four men finished as 14th and the best female team as 59th. Congratulation – we are looking forward to the next years Chemnitz City Run!

Wissenschaft trifft Kunst

Fraunhofer ENAS publizierte nach der zehnten Ausstellung das Buch „Wissenschaft trifft Kunst" über die gleichnamige Ausstellungsreihe am Institut. Es zeigt eine Auswahl an Kunstobjekten, Grafiken, Malerei und Skulpturen, die in den Ausstellungen seit 2010 am Fraunhofer ENAS gezeigt wurden. Die elfte Ausstellung war gleichzeitig die erste Ausstellung eines Fotografen. Dirk Hanus präsentierte Menschen und Räume als zentrale Themen seiner Arbeiten.
Im Herbst erinnerten wir an Heinz Tetzner, einem berühmten Grafiker und Maler, der 2007 verstarb. Seine Tochter und die Neue Sächsische Galerie in Chemnitz stellten für die Ausstellung verschiedene Arbeiten von Heinz Tetzner zur Verfügung. Im November luden wir zum Galeriegespräch mit Wegbegleitern Tetzners ein. Unser Kurator Georg Felsmann sprach mit Brigitta Milde von den Kunstsammlungen Chemnitz und den Malern Klaus Hirsch und Siegfried Otto-Hüttengrund über die Arbeit Heinz Tetzners als ein Stück Zeitgeschichte.
In einer öffentlichen Ausstellung unter dem Thema „Arbeit – Wohlstand – Schönheit" präsentierte das Fraunhofer ENAS in der Chemnitzer Innenstadt die Ausstellungsreihe „Wissenschaft trifft Kunst" der breiten Öffentlichkeit.

Chemnitzer Firmenlauf

Zum Chemnitzer Firmenlauf 2015 startete eine 24-köpfiges Team des Fraunhofer ENAS und des Zentrums für Mikrotechnologien der TU Chemnitz. Die vier Läuferinnen und 20 Läufer unseres Teams erreichten unter insgesamt 6007 Teilnehmern gute Platzierungen. In der Einzelwertung belegte unser bester Läufer insgesamt Platz 86 und unsere beste Läuferin Platz 267. Unser bestes Vierer-Team der Männer erreichte Platz 14 und das Team der Frauen Platz 59. Wir gratulieren und freuen uns auf den nächsten Chemnitzer Firmenlauf!

CONFERENCES

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

Smart Systems Integration Conference – co-organizer	Copenhagen, Denmark	March 11–12, 2015
World Micromachine Summit 2015	Berlin, Germany	May 10–13, 2015
Conference "MicroClean 2015"	Dresden, Germany	May 19–20, 2015
ISMOT 2015	Dresden, Germany	June 29–July 1, 2015
ENDOR Workshop	Chemnitz, Germany	September 24, 2015
Printing Future Days 2015	Chemnitz, Germany	October 5–7, 2015
Autumn School of Printed Functionalities	Chemnitz, Germany	October 8–9, 2015
CMP Wet User Meeting	Regensburg, Germany	October 29–30, 2015
3rd European Expert Workshop on Reliability of Electronics and Smart Systems – 2015 EuWoRel	Berlin, Germany	November 3–4, 2015
11th Fraunhofer Symposium	Sendai, Japan	November 27, 2015

In 2015 the scientists of Fraunhofer ENAS presented their results at 76 conferences and exhibitions accompanying conferences. The following table gives a selection of conferences and workshops our scientists showed their research and project results. Moreover, papers have been presented at all conferences listed in the table above.

nano tech 2015	Tokyo, Japan	January 28–30, 2015
SPIE Photonics West	San Francisco, USA	February 7–12, 2015
The AIMR International Symposium 2015	Sendai, Japan	February 16–19, 2015
FlexTEch Alliance 2015 Flexible & Printed Electronics Conference & Exhibition	Monterey, USA	February 23–26, 2015
LOPEC 2015 Large-area, Organic & Printed Electronics Convention	Munich, Germany	March 2–4, 2015
13th Symposium Magnetoresistive Sensors and Magnetic Systems	Wetzlar, Germany	March 3–4, 2015
IWEPNM 2015 – International Winterschool on Electronic Properties of Novel Materials	Kirchberg in Tirol, Austria	March 7–14, 2015
SPIE Smart Structures/NDE 2015	San Diego, USA	March 9–14, 2015

CONFERENCES

China Semiconductor Technology International Conference (CSTIC) 2015 and Suss Technology Forum	Shanghai, China	March 15–16, 2015
DPG-Frühjahrstagung der Sektion Kondensierte Materie (SKM) (DPG Spring Meeting)	Berlin, Germany	March 15–20, 2015
IEEE International Conference on Signal Processing and Communication (ICSC)	Noida, India	March 16–18, 2015
46th Lunar and Planetary Science Conference	The Woodlands, USA	March 16–20, 2015
ISISS 2015 – IEEE International Symposium on Inertial Sensors and Systems	Hapuna Beach, USA	March 23–26, 2015
MRS Spring 2015	San Francisco, USA	April 6–10, 2015
EuroSimE 2015 – International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems	Budapest, Hungary	April 20–22, 2015
IDTechEx Printed Electronics	Berlin, Germany	April 27–28, 2015
PESM – Plasma Etch And Strip In Microtechnology	Leuven, Belgium	April 27–28, 2015
E-MRS	Lille, France	May 11–15, 2015
MAM 2015 – Materials for Avanced Metallization	Grenoble, France	May 18–21, 2015
HOSPITALAR 2015	São Paulo, Brazil	May 22, 2015
Transducers 2015 – 18th International Conference on Solid-State Sensors, Actuators and Microsystems	Anchorage, USA	June 21–25, 2015
ALD 2015 – 5th International Conference on Atomic Layer Deposition	Portland, USA	June 28–July 2, 2015
NT15 – Science and Application of Nanotubes	Nagoya, Japan	June 29–July 3, 2015
MEMSWAVE 2015	Barcelona, Spain	June 30, 2015
ICM 2015 – 20th International Conference on Magnetism	Barcelona, Spain	July 5–10, 2015
18. Tagung Festkörperanalytik	Vienna, Austria	July 6–8, 2015
Summer School on ALD	Brescia, Italy	July 6–10, 2015
AMAA 2015 – 19th International Forum on Advanced Microsystems for Automotive Applications	Berlin, Germany	July 7–8, 2015
IEEE NANO 2015 – INTERNATIONAL CONFERENCE ON NANOTECHNOLOGY	Rome, Italy	July 27–30, 2015

CONFERENCES

SPIE Optics + Photonics	San Diego, USA	August 9–13, 2015
International Conference on Diamond and Carbon Materials	Bad Homburg, Germany	September 6–10, 2015
Psi-K 2015 Conference	San Sebastian, Spain	September 6–10, 2015
Microscopy conference	Göttingen, Germany	September 6–11, 2015
5th CEAS Air & Space Conference	Delft, The Netherlands	September 7–11, 2015
Advanced Metallization Conference	Austin, USA	September 9–10, 2015
20th European Microelectronics and Packaging Conference (EMPC)	Friedrichshafen, Germany	September 14–16, 2015
DGO Oberflächentage	Berlin, Germany	September 23–25, 2015
Therminic 2015	Paris, France	September 30–October 2, 2015
International MERGE Technologies Conference for Lightweight Structures	Chemnitz, Germany	October 1–2, 2015
SFB953 – Symposium on Synthetic Carbon Allotropes	Erlangen, Germany	October 4–7, 2015
Nanomercosur	Buenos Aires, Argentina	October 6–8, 2015
Plastic Electronics Conference Europe	Dresden, Germany	October 6–8, 2015
ILaCoS – International Laser and Coating Symposium	Dresden, Germany	October 7, 2015
International Wafer-Level Packaging Conference – IWLPC 2015	San Jose, USA	October 13–15, 2015
9th MNBS Consultation and Concertation workshop on Micro-Nano-Bio Convergence Systems	Leuven, Belgium	October 14–15, 2015
7th European Aeronautic Days 2015	London, UK	October 20–23, 2015
MikroSystemTechnik Kongress 2015	Karlsruhe, Germany	October 26–28, 2015
COMPAMED 2015 / IVAM Forum	Düsseldorf, Germany	November 16–19, 2015

EXHIBITIONS AND TRADE FAIRS

European 3D TSV Summit 2015	Grenoble, France	January 19–20, 2015
nano tech 2015	Tokyo, Japan	January 28–30, 2015
LOPEC 2015	Munich, Germany	March 4–5, 2015
Smart Systems Integration 2015	Copenhagen, Denmark	March 11–12, 2015
SEMICON China 2015	Shanghai, China	March 17–19, 2015
HANNOVER MESSE 2015	Hanover, Germany	April 13–17, 2015
nano micro biz 2015	Yokohama, Japan	April 22–24, 2015
SENSOR + TEST 2015	Nuremberg, Germany	May 19–21, 2015
HOSPITALAR 2015	Sao Paulo, Brazil	May 19–22, 2015
Le Bourget – Paris Air Show 2015	Paris, France	June 15–21, 2015
SEMICON Russia 2015	Moscow, Russia	June 17–18, 2015
10th Silicon Saxony Day 2015	Dresden, Germany	July 7, 2015
SEMICON West 2015	San Francisco, U.S.A.	July 14–16, 2015
SEMICON Europa 2015	Dresden, Germany	October 6–8, 2015
MST-Kongress 2015	Karlsruhe, Germany	October 26–28, 2015
Feira Internacional da Amazônia – FIAM 2015	Manaus, Brazil	November 18–21, 2015
COMPAMED 2015	Düsseldorf, Germany	November 16–19, 2015

PATENTS

Fraunhofer ENAS holds 117 patents in 75 families. Moreover, employees of Fraunhofer ENAS belong to the inventors of additional 13 patent families held by industry.
In 2015 the following patents have been published or granted:

Title: Microstructure, Method for Producing the Same, Device for Bonding a Microstructure and Microsystem
Number: JP 5807292 B2

Title: Electrostatically actuated micro-mechanical switching device
Number: CN 102290289 B

Title: Sensormodul mit Weckeinrichtung
Number: EP 2 646 837 B1

Title: Highly efficient gas phase reduction of ultrathin copper oxide films due to introduction of catalytically active ruthenium
Number: US 9,005,705 B2

Title: Metallischer Trägerkörper mit Transponder
Number: DE 102011087928

Title: Integrierte Ausfall-Frühindikatoren
Number: DE102015210851.1

Title: Integrated Canary Features
Number: EP15162264.4

Title: Verfahren zur Material- bzw. Bauteilcharakterisierung durch den Einsatz integrierter nanoskalierter und exotherm reagierender Systeme
Number: DE 102015111328.7

Title: Bauteil zur Steuerung der Lichtintensität und Verfahren zur Herstellung
Number: DE 800446761

MEMBERSHIPS

Memberships of Fraunhofer ENAS Scientists (selection)

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, USA	Prof. S. E. Schulz	member of the executive committee
ALD Lab Saxony	Prof. S. E. Schulz, Dr. C. Georgi	members
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
Conference on Wafer Bonding for Microsystems and Wafer Level Integration	Dr. M. Wiemer	committee 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	fellow
Dresden Center for Computational Materials Science (DCCMS)	Prof. T. Gessner, Prof. S. E. Schulz, Dr. J. Schuster	members
Dresdner Fraunhofer Cluster Nanoanalytics	Prof. S. Rzepka, Dr. D. Vogel	steering committee members
ECSEL	Prof. T. Gessner	delegation member governing board
Engineering and Physical Science Research Council, UK	Prof. B. Michel	referee
EPoSS (European Platform on Smart Systems Integration)	Prof. T. Gessner Prof. T. Otto, Prof. S. Rzepka	member of the board members of the executive committee
European Center for Micro- and Nanoreliability (EUCEMAN)	Prof. B. Michel Prof. S. Rzepka, Prof. B. Wunderle, J. Hussack	president committee members
European MEMS Summit	Dr. M. Vogel	committee member
EuroSimE Conference	Prof. S. Rzepka, Prof. B. Wunderle, Dr. R. Dudek	members of the conference committee
German Science Foundation	Prof. T. Gessner	referee
Humboldt Foundation	Prof. B. Michel	referee
Heterogeneous Technology Allicance SOI MEMS	Dr. M. Wiemer	Fraunhofer representative

MEMBERSHIPS

International Conference ICEPT, Shanghai, China	Dr. J. Auersperg	technical committee member
International Conference IPTC, Singapore	Dr. J. Auersperg	technical committee member
International Conference on Planarization/CMP Technology	Dr. K. Gottfried	program committee member
IS&T – Society for Imaging Science & Technologies	Prof. R. R. Baumann	vice president
ITherm Conference	Prof. B. Wunderle, Dr. R. Dudek	program committee members
Large-area, Organic and Printed Electronics Convention, LOPEC	Prof. R. R. Baumann	scientific board and advisory board
Materials for Advanced Metallization MAM	Prof. S. E. Schulz	member of scientific program committee
MEMS Industry Group, Executive Congress Europe	Dr. M. Vogel	committee member
MEMUNITY	Dr. S. Kurth	member of executive committee
Microsystems Technology Journal	Prof. B. Michel	editor-in-chief
Materials Research Society (MRS)	Prof. R. R. Baumann, Dr. A. Willert, Dr. T. Blaudeck, Dr. S. Hermann	members
National Research Agency, France	Prof. B. Michel	referee
NEWCAS 2015 – 13th IEEE International NEW Circuits And Systems (NEWCAS) conference	Dr. C. Hedayat	referee
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	Dr. M. Vogel	program committee member of MEMS session
Silicon Saxony e. V.	Prof. T. Gessner, Prof. S. E. Schulz Prof. T. Gessner, Dr. M. Vogel	members of scientific board leaders of work group Smart Integrated Systems
Smart Systems Integration Conference	Prof. T. Gessner Prof. T. Otto, Prof. S. Rzepka, Dr. C. Hedayat, Prof. K. Hiller, Prof. R.R. Baumann	conference chair members of program committee
Swiss National Foundation	Prof. B. Michel	referee
Therminic Workshop	Prof. B. Wunderle	conference chair
Waferbond Workshop 2015	Dr. M. Wiemer	member in organizer board

MEMBERSHIPS

Memberships of Fraunhofer ENAS

AGENT-3D e. V.	Dresden, Germany
ALD Lab Dresden	Dresden, Germany
Cool Silicon e. V.	Dresden, Germany
Dresdner Fraunhofer-Cluster Nanoanalytik	Dresden, Germany
Eureka Cluster Metallurgy Europe	Ulm, Germany
European Center for Micro and Nanoreliability EUCEMAN	Berlin, Germany
European Platform on Smart Systems Integration EPoSS	Berlin, Germany
Fraunhofer-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
Micromachine Center	Tokyo, Japan
Nano Technology Center of Competence "Ultrathin Functional Films"	Dresden, Germany
Organic Electronics Association OE-A	Frankfurt/Main, Germany
Organic Electronics Saxony e. V. OES	Dresden, Germany
Semiconductor Equipment and Materials International (SEMI)	San Jose, USA
Silicon Saxony e. V.	Dresden, Germany

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BOOKS

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Gaebler, C.; Schliebe, C.; Adner, D.; Blaudeck, T.; Hildebrandt, A.; Lang, H.: Chapter Inkjet Printing of Group-11 Metal Structures. in the book: Comprehensive Guide for Nanocoatings Technology. Volume 1: Deposition and Mechanism, ed. by Aliofkhazraei, M. (2015), Nova Science Publishers Inc., pp 117-144. ISBN: 978-1-63482-447-7

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Ali, E.; Rahajandraibe, W.; Haddad, F.; Tall, N.; Hangmann, C.; Hedayat, C.: Modeling and PVT characterization of arbitrary ordered VSCPPLL using an efficient event-driven approach. IEEE 13th International New Circuits and Systems Conference, 2015.

Auersperg, J.; Breuer, D.; Machani, K.V.; Rzepka, S.; Michel, B.: FEA Study of Damage and Cracking Risks in BEoL Structures under Copper Wirebonding Impact. International Conference on Thermal. Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems EuroSimE, Budapest (Hungary), 2015 Apr 19-22.

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Hangmann, C.; Hedayat, C.; Hilleringmann, U.: Fast and Accurate Event-Driven Simulation of a Mixed-Signal System Using the Example of a PLL. Smart Systems Integration Conference 2015 (SSI), Copenhagen (Denmark), 2015 Mar 11-12; Proceedings, pp 396-401, ISBN: 978-3-86359-296-7.

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EDITORIAL NOTES

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

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

Director: Prof. Dr. Thomas Gessner

Editorial
Dr. Martina Vogel

Layout
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Photos
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