TECHNISCHE UNIVERSITÄT
CHEMNITZ

Faculty of Electrical Engineering and Information Technology

Center for Microtechnologies (ZfM)

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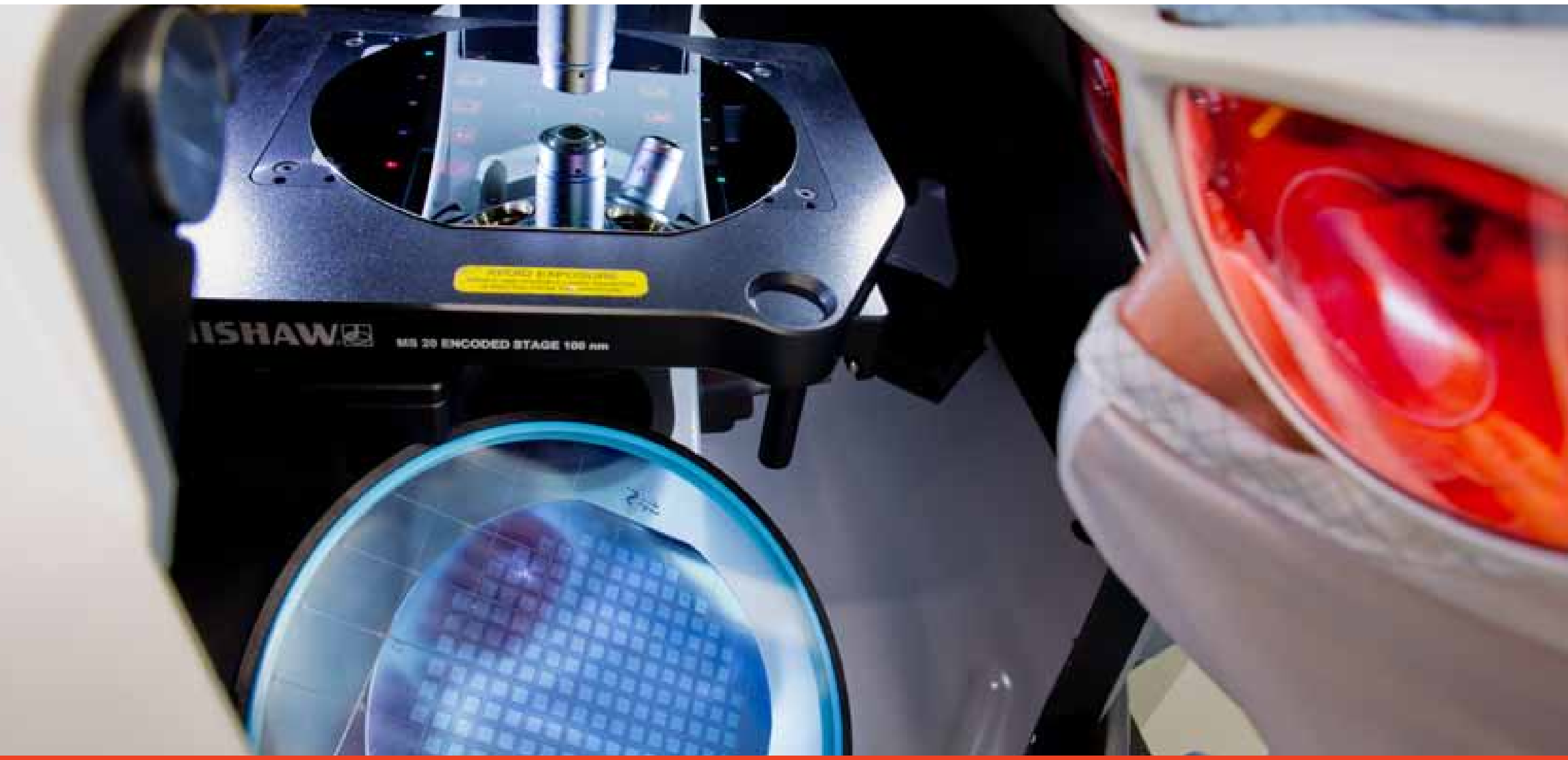
Annual Report 2013 / 2014



Education and training of students and young academics

Basic research and research for industry
in the fields of micro and nanoelectronics,
micro mechanics and microsystem technologies

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Preface

Dear friends and partners of the Center for Microtechnologies, dear readers,

The years 2013 and 2014 have been very successful for the Center for Microtechnologies.

In 2013, the reconstruction of the building of the Faculty of Electrical Engineering and Information Technology, the Weinholdbau, has been finished. In October 2013 the building has been ceremonially reopened. Now all professorships have got upgraded laboratories. Even in the time of reconstruction of the building the professors of the Center for Microtechnologies could extend their third-party funds, leading to a budget of contract research of 8.5 million Euro in 2013.

To the Center for Microtechnologies belong also two departments, the department layer deposition and the department lithography/etch/mask. These two departments are responsible for running all processes within the clean rooms of the Center for Microtechnologies. Their excellent work is the basis for many public founded and industry projects. In 2014, the baton was and will be handed over to the next generation of scientists due to the retirement of both department managers.

Thanks to Dr. Christian Kaufmann and Dr. Andreas Bertz for their excellent work. I feel confident that the excellent level of research and development will be continued by Dr. Sven Zimmermann, department manager layer deposition since July 2014, and Dr. Danny Reuter, currently project manager of the nano system integration network of excellence nanett.

In July 2014, the evaluation of the Research Unit 1713 “Sensoric Micro and Nano Systems” at the Technische Universität Chemnitz took place at the Deutsche Forschungsgemeinschaft. The research unit has been positively evaluated again for a period of three years. Professorships of the Center for Microtechnologies from the Faculty of Electrical Engineering and Information Technology, the Faculty of Natural Sciences, the Leibniz Institute for Solid State and Materials Research (IFW Dresden) and Fraunhofer ENAS are involved in the research unit.

Scientists of the Center for Microtechnologies work successfully in two clusters of excellence. The first one is the Cluster of Excellence of the Technische Universität Chemnitz “Merge Technologies for Multifunctional Lightweight Structures – MERGE”, which is coordinated by Prof. Lothar Kroll, Director of the Institute of Lightweight Structures of the Faculty of Mechanical Engineering. The main object of the cluster is the fusion of fundamental technologies suitable for the resource-efficient massproduction of lightweight structures of high-performance and functional density. In order to make the structures much more smart, micro systems, sensors, actuators and electronics will be integrated.

The second one is the Cluster of Excellence “Center for Advancing Electronics Dresden” of the TU Dresden. Scientists of the Center for Microtechnologies also work in two paths of this cluster, the carbon path and biomolecular assembled circuit path. Carbon is clearly an outstanding candidate for advancing electronics beyond today’s boundaries. Within the carbon path the scientists of the cluster will explore carbon nanotubes (CNTs) as the currently most advanced form of carbon for use in electronic systems, with wireless communication as the main application. The actual work is focused on the design and construction of carbon nanotube based field-effect transistors.

The Professors of the Center for Microtechnologies work as chairs of different important international conferences, like Smart Systems Integration Conference, THERMINIC, Materials for Advanced Metallization, Symposium on Environmental Instrumentation and Measurements. This clearly demonstrates the excellent science of the Chemnitz Professors.

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

Prof. Dr. Thomas Geßner
President of the board of directors
of the Center for Microtechnologies

Center for Microtechnologies

Profile

of the Center for Microtechnologies (ZfM) at the Technische Universität Chemnitz

President of the board
Professor Dr. Thomas Geßner

Deputy of the president
Professor Dr. Karla Hiller

The Center for Microtechnologies (ZfM), founded in 1991, belongs to the Faculty of Electrical Engineering and Information Technology of the Technische Universität Chemnitz. It is the basis for education, research and developments in the fields of micro and nanoelectronics, micro mechanics and microsystem technologies in close cooperation with various chairs of different faculties of the Technische Universität Chemnitz.

The ZfM's predecessor was the "Technikum Mikroelektronik" which was established in 1979 as a link between university research and industry. For that reason the Technische Universität Chemnitz has a tradition and experience for 35 years in the fields of microsystem technology, micro and nanoelectronics as well as optoelectronics and integrated optics.

The key of success is the interdisciplinary cooperation of different chairs within the ZfM. The board of directors consists of
» Professorship of Microtechnology – Prof. Geßner
» Professorship of Microsystems and Biomedical Engineering – Prof. Mehner
» Professorship of Circuit and System Design – Prof. Heinkel
» Professorship of Electronical Devices of Micro and Nano Technique – Prof. Horstmann
» Professorship of Electrical Measurement and Sensor Technology – Prof. Kanoun
» Professorship of Power Electronics and Electromagnetic Compatibility – Prof. Lutz
» Professorship of Materials and Reliability of Microsystems – Prof. Wunderle.

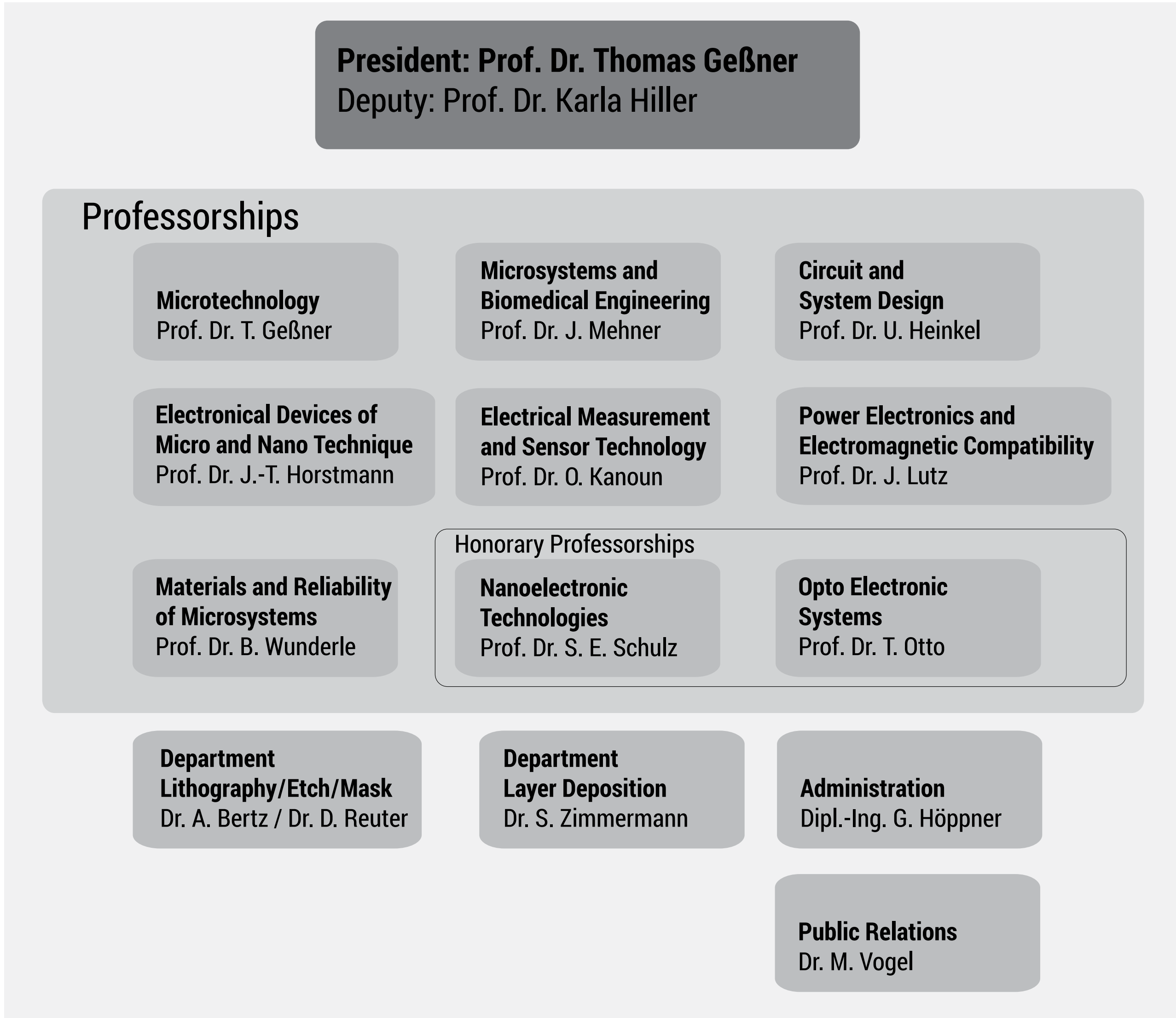
Additionally, two departments belong to the ZfM, the department Lithograpy/Etch/Mask as well as the department Layer Deposition. The ZfM facilities include 1000 m^2 of clean rooms, whereby 300 m^2 of them belong to clean room class ISO4. Modern equipment was installed for processing of 4", 6" and 8" wafers.

The ZfM carries out basic research, practical joint projects and direct research & development orders for the industry in the following fields:
» Basic technologies and components for micro systems and nano systems (sensors, actuators, arrays, back-end of line)
» Design of components and systems
» Nanotechnologies, nano components and ultra-thin functional layers

Within the last years a very strong cooperation has been established with the Fraunhofer Institute for Electronic Nano Systems ENAS and the other partners within the Smart Systems Campus Chemnitz.

Please visit our homepage: http://www.zfm.tu-chemnitz.de/

Organigram of the Center for Microtechnologies



Professorship of Microtechnology

Professor Dr. Thomas Geßner

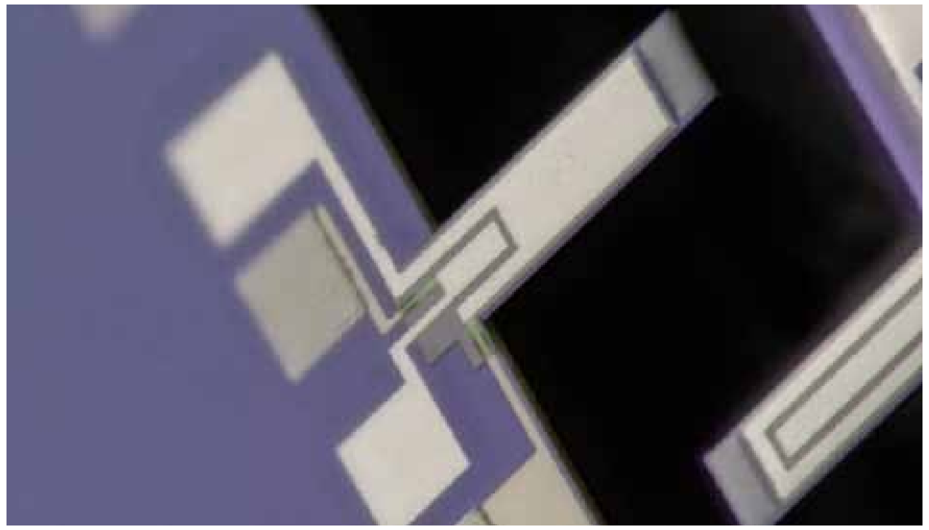
Phone: +49 371 531-33130

E-mail: thomas.Geßner@zfm.tu-chemnitz.de

Characteristics:
number of employees at the professorship and the ZfM: 47
member in networks: Silicon Saxony, Cool Silicon, IVAM
special projects: SIMEIT, Nano3PT, SIRKO, Cool-Pod, GIPRIS, VW-Stiftung, Mikromonitor, MechProNo, MERGE, cfaed, Forschergruppe 1713 TP 1,3,5, IRTG

Main research topics:
» Development of new materials and processes for metallization systems to be applied in micro and nanoelectronics, sensors and actuators
» Simulation and modeling of equipment and processes for micro and nano materials, structures and electronics
» Development of nanotechnologies, nano components and ultra-thin functional films
» Development of technologies and components for micro and nano systems
» Development of integration technologies
» Processing service and prototype fabrication of micro and nano systems

Teaching:
» Advanced Integrated Circuit Technology (S.E. Schulz, R. Streiter)
» Process and Equipment Simulation (T. Geßner, R. Streiter)
» Microelectronics Technology (T. Geßner, S.E. Schulz)
» Micro Technology (T. Geßner, R. Streiter)
» Microoptical Systems (T. Otto)
» Micro and Nano Technology (T. Geßner, D. Reuter)
» Technology for Micro and Nano Systems (K. Hiller, D. Reuter)
» Lectures for IRTG (T. Geßner, S.E. Schulz, R. Streiter)



Piezoelectric aluminum nitride cantilever for micro and nano analytic applications.

Research topics:
One of the main focuses of research work is put on technologies for silicon based micro and nano systems. Several MEMS basic technologies, such as bulk technology, the patented AIM (air gap insulated microstructures), the BDRIE (bonding and deep reactive ion etching), in combination with wafer level encapsulation methods like wafer bonding and thin film encapsulation, have been established. They are applied in order to develop and fabricate high precision inertial sensors, such as acceleration, vibration and inclination sensors, RF switches and resonators, gyroscopes, optical mirrors and filters as well as actuators for MEMS measurement platforms. The designs for these devices are developed in close co-operation with Fraunhofer ENAS and the Professorship of Microsystems and Biomedical Engineering, or are supplied directly by several customers. Recently, the focus is put on increasing the aspect ratio of the structures and hence increasing of the sensitivity of the devices by means of improved silicon etch technology (structure height up to 100 µm) and by post-process gap reduction methods. Furthermore, besides the well established electrostatic drive and capacitive sensing transducer principles, new excitation and sensing methods are under investigation. One example is the direct MOS detection, which exploits the piezoresistive effect directly in the channel region of a MOS transistor. By this technology, the level of integration for piezoresistive sensors can be increased dramatically.

Another example is a thermal actuator, which is used within a MEMS test platform in order to apply a defined force on a nano probe (e.g. a carbon nanotube). Furthermore, effort is put on exploiting aluminum nitride as a piezoelectric material, which can serve both as an actuator and sensor material. Compared to other piezoelectric materials like PTZ, it has lower piezoelectric constants, but the main advantage is the compatibility of the processes for layer deposition (sputtering) and patterning (etching) with the MEMS technology. Technologies for several material combinations for top and bottom electrodes are under investigation and prototypes of Power-Down-Interrupt-Generators have been successfully demonstrated.

A major topic within the MEMS field is packaging and integration of components and systems. For hybrid integration of micromechanical elements and sensor electronics the so called silicon 2.5 D integration can be used for further shrinking the size of a system. Therefore, the Center for Microtechnologies together with the Fraunhofer ENAS works on solutions for backside connection of MEMS on silicon interposers using bumping technologies. Through silicon vias (TSV) are integrated in the MEMS wafers using different approaches. A special focus lies on the minimization of the thermomechanical stress acting on the MEMS and the interposer package with respect to high-precision sensor systems.

Special attention is paid to thin films ranging from several nanometers to a couple of microns in thickness. They are used as active and functional layers in microelectronic devices, as intermediate layers for packaging processes or protective coatings for micro machines or even as functional films in optical components like mirrors or interferometers.

Selected publications in 2013 and 2014:
Haas, S.; Schramm, M.; Loebel, K.-U.; Heinz, S.; Reuter, D.; Bertz, A.; Horstmann, J.T.; Geßner, T.: Studies on the piezoresistive effect in MOS transistors for use in integrated MEMS sensors. Smart Systems Integration Conference 2013, Amsterdam (The Netherlands), 2013 March 13-14.
Meinecke, C.; Hofmann, L.; Bertz, A.; Gottfried, K.; Geßner, T.: Technologieentwicklung für optimiertes MEMS Packaging durch Si-TSV-Rückseitenkontaktierung. Mikrosystemtechnik-Kongress, 2013, Aachen (Germany), 2013 Oct 14-16.
Stoeckel, C.; Hofmann, K.; Forke, R.; Billep, D.; Geßner, T.: Optimization of MEMS/NEMS for reliable resonance frequencies. Smart Systems Integration Conference 2013, Amsterdam (The Netherlands), 2013 March 13-14.
Wagner, C.; Fuchs, F.; Teichert, F.; Schuster, J.; Geßner, T.: Theoretical investigation of CNT transistors used as strain sensors. IWEPNM, 2013, Poster presentation.
Zienert, A.; Schuster, J.; Geßner, T.: Comparison of quantum mechanical methods for the simulation of electronic transport through carbon nanotubes. Microelectronic Engineering, 106 (2013) pp 100-105.
Koehler, D.; Hiller, K.; Forke, R.; Konietzka, S.; Pohle, A.; Billep, D.; Heinz, S.; Lange, A.: Development and characterization of a high precision vibratory MEMS gyroscope system with low-noise integrated readout and control electronics. AMA Conferences 2013, SENSOR 2013, pp 736-738.
Meinig, M.; Kurth, S.; Hiller, K.; Seifert, M.; Ebermann, M.; Neumann, N.; Gittler, E.; Geßner, T.: Electrically tunable Fabry-Pérot interferometer with inherent compensation of the influence of gravitation and vibration. SPIE Photonics EUROPE 2014.

Professorship of Microsystems and Biomedical Engineering

Professor Dr. Jan Mehner

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Characteristics:

number of employees: 16 (09/2014)
special projects:

- Development of a parametric ROM technique for precise and fast simulation of NEMS/MEMS
- Design and characterization of micro systems for acoustic emission and vibration detection
- Development of test structures based characterization technique for the extraction of critical technological parameters for micro systems on wafer-level
- Development of vibrational energy harvester
- Pressure Sensor System for human bladder
- Pressure measurement catheter for the human esophagus

Main research topics:

The Professorship of Microsystems and Biomedical Engineering is mainly focused on design, experimental characterization and application of micro-electro-mechanical systems (MEMS), additionally applications of sensors and precision engineering in the field of biomedical engineering completing the working field. Innovative techniques are investigated in order to link mechanics, optics, electrical engineering and electronics for highly integrated smart systems.

- Modeling and simulation of physical domains and their interactions
- Experimental characterization and measurement methodologies
- Sensor and actuator development
- Biomedical application

Research topics:

Micro systems are key components of complex heterogeneous devices such as automotive products, industrial automation and consumer applications. Academic research and education is strongly related to partners from industry and research institutes.

One of the most advanced topics in the field of design is the challenge to establish fast and precise behavioral models for micro systems and nano systems. Parametric reduced order modeling (ROM) technique, Fig. 1, is the most promising approach to this. The technique was expanded to integrate results from ab-initio atomistic simulations for NEMS. The parametric ROM macromodels capture the complex nonlinear dynamics inherent in N/MEMS due to highly nonlinear electrostatic forces, residual stresses, stress stiffening and supports multiple electrode systems and mechanical contact phenomena. Geometrical nonlinearities, such as stress stiffening, can be taken into account if the modal stiffness is computed from the second derivatives of the strain energy with respect to modal coordinates. The ROM technique based on the mode superposition method is a very efficient technique for fast transient simulation of N/MEMS components in order to export macromodels for external system simulators. This advanced design technique is successfully used for instance for the design of the acoustic emission sensor (vibrational sensor) shown in Fig. 2.

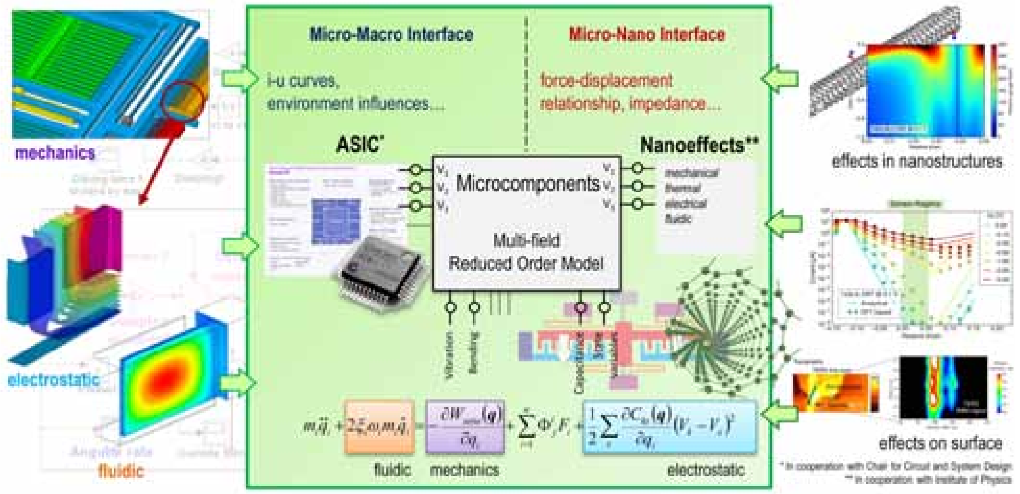

Figure 1: Parametric reduced order modeling.

The Professorship of Microsystems and Biomedical Engineering is equipped with a state of the art characterization lab containing an atomic force microscope (AFM), autofocus topography, dynamics measurement system and different types of interferometrical measurement systems. Fig. 3 shows the currently most advanced tool which is a PVM-200 Vacuum Wafer Prober equipped with a Micro System Analyzer MSA 500 enabling dynamic and topographic characterization of MEMS at adjustable vacuum and thermal interference. The MSA uses laser doppler vibrometry with scanning laser beam and stroboscopic illumination for out-of-plane and in-plane motion analysis respectively. White light interferometry allows topographic measurements in vacuum conditions.

Figure 2: Acoustic emission sensor.

One of the current medical related projects is the research on a catheterless pressure measurement method in the bladder. The measurement system consists of an implantable intravesical capsule that measures the pressure for a period of more than 72 hours. The flexible capsule consists of a MEMS pressure sensor, an EEPROM for storing the measured time and pressure data, a microcontroller and a battery based power supply (see scientific report page 36 for further details).

Figure 3: PVM-200 vacuum wafer prober.

Selected publications in 2013 and 2014:

Mehner, J.: Modal-Superposition-Based Nonlinear Model Order Reduction for MEMS Gyroscopes. In: System-level Modeling of MEMS. Weinheim: Wiley-VCH, 2013, pp 291-308.

Voigt, S.; Rothhardt, M.; Becker, M.; Mehner, J.: Investigations on pressure sensors for medical applications based on fiber Bragg gratings. The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, 2013, June 16-20, Barcelona (Spain).

Kolchuzhin, V.; Mehner, J.; Shende, M. A.; Markert, E.; Heinkel, U.; Wagner, C.; Geßner, T.: Integration of MEMS/NEMS models at the system level using VHDL-AMS. Smart Systems Integration Conference 2013; Amsterdam (The Netherlands), 2012, March 13-14. 7th European Conference & Exhibition on Integration Issues of Miniaturized Systems – MEMS, MOEMS, ICs and Electronic Components; Berlin; Offenbach: VDE VERLAG GMBH, 2013.

Sorger, A.; Auerswald, C.; Shaporin, A.; Freitag, M.; Dienel, M.; Mehner, J.: Design, modeling, fabrication and characterization of a MEMS acceleration sensor for acoustic emission testing. The 17th International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS & EUROSENSORS XXVII), 2013, June 16-20, Barcelona (Spain); pp 726-729.

Sommer, R.; Voigt, S.; Mehner, J.: Minimized Bioimpedance Analyzer Based on AD5933. International Workshop on Impedance Spectroscopy, Chemnitz, 2013, Sep 25-27.

Professorship of Circuit and System Design

Professor Dr. Ulrich Heinkel

Phone: +49 371 531-33175

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Characteristics:
number of employees: 28 + a Foundation Chair

Main research topics:
» Design of ASICs (Application Specific Integrated Circuits) and FPGAs (Field Programmable Gate Arrays)
» Design of heterogeneous systems (MEMS) in cooperation with the Chairs of the Center for Microtechnologies
» Formal specification/verification and simulation methodologies for digital, analog and heterogeneous systems with VHDL, VHDL-AMS, SystemC, SystemC-AMS, SystemVerilog, PSL
» Efficient communication (Car2X, application of wireless networks, ad-hoc networks, network management, bandwidth reduction with digital image processing, localization algorithms)
» E-Mobility
» Applications for Ambient Assisted Living & Rehabilitation

Teaching:
» Design for Testability for Circuits and Systems
» EDA-Tools
» Design of Heterogeneous Systems
» Components and Architectures of embedded Systems
» Mikroprozessortechnik
» Rapid Prototyping
» Schaltkreisentwurf
» Software Environments of Smartphone Applications
» System Design
» FPGA Komplexpraktikum ASIC Robo

Daniel Kriesten on an E-Bike - one part of the research topic E-Mobility

Research topics:
During many years of work in the area of circuit and system design, a huge knowledge in application specific integrated circuits (ASIC) design has been accumulated. Special know-how and experience exist in the field of PLD and FPGA (field programmable gate arrays) design and application. Many different systems have been designed, e.g. systems for real time processing, rapid prototyping systems for image processing, vibration pattern recognition systems and coupling of simulators and emulators. Research areas include:
» System design of heterogeneous micro systems in cooperation with the the Center of Microtechnologies
» Research work in logic and system design and application of FPGAs and PLDs
» High performance arithmetic for different special purposes (e.g. MPEG video decoders, image compression, graphic controllers)
» Design of re-usable components and IP (Intellectual Properties), development of design environments for re-usable components and applications
» Specification capturing, formal specification with interface-based design methods
» Development and application of a modular system (including graphical user interface) for real-time functions (inspection of textile surfaces, analysis of skin diseases, real time image processing, fuzzy classification systems)
» Low power design
» Methods to improve reliability and testability of systems
» Design of analog and digital circuits and short-range communications for sensors (fracture and humidity detection, sports equipment)

Recently, the chair has 28 employees and additionally a Foundation Chair (Stiftungsprofessur für Systemzuverlässigkeit in Elektromobilität und Energiemanagement). Most of the employees work on application specific industrial research projects. Some of those projects, for example, are:
» Freiluftlabor Neue Mobilität am Sachsenring (NeMo)
» E-Motorrad, E-Bikes, E-Auto
» Bildungsinitiative „Schaufenster Elektromobilität“ Bayern/Sachsen
» Herbstschule mit IFX
» Generische Infrastruktur zur nahtlosen energetischen Kopplung von Elektrofahrzeugen (GINKO)
» passive Lokalisation von Fertigungsteilen mit RFID-Tags in Just-in-Sequence-Gestellen der Automobilzuliefererindustrie (PLoRFID)
» Generische Plattform für Systemzuverlässigkeit und Verifikation (GPZV)
» Batterielogger
» intelligent Power Distribution Units (iPDU)
» LTE: Monitoring von Mobilfunknetzen
» Funknetzanalyse
» EMV-Kammer

Selected publications in 2013 and 2014:

Graichen, T.; Manns, D.; Quinger, S.; Heinkel, U.: OpenStreetMap basierte Indoor-Navigation für Elektrofahrzeuge. 6. Wissenschaftsforum Mobilität – „Decisions on the Path to Future Mobility“, 2014, May 8, Duisburg.
Wegener, M.; Froß, D.; Rößler, M.; Heinkel, U.: Einsatz industrieller RFID-Reader zur Lokalisierung von Objekten. DASS 2014, 29-30 April 2014, Dresden, Fraunhofer Verlag.
Kolchuzhin, V. A.; Mehner, J.; Markert, E.; Heinkel, U.; Wagner, C.; Schuster, J.; Geßner, T.: System-level-model development of an SWCNT based piezoresistive sensor in VHDL-AMS. In proceedings of: 15th International Conference on Thermal, Mechanical & Multi-Physics Simulation and Experiments in Microelectronics and Microsystems, EuroSimE 2014, April 2014, Ghent (Belgium).
Rößler, M.; Langer, J.; Heinkel, U.: Finding an Optimal Set of Breakpoint Locations in a Control Flow Graph. Journal Transactions on Systems, Signals & Devices, IEEE, vol. 9, no. 3, April 2014, pp 1-17.
Wegener, M.; Froß, D.; Rößler, M.; Heinkel, U.; Adler, M.: Localisation of Objects using Passive RFID Technology. SSD 11th International Multiconference on Systems, Signals & Devices, 2014, Feb 10-14, Barcelona (Spain).
Sahm, H.; Sauppe, M.; Markert, E.; Horn, T.; Heinkel, U.; Otto, K.-H.: Optimized ASIC/FPGA Design Flow for Energy Efficient Network Nodes. Bell Labs Technical Journal, Wiley Publishers, vol. 18, no. 3, December 2013, pp 195-209.
Heinkel, U.; Langer, J.: Verfahren zur Erzeugung einer Schaltung aus einer Darstellung von Eigenschaften in einem Eigenschaftparagraphen. 2013, October 1, Patent Nummer 10 2009 041 815, TU Chemnitz.

Professorship of Electronical Devices of Micro and Nano Technique

Professor Dr. John Thomas Horstmann

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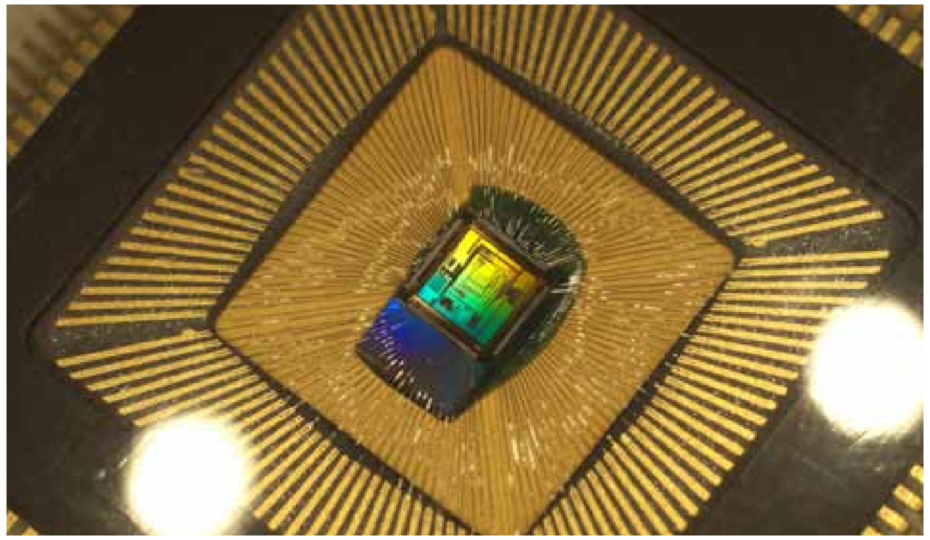
Characteristics:
number of employees: 11
special projects: DFG-Forschergruppe 1713 "SMINT - Sensoric Micro- and Nanosystems"
BMBF-Verbundprojekt "InFil - Modulares, hochintegriertes Mikrosystem für intelligente, emissionsreduzierende Filtereinheiten"
BMBF-Verbundprojekt "ModElan - Modulplattform für kundenspezifische kompakte Elektroantriebe"

Main research topics:
» Integrated circuit design
» Device and circuit characterization on wafer-level
» Modeling of electronic devices

Teaching:
» Microelectronic circuit design (analog, digital, mixed-signal): System design on a behavioral level, simulation, layout, verification
» Microsystem electronics for sensor signal processing and actuator control (discrete, integrated)
» Operating principles of electronic components (modeling and simulation)
» Electrical measurement technology, test structures and parameter extraction



µ-Controller based on the Intel 8051

Research topics:
» Layout and verification of analog and mixed-signal circuit designs for microsystem technology
» Sensor signal evaluation and actuator control of discrete and integrated micro systems
» Modeling and simulation of electronic devices for microsystem electronics and sub-50nm-MOS-transistors
» Electrical measurement, development of test structures and parameter extraction on wafer-level
» Matching analysis on nano-sized CMOS transistors
» Integrated circuit design for microsystem electronics, especially low-noise, low-power and high-voltage
» Development, analysis and characterization of next generation nanoelectronic devices

The main research topics at the Professorship of Electronical Devices of Micro and Nano Technique are:
» Development of new circuit concepts for nanoelectronic mechanical systems,
» Evaluation of In-Die parameter variations, planning of experiments to reduce parameter deviations and assistance for suitable test structures creation,
» Evaluation and investigation of trench isolations and characterization of the electrical behavior,
» Development of strategies to reduce statistical parameter fluctuations of very small MOS-transistors,
» Development of low-power circuits using the weak-inversion region of MOS-Transistors for autarkic sensors and energy harvesting systems,
» Characterization and simulation of sub-50nm-MOS-transistors,
» Analysis of physical mechanisms of micro- and nanoelectronic devices,
» Evolution of measurement methods for analysis of the electrical parameters of next generation nanoelectronic devices,
» Invention of new materials in the CMOS-process for next generation nano devices.

Main areas of responsibility in the research activities of the "Microsystem Electronics" working group at the Professorship of Electronical Devices of Micro and Nano Technique are the development of integrated electronic micro systems and electronic micro and nano devices and the solution of customer-oriented problems.

The current research projects are:
» In the BMBF project "ModElan" a module platform for customized solutions of compact electrical drives are investigated
» Smart-power applications realized by a trench isolation, which contains the design of integrated high-voltage electronics and characterization of high-voltage isolation structures to optimize the production technology
» Research and development of applications for energy-efficient sensor systems and investigation of weak-inversion circuit techniques are the content of the "nano system integration network of excellence – application of nano technologies for energy-efficient sensor systems"
» The DFG-Research Unit 1713 "Sensoric Micro- and Nanosystems" investigates at the integration of different technologies and functionalities in a micro system to transmit signals and information and to interact with the environment
» "SmartFilter – intelligent filter monitoring system" is a further BMBF project. The development of a system for accurate monitoring of the filter contamination level and the temperature is the project objective.
» Design of intellectual properties for the MEMS-technologies, currently for a 1µm-CMOS-technology with monolithic integrated pressure sensors
» Development of next generation electrical drive systems, e.g. electric motors with high efficiency and smart power control concepts
» Development of customized measuring strategies and characterization of In-Die parameter variations for semiconductor structures in nanotechnologies
» Electrical and physical design and characterization of analog and mixed-signal standard circuits for the CMOS-process
» Creation of simulation models for SOI-devices
» Investigation and modeling of isolation structures for high-voltage ICs

Selected publications in 2013 and 2014:

Schramm, M.; Haas, S.; Reuter, D.; Loebel, K.-U.; Heinz, S.; Bertz, A.; Horstmann, J.T.; Geßner, T.: Integration of MOS transistors as transducers for mechanical stresses. Posters, DPG Spring Meeting of the Condensed Matter Section, Dresden, 2014, Mar 30-Apr 4, ISSN 0420-0195.
Mining, B.; Aschauer, S.; Bähr, A.; Hermenau, K.; Horstmann, J.T.; Running, T.; Lechner, P.; Majewski, P.; Meidinger, N.; Reiffers, J.; Richter, R.; Sandow, C.; Schaller, G.; Schopper, F.; Stefanescu, A.; Strüder, L.; Treis, J.: Electrical characterization of different DEPFET designs on the level. 15th International Workshop on Radiation Imaging Detectors (IWORID), Journal of Instrumentation, Volume 9, January 2014, doi: 10.1088 / 1748-0221 / 9/01 / C01020.

Professorship of Electrical Measurement and Sensor Technology

Professor Dr. Olfa Kanoun

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E-mail: kanoun@iee.org

Characteristics:

number of employees: approx. 25

member in networks: IEEE, IMEKO, Arbeitskreis der Hochschullehrer für Messtechnik e.V., AMA Verband für Sensorik e.V., AccuSharing

special projects: AIS, Adante, SmartLic, SAV

Main research topics:

- Impedance spectroscopy for materials and sensor systems
- Impedance sensors (conductive, capacitive, inductive)
- Battery diagnosis (SoH, SoC, SoF)
- Cable diagnostics and fault localization
- Bio-impedance spectroscopy

- Energy aware wireless sensor system
- Availability and conversion of ambient energy
- Energy management for solar cells
- Vibration energy converters
- Wireless sensor networks for environmental applications

- Flexible sensors based on nanocomposites
- Strain and pressure sensors based on nanocomposites
- Infrared detectors based on nanocomposites
- Sensors at the periphery of human bodies

Teaching:

- Measurement technology
- Sensors and sensor signal pre-processing
- Smart sensor systems
- Sensor signal processing
- Automotive sensor systems
- Energy Storage Seminar
- Embedded systems lab
- Practice seminar measurement and sensor technology
- Photonics

One of our modern labs used for the research in the field of nano materials.

Research topics:

The research activities at the chair for measurement and sensor technology (MST) have a strategic focus on the improvement of measurement and sensor principles, the design of smart sensor systems and the model-based signal processing. The research topics are organized in three major topics focusing on impedance spectroscopy, energy aware wireless sensors and flexible sensors based on nanocomposites.

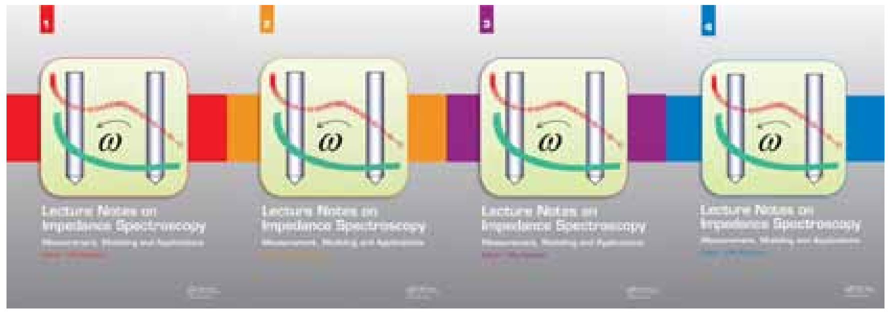
With the aid of impedance spectroscopy the dependence of the complex impedance on frequency is used to detect and investigate effects with variable frequency dependence. This results in an increased amount of measured data containing more information. By the help of advanced data analysis algorithms and model based approaches these information are made accessible. The use of this method in sensor systems exhibits a special challenge due to limited resources, the influence of changing usage conditions and the necessity of non-monitored online signal processing. Our research activities using this method focus on the investigation of cables, biological tissues, materials, energy storage devices and sensor systems.

In the field of energy aware wireless techniques and methods are being developed to power systems with ambient energy from the environment. The autonomy of a stationary energy source of an electrical system enables the usability of sensors systems in various usage conditions. This allows a flexible use in harsh fields of application or areas which are difficult to access and reduces the installation and maintenance effort. In mobile applications the space and weight for batteries is being reduced or they will be left out completely.

Ambient sources are investigated for energy supply, such as ambient temperature, light, vibration or air flow. The energy out of those sources is converted into electrical energy which supplies the electrical system. Thereby the focus is on special energy-saving electronics. The circuits shall have various operation modes and profit from often sleep mode. A key role plays the energy management system, which administrates the distribution of energy between storage and application. Depending on the energy balance and the demands of an application, different modes of operation shall be used to minimize the overall consumption.

Nanomaterials such as carbon nanotubes (CNTs) and graphene are promising candidates for different sensor applications. In macroscopic films CNTs form a conductive network at low filler concentration ratios. Carbon nanotubes/graphene oxide nanocomposites showed excellent optical properties and can be used as optical sensor e.g. in the infrared spectrum. The overall resistance of CNT/polymer resistor network changes under applied mechanical load. This effect can be used for applications as strain sensor. Such devices exhibit a higher sensitivity than common metallic strain sensors. Strains in CNT or graphene based flexible sensors can be even measured wirelessly by measuring the change in the complex impedance of a coupled coil.

A highlight in 2014 is the strengthening of the equipment of the chair with a multifunctional impedance spectroscopy equipment combining an atomic force microscope with impedance spectroscopy. This allows us to characterize materials down to the nanoscale with frequencies up to the microwave spectrum by combining electrical properties and topographical properties.



The International Workshop on Impedance Spectroscopy is taking place for the 7th time, which is established and successfully organized by Prof. Kanoun and her staff.

Selected publications in 2013 and 2014:

Guermazi, M.; et al.: Investigation of Long Time Beef and Veal Meat Behavior by Bioimpedance Spectroscopy for Meat Monitoring. IEEE Sensors, Vol. 14, Iss. 10, pp 3624-3630, 2014.

Wendler, F.; et al.: Effiziente Parameterschätzung impedanzbasierter Sensoren durch lokale, lineare Transformation. Technisches Messen. Vol. 81, Iss. 9, pp 450-456, 2014.

Gruden, R.; et al.: Electrochemical analysis of water and suds by impedance spectroscopy and cyclic voltammetry. J. Sens. Sens. Syst. (JSSS), 3, pp 133-140, 2014.

Shi, Q.; et al.: A new algorithm for wire fault location using time-domain reflectometry. IEEE Sensors Journal 14 (4), 6678706, pp 1171-1178.

Khriji, S.; et. al.: Precision irrigation based on wireless sensor network. IET Sc., Meas. and Techn., Vol. 8, Iss. 3, 2014, pp 98-106.

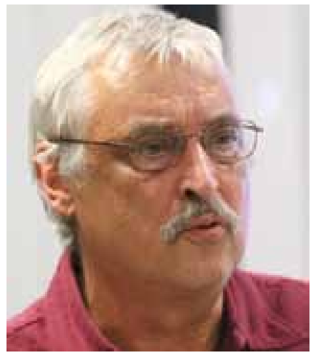
Kanoun, O.; et al.: Flexible Carbon Nanotube Films for High Performance Strain Sensors. Sensors 2014, 14(6), 10042-10071.

Bouchaala, D.; et al.: Portable Bioimpedance Spectrometer for Total Frequency Range of β-Dispersion. Technisches Messen, Band 80, Heft 11, pp 373-378, Oldenbourg Verlag, 10.1515/teme.2013.0045, 2013.

Zhao, X.; et al.: Energy harvesting for a wireless-monitoring system of overhead high-voltage power lines. IET Generation, Transmission & Distribution, Volume 7, Issue 2, February 2013, pp 101-107.

Professorship of Power Electronics and Electromagnetic Compatibility

Professor Dr. Josef Lutz



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Characteristics:
number of employees: 15
member in networks: Competence center of the European Center for Power Electronics ECPE
special projects: Member of Chemnitz Initiative Technologies of Electric Mobility CITE

Main research topics:
The main focus of research lies on power device ruggedness and reliability. IGBTs are investigated regarding their overload capability esp. in short-circuit events, including possible measurements for improvement. Freewheeling diodes are improved regarding reverse recovery and dynamic avalanche, new structures are developed. Devices of Wide Bandgap materials (SiC) are analyzed regarding robustness. Failure mechanisms in device packages are identified by power cycling (10 test stations) and models for lifetime prediction are derived with the help of electro-mechanical simulations. Methods for online state of health analysis are developed especially for electric vehicles.

Teaching:
The education covers power devices, thermo-mechanical problems of power electronic systems, power circuits and electromagnetic compatibility. The lecture on "Semiconductor Power Devices" is given in English, the others are held in German. The teaching consists of lectures, where students get theoretical input on power electronics. Tutorials and field work accompany these lectures and help students to practically apply their new-gained knowledge. Courses include: Power electronics, Energy electronics, Power semiconductor devices, Simulation of electro-energetic systems, Renewable energy technology and Photovoltaics.

Figure 1:
Current Publications by Prof. Lutz:
"Semiconductor Power Devices - Physics, Characteristics, Reliability" (in English, Chinese and German).

Research topics:
The professorship of Power Electronics and Electromagnetic Compatibility covers basic research as well as application-oriented research in cooperation with industry partners Infineon, General Electric, Siemens and Mitsubishi. Three main research areas are:

1) Power Semiconductor Devices: This area of research focuses on robustness and ruggedness of power devices at overload conditions and at the edge of the safe operating area. It includes dynamic avalanche effects in silicon devices, short-circuit ruggedness of diodes and IGBTs, surge current capability of diodes and IGBTs. Research on SiC devices is supported by the European Union in the Framework of ENIAC/ERG.

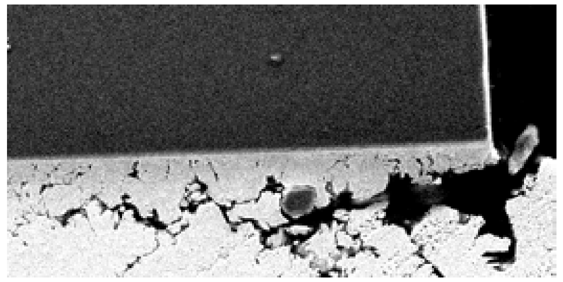

Figure 2:
SEM image of metallographic section of degraded chip solder layer at the edge of a tested SiC-diode.

2) Packaging Technology and Reliability: This area of research investigates the reliability of modules as well as of discrete power semiconductor packages. A part of the work is supported by ECPE Engineering Center for Power Electronics. 10 power cycling stations from 100 A up to 2000 A have been built. In parallel, the system analysis based on thermal and thermo-mechanical FE-simulations is executed and models for failure mechanisms are derived. HTRB- and H3TRB tests for the evaluation of different packages are performed. One part of the work is supported by ECPE Engineering Center for Power Electronics, one part by the Norwegian Research Council, and one part by the German Research Society.

3) Electro Mobility: In the European project COSIVU (compact, smart and reliable drive units for fully electric vehicles) a SiC-based low-loss-low-volume inverter suitable for commercial electric vehicles is developed. The AdAnTe project deals with an IGBT based inverter with new methods for online state-of-health analysis. A further project is "showcase ELEKTROMOBILITÄT VERBINDET Bavaria-Saxony", an academic education initiative for electromobility. The focus lies on the preparation, realization and evaluation of teaching modules on electromobility within workshops, summer universities and master courses.

Selected publications in 2013 and 2014:

Lutz, J.; Baburske, R.: Some aspects on ruggedness of SiC power devices. Microelectronics Reliability. 54. 2014, Vol. 1, pp 49-56.
Lutz, J.; Basler, T.; Pfaffenlehner, M.; Felsl, H.; Niedernostheide, F.-J.; Pfirsch, F.; Schulze, H.-J.; Baburske, R.: Switching ruggedness and surge-current capability of diodes using the self-adjusting p emitter efficiency diode concept. IET Circuits, Devices & Systems; Special Issue: Power Semiconductor Devices and Integrated Circuits. 8. 2014, Vol. 3, pp 205-212.
Steinhorst, P.; Poller, T.; Lutz, J.: Approach of a physically based lifetime model for solder layers in power modules. Microelectronics Reliability. 53. 2013, Vol. 9-11, pp 1199-1202.
Baburske, R.; Niedernostheide, F.-J.; Lutz, J.; Schulze, H.-J.; Falck, E.; Bauer, J.G.: Cathode-side Current Filaments in High-Voltage Power Diodes beyond the SOA Limit. IEEE Transactions on Electron Devices 60. 2013, Vol. 7, pp 2308-2317.
Poller, T.; D'Arco, S.; Hernes, M.; Ardal, A. R.; Lutz, J.: Influence of the clamping pressure on the electrical, thermal and mechanical behaviour of press-pack IGBTs, Microelectronics Reliability. 53. 2013, 9-11, pp 1755-1759.

Professorship of Materials and Reliability of Microsystems

Professor Dr. Bernhard Wunderle

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Characteristics:

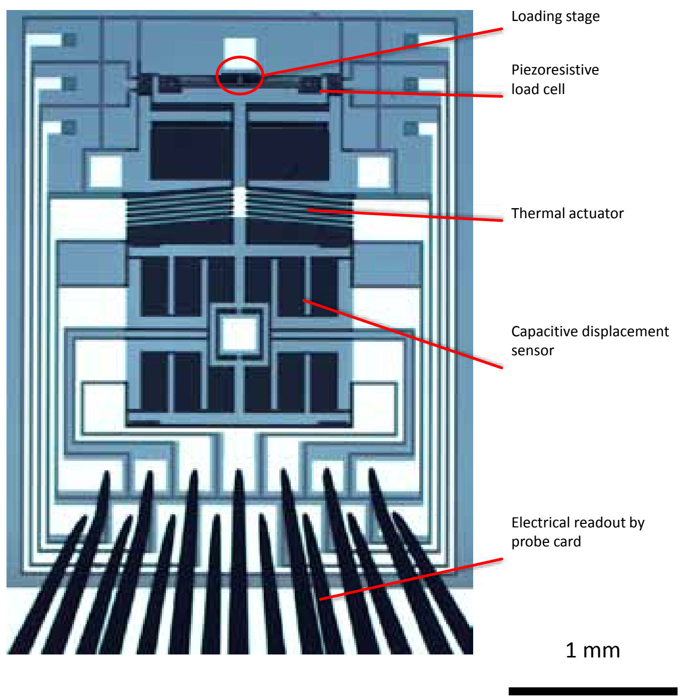
number of employees: 12
number of PhD Students: 14 (5 from industry)
member in networks: General Chair THERMINIC 2015 in Paris; Fraunhofer ENAS; Co-Director of Joint Lab Berlin; European Center for Micro and Nano Reliability (EUCEMAN)
special projects: DFG Forschergruppe 1713; EU FP-7 IP “Smartpower”, “Nanotherm“; EU FP-7 STREP “Hyperconnect”, “CarriCool”

Main research topics:

» Thermo-mechanical reliability
» Thermal management

Teaching:

» Reliability of Micro and Nano Systems
» Werkstoffe der Elektrotechnik/Elektronik
» Werkstoffe der Mikrotechnik
» Technische Zuverlässigkeit
» Qualitätssicherung



Fully integrated MEMS tensile load application device for the in-situ characterization of nano-functional elements such as e.g. CNTs, smart-tubes, nanowires, etc. It allows for the first time complete remote control and readout of all important variables. This platform is being developed in cooperation within the framework of the DFG-funded FOR 1713 [3].

Research topics:

Reliability as a scientific discipline is concerned with the analysis, assessment and prediction of the lifetime of micro-electronic systems (e.g. of interconnects and interfaces of standard and advanced packages, BEOL-layers, MEMS, 3D-architectures, SIP, power packages, etc).
The professorship is technology-open, i.e. the group develops experimental and simulative methods for reliability assessment and prediction for various integration technologies in the field of electronic systems in cooperation with technology partners from industry and academia. These methods also involve stress testing and failure analysis as well as thermal management concepts.
Reliability prediction crucially hinges upon the correct and accurate description of the respective failure mechanisms. The research therefore comprises the development of lifetime models for micro systems starting from the material level up to the system level, based on the physical understanding of the materials involved in terms of their properties and failure mechanisms as function of their structure and external loading conditions (“physics of failure”).

Core competencies:

Material characterization:

» Thermal and mechanical characterization of materials and compounds of micro systems under typical, application-relevant loading conditions such as e.g. temperature, moisture and vibration. Special customized equipment is available enabling characterization and accelerated stress testing along the length-scale.
» Characterization of cracks in materials and interfaces by means of fracture-mechanical methods. A special competence of the professorship is the development of customised loading stages which allow e.g. rapid interface delamination testing by Advanced Mixed-mode Bending (AMB).
» Thermal material and system characterization by pulse IR thermography and special customized precision test stand to characterize even thin and highly conductive thermal interface materials such as e.g. sintered silver. Special thermal test dies are available, too.

Simulation:

» Calculation of failure parameters as a function of external loading conditions. Selected lifetime models are available, e.g. for eutectic solders.
» Multi-physics approaches to couple e.g. electrical, thermal and mechanical (Finite Element simulations) for system simulation.
» Multi-scale approaches (e.g. Molecular Dynamics simulation) to obtain structure-property correlations between the nano-scale and the continuum. Current research topics include CNT-metal interfaces or polymers under moisture influence.

Experimental analytics:

» Modern non-contact deformation analysis to verify simulation results on various length scales. So cracks can be observed in-situ in the micro and nano domain (e.g. nm-resolution by DIC in combination with REM, AFM or FIB)
» Mechanical testing, reliability testing and crack tracing (e.g. by pulse IR thermography) on specimens of small geometry under combined loading conditions.
» A new high vacuum chamber is now available allowing in-situ optical and IR microscopy for local temperature and deformation measurements on in-situ powered devices.

Selected publications in 2013 and 2014:

[1] Hartmann, S.; Blaudeck, T.; Hölck, O.; Hermann, S.; Schulz, S.E.; Gessner, T.; Wunderle; B.: Quantitative In-Situ Scanning Electron Microscope Pull-Out Experiments and Molecular Dynamics Simulations of Carbon Nanotubes Embedded in Palladium. Journal of Applied Physics 115, 144301, 2014.
[2] Zschenderlein, U.; Vogel, D.; Auerswald, E.; Hölck, O.; Rajendran, H.; Ramm, P.; Pufall, R.; Wunderle, B.: Residual stress investigations at TSVs in 3D micro structures by HR-XRD, Raman Spectroscopy and fibDAC. Proc 64th ECTC, Orlando, USA, May 27-30, 2014.
[3] Meszmer, P.; Hiller, K.; Hartmann, S.; Shaporin, A.; May, D.; Rodriguez, R.D.; Arnold, J.; Schondelmaier, G.; Mehner, J.; Zahn, D.R.T.; Wunderle, B.: Numerical Characterization and Experimental Verification of an In-Plane MEMS-Actuator with Thin-Film Aluminum Heater. Journal of Microsystem Technologies, Springer, Vol. 20, No. 6, pp. 1041-1050, 2014.
[4] Wunderle, B.; Springborn, M.; May, D.; Manier, C.-A.; Abo Ras, M.; Mrossko, R.; Oppermann, H.; Xhonneux, T.; Caroff, T.; Maurer, W.; Mitova, R.: Double-Sided Cooling and Transient Thermo-Electrical Management of Silicon on DCB Assemblies for Power Converter Modules: Design, Technology and Test. Proc. 14th Itherm Conf., Orlando, USA, May 27 – 30, 2014. (Best Paper Award)

Honorary Professorship of Nanoelectronic Technologies

Professor Dr. Stefan E. Schulz

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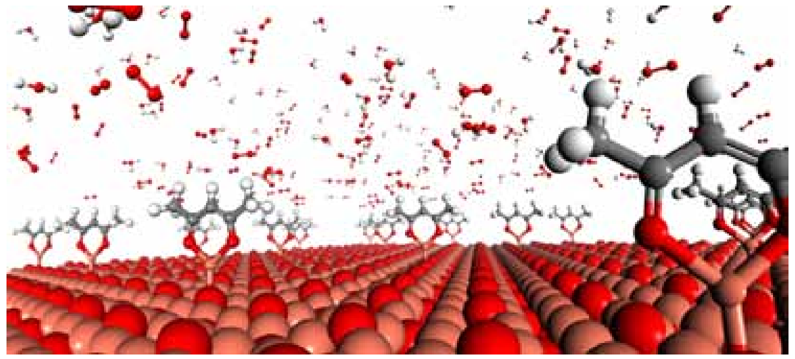
Characteristics:
Number of employees: 15
Member in networks: CoolSilicon, Silicon Saxony, Herald, ALD Lab Dresden
Special projects: Cluster of Excellence cfaed, DFG FOR 1713, DFG GRK 1215 (IRTG), SAB project BENGALOS

Main research topics:

» Process and material development for advanced on-chip interconnect systems
» Concepts and metallization for 3D integration of electronic and micro/nano sensor components
» Carbon nanotube (CNT) integration for interconnect, sensor and transistor application
» Atomic layer deposition of metal, metal oxide and metal nitride layers
» Sensors based on nanotech: magnetic field sensors based on XMR principles, carbon nanotube based sensors
» CNTFET technology for analog high frequency application
» Multi-scale simulation of thin film deposition processes and equipments
» Micro- and nano device simulation
» Ab-initio simulation of the electronic structure of nanomaterials

Teaching:

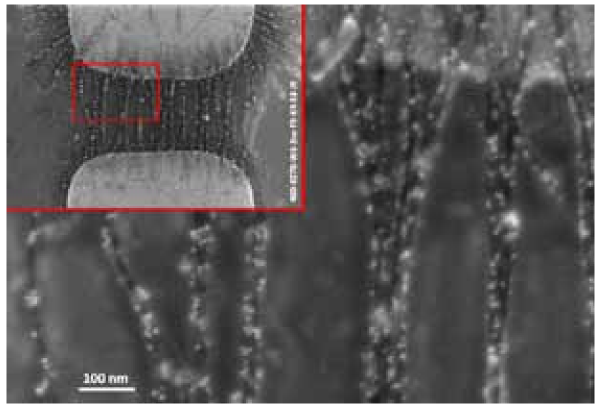
» Advanced Integrated Circuit Technology (Master)
» Microelectronics Technology (PhD, IRTG)
» Interconnect Processes and Technology (PhD, IRTG)



Simulation snapshot: dissociation of a Cu(I)-precursor on a copper oxide surface.

Research topics:
Embedded into the **cluster of excellence cfaed**, the Carbon path is aiming at establishing a sustainable research platform for carbon based electronics with focus on a CNTFET technology for wireless communication systems. Extensive and complementary multi-disciplinary competences at TU Dresden and TU Chemnitz are combined covering materials science, multi-scale device modeling, RF circuit design and fabrication, and wireless communications. In particular in the group “CNT integration and applications” at the ZfM we focus on developing a wafer level technology for CNTFET fabrication.

The goal of the technology development (subproject TP5, 2011-2014) in the **DFG Research Unit 1713 „Sensoric Micro and Nano Systems“** was a scalable integration of semiconducting CNTs on wafer scale. The aligned deposition of CNTs and the contact formation with the electrodes was considerably improved. The integration in a M(N)EMS was proven for realization of a piezoresistive sensor. Further, a procedure for functionalization of CNTs with metal nanoparticles based on flow chemistry was realized (see figure), aiming for optoelectronic devices with a high integration density.



Scanning electron microscope image of CNTs aligned between Pd electrodes, decorated with metal nanoparticles.

Within the International Research Training Group “Materials and Concepts for Advanced Interconnects and Nanosystems”, **Atomic Layer Deposition (ALD)** is a field of intense research. In cooperation with the Chair Inorganic Chemistry at TU Chemnitz, new precursors and ALD processes based thereon are developed. The work focuses on processes for metals, but also metal nitrides and oxides are of interest. Three PhD students are working on this topic which also includes studies by in-situ X-ray photoelectron spectroscopy for surface chemistry and film composition.

As project partner together with GLOBALFOUNDRIES and Fraunhofer IPMS-CNT in the joint **R&D project ”BENGALOS”** (funded by SMWK/SAB), the ZfM investigated three tasks: (1) alternative low-k integration (see scientific report page 30), (2) Cu / low-k compatible wet cleaning process after patterning of the porous dielectric using a TiN hardmask and (3) plasma induced damage (PID) of gate isolators by BEOL processing.

Magnetoresistive layer stacks need to be patterned for application in GMR based sensor systems developed in the subproject A of the **competence network for nano system integration “nanett”**. These layer stacks consist of multilayers like [4.2 nm Pt/ 4x(0.8 nm Pt/0.4 nm Co)/1.5 nm Cu/1.6 nm Co/3 nm Pt], which are difficult to pattern by RIE because of the different materials and as Pt does not form volatile compounds at low temperatures. Therefore, an Ar sputter etch process has been developed for patterning using a Ta hardmask.

Selected publications in 2013 and 2014:

Dhakal, D.; Waechtler, T.; Schulz, S.E.; Geßner, T.; Lang, H.; Mothes, R.; Tuchscherer, A.: Surface chemistry of a Cu(I) beta-diketonate precursor and the atomic layer deposition of Cu_2O on SiO_2 studied by x-ray photoelectron spectroscopy. Journal of Vacuum Science and Technology A, 32 (2014) pp 0415051-0415059.
Fiedler, H.; Toader, M.; Hermann, S.; Rodriguez, R.D.; Evegniya, S.; Rennau, M.; Schulze, S.; Waechtler, T.; Zahn, D.R.T.; Hietschold, M.; Schulz, S.E.; Geßner, T.: Carbon nanotube based via interconnects: Performance estimation based on the resistance of individual carbon nanotubes. Microelectronic Engineering, 120 (2014) pp 210-215.
Schuster, J.; Schulz, S.E.; Herrmann, T.; Richter, R.: Modeling and Simulation of the Interplay between Contact Metallization and Stress Liner Technologies for Strained Silicon. Microelectronic Eng., 107 (2013) pp 161-166.
Toader, M.; Fiedler, H.; Hermann, S.; Schulz, S.E.; Geßner, T.; Hietschold, M.: Conductive AFM for CNT characterization. Nanoscale Research Letters, 8 (2013) p 24.

Honorary Professorship of Opto Electronic Systems

Professor Dr. Thomas Otto

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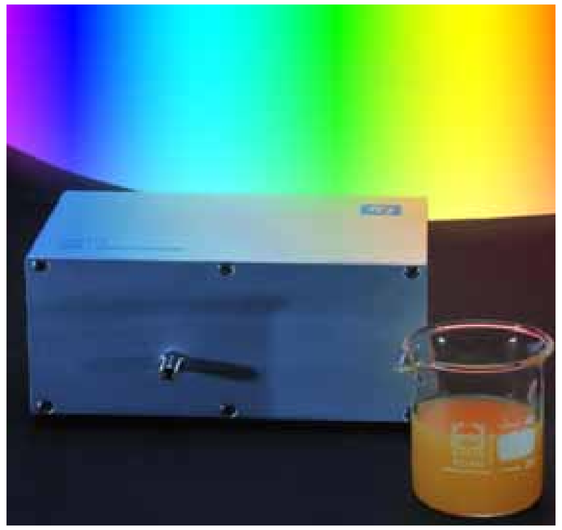
Characteristics:
Number of employees: 17
Member in networks: EPoSS – European Technology Platform on Smart Systems Integration
Special projects: Cluster of Excellence "Merge Technologies for Multifunctional Lightweight Structures – MERGE"; International Research Training Group "Materials an Concepts for Advanced Interconnects and Nanosystems" (GRK 1215); VIP Seron; Forschergruppe FOR 1713 SMINT; SAB QuaSpink

Main research topics:

- Development of micro-opto-electro-mechanical systems MOEMS
- Development of polymer based (functional polymers, nanocomposites) technologies and components for sensors and actuators
- Development of polymer based microfluidic systems for different lab-on-chip systems
- Prototype service of components and systems

Teaching:

- Micro Optical Systems (Master)
- Design and Simulation of Micro- and Nanosystems (PhD, IRTG).



Research topics:
Exemplary for the activities in the field of microoptics is the development and validation of infrared MEMS spectrometers. Such a miniaturized spectrometer has been developed together with the company TQ Systems GmbH Chemnitz. The systems can be configured for different wavelength bands and hence used in various applications. To the fields of application of this spectrometer belong, for example, food studies, environmental monitoring, medical diagnostics, metrology or the physical forensic analysis.
Nanocomposite materials offer certain advantages over classical inorganic materials such as easy processing and nearly unlimited design of components. Additionally, typical included nano effects (e. g. quantum confinement) enhance the system performance substantially or provide completely new functionalities. A big challenge is to bring nanoparticles, nanorods or nanowires in contact to the micro and macro world. To overcome these difficulties, we favor different approaches such as the use of special conditioned composits (interfaces, orientation of inclusions) or self-assembling technologies.
Lab-on-chip technologies, i.e. the realization of whole laboratory scale analytical processes on chip-scale devices, promise a giant leap in the quality and availability of health services for the public. Challenges for the development of such smart systems are the integration of all necessary components like fluid transport, temperature control, optical/electrical readout and data interpretation and management. Microfluidics, enabling the handling of small fluid volumes in the µl- and nl-range (less than one drop) is one of the key elements on the way to miniaturization. The decrease of sample volume leads also to a decrease in the use of pricy reagents and thus in the reduction of the overall cost per test. Typical fields of application for such smart systems are the direct detection of pathogens in various scenarios (bedside testing, food testing,...) as well as the detection of pathological states.
In current projects, humidity and magnetic positioning sensors are being developed by means of nanocomposites. First results look very promising and it seems that the big advantage of composites, namely the separate conditioning of inorganic (nano) inclusions and the organic matrix, lead to cost efficient sensitive sensors with simultaneously high-reliability and sensor lifetime.
For all micro systems, appropriate electronics for data processing and control, respectively, is developed and manufactured. Thereby, the key features of the electronics are, among others, noise reduction and energy efficiency.

Selected publications in 2013 and 2014:

Enderlein, T.; Baum, M.; Nestler, J.; Otto, T.; Besser, J.; Wiemer, M.; John, B.; Hänel, J.; Geßner, T.: Laser Micromachining and micro hot embossing for highly integrated Lab-on-Chip Systems. Smart Systems Integration (SSI) 2012, Zurich, 2012 March 21-22, Proceedings, Paper 34, VDE Verlag GmbH, Berlin. (ISBN 978-3-8007-3423-8)
Möbius, M.; Weiss, A.; Otto, T.; Geßner, T.: Chip-based optical sencor to determine the arterial oxygen concentration. Smart Systems Integration (SSI) 2012, Zurich, 2012 March 21-22, Proceedings, Paper 78, VDE Verlag GmbH, Berlin. (ISBN 978-3-8007-3423-8)
Schumacher, S.; Nestler, J.; Otto, T.; Wegener, M.; Ehrentreich-Foerster, E.; Michel, D.; Wunderlich, K.; Palzer, S.; Sohn, K.; Weber, A.; Burgard, M.; Grzesiak, A.; Teichert, A.; Brandenburg, A.; Koger, B.; Albers, J.; Nebling, E.; Bier, F.F.: Highly-integrated lab-on-chip system for point-of-care multiparameter analysis. Lab Chip 12 (2012), pp. 464-473. (in press) (ISSN1473-0197)
Streit, P.; Schulze, R.; Billep, D.; Otto, T.; Geßner, T.: Comparison of lumped and finite element modeling for thermoelectric devices. Smart Systems Integration (SSI) 2012, Zurich, 2012 March 21-22, Proceedings, Paper 88, VDE Verlag GmbH, Berlin. (ISBN 978-3-8007-3423-8)
Otto, T.; Geßner, T.; Nestler, J.: Zweckentfremdete Leiterplatten: Das Labor auf dem Chip Vollintegrierter Transport von kleinen Flüssigkeitsmengen für integrierte biochemische Nachweisverfahren. PLUS Fachzeitschrift für Aufbau- und Verbindungstechnik in der Elektronik, Eugen G. Leuze Verlag KG, Bad Saulgau, Ausgabe 2/2013. (ISSN 1436-7505)
Luo, J.; Billep, D.; Blaudeck, T.; Sheremet, E.; Rodriguez, R. D.; Zahn, D. R.; Toader, M.; Hietschold, M.; Otto, T.; Geßner, T.: Chemical post-treatment and thermoelectric properties of PEDOT:PSS thin films. Journal of Applied Physics Vol. 115, Issue 5. (DOI: 10.1063/1.4864749)
Otto, T.: Smart Systems Integration at Fraunhofer ENAS – Trends and Examples; Smart Systems Integration for Micro- and Nanotechnologies. Honorary volume on the occassion of Thomas Geßner's 60th birthday, pp.11-22, August 12, 2014, goldbogen verlag, Dresden, Germany. (ISBN 978-3-932434-78-5)
Otto, T.; Saupe, R.; Stock, V.; Seider, T.; Geßner, T.: A new generation of MEMS middle-infrared spectrometers. SPIE Photonics West, San Francisco (USA), 2014 Feb 1-6, Proceedings SPIE Vol. 8977, MOEMS and Miniaturized Systems XIII, 89770F.1 – 89770F.6. (DOI: 10.1117/12.2042679)

Department Lithography / Etch / Mask

Dr. Andreas Bertz
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Dr. Danny Reuter
(from 12/2014)

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The department "Lithography/Etch/Mask" represents the technological basis for all patterning processes of the Center for Microtechnologies and its partners. In a class 4 (ISO 14644-1) clean room a complete process line for mask fabrication and lithography is available:

- Large variety of wet and dry etching steps, including DRIE
- 4 inch and 6 inch wafers are typically processed
- 5 inch and 7 inch mask fabrication
- Partially process tools are available even for 8 inch wafers
- Optical lithography is based on a mask aligner (up to 8 inch wafers) and an i-line wafer stepper (up to 6 inch wafers)

In addition to the conventional lithography processes, the department is experienced with double-side exposure, spray coating on 3D-surfaces and the treatment of special resist types like SU-8 by using advanced systems. Furthermore, cavities can be filled individually by a special spray robot.

With respect to nanopatterning, more than 20 years experience exists within the e-beam lithography field. In combination with about 10 dry etch tools, typically sub quarter micron structures have been etched into numerous materials. Using resist patterns made by partners and special hard masks, feature sizes smaller than 100 nm have been transferred. With the end of the year 2014 a new e-beam writing system SB 250 from VISTEC Electron Beam GmbH will be deployed even for very small dimensions down to 20 nm.

Beside these technology services for internal and external partners, the department is performing R&D projects focusing on dry etching processes and High-Aspect-Ratio-MEMS (HAR-MEMS). This work is addressing applications in microsystems technologies, microelectronics, spintronics and photovoltaics as well. Therefore, etching of new materials and surface modification steps are investigated. Based on the developed and patented AIM technology (Airgap Insulation of Microstructures) a sensor and actuator fabrication platform is available. Using this technology, high performance low-g and vibration sensors are provided to several partners for system integration. For this, much effort has been spent additionally in device characterization at wafer-level and yield improvement too. Another example of successful technology research is the development of a thin film encapsulation procedure and several innovative solutions for the fabrication of backside contacts in order to reduce the package size and costs of MEMS/NEMS.

Department Layer Deposition

Dr. Sven Zimmermann

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E-Mail: sven.zimmermann@zfm.tu-chemnitz.de

The department "Layer deposition" is highly competent in the development and fabrication of conductive and isolating layers and layer stacks for microelectronic and microsystems technologies. For this purpose, the department owns state-of-the-art equipment including a new clean room. The department offers support for advanced process modules for research and development purposes and small volume prototyping.

Process modules available include:

Physical Vapor Deposition (sputtering, electron beam):

- Vertical sputtering system MRC 643 (materials: Ti, TiN, Ta, TaN, Cu)
- Vertical sputtering system MRC 643 (materials: Al, Al-Alloys, Cr, TiW, W)
- R&D sputtering system FHR MS 150 x 4 AE (materials: Ag, Al, Au, Cr, Ti, TiN, TiO_2, NiMo, Ta, Ni)
- R&D sputtering system FHR MS 150 x 4–AE-B (materials: Al, Al-Alloys, Hf, Pyrex)
- R&D Electron-Beam-Evaporation (materials: Cu, Pd, Pt, Co, Ni …)

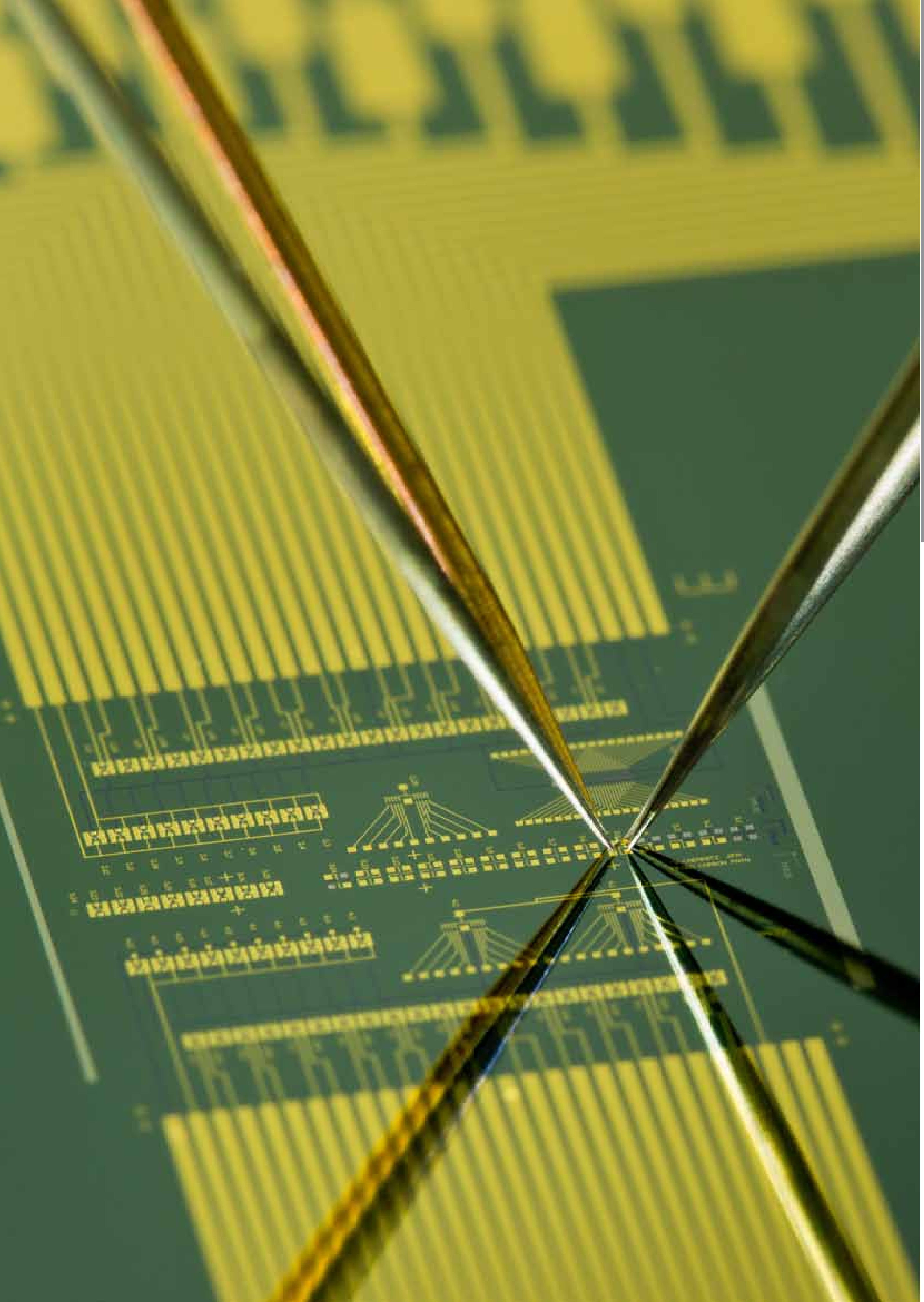
Chemical Vapor Deposition (MO-CVD, PE-CVD, LP-CVD):

- PE-CVD system Precision 5000 Mark II Applied Materials (materials: SiO_2, Si_3N_4, $Si_xO_yN_z$, Black Diamond, SiCH, TEOS-SiO_2)
- PE-CVD system Plasmalab DP 80 (materials: SiO_2, Si_3N_4)
- PE-CVD system Microsys 400 Roth & Rau (material: Diamond-like Carbon)
- LP-CVD system LP-Thermtech Sirius 9000 (materials: Si_3N_4, polysilicon, LP-TEOS-SiO_2)

High-temperature processes (diffusion / thermal oxidation / annealing)

For the characterization of the deposited layers and layer stacks we use a lot of measuring methods and systems, for example:

- KLA Tencor surface profiler VEECO Dektak 8
- Thin film stress measurement system TENCOR FLX 2900
- White light interferometer Nanometrics NanoSpec / AFC
- Ellipsometer: Gaertner L11B (632.8 nm)
- Spectroscopic Ellipsometry: Sentech instruments GmbH SE 850 (190 nm – 2550 nm)
- White Light Interferometrie



Selected Scientific Reports of the Professorships of the Center for Microtechnologies

In-situ growth monitoring of ultra-thin films of Cu_2O and Cu deposited by atomic layer deposition

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Introduction

Atomic Layer Deposition (ALD) is emerging as a ubiquitous method for the deposition of conformal and homogeneous ultra-thin films on complex topographies and large substrates in microelectronics [1,2]. The electrochemical deposition of Cu necessitates an electrically conductive seed layer for filling the interconnect structures [1]. ALD is now investigated as a novel solution for conformal deposition of Cu seed layers on very high aspect ratio structures. Since 1991, ultra-thin Co/Cu multi-layer structures have also been extensively studied towards realization of giant magnetoresitive (GMR) spin valve systems for magnetic sensors, read heads, and random access memories. It was reported that the GMR effect increases substantially below 45 Å of Cu thickness because below this thickness range exchange coupling becomes stronger due to parallel arrangement of magnetic moment [3].

In-situ growth monitoring by X-ray photoelectron spectroscopy (XPS)

For developing suitable ALD processes, it is indispensable to study the surface chemical processes occurring during the film growth from metal-organic precursors. Furthermore, the film composition must be studied without vacuum break, excluding detrimental effects of intermediate exposure to ambient air.

XPS is one of the indispensible analysis tools for the investigation of ultra-thin films. On the one hand, it is a highly surface sensitive technique. On the other hand, it gives valuable information about the atomic composition and the chemical state of the film. XPS is very surface sensitive because only the electrons from the upper few nanometers of the sample can reach the detector [4]. For monitoring the growth of ultra-thin films, an in-situ XPS system is attached to a 200 mm cluster deposition tool, also featuring two ALD chambers. Growth of Cu_2O and Cu was carried out in one ALD chamber and the respective films were immediately monitored in the in-situ XPS chamber. The Cu precursor was prepared by mixing 99 mol% of $[(^{n}Bu_3P)_2Cu(acac)]$ as Cu(I) β-diketonate precursor and 1 mol% of $[Ru(\eta^5\ C_5H_4SiMe_3)(\eta^5\text{-}C_7H_{11})]$ as ruthenium precursor. Ruthenium is used to introduce catalytic activity for the later reduction of Cu_2O by formic acid. Temperature limit with this precursor mixture was found to be between 145 °C and 200 °C on SiO_2 [5]. ALD was carried out using the Cu precursor mixture and wet O_2 as co-reactants on SiO_2 at 145 °C. After 500 ALD cycles, Cu_2O was identified on SiO_2 (Fig. 1). When Ru doped Cu_2O was reduced by formic acid at 120 °C, in-situ XPS showed very promising results (Fig. 2). The film was composed of more than 90 % of metallic Cu with very low concentration of Cu(I) and Cu(II) species left on the surface. It was thereby observed in the in-situ XPS investigation that the incorporation of catalytic amounts of Ru in the Cu_2O ALD film has a huge influence on the reduction of Cu_2O to Cu, when deposited on a non-catalytic substrate like SiO_2.

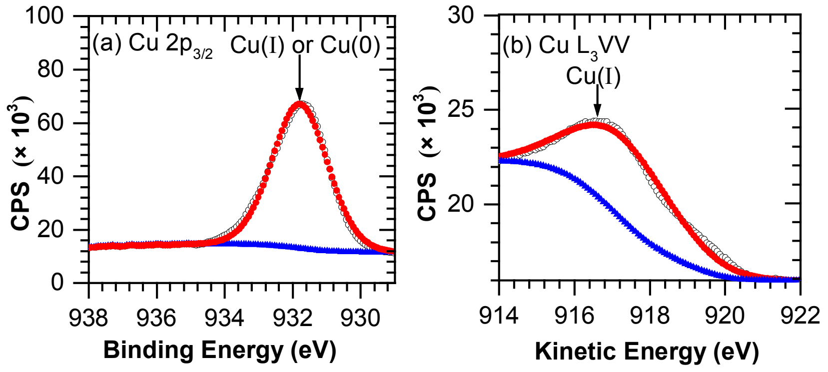

Fig. 1: In-situ XPS spectra of the Cu_2O grown by ALD on SiO_2 at 145 °C. The Auger parameter from the peak maxima was found to be 362.2 eV, which is comparable to Cu in Cu(I) chemical state or Cu_2O in thin-films [5,6]. The ellipsometric investigation resulted in 1.8 nm of ultra-thin film of Cu_2O deposited with a growth per cycle of 0.036 Å/cycle.

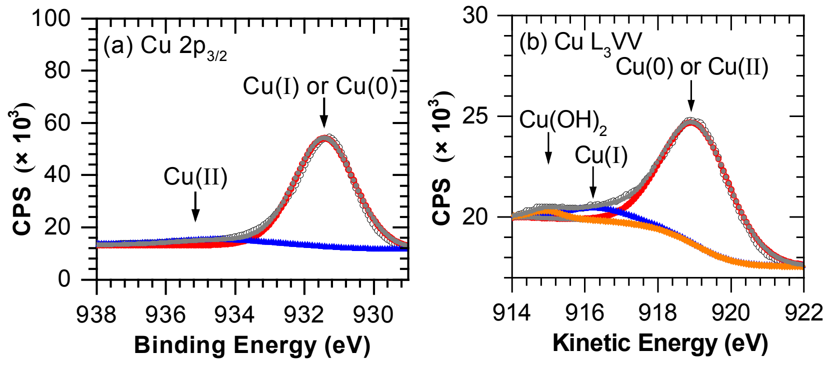

Fig. 2: In-situ XPS spectra of an ultra-thin film of Cu_2O after reduction with formic acid. The Auger parameter from the peak maxima was found to be 363.8 eV, which is comparable to Cu in Cu(0) chemical state or metallic Cu in thin-film [6].

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Alternative integration of low k-materials

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Introduction / motivation

The continuous miniaturization of integrated circuits (IC) is one of the biggest issues in industrial production. The main target is defined by the performance of the interconnect system and to improve that by decreasing the feature sizes, RC delay, power consumption and crosstalk which occur due to parasitic capacitances. The solution to mastering those issues was to introduce copper in the ICs already done 1997 by IBM at the 250 nm node [1] and using dielectrics with a low permittivity, so called low-k materials. Those low-k-materials are characterized by incorporating of carbon within the Si-O-based dielectric network. However, the integration of such materials is very challenging. Porosity and organic species lead to a high sensitivity of the dielectric towards plasma processes and a distinct reduction of mechanical properties like Youngs modulus and hardness, which can lead to the formation of cracks and delaminations with further processing [2] [3]. An alternative indirect integration of porous low-k dielectrics may be a promising approach to avoid integration issues.

Experimental procedure:

For the alternative indirect integration regime of low-k a Damascene structure is necessary. That structure was produced visible in Fig. 1. It is seen a cross section of the test structure. Starting with a thermal oxidized silicon wafer a silicon carbide film (SiC) was deposited with plasma enhanced chemical vapor deposition (PECVD). Followed by the deposition of silicon oxide (SiO_2) with PECVD, too, the oxide film was patterned using reactive ion etching (RIE). The conductive barrier material tantalum nitride (TaN) was deposited by physical vapor deposition (PVD). Electrochemical deposition (ECD) was used for depositing the copper film. After chemical-mechanical polishing (CMP) the structure was etched with hydrogen fluoride acid (buffered HF) to remove the sacrificial SiO_2. The now free standing metal lines were refilled with low-k dielectric by a spin-on process. Basic studies on blanket wafers to investigate the resistance of Cu and TaN towards HF, the etch rate of SiO_2 and spin on behavior was done.

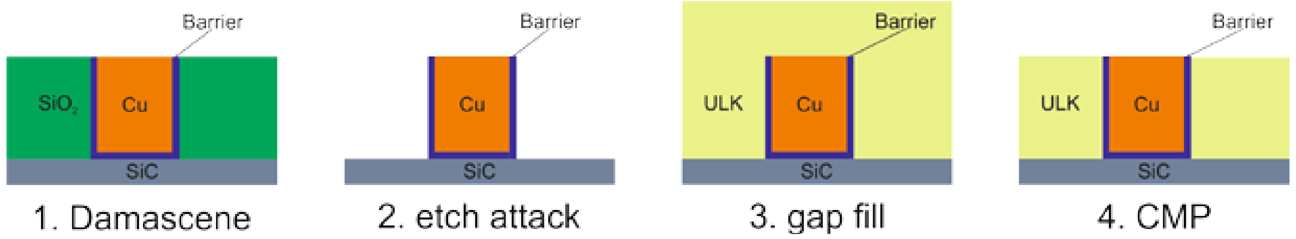

Fig. 1: Alternative indirect integration regime.

Results and discussion:

The result by following the alternative indirect integration is presented in Fig. 2. It is shown the full removal of the sacrificial SiO_2 (Fig. 2 b)). During the investigations of the surface there were no particles or residuals visible. An attack at barrier (TaN) and Cu was also not observed. Delamination of the barrier film is not occurred, too. This result agrees with the studies on the blanket wafers. An etch attack on Cu and TaN with buffered HF acid does not show a significant change in the sheet resistance and roughness, respectively.
After successfully removing of the SiO_2 the gaps were filled with the spin-on ULK by spin-coating (see Fig. 2 c)). The gaps were completely filled without any cracks or defects. The small holes between copper and ULK becomes from the preparation of the cross section. Copper is a ductile material which will be pulled out of the sample during cross cutting.

Fig. 2: Process flow of the alternative indirect integration of low-k material; a) starting point; b) removed SiO_2 (BHF; 300s); c) gap fill with porous ULK .

Conclusion

It is demonstrated an alternative indirect integration of low-k-materials. With the new technology approach it is possible to exclude problems like sidewall damage and pattern collapse. The investigation done here is showing the principle possibility. Future studies in order to include this concept in the current technology node are necessary.

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Influence of contamination on the hysteresis in carbon nanotube based field effect transistors

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Introduction / motivation

The integration of new materials like carbon nanotubes (CNTs) into electronic devices can provide a low signal distortion, appearing e.g. in signal transmission of data in communication application. Within the cluster of excellence „Center for Advancing Electronics Dresden“ (cfaed) carbon nanotube based field effect transistors (CNT-FETs) are developed at the Center for Microtechnologies of the Technische Universität Chemnitz. Charge traps in the channel region can lead to a hysteresis in the transfer characteristics of the transistors and to a hardly controllable device behavior in circuits [1]. Therefore, this serious issue needs to be solved. Water molecules and surface defects are assumed to act as charge traps, causing hysteresis [2]. Contaminations originating from fabrication processes are known to have a large impact on charge carrier transport as well [3]. In contrast to [3] we first clean the surface by plasma treatment and deposit CNTs afterwards. With this new approach the effect of residual particles can be evaluated more precisely, since we do not influence the nanotubes by this treatment.

Experimental procedure

A p-doped Si wafer is oxidized to gain a 100 nm thick SiO_2 as gate dielectric. Source and drain electrodes are composed of two metal layers (see Fig. 1). At first thin Pd electrodes with Al adhesion layer are structured by a lift off procedure. Pd is known to provide good electrical contact to the CNT [4]. Thicker connecting electrodes out of Cr/Au are structured by wet etching and have no direct contact with the CNTs later on. Since small contaminations appear on top of the electrodes as well as on the SiO_2 substrate next to the electrode site, a second etch treatment is applied. This is done to exclude a too short etching time as possible origination of the contaminations. A plasma treatment is applied on three comparable samples for 5 up to 20 minutes.
Afterwards, 99.9 % pure semiconducting nanotubes are dispersed in sodium dodecyl sulfate solution. After sonication and centrifugation, the nanotubes are integrated into the transistor structures by using dielectrophoresis [5]. This deposition technique enables aligned assembly of nanotubes between the electrodes. In the resulting test structures (see Fig. 1), the whole Si wafer is used as back-gate electrode. Electrical characteristics as well as height profile measurements by AFM were performed after CNT deposition. By that, correlations between topography and electrical characteristics can be investigated. The results gained by these basic test structures can be transferred for improvement of sample preparation of high-frequency CNT-FETs.

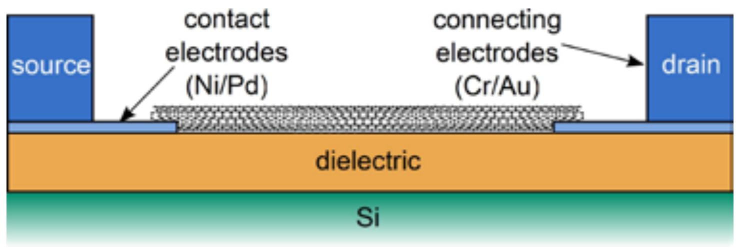

Fig.1: Schematic cross-section of a back-gated CNTFET teststructure.

Conclusion

To remove the contaminations at a reasonable effort we applied an O_2 plasma treatment for four different process times. Since plasma is supposed to influence or damage oxide surfaces [6] it is desirable to shrink the process time as much as possible but still providing sufficient cleaning. AFM measurements of single transistor test structures after CNT deposition can be seen in Fig. 2a until 2d. The transistors shown are situated at four different chips from the same wafer, which were treated by the oxygen plasma from 5 minutes to 20 minutes. For better comparison, Fig. 2a shows a structure, which was not exposed to plasma at all. The number of particles in the transistor area is reduced with increasing treatment time. Therefore, the root-mean-squared roughness (RMS) values are reduced (see Fig. 3). After 10 minutes of treatment, residues seem to be completely absent, inferring from the AFM measurements. After 20 minutes of treatment, small holes occur in the AFM data, indicating defects in the gate dielectric. The increase of RMS compared to 10 minutes treatment is supporting this appearance (see Fig. 3).

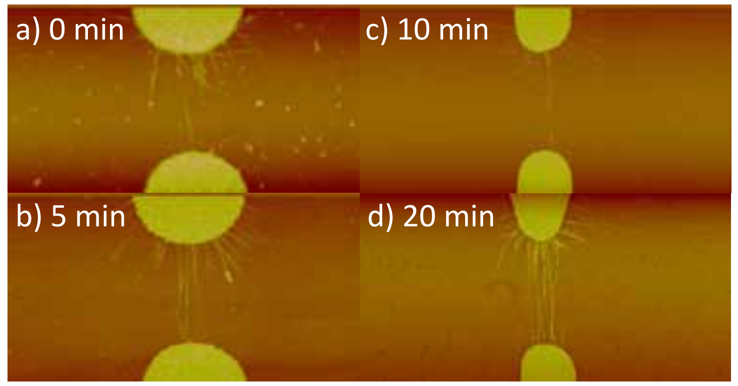

Fig. 2: AFM measurements of CNTFETs after different oxygen plasma treatment durations.

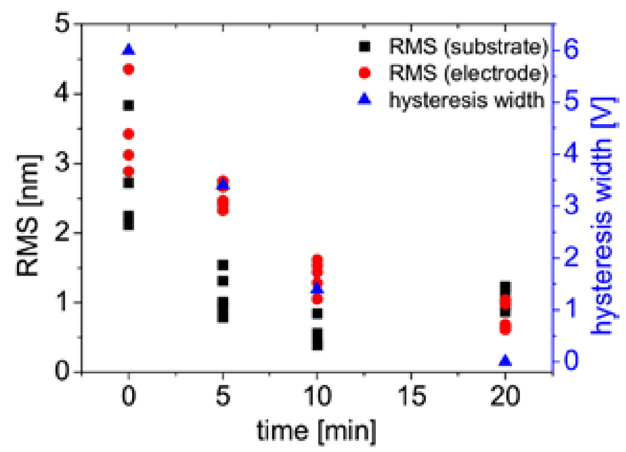

Fig. 3: Root-mean-squared roughness (RMS) of SiO_2 substrate (black square) and of Pd electrodes (red circle) and hysteresis width of transistor transfer characteristic (blue triangle) depending on applied oxygen plasma time.

Electrical characterization of those transistors was performed by standard DC measurements (-10 V < V_g < 10 V, V_{ds} = 0.5 V) right after fabrication and has been repeated after 9 weeks. The hysteresis width is extracted from the transfer characteristics at half difference between I_{on} and I_{off} and is shown in Fig 3 as blue triangles. The values correspond to the structures shown in Fig. 2 and were taken during the second measurement (9 weeks after fabrication). The hysteresis in the transfer characteristics is reduced with increased plasma treatment time. This indicates that the particles influence the transistor behavior, maybe by acting as charge traps.
The fact that those transistors have been stored in air without any passivation for approximately 9 weeks without significant change in threshold voltage or on-current is remarkable. [2] claims, that CNT-FETs are not stable under ambient conditions without passivation. With the results shown above, we prove the opposite. Furthermore, the transistor with 20 minutes plasma treatment (see Fig. 2d) does not show hysteresis. This leads to the conclusion, that a clean surface in the CNT's surrounding is an important condition for hysteresis-free CNT-FETs.

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Electron transport in metallic carbon nanotubes with metal contacts

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Introduction

Carbon nanotubes (CNTs) are quasi one-dimensional tubes with atomically well defined sidewalls, as thin as a single layer of carbon. Their outstanding mechanical and thermal stability and their ability to carry high current densities are very interesting properties for applications in nanoelectronics [1]. Current and future copper-based interconnect systems in ultra-large scale integrated (ULSI) circuits will be increasingly prone to electromigration and heat dissipation issues. Thus, CNTs are nearly ideal candidates for the (partial) replacement of copper wires in future ULSI circuits. However, besides some technological challenges, large contact resistances between CNTs and metal electrodes are a serious fundamental obstacle.

Theoretical framework

In order to model electron transport at the atomic scale, one needs to link a theory that describes the electronic structure and another one that describes the transport. Electron transport in short CNTs at low bias is quasi ballistic. An appropriate and very successful approach, also used in the present work, is to combine density functional theory (DFT) with the formalism of non-equilibrium Green's functions (NEGF) [2, 3]. The former can be applied to arbitrary materials, while the latter is a powerful general theory for electron transport, capable to include various sources of electron scattering (e.g. with phonons) and electron distributions out of equilibrium (i.e. when a large bias voltage is applied). However, for computational simplicity we consider the limit of small bias voltage (linear response) and neglect inelastic electron scattering.
A much faster approach to describe the electronic structure (compared to DFT) is the selfconsistent version of extended Hückel theory (sc-EHT) [4, 5]. This method has recently been improved in our group by providing a new set of Hückel parameters for carbon [6]. All calculations are performed in a consistent way using software code ATK [7].

Model of a CNT with metal electrodes

In the present work we study the contact quality and transport properties of short to medium-sized (6,0) CNTs in end-to-end contact with the metals Al, Cu, Pd, Pt, Ag, Au. The atomistic structure of such a system is shown in Fig. 1. The theory assumes the structure to be periodic in the directions perpendicular to the tube, while the metal electrodes extend infinitely in the other direction (left and right in Fig. 1). In the Green's-function-based approach, only the central part containing the nanotube and five metal planes (5x5 atoms each) on both sides enter the main part of calculation, while the electrodes are taken as perfect crystals. In the following we consider a (6,0) CNT with a variable length of up to about 10 nm (i.e. 2 – 25 CNT unit cells). The geometry of the CNT metal interface is optimized with DFT regarding contact distance and rotational angle of the tube relative to the metal surface [3, 8].

Electron transport simulations

The most important quantity of a Green's-function-based quantum transport calculation is the transmission spectrum T(E). It contains the sum of all transmission probabilities of electrons at a given energy (right part of Fig. 2). Electron transport through short metal–CNT–metal devices is governed by the presence of discrete quantum mechanical states in the finite-length tubes. Those states can be nicely visualized by the energy-resolved local device density of states, depicted in Fig. 2. Only states that extend

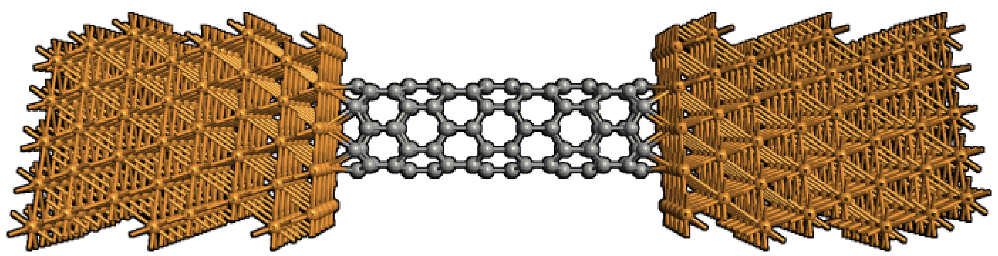

Fig. 1: Atomistic model of a metal–CNT–metal system. The theory assumes that the electrodes extend infinitely in the directions parallel to the tube.

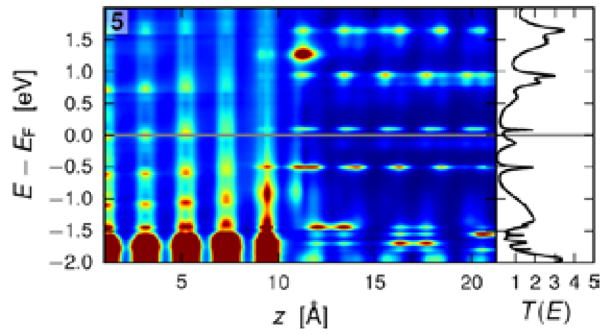

Fig. 2: Energy resolved local device density of states (left) and transmission spectrum T(E) (right) for the example of a Cu–CNT–Cu system. The length of the tube is five unit cells. Only the left half of the data is shown (the structure is symmetric in z-direction). The electronic structure of the five metal planes is clearly visible in the left part of the contour plot.

from the left to the right electrode contribute to the transport. This results in a multitude of peaks in the transmission spectrum. While the position of the peaks is determined mostly by the length of the CNT, the amplitude of the peaks is strongly influenced by the type of metal. When the length of the tube increases, the peaks get sharper, are gradually shifted, and more peaks appear. A more detailed discussion can be found in [3] and [8].
The conductance and the current through a nanodevice are linked with T(E) via the Landauer Formula [3]. The resulting conductances G (in units of the conductance quantum $G_0 \approx (12.9\ \mathrm{k\Omega})^{-1}$) and linear response currents I_{lin} are depicted in Fig. 3 as a function of the CNT length (CNT unit cells N_c). The conductance shows pronounced length dependent fluctuations. This is due to the length dependent shift of the transmission spectra and the fact that the conductance is highest, when a transmission peak crosses the Fermi level. Such size effects are typical for nanoscale electron transport.

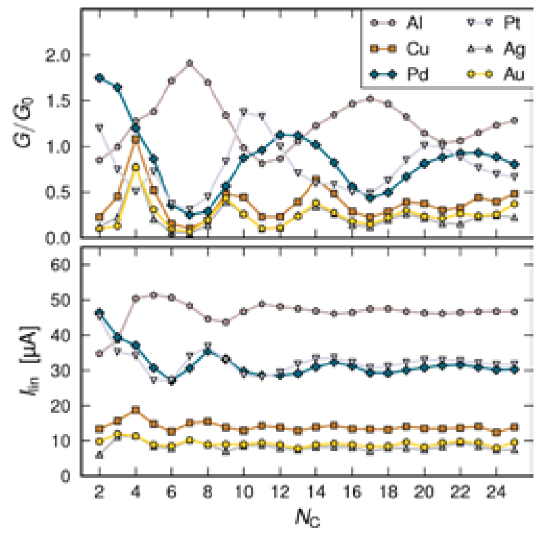

Fig. 3: Zero bias conductance (top) and linear response current for Vb = 0.5 V (bottom) for the metal–CNT–metal systems calculated with the improved sc-EHT. N_c is the number of CNT unit cells.

Electron transport is ballistic in short CNTs. Thus, besides the aforementioned oscillations, the linear response currents in Fig. 3 do not depend on the CNT length. The average values of G and I_{lin} (for $N_c > 10$) allow a ranking of the metals regarding their contact quality: Ag ≲ Au < Cu ≪ Pt ≈ Pd ≪ Al [3, 8].

Summary and conclusions

We have studied quasi-ballistic electron transport in metallic (6,0) CNTs in contact with Al, Cu, Pd, Pt, Ag and Au electrodes by using and comparing DFT and sc-EHT, combined with the NEGF formalism. Results from our improved set of EHT parameters are in reasonable agreement with computationally much more expensive DFT results. Based on the calculated transport properties (zero bias conductance and linear response current) the CNT metal contacts are ranked regarding their ability to form low-Ohmic contacts. Al appears to perform best, followed by Pt and Pd. Cu forms rather poor contacts with the tube, while the noble metals Au and Ag are even worse. In summary, the presence of metallic electrodes reduces the conductance of the tube to about 7% – 40% of its intrinsic value of 3 G_0.

Acknowledgement

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An intravesical measurement system for catheterless long-term urodynamics

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Introduction

The urodynamics is considered as a diagnostic test for urinary incontinence using catheter tip sensors to measure the pressure inside the bladder. Many urological patients present clinical symptoms, however most of them do not show any pathological findings during the conventional urodynamics. Standard urodynamics measurement takes 20-30 minutes, so this measurement shows only a short period in which the pathological change of pressure often cannot be detected. Additionally, different psychological factors could affect the results of standard urodynamics. The insertion of a transurethral catheter is embarrassing to the patient and may influence urodynamic results.

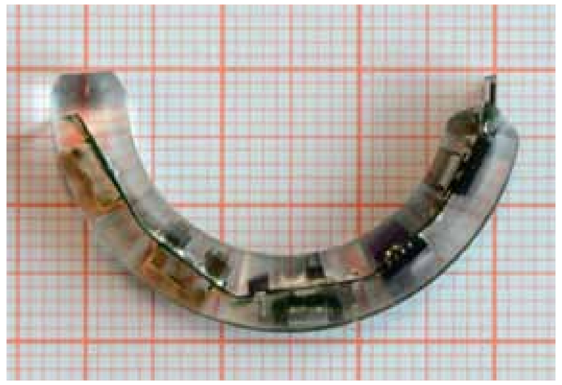

Fig. 1: Measurement system for intravesical pressure measurement (on scale paper).

In this paper we describe a new system for catheterless urodynamic measurement. Catheterless pressure measurement is generally of great interest for many medical applications such as intracranial pressure measurement [1] or real-time blood pressure measurement [2]. Some devices have been designed especially for intravesical pressure measurement [3-6], but they are too large to insert them through a cystoscope, or the operating time is not sufficient for long-term urodynamics. Furthermore, no satisfying solution for a fixation inside the bladder is given.
The system we have developed measures the pressure inside the bladder for a time of up to 72 hours. To prevent an expulsion out of the bladder during micturition, the capsule is C-shaped. The measurement capsule with moulded electronics is shown in Figure 1. The capsule is flexible and can be straightened to push or pull it through a cystoscope for implanting. In straightened state the capsule is approx. 45 mm long and 5 mm in diameter, therefore it fits the inner diameter of a cystoscope.

Methods

The new measurement capsule consists of a MEMS pressure sensor, an EEPROM for storing the measured time and pressure data, a microcontroller, a battery based power supply and a non-tactile, magnetically driven onswitch.
The supply current, especially of the microcontroller, strongly depends on the operating frequency and the supply voltage, so the system is operated at 1 MHz and 2.5 V. The lowest possible voltage is limited by write operations of the EEPROM.
The electronics is soldered on a double-sided flexible printed circuit board encapsulated in silicone, as it can be seen in Fig. 1.
Because the whole electronics is moulded in silicone, a non tactile switch is needed for switching on the system. A P-channel MOS transistor separates the battery from the circuitry. It is opened either by an externally switched reed (the non-tactile, magnetically driven switch) or by an output pin of the microcontroller. This allows it to test the battery charge or the system's functionality after sterilization process without switching the system on for measurement.

Results

The electronics has been built up and tested. The accuracy of the pressure sensor is 2.5 mbar (cm H_2O) with a resolution of 0.2 mbar. The sensitivity of the moulded pressure sensor has been measured inside a pressure chamber as nearly 1 mbar/mbar (Fig. 2), so there is practically no reduction of pressure sensitivity due to moulding.
To detect fast pressure changes, as they occur due to

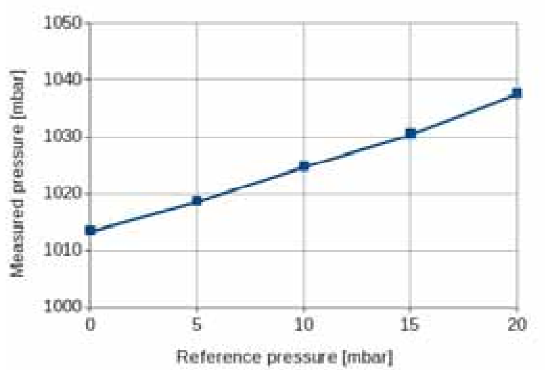

Fig. 2: Sensitivity of the moulded pressure sensor.

pathological spasms or cough, the sample rate of the pressure measurement is 4 Hz. For effective utilization of the EEPROM, a new pressure value is only stored in memory if it differs from the former stored value by a given threshold, or if the time to the last stored measurement value is 60 s. The maximum operating time results from battery capacity (8 mAh for used coin cell type 337) and mean current consumption of the measurement system. The current has been measured as voltage over a 100 Ω resistance in series to the battery via an instrumentation amplifier with an amplification of 5.

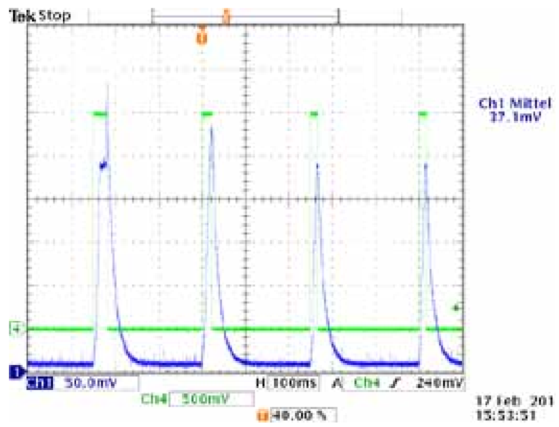

Fig. 3: Measured current consumption (blue) of the system; green: active-flag of the microcontroller.

The results of current measurement are shown in Fig. 3. The green signal shows the active-time flag of the microcontroller, and the blue signal shows the current consumption which is proportional to the measured voltage. The mean current can be calculated from the mean voltage as

$$I_q = \frac{U_q}{a \cdot R_m} = \frac{37.1\,\mathrm{mV}}{5 \cdot 100\,\Omega} = 74.2\,\mu\mathrm{A} \qquad (1)$$

From the battery capacity and the mean current consumption, calculated in (1), a theoretical operating time of 107 hours results. Measurements have ensured an operating time of 84 hours. The usable battery capacity depends on the output current, therefore the measured operating time is smaller than the calculated.
Cytotoxicity investigations, made at BMP GmbH in Aachen, have been passed successfully in November 2012, further tests of biocompatibility are ongoing currently. In February 2013 we have made first in-vitro tests of the C-shaped measurement capsule inside a bladder model at University Hospital of Cologne. The insertion of the capsule through a cystoscope works fine, handling of the capsule inside the bladder has appeared a little bit delicate, therefore the shape of the capsule will be modified to allow a better handling.

Discussion

We have developed a new measurement system for long-term urodynamic measurement. The measurement capsule can be implanted into the patient's bladder through a cystoscope and measures the pressure for a period of more than 72 hours, so the measurement can take place at home for about three days during the patient's normal daily routine. The proper functionality of the moulded pressure sensor has been proven. First in-vitro tests inside a bladder-model have been preponderantly successful, some modifications of the capsule shape will be made to enhance the handling inside the bladder. The results of extensive in-vitro tests in summer 2013 have been presented at the DGBMT conference in September 2013 in Graz. They have confirmed former measurements and tests.

Acknowledgement

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New technology approach for tunable IR filters

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Introduction

Infrared spectroscopy is a powerful analysis method for both natural science and engineering. Microspectrometers based on MEMS Fabry-Pérot (FP) interferometers as optical band-pass filters are a recently emerging solution. Fraunhofer ENAS and TU Chemnitz have been working on FP filters for tunable IR detectors together with InfraTec GmbH Dresden and Jenoptik Optical Systems GmbH Jena for more than 10 years. The filters are aimed for gas analysis e.g. in medical diagnostics, especially the detection and monitoring of carbon dioxide and anesthetic gases, such as halogenated ethers and nitrous oxide, in respiratory gas. Therefore they are combined with an IR detector and integrated in a spectrometer set-up as shown in figure 1.

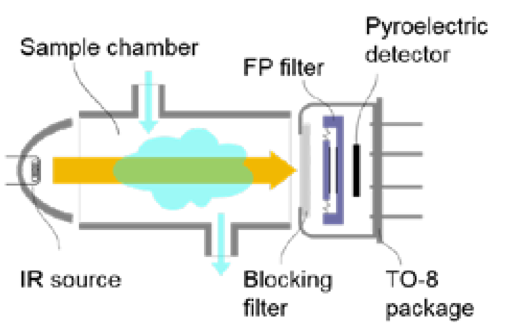

Fig. 1: Microspectrometer setup.

Improved spectrometer design

FP filters transmit and reflect electromagnetic waves of defined spectral ranges by multi-beam interference. They consist of an optical cavity as basic element, which is built between two parallel aligned and high reflective mirrors (Fig. 2). The electromagnetic waves enter the optical cavity through one of the mirrors and are reflected many times. They interfere and their amplitudes are attenuated or amplified depending on the phase difference. The transmitted wavelength is mainly influenced by the distance between the mirrors; by changing this gap size, e.g. with electrostatic forces, the filter can be tuned. As silicon is transparent in IR light, it can be used to build the reflector carriers as well as the electromechanical tuning system.

The reflectors in our approach are made of stacks of dielectric thin films and are optimized for high reflectance. Anti-reflection coatings avoid reflection on the outer surfaces and hence increase the transmission light intensity. In the working range 3…5 µm, 5…8 µm and 8…12 µm the optimized dielectric stack mirrors consist of Ge (high refractive) and ZnS (low refractive) and a third material with low refractive index. These layers are deposited selectively by an ion assisted evaporation process (IAD), using a shadow mask technology.

Our latest design incorporates two equally sized (especially nearly equal mass and stiffness) movable reflector carriers (2M design). Both reflector carriers are nearly equally deflected by the acceleration forces and the optical cavity length remains unaffected, which is particularly necessary for transportable spectrometers. The maximum control voltage for tuning the full wavelength range is significantly reduced in comparison to the previous design with one movable reflector carrier and a similar tuning range. The reflector carriers are designed with a small shape and rectangular footprint and are connected to the chip frame by four equal, meander shaped, flexible suspensions. The upper and lower parts are assembled perpendicular to each other in order to form an overlapping area in the middle and further overlapping parts with the chip frame of the opposite substrate. For actuation, a voltage difference is applied between both substrates. The electric force is generated between a fixed part and the opposite moveable reflector carrier as well as between both moveable parts, and hereby the reflector carriers are displaced.

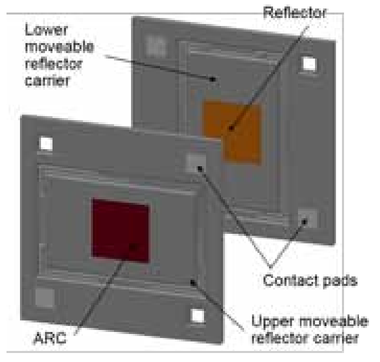

Fig. 2: Design with two moveable reflector carriers.

Fabrication technology

Specific bulk technologies combining wet and dry etching of the Si substrates in order to form the reflector carriers, the elastic suspension, the cavities and the electrodes have been developed. The latest, optimized process flow for the 2M design allows to process identical wafers for the upper and lower part and bond them together face to face by silicon fusion bonding. For the first time, this process has been successfully tested on 6" wafers. The main steps are shown in figure 3. A two-mask system is used for etching the cavities into Si first. Then, the isolation and bond oxide is deposited and patterned. A Si_3N_4 mask protects the wafer during wet etching of a membrane from both sides in order to define the spring thickness of 100 µm. After creating the metal contacts and the optical screen, the Si dry etch step is applied to define the spring geometry. Finally, the optical layers are deposited with IAD process using a shadow mask to define their geometric shapes. Hereby, a Si wafer with etched holes serves as the hard mask. It is aligned and clamped with the process wafer in a special tool in order to fit into the IAP equipment. Prior to bonding, a soft mechanical cleaning step and a surface activation in plasma are applied. The wafers are then annealed at 200 °C for 4 hours, leading to a sufficient bond strength and yield (70…85 %).

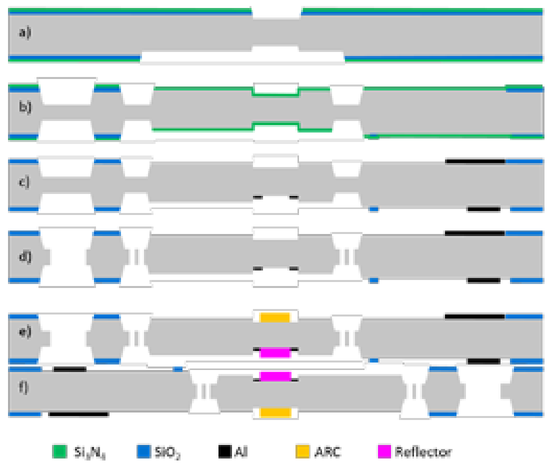

Fig. 3: Schematic process flow.

Figure 4 shows on the left side a photograph of a separated chip of the previous 1M design (having optimized spring shape and trenches for reduced damping) with a chip size of 8.6 mm x 8.6 mm. In comparison, a chip with 2M design and reduced chip size (7 mm x 7 mm) is shown on the right hand side. The reduction of the chip size becomes possible when running the filter in a higher order, and is highly recommended when looking for a cost effective fabrication process.

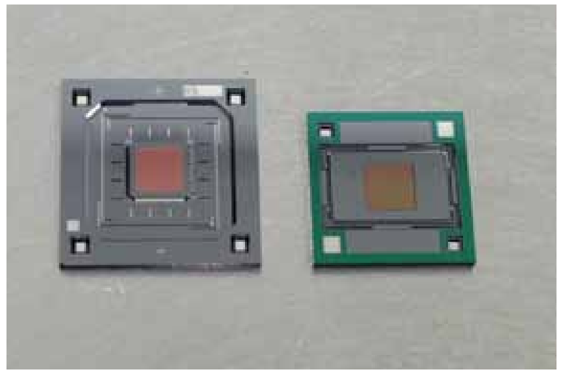

Fig. 4: Chip photographs of an 1M design (left) and a 2M design with reduced chip size (right).

Results and conclusion

Dual band filters (1st/2nd order) for the spectral range 3…4 µm and 8…10.5 µm have been tested successfully. A high tuning range of 2800 nm was reached with a tuning voltage of only 41 V. The peak transmittance is > 75 % and the FWHM is < 200 nm in the upper range and < 100 nm in the lower range. For filters with 1M and 2M designs, operated in a spectral range 3.1…3.8 µm and in higher interference order (3rd or 4th), it is possible to reduce the bandwidth to 20…30 nm, and hereby to increase the resolution of the filters. It is also found that the 2M design can enhance the stability against vibration and gravitation by a factor of 2…6. Furthermore, the latest samples of silicon fusion bonded 2M filters show very low temperature coefficients of the transmission wavelength of -0.25… -0.85 nm/K.

Acknowledgement

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Aluminium nitride integration for piezoelectric MEMS/NEMS

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Fig. 1: PiezoMEMS at wafer level. PDIGs with integrated piezoelectric aluminum nitride.

Introduction

Aluminum nitride (AlN) is a seminal material for MEMS and NEMS sensors and actuators. The energy density for piezoelectric active principles is much higher than for capacitive ones. This allows the shrinking of MEMS and NEMS, which reduces costs and energy consumption and increases the areas of application. Thereby, piezoelectric driven MEMS (piezoMEMS) could be a good alternative for actuators with smaller feature sizes.
Furthermore, AlN is highly capable of being integrated into micromechanical and CMOS processes. In contrast to the commonly used PZT, no high temperature powder sintering processes and no patterning with the formation of toxic byproducts are necessary for AlN as piezoelectric material. Rather deposition and patterning of AlN can be realized in conventional equipment for aluminum based back-end of line technologies. This enables the common fabrication of piezoMEMS and CMOS devices in the same production line. The Center for Microtechnologies develops the technology to sputter and characterize piezoelectric thin film AlN and integrates this material in silicon based MEMS and NEMS applications. This includes as well the development of patterning processes with adequate geometry and selectivity to subjacent materials.

Sensor applications for AlN

For MEMS and NEMS applications AlN is arranged between two electrodes and mechanically coupled with a movable silicon structure. An external mechanical energy (e.g. acceleration) deforms the movable silicon element and hence the coupled AlN structure. In result electric charges emerge. This working principle allows building energy efficient, low-power, ultra-low-power devices as well as energy harvester. Therefore, AlN can be used to create sensor systems which require no permanent or external energy source.
Exemplary the development of ultra-low-power piezoMEMS from the Center for Microtechnologies, the PDIG, is shown in Fig. 1 on wafer level and in Fig. 2 as separated devices. The Power-Down-Interrupt-Generator (PDIG) is a MEMS device with a spring-mass-system and a mechanically coupled AlN layer. In result of acceleration the PDIG will be deformed and the AlN generates electric charges. These charges will be used to wake up an electric circuit, e.g. a highly precise acceleration sensor. Normally, such sensors measure continuously and consume permanently electrical energy. With the use of the PDIG, the sensor is in the sleeping mode as long as a measurement is not required. If acceleration occurs, the PDIG wakes up the electrical circuit, which is responsible for sensor control and readout. As result, the effective energy consumption shrinks to a minimum. Especially for wireless systems energy saving solutions are essential to minimize energy consumption, rise battery lifetime and save resources. Furthermore, the longer battery lifetime imply longer maintenance intervals. For measurement systems with difficult accessibility the energy saving has special manageability advantages.

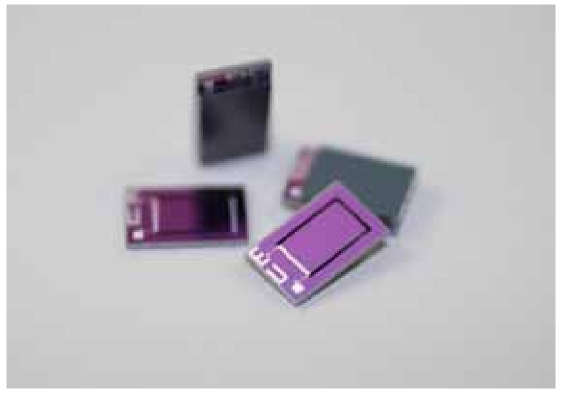

Fig. 2: Ultra-low-power PDIG microchips with and without packaging.

AlN as actuator

For actuators voltage can be applied at the electrodes and the piezoelectric material starts to deform. Especially for systems with requirements for small deformations and out-of-plane actuation functions piezoelectric AlN is innovative.
Piezoelectric actuators can be used in Atomic Force Microscopes (AFM). AFMs are essential for surface analytics with vertical resolutions down to 1 Å. The measurement system requires a mechanical moveable cantilever with a tip. The cantilever is externally shaked at its resonance frequency. The tip interacts with the probes surface. This interaction results in a shift of the resonance

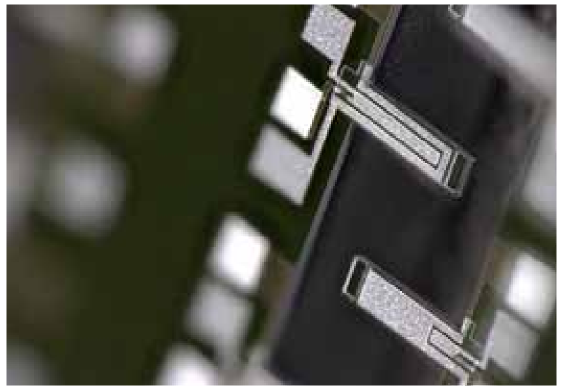

Fig. 3: Samples for tipless active AFM cantilever. Actuator and sensor are integrated on the AFM cantilever. No shaker or oprical system needed for driving.

frequency. State of the art is an optical detection of the cantilever resonance. The Center for Microtechnologies develops a piezo-active AFM cantilever, which includes actuator and sensor functionality as surface integrated elements, shown in Fig. 3. Advantage of this development is that no optical system and no external shaker is needed anymore. For this reason the operational area is more flexible, especially for light sensitive applications as TERS (tip enhanced raman spectroscopy). Furthermore, higher operation speeds and parallelization of the AFM cantilever is easily possible.

Conclusions

The industry-oriented piezoMEMS application of the Center for Microtechnologies bases on fundamental research results in micro technology and characterization. Wide knowledge of AlN growth processes exists. Detailed investigations of the dependencies of the piezoelectric behavior with the technology process are the fundament for high end piezoMEMS. The permanent optimization of the sputtering conditions and advancement of the piezoelectric characterization tools for thin films are unique at the Center for Microtechnologies. Furthermore, the development of AlN patterning processes using different electrode materials is the focus of current investigations. A high quality etch process is the key for the contemplated fabrication of AlN containing multilayers with enhanced piezoelectric behavior. Finally, the ZfM has several methods for the precise determination of the piezoelectric coefficients d_{33} and d_{31} of thin films. A highly precise characterization of the AlN is the key for innovate piezoMEMS research and development.
With AlN the Center for Microtechnologies has a CMOS compatible thin film material for the integration into silicon MEMS. In addition to permanently optimized AlN technology processes, the ZfM has unique and highly precise characterization tools for the determination of the piezoelectric coefficients for thin films. Based on this fundament, industry-oriented micro sensors and actuators are developed. The high coupling coefficient, CMOS compatible processes, intrinsic energy generation for ultra-low-power devices, out-of-plane actuation functions and many other advantages are the driving forces for the Center of Microtechnologies for the research and development of AlN based cutting edge innovate piezoMEMS.

Current publications

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Improvement of BDRIE technology for high precision MEMS

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Introduction

Since several years, the ZfM develops technologies for high precision inertial sensors. One of these approaches is the so-called BDRIE technology (Bonding and Deep RIE). Its basic idea is the bonding of a Si wafer on a basic wafer with pre-etched cavities. Afterwards, the Si wafer is thinned down to the desired thickness of the MEMS structure, and vertical trenches are etched with DRIE in order to define its lateral dimensions. While reaching the cavity, the MEMS structures will be released. Both Si-Si- and glass-Si versions are possible and have first been reported in 2005 [1]. In the meantime, especially the glass-Si approach has been improved in order to provide compact, vacuum sealed devices feasible for 3D sensing MEMS structures, with electrical through contacts in one of the glass wafers. A schematic cross section is shown in Fig. 1.

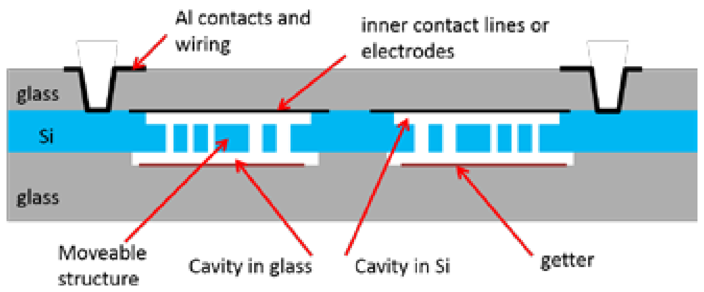

Fig. 1: Schematic cross section of a BDRIE sensor.

Improved features of BDRIE

The BDRIE technology allows for high flexibility in design, even large differences in the gap size are possible. Typically, small trenches for detection combs (< 2 µm) are combined with wider trenches for isolation and for lateral freedom of movement (30…50 µm). The structure height of the moveable structures is typically 50 µm…75 µm. Hence, we can realize aspect ratios up to 25…30 (Fig. 2). Due to the ARDE phenomenon of the RIE process, larger trenches will reach the cavity earlier than smaller trenches. During this “overetch” time, the backside of the structures may also be attacked. A very simple, but helpful method in order to protect the backside is the introduction of a very thin silicon oxide layer on the backside of the cavity (not shown in Fig. 1). It will be etched from the front side in order to release the structures, and can remain on the backside.

Inner metallic connections allow for a more compact design, electrodes underneath the moveable structure enable vertical capacitive detection in addition to the typical laterally sensing comb electrodes. A thin Al layer on top of the bottom glass wafer has been patterned in order to create these structures. Together with the bonded Si wafer, electrical pressure contacts are formed (see Fig. 3).

A small unbounded area will remain surrounding the contact area. With the chosen size of the contact area of about 100 x 100 µm² and 200 nm thickness of the Al, we have measured resistance of about 50 Ohm between two Si islands connected by such a contact line.

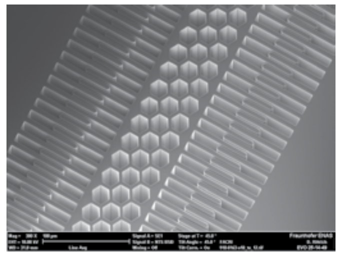

Fig. 2: Comb drive with aspect ratio of 28.

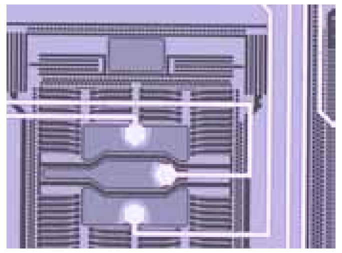

Fig. 3: Inner contact lines visible through the glass.

In addition to the underlying electrodes, an out of plane actuation or sensing can also be achieved by combs with different height. As an example, Fig. 5 shows a comb electrode whose fixed part is about 25 µm deeper than the moveable part.

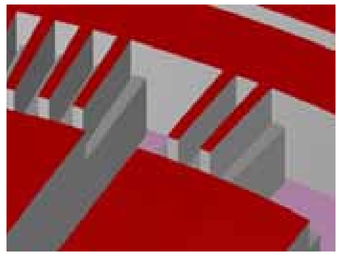

Fig. 4: Principle of two-mask approach for trenches.

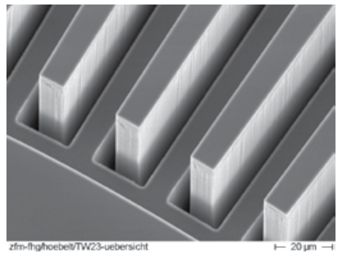

Fig. 5: Comb electrodes with different height.

Therefore, a two-step DRIE etch step can be easily integrated in the BDRIE technology flow. In this case, the mask system is provided by a combination of the usually applied resist mask with an additional, pre-patterned oxide hard mask. After a pre-etch step, the resist is removed and the etching is continued until the trenches reach the cavity and the desired thickness of the recessed area is reached (see Fig. 4). In principle, a similar method can also be applied for the patterning of the cavity from the backside, hereby allowing for even more complex structures.

Two methods of through contacts in the glass have been investigated. The first method uses glass wafers with pre-patterned holes, which are ordered from several suppliers of the glass wafers (e.g. Schott, Planoptics, Tecnisco). These sand-blasted holes have a typically conic shape (Fig. 6), with minimum diameters of the smaller (bottom) hole of about 150 µm. Depending on the glass thickness, which is usually 400 µm in our applications, the larger upper diameter is about 500 µm. These glass wafers with pre-patterned holes are anodically bonded to the Si wafers. In order to get metallic connection from the bottom of the holes to the top, attention must be paid to the quality of the lower edges of the holes, and according to our experience more than 3 µm thick (sputtered) metal layers are necessary for a good connection. As an alternative solution, we have created holes by (wet) etching of the glass. As this is an etch process with fully isotropic etch behavior, it is necessary to thin the glass down to about 150 µm, otherwise the holes will become too large. Thinning is done after second anodic bonding by grinding and polishing; and etching is achieved in concentrated HF solution using a Cr/Au hard mask and a thick resist layer in addition. The etching will stop on the Si, and smooth edges are created which can be metalized easily with much thinner metal (e.g. 1 µm Al), see Fig. 7.

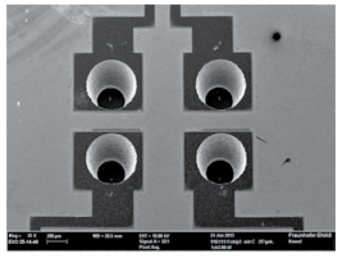

Fig.6: Sand blasted holes.

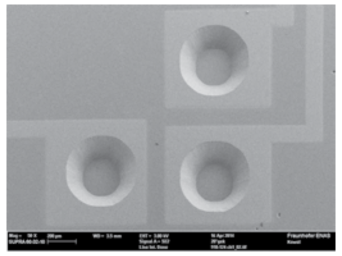

Fig. 7: Wet etched holes.

Vibration sensors and gyroscopes are expected to provide resonators with high quality factors and hence need to be sealed in vacuum with the least possible residual pressure. Hermetic sealing is achieved during second anodic bond process. As oxygen is set free from the glass during anodic bonding, according to our experience it will be necessary to integrate a getter material in case the residual pressure is expected to be lower than approx. 10 mbar. For this purpose we apply selective deposition (sputtering) of a Ti layer into the cavity of the lower glass wafer using a hard mask (see Fig. 1).

Application and results

The improved BDRIE technology has been successfully applied for the fabrication of acceleration, vibration and angular rate sensors. As an example, Fig. 8 and 9 show a single mass MEMS gyroscope which has been developed in close co-operation with the Fraunhofer ENAS (MEMS and system design) and the EDC Electronic Design Chemnitz GmbH (electronic design). The MEMS resonators work at vibration frequencies near 8 kHz; Q-factors are typically 220,000 for the drive mode and 100,000 for the sense mode (measured on wafer level). Typical parameters of the open-loop single mass gyroscope with ASIC are 1.1 °/h for the Bias instability (BI) and 0.1 °/√h for the angle random walk (ARW). The measurement range is 0.03-500 °/s with a bandwidth of 120 Hz [3].

Recently, we have fabricated MEMS gyro chips with two-mass and four-mass designs as well, which are about to be characterized and tested together with the electronics. We expect similar results for BI and ARW, but better vibration rectification and less influence from the method of packaging.

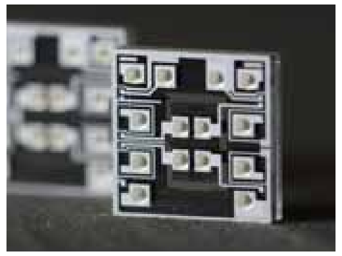

Fig. 8: Photograph of MEMS gyro chip.

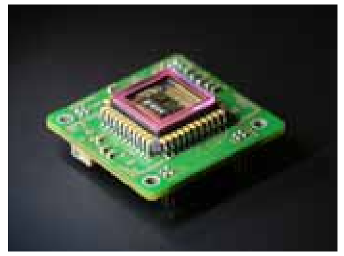

Fig. 9: Gyro prototype (ASIC on top of MEMS chip).

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Combining 2.4 GHz beacon enabled network and ultra low-power wake-up receiver protocol

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Abstract

Wake-up concepts for wireless sensor networks are an upcoming field of interest for many applications. An ultra low-power wake-up receiver (WuRx) allows sensor nodes to have the main radio disabled and still be able to react very fast to asynchronous events. Combining approved mechanism like duty cycle communication and wake-up concept can improve the performance, especially the latency. In this paper, the combined protocol, a lifetime analysis and current consumption measurements are presented.

Introduction

Wireless sensor networks become more and more important to many applications. Such sensor networks are used in applications where wired solutions are not possible or too complicate to adjust and maintain. To reduce size and increase autarchy of sensor nodes, power consumption is one of the key aspects of research and development. Not only the hardware has to be power efficient, but also the software including the network protocol.

Today's wireless sensor networks mainly depend on duty cycle mechanisms. Therefore, some or all members of the network have to be activated in discrete time spans, even if there is no information to be shared. In networks, where for example only unpredictable warnings are to be detected, these periodical wake-ups cause unnecessary power consumption. Lowering the duty cycles does not only reduce the consumption but also increases the latency, which can be very critical in alert based applications.

Synchronous networks can be replaced by asynchronous ones. In asynchronous networks communication can start at any time. For this reason, very low power wake-up receivers are in focus of actual development. The concept of using such receivers is to leave them active the whole time and listen to the medium. Meanwhile, all other components of the sensor node can be in minimal active state. If a wake-up signal is detected, the transceiver for normal communication is activated to start the proper data communication.

Concept of combined protocol

The sensor nodes can be divided into two main types. Utilizing infrastructure nodes with greater energy resource and higher duty cycle can be appointed tasks like routing. Here, the main focus is not energy consumption, since they can have mains supply. On the contrary, the ultra lower-power node is battery supplied and/or equipped with energy harvesters. Main responsibility is to send sensor data and alert user in case of an emergency.

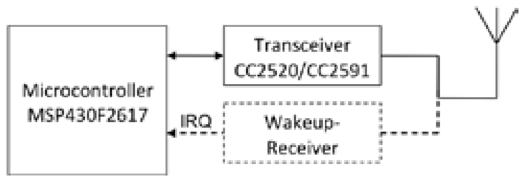

Fig. 1: Block diagram of sensor node.

A block diagram of the infrastructure and sensor node can be found in Fig. 1. Main blocks for communication are a microcontroller and a 2.4 GHz IEEE 802.15.4-based [1] transceiver. Optional hardware is an ultra low-power wake-up receiver. By receiving a wake-up signal the node can asynchronously wake-up and enable its main transceiver for normal radio communication. The wake-up receiver concept allows nodes to go into a deep power down mode and still be able to response very fast to alert-based events. For measuring the current consumption the components in Fig. 1. have been used on the sensor platform. The wake-up signal uses 32 kHz on-off keying in the 2.4 GHz ISM band.

The combined protocol is depicted in Fig. 2. The beacon interval of the ultra low-power sensor node can be much longer than that of the infrastructure node to reduce power consumption. The beacon is used for synchronization and bidirectional communication can take place inside the superframe. To allow asynchronous communication, the node needs to be equipped with a wake-up receiver. In pure sensor nodes (no actors), no alerts would be send to the sensor nodes. In this case, they do not need a wake-up receiver, which would further reduce the current consumption but only allowing an asynchronous unidirectional communication. Communication in direction sensor node can only take place inside the superframe of coordinating infrastructure device.

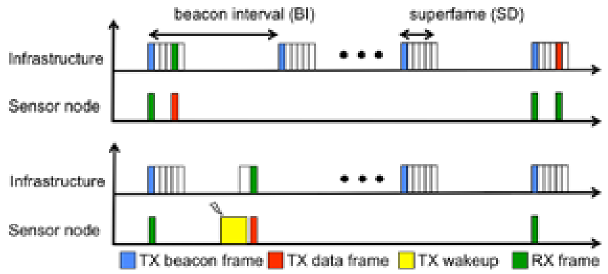

Fig. 2: Combined duty cycle and wake-up receiver communication protocol.

Lifetime analysis

Since the amount of data in sensor networks and power consumption of nodes are extremely dependent on the running application, only the part for synchronization and waking up devices is considered in this lifetime analysis. In beacon enabled network, the duty cycle is calculated out of the superframe duration and beacon interval and can be found in equation 1. The superframe order (SO) and beacon order (BO) can be chosen by user to optimize current consumption and data throughput in network.

$$duty\ cycle = \frac{SD}{BI} = \frac{2^{SO}}{2^{BO}} \qquad (1)$$

Here, only the ultra low-power node is considered since for those nodes an optimized current consumption is essential. A lifetime estimation of the pure 802.15.4 beacon enabled network can be found in table 1. Important parameters for the calculation are also listed. The life time would be further reduced if the sensor data communication would be considered. For example, a sensor node running on a 25 mAh coin cell would almost last 2 years if only synchronization is considered.

As can be seen in Table 2, a wake-up receiver with a current consumption of 30 µA (for comparable wake-up receiver, see [2,3,4,5]) would last for roughly a month. A node without wake-up receiver only using unidirectional communication towards coordinating device would last 41 years when only considering wake-up signalization (150 mA TX current for 40 ms) once a day. In the combination of duty cycle approach and wake-up concept, the impact of sending wake-up signal can be neglected. Hence, the duty cycle will be the major factor limiting the lifetime. At very low duty cycle, considering the low-power mode current consumption will be more and more important. For example, a sensor node with 3 µA standby current consumption will last for almost a year.

Duty cycle	12.5 %	1.56 %	0.10 %
Beacon interval	0.98 s	7.86 s	2.10 min
RX current	25 mA	25 mA	25 mA
RX duration	7.68 ms	7.68 ms	7.68 ms
Electric charge per day	4.57 mAh	0.57 mAh	0.036 mAh
Life time (coin cell 25 mAh)	5 days	44 days	683 days

Table 1: Lifetime estimation 802.15.4

Type	only WuRx	without WuRx	0.10 %
Duty cycle	alwas on	1 wake-up a day	2.10 min
RX/TX current	30 µA (RX)	150 mA (TX)	25 mA
RX/TX duration	–	40 ms	7.68 ms
Electric charge per day	0.72 mAh	0.0017 mAh	0.036 mAh
Life time (coin cell 25 mAh)	35 days	41 years	683 days

Table 2: Lifetime estimation with and without wake-up receiver.

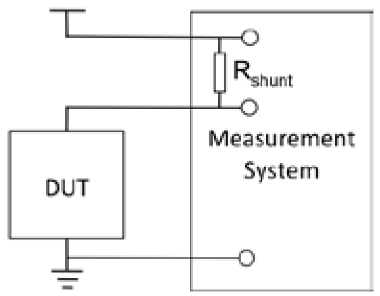

Fig. 3: Measurement setup.

Measurement setup

For logging the current consumption of a sensor node, a shunt resistor is used and the voltage drop across it is measured. The voltage drop is amplified and feed to microcontroller. The measurement setup can be seen in Fig. 3. The measurement equipment [6] and software for displaying are developed at the Professorship Circuit and System Design, TU Chemnitz. It is a mobile device and uses the analog-to-digital converter in MSP430-microcontroller for sampling the voltage across the shunt resistor. The measuring range can be adjusted by changing the shunt resistor. Here, a 1 Ohm resistor is used to achieve a linear range of 3.3 – 33 mA. Greater currents will be limited to the maximum value and lower ones will show a non-linear behavior. Currently, to achieve trustworthy values below 3.3 mA the shunt resistor needs to be replaced with a higher value.

Result

Fig. 4 shows the current consumption during a superframe duration. First, a beacon is send for synchronization reason. In the following slot (at 8.77 s), data communication (TX and RX) is performed. The node can enter low-power mode (3 µA) even between slots because of the fast startup time of transceiver. The RX current is 25 mA and the TX current is limited to 33 mA in the graph due to the shunt resistor.
Fig. 5 shows the combined communication protocol of the ultra low-power sensor node. Here, a beacon interval of 2 s has to be chosen during the current consumption measurement. At 4 s, the node is enabling its main transceiver in RX-mode (25 mA) and is receiving a beacon from coordinating device. At 4.7 s, an alert situation takes place and the sensor node is asynchronously sending a wake-up signal following by a data packet. The last spike at 6 s is the next listening time for synchronization, i.e. receiving a beacon.
A detailed view of wake-up communication is shown in figure 6. The node is enabling the transceiver very fast and sends a wake-up signal for 40 ms. Afterwards, a data frame (1 ms) is send following by receiving an acknowledgement frame.

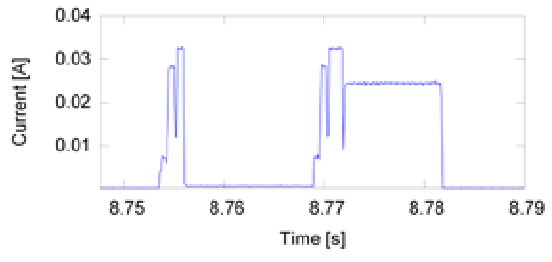

Fig. 4: Communication in superframe.

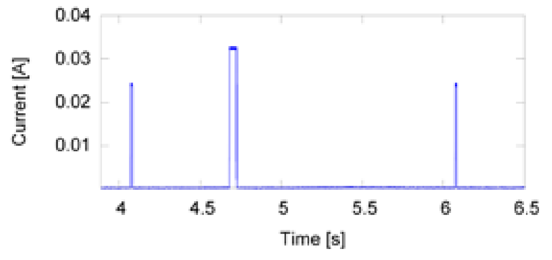

Fig. 5: Combined duty cycle and wake-up protocol communication of ultra low-power sensor node.

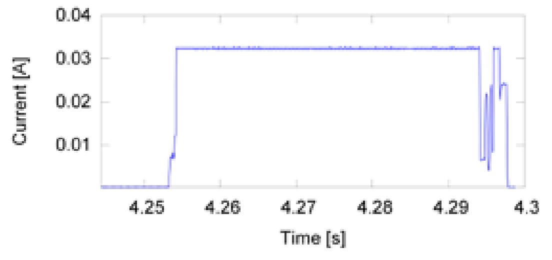

Fig. 6: Wake-up protocol communication.

Conclusion and outlook

Combining a very low duty cycle network with a wake-up concept can reduce current consumption of the ultra low-power sensor nodes and still allow to react very fast to asynchronous event. This concept is very suitable for alert based applications running in a network. For applications that periodically send sensor data to a sink and where latency is not the main focus, a pure duty cycle network can be more efficient.

An important factor not included in the lifetime calculation is collision during wake-up signalization. Due to the long wake-up signal compared to a normal data frame, it is more costly in terms of power consumption to retransmit the wake-up than a normal frame. Further work would be to investigate the impact of collisions on the current consumption and effectiveness of combined protocol.

Acknowledgment

The presented work has been established in association to the nanett project "Kompetenznetzwerk für Nanosystemintegration – Anwendung von Nanotechnologien für energieeffiziente Sensorsysteme", 03IS2011A, founded by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung).

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Simulation of press-pack IGBTs under power cycling conditions

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Introduction

In the last years, the share of renewable and sustainable energy sources in the field of power grids has increased significantly. Two aspects have a strong impact on the choice of the energy sources used for generating the power. These aspects are the so-called consumption of landscape and the yield of energy. Due to the possibility of placing wind energy plants out of sight and with a higher yield, Offshore Wind Energy (OWE) is getting more and more important.
Because of remote offshore locations, the costs for maintenance are high and the timeframes for repair are limited. Therefore, the reliability requirements on the components are very high. The reliability of the power electronic components was the main topic in the Offshore Power Electronics (OPE) project (2010-2014) hosted by SINTEF Energy Research Trondheim with the Chair of Power Electronics and EMC at TU Chemnitz as partner. During this project, Press-Pack IGBTs were tested at the SINTEF 2000 A Power Cycling Tester (PCT). The basic structure of such a Press-Pack IGBT is shown in Figure 1. This housing was chosen because of the expected high reliability due to the absence of solder joints and bond wires which are known to be weak points in the module technology. Furthermore, Press-Pack IGBTs have the advantage of double sided cooling and that they fail to short-circuit, which is an essential property when series connection of devices is required for obtaining medium to high voltage converters.

During the power cycling test the devices failed in an unexpected way. Hence, Finite Element Method (FEM) simulations were carried out to understand the behavior of this housing under these conditions and to explain the previous unknown failure mechanisms.

Approach and FE-model

The thermo-mechanical behavior of a Press-Pack housing under power cycling conditions is very complex. In order to get a better understanding of the mechanisms leading to failure, a FE-model was generated. It consists of a Press-Pack with an internal structure as shown in Fig. 1 and heat sinks on both sides. In contrast to the module-technology, all thermal and electrical contacts are force-initiated, which means that a clamping force is applied with a clamping device which is represented by stamps on both sides. A cross section of the generated model with all boundary conditions and symmetry axis is shown in Fig. 2. The calculation was divided into two load steps. In the first the clamping force was applied and in the second the load current was applied in the same form as in the power cycling test. To get a good representation of the spring behavior of the clamping device, the spring characteristic was used to calculate the elastic foundation stiffness (EFS) of the elastic support. The EFS-value is the force applied to an area of 1 m² which is necessary to move this area 1 m normal to the surface. Furthermore, a frictionless support was defined on a small surface of the housing in order to restrict lateral movement and reduce numerical problems. As in the real clamping device, the force is applied through a plunger into the upper stamp which distributes the force homogeneously. For the cooling boundary conditions, a convection layer in the middle of the heat sinks was defined representing a strong water cooling. As the device is heated up due to power dissipation of the IGBTs, a current is applied to the upper lid of the Press-Pack whereas the ground potential is defined on the bottom lid. Since the contacts are all force initiated, special focus was set on their modelling. A bonded connection was set for the contacts between the device, the heat sinks and the parts from the clamping device. Consequently, no relative movement or liftoff is possible and the thermal and electrical conductivity is assumed to be ideal. Inside the housing, the contacts between the molybdenum plates, the chips and lids are set to be frictional. Hence, a lateral movement, depending on the coefficient of friction and a liftoff is possible. Furthermore, the thermal and electrical contact conductivity is dependent on the actual pressure. The calculation of these conductivities is described in [1]. The strong dependency of the thermal and electrical contacts from the applied pressure makes it necessary to couple the thermal, electrical and mechanical degrees of freedom (DOF) and calculate the solution together in one step.

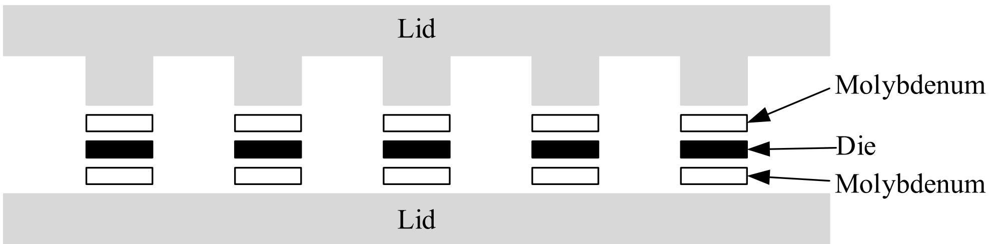

Fig. 1: Basic concept of a Press-Pack IGB.

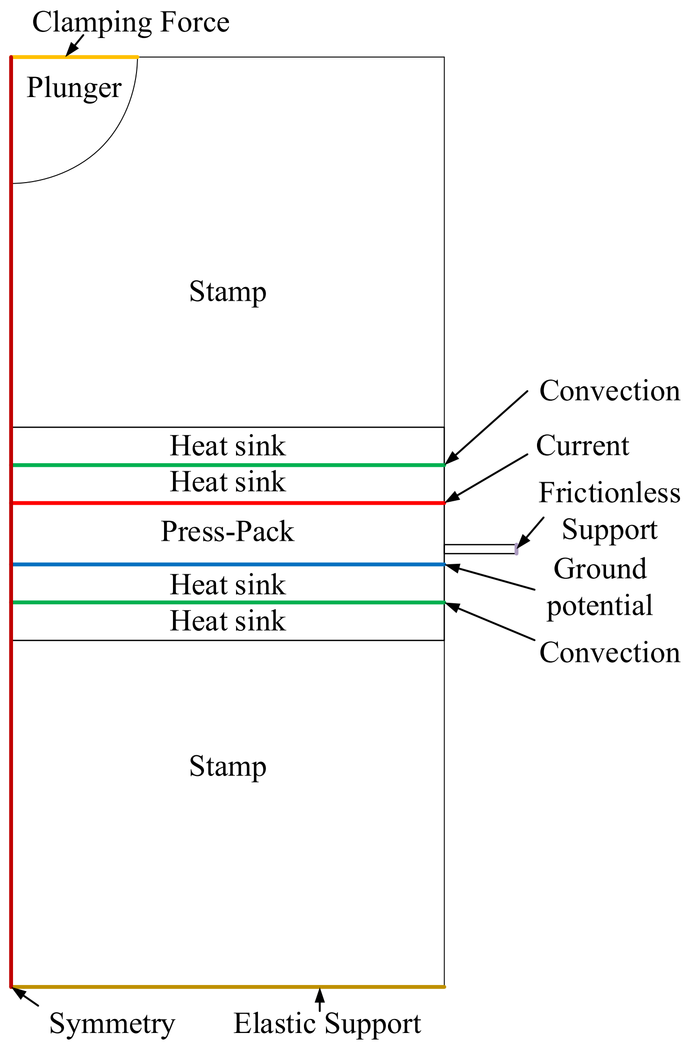

Fig. 2:
Cross section of the three- dimensional Press-Pack model with boundary conditions and symmetry axis.

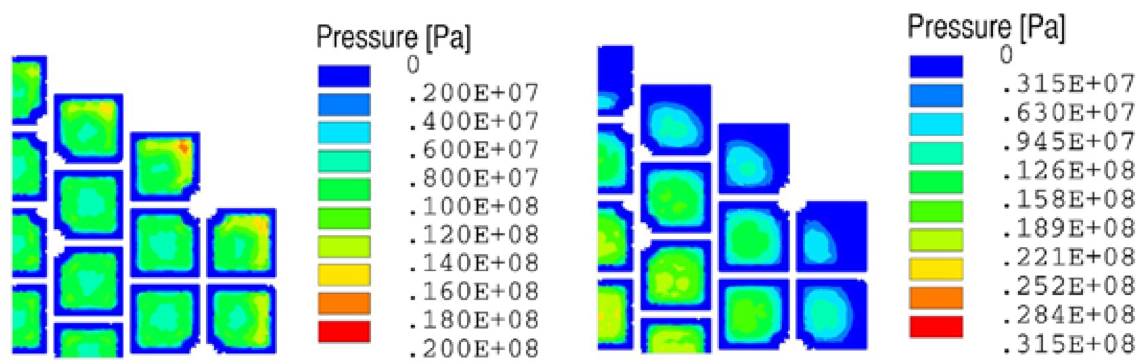

Fig. 3: Pressure distribution after clamping and after the heating phase [2].

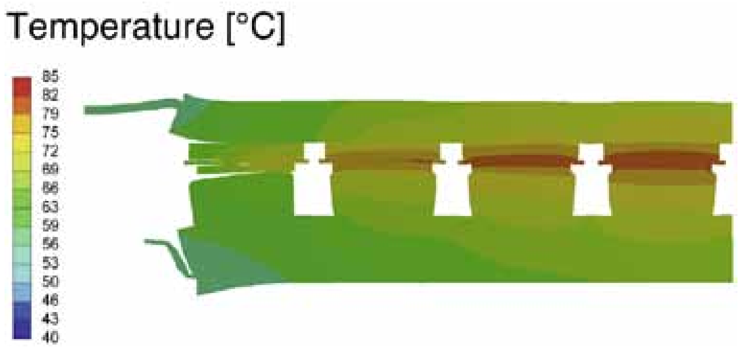

Fig. 4: Deformation of the Press-Pack overlaid by the temperature distribution, scaling factor: 500[2].

Results

Pressure inside the package is needed to be homogeneous in order to provide good thermal and electrical contact for all chips. Therefore, the pressure after the clamping process and after the heating phase was of major interest. In Figure 3 the pressure distribution on the chips is displayed after the clamping process (left picture) and after the heating phase (right picture). It can be seen that after the clamping process the clamping device provides a mostly homogeneous pressure distribution as expected, but some single high pressure spots are revealed as well. After the heating phase (Figure 3, right picture), the pressure on the chips in the center of the Press-Pack is increased whereas it is reduced on the chips on the periphery. It has to be emphasized that the contacted area of the outer chips after clamping can be as low as 25 % of the initial area. This partial loss of contact is a result of the temperature distribution in the lid, as shown in Figure 4. There the deformed housing is overlaid by the temperature. The maximum temperature reached in this load case is 85 °C, which is quite low compared to the specified maximum temperature of 125 °C. Already at these low temperatures, the reduction of contacted area is significant and it can be expected that the loss of contact at higher temperatures might become crucial. In Figure 5 the temperature distribution in the whole simulation model is depicted. Due to the higher temperature gradient in the upper lid the bending is worse compared to the one at the bottom.

Conclusion

A detailed model of a Press-Pack housing was generated and simulated under power cycling conditions. A bending of the lids has already occurred at comparatively moderate temperatures; and therefore a weak point of this housing was identified. The clamping device should oppose this bending and provide a homogeneous pressure distribution under all conditions. However, the impact of this on the reliability of the device will be dependent on the applied stress level and the duration of the resulting thermal cycles.
Due to the bending, the chips on the periphery are stressed mechanically, which could lead to serious damage.

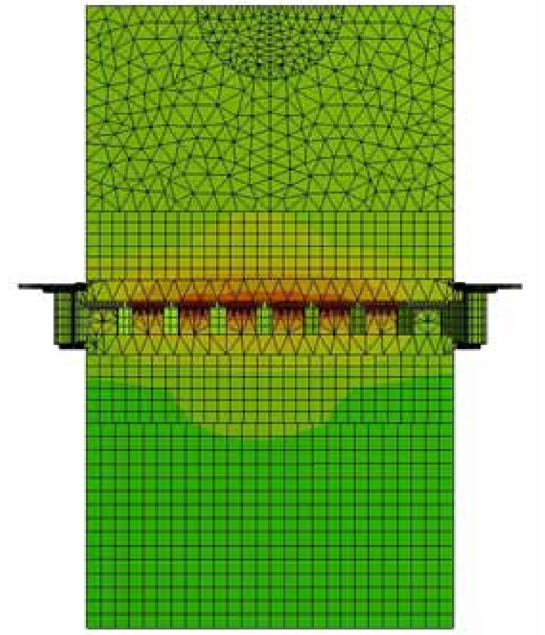

Fig. 5: Temperature distribution in the whole model after the heating phase.

Acknowledgement

The Research Council of Norway is acknowledged for financial support.

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Selected Scientific Events

International Symposium on Smart Integrated Systems

The "International Symposium on Smart Integrated Systems" was held on August 12th, 2014 in Chemnitz at the Technische Universität Chemnitz. It was a scientific symposium on occasion of the 60th birthday of Professor Thomas Geßner, the director of the ZfM of TU Chemnitz. 320 participants from industry, research and politics took place.

At the beginning, representatives of Fraunhofer-Gesellschaft, the Saxon State Ministry for Higher Education, Research and the Arts, the City of Chemnitz and Technische Universität Chemnitz underlined the importance of Professor Geßner´s work.

Dr. Hans-Otto Feldhütter, Head of Department Technology Marketing and Business Models of Fraunhofer-Gesellschaft, honored Professor Geßner with the Fraunhofer Medal to appreciate his committed and successful work which is always focused on the strengthening and successful development of Fraunhofer ENAS.

In recognition of his significant achievements in microelectronics and microsystems technology at the TU Chemnitz as well as the development of a successful innovation network between Technische Universität Chemnitz, Fraunhofer Institute for Electronic Nano Systems ENAS and further scientific institutions and companies, Professor Dr. Thomas Geßner received the Medal of TU Chemnitz from the Rector Professor Arnold van Zyl.

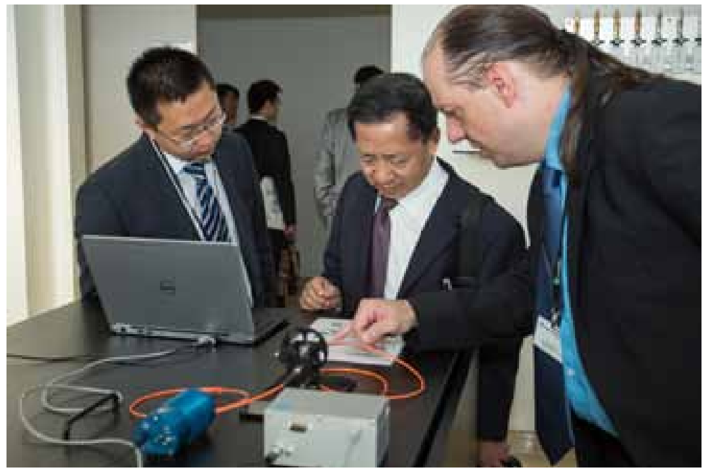
After the award ceremony national and international scientists and experts from preeminent companies and research institutes presented the latest advancements in microelectronics, microsystems technology and smart systems for various applications. So Prof. Anton Grabmaier, Fraunhofer VµE/Fraunhofer IMS addressed the trends and perspectives of microelectronics in Germany and Europe.

Smart systems integration belongs to the key topics in Horizon 2020. Dr. Günter Lugert from Siemens AG, Chairman of the Executive Board of EPoSS and Vice Chairman of the European Green Car Initiative (EGCI) Advisory Group of the European Commission addressed this topic. Dr. Gerd Teepe from GLOBALFOUNDRIES focused on leading edge foundry technology for the next generation of smart systems. The next generation of electronic systems leads also to new the challenges and solutions for microelectronic packaging. These aspects have been pointed out by Rolf Aschenbrenner from Fraunhofer Institute for Reliability and Microintegration IZM in Berlin.

Smart systems are enabled by many technologies and act as enabler for new technologies, too. Three presentations focused on technology aspects, namely the presentation of Tino Petsch from 3D Micromac AG to novel laser processing methods, Prof. Tanaka from Tohoku University to wafer level transfer by adhesive bonding and Dr. Wei-Shang Wan from Fraunhofer ENAS to low temperature bonding using nanoporous gold.

MEMS are a main component of smart systems. There are different tendencies to observe. Dr. Jean Philippe Polizzi, CEA LETI spoke about the MEMS evolution towards smaller and more standardized devices. The status of flexible mircosystems has been reported by Prof. Ran Liu from Fudan University Shanghai. The status MEMS business in China has been presented by Dr. Gong Li from Suss MicroTec Shanghai LTD. Prof. Bechtloff from KSG Leiterplatten GmbH clearly demonstrated the competition and chance for Europe of micro systems and printed board technology.

Last but not least different applications had been addressed, so miniaturized smart systems for health and lifestyle applications by Dr. Sywert Brongersma from IMEC and smart sensor systems for invasive pressure monitoring by Prof. Mokwa from RWTH Aachen.



The international guests visit the labs of the Center for Microtechnologies and Fraunhofer ENAS before the symposium started. Photo © Dirk Hanus

Professor Thomas Geßner received the Medal of TU Chemnitz from the Rector Professor Arnold van Zyl. Photo © Dirk Hanus

Professor Shuji Tanaka from the Tohoku University in Sendai, Japan, presents the talk "Wafer level transfer by adhesive bonding for integrated MEMS". Photo © Dirk Hanus

Greeting words were given by Prof. Arnold van Zyl, Rector of TU Chemnitz, Dr. Hans-Otto Feldhütter, Head of Department Technology Marketing and Business Models of Fraunhofer-Gesellschaft, Barbara Ludwig, Mayor of the City of Chemnitz, and Dr. Reinhard Zimmermann, Deputy Head of Research, Technology, State Ministry for Higher Education, Research and the Art. (from left)
Prof. Bernd Michel (right) presented the honorary volume "Smart Systems Integration for Micro- and Nanotechnologies" on the occasion of Prof. Gessner's 60th birthday. Photo © Dirk Hanus

19th International Workshop on THERMal INvestigations of IC and Systems “THERMINIC” held in Germany for the first time

“What makes THERMINIC so interesting and special is that is has exactly the right size and blend for an annual scientific exchange within the community” says Bernhard Wunderle, TU Chemnitz and Fraunhofer ENAS, program chair and co-organizer of THERMINIC 2013. Indeed, this conference, that has been going strong for 19 years now, bringing together thermal experts from around the globe, has proven to be the prime conference for the electronics cooling and thermal management community in Europe. And for the first time now it was held in Germany. With Fraunhofer ENAS being the leading organizer, the Fraunhofer Forum in Berlin, just opposite the Berlin dome next to the river Spree, was chosen as location to house the more than 100 attendees from 22 countries (51 oral and 23 poster presentations in 12 scientific, 2 special and 1 poster sessions): ”We were quite confident that Therminic and Berlin together would draw a large audience, especially also from industry”, states Jürgen Keller, AMIC Berlin, also one of the local organizers and CEO of this SME, “and be a good chance for us to present us to our customers”. Ralph Schacht, BTU Cottbus-Senftenberg and Fraunhofer ENAS and co-organizer knows why: “As thermal management poses new challenges to industry and academia alike, it is important to discuss matters and future perspectives in depth and face to face at least once a year.” This fact is also highlighted by three top industrial keynotes from IBM, Audi and Philips: “This is an excellent opportunity for us as global player to tell our academic partners what competencies we need in the future”, comments Thomas Brunschwiler from IBM Zurich, keynote speaker on the first day.

Two and a half days the community discussed topical items concerning thermal phenomena in micro- and nanoelectronics, solid state lighting and power electronics. Aspects ranged from design, coupled field simulation, thermal and fluidic characterization, thermal metrology and failure analysis to system aspects and reliability.

As thermal issues are becoming ever more critical with the increasing element density of circuits and with the continual move toward nanotechnology, heat transfer on

THERMINIC 2013

((19th INTERNATIONAL WORKSHOP
Thermal Investigations of ICs and Systems))

the nanoscale has also been revisited on the agenda at THERMINIC 2013, revealing the topical character of the conference. Here, characterization and simulation issues still pose unresolved challenges. These challenges have been taken up by a variety of vendors which used the workshop as a forum to present their products, all of them dealing with advanced thermal characterization methods: Mohamad Abo Ras, CTO of Nanotest, vendor and one of the sponsors of THERMINIC 2013, argues: “We know that industry needs practical and accurate thermal characterization methods for rapid material screening. This is what all of us are working on.” For the first time also parallel sessions on the last day were held presenting results from two European FP7-funded projects: Smartpower and Nanotherm, addressing novel cooling solutions for power system in package and novel thermal technologies based on nanoeffects respectively.

Apart from scientific discussions, THERMINIC 2013 also marked a change in generations: After 19 years of scientific, administrative and personal presence one of the founders of THERMINIC, Bernard Courtois, TIMA, France, was presented an award and a present for his merits and dedication to THERMINIC over the years. “Good to see so many young scientists here”, the laureate commented, anticipating the next 19 years of THERMINIC in Europe.

It is sure, however, that the next THERMINIC will be held in Greenwich, London, England next year. Undoubtedly a great venue for then celebrating the 20th anniversary of THERMINIC.


The all-time conference classic: Conversations over cups of coffee.


THERMINIC 2013 audience at the Fraunhofer Forum Berlin.


Attendees discussing the presented characterization methods at one of the vendors.


Prof. Courtois (left) being presented an engraved fountain pen by Prof. Wunderle (TU Chemnitz, right) and Prof. Raad, General Chair (SMU, USA) as a gift for 19 years of chairmanship of THERMINIC. “And thanks to the team!”

Cooperations

Smart Systems Campus Chemnitz

Scientific Environment in Chemnitz
The Center for Microtechnologies is located at the Smart Systems Campus Chemnitz, which is an innovative network with expertise in micro and nano technologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close cooperation of science, applied research and industry is there an everyday reality and reflects a strategy that is being fulfilled.

The partners of the Smart Systems Campus Chemnitz are:
- Technische Universität Chemnitz with Institute for Physics, Center for Microtechnologies (ZfM) and Institute for Lightweight Structures,
- Fraunhofer Institute for Electronic Nano Systems ENAS,
- Young companies within the start-up building,
- Companies within the business park.

Technische Universität Chemnitz
The Technische Universität Chemnitz is the main partner for basic research. The Institute of Physics belongs to the Faculty of Natural Sciences. The research is characterized by an exemplary close intertwining between chemistry and physics. It is reflected particularly in the focused research topics overlapping between both institutes of the faculty.

The Institute of Lightweight Structures belongs to the Faculty of Mechanical Engineering. The scientific work is focused on the development and investigation of integrative plastic processing technologies for the resource efficient manufacturing of lightweight structures and systems. The coupled structure and process simulation together with analytical and numerical methods provide important information for optimized structure and process parameters.

Fraunhofer Institute for Electronic Nano Systems ENAS
The particular strength of the Fraunhofer Institute for Electronic Nano Systems ENAS lies in the development of smart integrated systems for different applications.

The product and service portfolio of Fraunhofer ENAS covers high-precision sensors for industrial applications, sensor and actuator systems with control units and evaluation electronics, printed functionalities like antennas and batteries as well as material and reliability research for micro electronics 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 nano electronics and 3D integration are especially in the focus of the work. Special attention is paid to security and reliability of components and systems. Application areas are semiconductor industry, medical engineering, mechanical engineering, security sector, automotive industry, logistics as well as aeronautics.

smart systems campus
TechnoPark Chemnitz

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.

Start-Up Building
The start-up building for companies related to the sector mentioned before forms an important part of the campus. There is space for approx. 15 start-up companies. In the present time the following companies are working there:
- Berliner Nanotest und Design GmbH (common labs with EUCEMAN, Chemnitzer Werkstoffmechanik GmbH, AMIC Angewandte MicroMesstechnik GmbH, Amitronics GmbH, SEDEMAT GmbH, Clean Technologies Campus GmbH),
- memsfab GmbH, common lab with Leibniz IFW,
- FiberCheck GmbH,
- LSE Lightweigth Structure Engineering GmbH,
- Steinbeis GmbH & Co. für Technologietransfer,
- BiFlow Systems GmbH,
- SiMetrics GmbH.

Business Park
The campus does not only open doors for young entrepreneurs in the start-up building, but expanding companies can also make use of neighboring space on a business park. Companies can build their own building according to their requirements on an area measuring up to 7 hectares.

The 3D-Micromac AG develops and manufactures highly efficient and innovative machines for laser micro machining. The microFLEX Center is rent by 3D-Micromac AG and Fraunhofer ENAS as a common research and production line.

The EDC Electronic Design Chemnitz GmbH develops, produces and sells customer and application specific electronic solutions. The building is the newest one. It was finished in 2013.

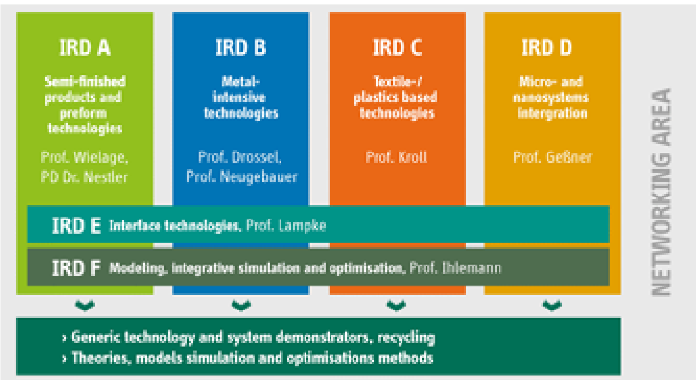
Networking
Networking is the formula for success. The partners of the smart systems campus Chemnitz are members of different national and international networks. So the ZfM belongs to:
- Silicon Saxony
- IVAM e.V. Fachverband für Mikrotechnik
- Nanotechnology Center of Competence "Ultrathin Functional Films"
- CoolSilicon
- Organic Elctronics Saxony

Clusters of Excellence

The Center for Microtechnologies works in two clusters of excellence, which have been accepted in June 2012.

Merge Technologies for Multifunctional Lightweight Structures – MERGE

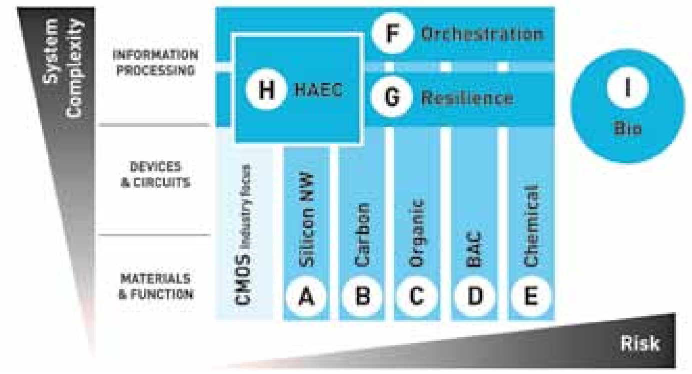
The Cluster of Excellence of the TU Chemnitz "Merge Technologies for Multifunctional Lightweight Structures – MERGE" is coordinated by Prof. Kroll, Director of the Institute of Lightweight Structures of the Faculty of Mechanical Engineering. The main object of the cluster is the fusion of fundamental technologies suitable for the resource-efficient massproduction of lightweight structures of high-performance and functional density. In order to make the structures much more intelligent, micro systems, smart sensors, actuators and electronics will be integrated. The ZfM is mainly working in research area D - Micro- and Nanosystems Integration, where innovative continuous manufacturing technologies for active systems based on micro- and also nanoeffects are investigated. The integration of microelectronic components such as sensors, actuators and electronics will lead to a further improvement of the performance and functional density of hybrid components.



For more information please visit:
www.tu-chemnitz.de/MERGE

Center for Advancing Electronics Dresden – cfaed

In 2012, the Center for Advancing Electronics Dresden (cfaed) achieved the status of a Cluster of Excellence with a funding of 34 Mio. € until Oct. 2017. It aims at inducing breakthroughs in promising technologies which may complement today's leading CMOS technology, since it will be facing physical limits in performance enhancement soon. Therefore, research teams of 57 investigators from 11 institutions are interdisciplinary cooperating in different scientific fields, as can be seen in the figure below. Within the carbon path, Chemnitz acquired one research group leader, one post-doc position, one PhD student position and a second PhD student position since November 2014. Therefore, the Chemnitz part represents the center of the technological work package. Moreover, the Center for Microtechnologies at the Technische Universität Chemnitz is involved into the innovative research field of the Biomolecular Assembled Circuits (BAC) path with one PhD student.



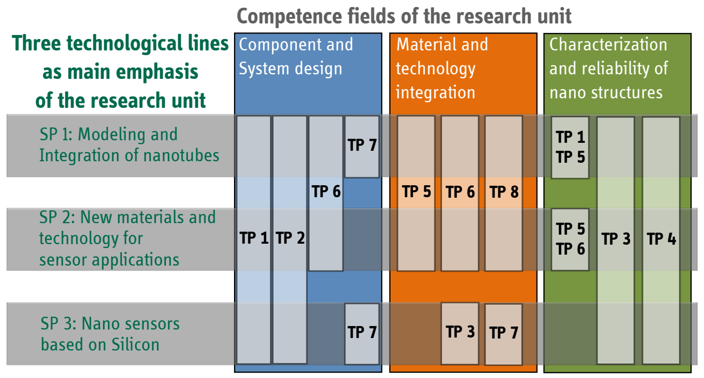
For more information please visit:
http://tu-dresden.de/cfaed

Joint Projects

DFG Research Unit 1713 "Sensoric Micro and Nano Systems"

The research unit 1713 "Sensoric Micro and Nano Systems" was established by the German Research Foundation (DFG) in 2011 at the Technische Universität Chemnitz. Three partners – the Fraunhofer ENAS, Technische Universität Chemnitz, especially the Center for Microtechnologies, and the IFW in Dresden – are joining their efforts to work on novel sensor principles in micro and nano electronics. The project was first established for a period of three years. In the beginning of 2014, the continuation for the next three years was brought on the way. The scientific focus lies on three main competence fields:

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



For more information please visit:
www.zfm.tu-chemnitz.de/for1713/

International Research Training Group "Materials and Concepts for Advanced Interconnects and Nanosystems"

Together with Fudan University Shanghai, the Shanghai Jiao Tong University, the Fraunhofer Institute for Electronic Nano Systems ENAS Chemnitz, the Fraunhofer Institute for Micro-integration and Reliability IZM, the Technische Universität Berlin and the Technische Universität Chemnitz work within the International Graduate School "Materials and Concepts for Advanced Interconnects and Nanosystems". There are two faculties involved, the Faculty of Electrical Engineering and Information Technology with the Center for Micro-technologies and the Faculty of Natural Sciences with the Institute of Chemistry and the Institute of Physics.

It is just a tradition to hold a summer school alternating in China and Germany. In 2014 the 9th summer school was held in Warnemuende.

There, the German PhD students discussed their research results together with the Chinese PhD students from Fudan University Shanghai. The Fudan University belongs to the top universities in China. At the summer school six PhD students from this university as well as their professors took part. The program of this workshop included additionally five invited presentations of top-class scientists. Professor Jana Zaumseil from the University Erlangen presented her scientific work in the field of novel transistors based on carbon nano tubes (CNT). Another highlight was the presentation of Dr. Ralf Prien from Leibniz Institute for Baltic Sea Research. He spoke about the application of sensors under extreme deep sea conditions. Prof. Geßner, the German speaker of the IRTG, explained: "This summer school is not only a week of very interesting science and research. Moreover, the summer school is an excellent possibility for PhD students to exchange ideas, to get new input for their work and for the successful completion of their doctoral thesis."

There are 16 German and 15 Chinese PhD students working within the International Research Training Group „Materials and Concepts for Advanced Interconnects and Nanosystems". The IRTG is funded by the German Research Foundation (DFG) of the Federal Republic of Germany and the Ministry of Education (MoE) of the People's Republic of China. After a successful evaluation in March 2010, the second period of the IRTG program started in October 2010, now extending the scientific topic to "Materials and Concepts for Advanced Interconnects and Nanosystems". The International Research Training Group will be funded until March 2015.

For more information please visit:
www.zfm.tu-chemnitz.de/irtg/

nanett – Nano System Integration Network of Excellence

Nanotechnology for tomorrow's sensors

Competence network nanett brings nanotechnology to applications

The nano system integration network of excellence (nanett) is one of the successful initiatives of the program "Spitzenforschung und Innovation in den Neuen Ländern", funded by the Federal Ministry of Education and Research. The interdisciplinary network under the direction of the Technische Universität Chemnitz and the Fraunhofer Institute of Electronic Nano Systems ENAS combines the expertise and resources of nine renowned and successful research institutions in Germany's new federal states. For the stakeholders, nano system integration means the technological utilization of known and newly discovered effects, the influence of which is based on the size of functional elements in the nanometer range, and have been integrated into materials, chips or complete systems. The strategic direction of the network is based on a blend of fundamental research and applied research in the fields of nanotechnology and system integration and it aims at translating the scientific results into applications.
Relevant technical and scientific issues and barriers confronting the applications have been identified as the basis for these activities and summarized into the three topics, namely "processes and technologies for nanoscale material systems", "micro-nano-integration" and "nanomaterials". Each of these topics will be handled in a flagship project by an interdisciplinary research team comprising electrical engineers, physicists, mechanical engineers, chemical engineers and computer engineers. In the initial three-year phase, the focus is on the integration at the component level, where, based on concrete problems, overlying approaches to solutions for the topics are pursued. In a second phase, the flagship projects are combined, in which the integration is continued at the system level. In all, more than 50 scientists are involved in the implementation of the objectives. The following pages provide an overview of the technical contents of the three flagship projects and of the work done during the first three years of the project period.

Interregional and multidisciplinary collaboration

To achieve sustainable internationally conspicuous R&D and competitive innovations in the field of micro and nanotechnologies interdisciplinary cooperation of a high degree is essential. This applies to the required expertise of the scientists involved as well as to the required manufacturing and metrology equipment. Against this background, interregional cooperation of research institutions, each of which is outstanding in its respective field, is the consequential step by forming a network on a long-term basis.
The structural and content base of the nano system integration network of excellence nanett is the Smart Systems Campus Chemnitz (SSCC), which is the Chemnitz Cluster for micro, nano and integration technologies. Among the players in the SSCC belonging to the competence network are institutions such as the Center for Microtechnologies (ZfM) of the Faculty of Electrical Engineering and Information Technology, the Faculty of Natural Sciences, the Center for Integrative Lightweight Design Technologies of the Faculty of Mechanical Engineering and the Fraunhofer Institute of Electronic Nano Systems ENAS.
Furthermore, the Leibniz Institute for Solid State and Material Research (IFW) Dresden is associated with the Technische Universität Chemnitz through a common mission and is a partner in the network. The institutes for Integrative Nanosciences and for Solid State Research at the IFW possess a variety of techniques for the production of nanometer to sub-nanometer thin layers, for the production of nanostructures and their integration. They are working on the entire range between fundamental research and industry-oriented applications with world-renowned expertise in the field of nanoscale magnetic materials for spintronics.
Another regional partner is the Laser Institute of the University of Mittweida. At the local laser micromachining center, investigations can be performed by using ultra-short pulse radiation in regard to nanostructuring and novel modification of spintronic layer systems.
However, for the integration of nanostructures into intelligent systems and for the development of autonomous sensor systems other competences are necessary which are currently not available in the region of Chemnitz. In this respect, an important field is the construction and joining technology for miniaturized and highly integrated systems, which establish the connection between the components and the overall technical system. The Fraunhofer IZM in Berlin is playing, in this regard, a global leadership role. The heterogeneous integration of micro- and nano-electro-mechanical systems (MEMS and NEMS) into a complex micro system forms the main task for the departments involved in the network.
Another important aspect for the wirelessly networked sensor systems is the further development of technologies for the monolithic integration of MEMS/NEMS and electronics with regard to size, reliability and cost of the systems. With the Leibniz Institute of Innovative Microelectronics IHP in Frankfurt/Oder joining the team, the network was able to gain one of the leading institutes for high frequency integrated circuits.
Two leading institutions in the field of materials, the Fraunhofer IAP in Potsdam and the Leibniz Institute IPF in Dresden could be won over with their expertise in the development of materials with integrated sensor functionality for cooperation in the network. The department of "Functional Polymer Systems" of the Fraunhofer IAP has been working on the synthesis and processing of polymers, which selectively cause couplings between electrical, mechanical and optical properties (conjugated polymers, electroluminescent polymers, photovoltaic materials, piezoelectric polymers and composites). The IPF Dresden contributes its expertise to the network particularly in the field of CNT composites. The emphasis is on the influence of the morphology of nanocomposites by technological parameters, but also new methods for the characterization of nanocomposites and their use as sensor materials, for example, for detection of liquids.

The Center for Microtechnologies has been involved in the three different flagship projects with six Professorships. The research areas of the Center for Microtechnologies within the nanett consortium will be presented on the following pages.

FLAGSHIP PROJECT A – Functional nanostructures and novel magnetic sensors

The topic "Processes and technologies for nanoscale material systems"

The magnetoresistive effect, MR effect in short, has been known for 150 years. However, advancement in its sensory exploitation could only be made with the thin-film technology just about 30 years ago. Since then, MR sensors have been continuously conquering new fields of application in the magnetic field measurement, whether as an electronic compass, as a displacement and angle measurement system or as small, floating current sensors.
The family of magnetoresistive sensors is based on various physical principles. What is common for all principles of sensors is that the electrical resistance of a sensor changes under the influence of a magnetic field. By arranging the structures differently, entirely different sensors can be implemented to detect, for example, a path, a position, an angle, a magnetic field strength or a magnetic field gradient.
The aim of the project is to develop novel high-resolution magnetoresistive sensors based on the giant magnetoresistance effect (GMR). Depending on the angle of the magnetization in the two thin ferromagnetic layers separated by a thin non-magnetic layer, the electrical resistance changes and delivers the resistance changes up to 50%.
In this project two different magnetoresistive sensors are implemented, on the one hand, sensors on flexible substrates, polymer-based as well as on silicon membranes. These can be integrated easily by wrapping bodies such as pipes into measurement systems. Furthermore, dual-axis sensors are prepared by spin-valve structures, where both directions of detection are expected to occur directly on a single chip.

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Atomic Layer Deposition – functional layers in the nanometer range

Thomas Wächtler

In the project nanett, the Atomic Layer Deposition (ALD) is being studied as a novel process for producing spintronic layer systems. It is particularly suited, due to the potential of deposition of ultra-thin layers in the nanometer range, while simultaneously controlling the layer thickness extremely well, for the production of multilayer stacks, for which the tenth of a nanometer is important. However, especially for the production of metallic layers and layer systems using the ALD, there is still a great need for research, on the one hand, to find suitable chemical processes, and on the other hand, with regard to the process design itself. Therefore, the project task is first to develop customized chemicals as starting materials for the ALD of metal layers. In this respect, materials like copper as a non-magnetic metal and nickel and cobalt as magnetic materials are the primary targets.

The organometallic precursors required for this, so to say, the ingredients for the reaction, are explored by the Professorship of Inorganic Chemistry led by Prof. Heinrich Lang and serve as a starting point for the specific growth of ultra-thin metal layers.

The ALD method is studied by the research group led by Prof. Stefan E. Schulz at the Fraunhofer ENAS. There are two special vacuum systems available, where the processes are developed. On a specially designed cluster system (see photo), the samples can be analyzed immediately after production without letting them come into contact with air. The researchers have succeeded in developing a process sequence for producing metallic copper layers in which first a thin copper oxide layer grows by means of ALD, which is subsequently reduced to metallic copper. The challenge particularly in the case of copper is to keep the process temperatures so low that the ultra-thin layers do not clump together and form isolated clusters instead of a continuous layer.

As part of the work, it was found that the ALD-grown copper oxide layers can be converted particularly elegantly if catalytically active metals are incorporated into the ALD layers, which are already added to the corresponding precursor. This method was therefore registered for a patent. However, for the intended application of the layers in spintronic devices, it is important to transfer the thin copper oxide in high quality pure copper layers. On this point, the Professorship of Semiconductor Physics, led by Prof. Dietrich R.T. Zahn, is conducting investigations at the major research facility BESSY II of the Helmholtz Centre Berlin. In ultrahigh vacuum, the layers are there exposed to various reducing gases in metered quantities targeted and thereby converted into copper. To assess the result, the X-ray radiation from the synchrotron BESSY II is deflected, which spurts out electrons from the top two nanometer layers. The speed and number of these electrons then disclose exactly whether there is still oxygen in copper, how it is bonded and if possibly residues of the precursor molecules contaminate the layer.

If methods have now been found to produce pure layer systems, their magnetic properties, too, are of interest for the subsequent application. For this purpose, researchers belonging to the Professorship of Semiconductor Physics in the workgroup led by Prof. Georgeta Salvan have conducted magneto-optical investigations. In this, a condition is utilized that an applied magnetic field affects the light reflection at the layer surface in a defined way. By this the analysis of the layer composition can be further refined. It was also found in this work that the magneto-optical activity of a ferromagnetic layer, such as nickel can be enhanced if an ultra-thin copper oxide layer is deposited as a top layer by means of ALD. Like in the case of magneto-optical storage media, this is very helpful for the optical measurement of magnetization in layer stack systems, as those used in spintronic components.

Dr. Thomas Wächtler and Dr. Jens Erben at the ALD cluster unit with integrated XPS analysis system for the in-situ characterization of nanometer-thin layers. Photo: Ralph Kunz

FLAGSHIP PROJECT B – Technology integration for networking sensors

The topic "Micro-Nano-Integration"

Today, sensors are present in virtually all technical objects, for example, to inject optimum amount of fuel into engines, to signal when the filter is exhausted in the vacuum cleaner or, for example, to monitor the main parameters of drinking water within the supply network. In sensor nodes, the sensors receive additional intelligence through further signal processing and data analysis and communication interfaces, so that they can be integrated into data networks or even form sensor networks themselves. In addition to a controller and wireless interfaces, a power module and the operating software with special algorithms are included for data processing and routing. The use of miniaturized sensor nodes is foreseeable in many areas of life and in industrial production. At present, investigations are underway to examine the application in the field of automation technology, monitoring of machine tools or high voltage power lines, building automation and security technology. Connections with existing data networks (UMTS, WLAN) will facilitate the introduction into daily life and initialize applications so far unnoticed. Another aspect concerns the data rate which has been so far small in the above-mentioned applications, but predictably will become immensely greater. This requires the use of ultra-wideband technologies and the development of frequency bands in the millimeter-wave range, for example, at 60 GHz in order to enable wireless displays, telematics in transport or video transmission in transport. New components of the microwave and millimeter wave technology, the ultra-wideband communications and new technologies are required for the production of these components and for the integration into components or into devices so as to bolster the foundations for a development lead. In addition, effective communication strategies, including data compression and routing that are adapted to the specificities of miniaturized sensor nodes with limited processing power and energy resource need to be qualified or explored anew.

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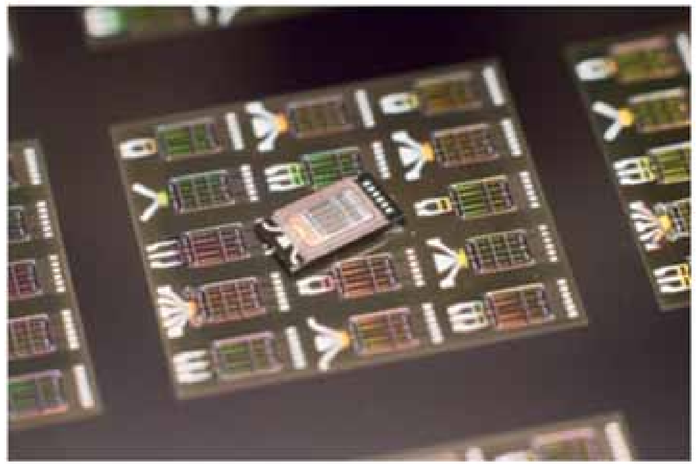
Tiny and not so power-hungry

Steffen Kurth

No power network in the vicinity and battery changing is not desirable – these are often the constraints on sensor systems. For example, if the temperature is to be monitored in bulk materials to prevent overheating and eventually a fire, or if the temperature and the sag in high voltage power lines is monitored in order to utilize this better when transporting renewable wind energy. For this purpose, new ways of combining sensors and electronics must be explored.

Not only sensors but also components for radio communication are implemented in integrated circuits, in order to maintain very small systems with high functionality and data rate. Minimal energy consumption and, possibly, a self-powered operation are the central topics. Often, not much more than 500 microwatts of average power from correspondingly small power converters (solar, thermal generator, vibration generators) are available and, if at all allowed, batteries should have a life span of many years. An extremely low power consumption of all modules is an important prerequisite.

Reserves have been identified especially in the area of wireless receivers and electronics with regard to sensor data preparation and approaches to solutions are pursued in the competence network of nanett by developing a special wake-up receiver and an electronic circuit technique based on the so-called weak inversion of CMOS transistors. Moreover, investigations are carried out as to how power converters with complementary behavior can be effectively used in combination with energy storage by a special energy management. Algorithms for initialization and localization of wireless sensor nodes and new concepts for the sleep/wake-up strategies in wireless ad hoc networks and for energy efficient routing are other important topics for the research.



Micromechanical wake-up receiver with bonded glass cover, produced at Airgap Insulated Microstructures Technology. Photo: Sven Voigt

Thus, the project nanett deals with applied research in the field of nano system integration. The aim is to integrate nanoelectric circuits (NEMS) and micromechanical systems (MEMS) into a complex sensor node. To demonstrate the concepts and technologies, wireless sensor nodes were developed as demonstrators, whose power consumption is reduced mainly by the use of an NEMS/MEMS wake-up receiver and multiple, heterogeneous energy harvesting components and the associated energy management module.

Combination of microtechnologies

Steffen Kurth

The AIM technology developed at the Center for Microtechnologies at the Technische Universität Chemnitz for the production of micromechanical structures in silicon (AIM - air gap insulated micro structures) was used together with the Fraunhofer ENAS for the manufacture of components for radio communication and modified accordingly. In this technology, 50 microns deep vertical structures are produced by a first step of directed etching and in a second, so-called isotropic step of etching, mechanically moving components of submicron range dimensions are created.

In the high frequency region of chips, also metal is deposited so as to form electrode pairs with low series resistance for sufficiently small high frequency signal losses. In addition, a special process was necessary, in which the resting position of the movable structure is moved so that an electrode gap of approximately 400 nanometers is set. This reduces signal loss and reduces the required operating voltage.

In the project consortium, the Leibniz IHP assumes the work on the electronics. There are two pilot lines in BiCMOS technology available for the production of transistors with minimum structural widths of 250 and 130 nanometers. In this, signal frequencies up to 500 GHz and ring oscillator delays of 1.9 picoseconds can be achieved, which is a world record for silicon-based transistors. The integration of the HF-MEMS components results in improved electrical performance and enables new types of functions, for example, in complex systems for communications and sensor applications.

Until now, various technological production methods such as the monolithic integration of RF-MEMS, the substrate etching for component with high quality and electrical connections by means of Through Silicon Vias (TSV) were developed in the project. Compared to a heterogeneous integration, the monolithic integration by shortest electrical connections provides minimization of parasitic effects.

As an example, an RF MEMS switch has been developed which operates in the frequency range of 30-100 GHz and can be used as an antenna switch or variable oscillators. This has demonstrated excellent performance and very good reliability, which can be seen in comparison with conventional switches. While reed relay switches, considered very reliable, provide approximately 50,000 switching cycles reliably, the switches from this project achieve more than 50 trillion cycles.

The integration of additional components into the BiCMOS technology enables a new quality of system function. On the one hand, micromechanical structures (MEMS) produced in the AIM technology can be connected to high-performance microelectronics and, on the other hand, there is even the possibility of integrating different MEMS components with each other in a chip. With the new approach of BiCMOS AIM integration, the backside of the wafer is also functionalized, by which the application width can be increased enormously without increasing the total volume. Applications in the areas of reconfigurable HF circuits, sensory functions (biological and chemical sensors), communication units or analysis head (e.g. glucose) were identified.

Sven Haas of the Center for Microtechnologies is examining under the scanning electron microscope micromechanical silicon structures of minute dimensions less than a micrometer. Photo: Wolfgang Thieme

Energy-efficient network communication and integration of information technology

Matthias Vodel

Individual sensor nodes with reduced energy consumption do not necessarily lead to an energy-efficient sensor network. In order to reduce the energy requirement of this network with all its applications, communication concepts must be adapted first to the new technologies of the individual nodes, and then to other applications. The Professorships of Technical IT and Circuit and System Design of the Technische Universität Chemnitz are carrying out research and development in the field of information technology integration. Under the motto “from nano to macro” they design, implement and evaluate network protocols and applications.

Dr. Matthias Vodel and Mirko Lippmann of the Professorship of Technical Information Technology and Anders Johannson of the Professorship Circuit and System Design are examining the demonstrator platform for the energy-efficient sensor network. Photo: Ralph Kunz

The exploration of energy-efficient communication concepts, which utilizes the developed technologies of other sub-projects, besides the wake-up receiver, for example, also those of energy harvesters, has been recognized as a particular challenge. More emergence effects are expected by the combination of local, technological energy efficiency improvements, on the whole resulting into lower energy requirement for the entire system. However, such technologies do not offer benefits necessarily in every context of an application. The application itself has a significant impact on the energy requirement and efficiency potential of the overall system. Consequently, the influence of available energy resources on the application and on the integral individual processes must also be considered conversely. In the course of the project, the concepts were evaluated on two levels. First, a complex simulation environment ensued, which can adjust various interactions of the individual subsystems in large network topologies. Here, different application scenarios can be generated and analyzed in a simple manner.

Using the simulator, the computer engineers analyzed the requirements and effects of asynchronous communication concepts on the energy efficiency and the quality of the overall system. From the results, they derived key parameters that have significant impact on the applicability of the technology and communication concepts. Thus, a number of meaningful application scenarios are expected to be identified and specific determining factors classified. Applying the simulations, various procedures could also be tested for node localization. The aim is to exactly and spatially correlate the measured sensor data. Based on the obtained location data in turn adaptations in the algorithms are possible, which may have a positive impact on energy efficiency. Also, the network initialization of large, mobile sensor network topologies represented an important topic of research within the subproject. Here, procedures were designed and analyzed, which explore and organize an initially unknown network structure. The automatic configuration of an initially unknown communication infrastructure is essential especially for large application scenarios with many network nodes and provides developers as well as users with a significant added value. In the simulations, the individual procedures are specifically compared in terms of energy efficiency.

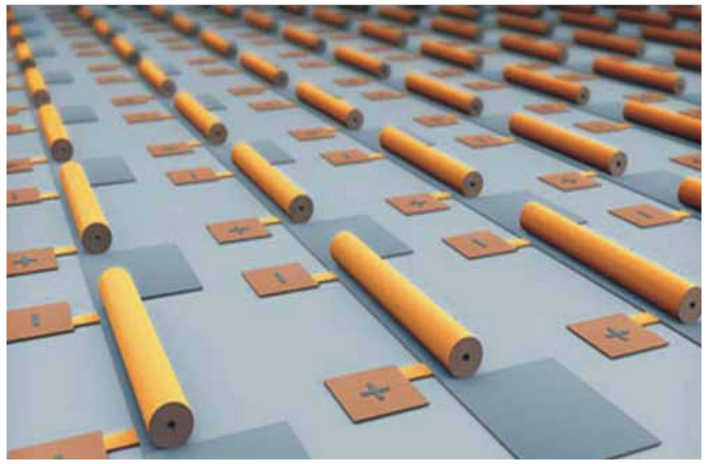
In the second level of evaluation, the findings from the simulations were tested under real conditions. In this, a specially developed demonstrator platform was used, on which the hardware and software components of all subprojects have been integrated. The objective is to quantify possible enhancements of energy efficiency based on a concrete case of application.

With reference to network initialization and localization methods used, the robustness and the quality of the test setup was found to be good. Also the influences and effects of external disturbance factors were analyzed.

New ways of power supply and power saving

Jörg Schaufuß, Matthias Fritzsch, Jörg Schadewald, Christian Viehweger

For the power supply of an autonomous sensor node, it is not always possible to use batteries. In such cases, energy often present in the vicinity of the sensor nodes in the form of, for example, light, heat or vibrations can be converted into electrical energy and used for power supply.
The Professorship of Microsystems and Precision Engineering of the Technische Universität Chemnitz developed for this purpose an energy converter that generates electrical energy based on the electrostatic principle from smallest vibrations with acceleration amplitudes in the range of one hundredth to a thousandth of the gravitational acceleration. This so-called harvester combines silicon microstructures to produce large changes in capacitance with precision engineering components for low operating frequencies and a sufficiently large mass for coupling of energy. In a volume, which is smaller than a LR14 coin cell, a mechanism was integrated for adjusting the operating frequency to the vibrating frequencies of potential energy sources in order to achieve a high power output.
To ensure the reliability and security of supply during continuous operation of autonomous sensor nodes, the Professorship of Electrical Measurement and Sensor Technology at the Technische Universität Chemnitz is working on complementary energy converters. Differences in the characteristics of the individual converters can be exploited by combining complementary sources of energy. For example, vibration converters in switched-off pumps and drives do not generate any energy. However, since the system function must be nonetheless ensured at such time, at least a second source is required for compensation. This can be, among other things, a thermoelectric converter or a solar cell. An intelligent energy management of the sensor node is an essential aspect of the research activities in this respect to maximize overall efficiency and for planning the activities within the surrounding network comprising identical nodes.
For periods of low energy availability or increased energy requirements, necessary energy reserves must be provided. In this context, the Institute for Integrative Nanosciences of the Leibniz Institute of Solid State and Materials Science (IFW) in Dresden developed microcapacitors with high energy density. Through proper selection of suitable parameters, stressed, thin layer systems can be produced. These curl up by dissolving a sacrificial layer into tube with an adjustable diameter. By this the energy density of the planar capacitors can be increased by a factor of 10. Work at the IFW also showed that solid electrolytes can be incorporated into these systems. The super capacitors produced thus store electrical energy electrostatically like classic capacitors as well as electrochemically like batteries.



Ultra-thin layer systems wrap themselves up into small energy storages. The combination of layers can be chosen almost arbitrarily, so that different types of energy storage are possible: capacitors release the energy quickly, batteries store energy on long-term basis. Image: Professorship of Material Systems of Nanoelectronics

FLAGSHIP PROJECT C – Functional materials for sensor effects in lightweight components

The topic "Nano materials"

The flagship project C includes the development of functional materials with properties based on the integration of nano effects into the material, particularly polymers, so that sensor functions can be integrated into the material. Unlike conventional sensor systems, no discrete sensors are integrated in or on a component, but the material itself contains this feature.
Since monitoring of load conditions are of particular importance especially for lightweight structures, such sensor functionalities based on nanomaterials are built into high performance composites. Continuous monitoring of structures is, however, mostly technically and economically not viable, which makes energy-independent load indicator with memory function necessary.
The aim of the development is a smart component which visualizes structural damage over a load indicative layer by means of so-called quantum dots and thus outputs information about the location and intensity of load.
Another goal of development is a mechanism for the detection of cracks or breaks in structural components by means of so-called smart tubes. These micron-scale tubes are added to the initial material of fiber plastic structures. If these break at defined loads, a photo-luminescent substance flows out and identifies the location of the structural break.
In the future, other smart materials are planned to be developed, which have not only sensory but also actuator functionalities. Out of this combination of adaptive structures and components can emerge, that react automatically to environmental conditions and, for example, adjust their stiffness at current loads. Thus, the advantages of nano effects ultimately are available for series products.

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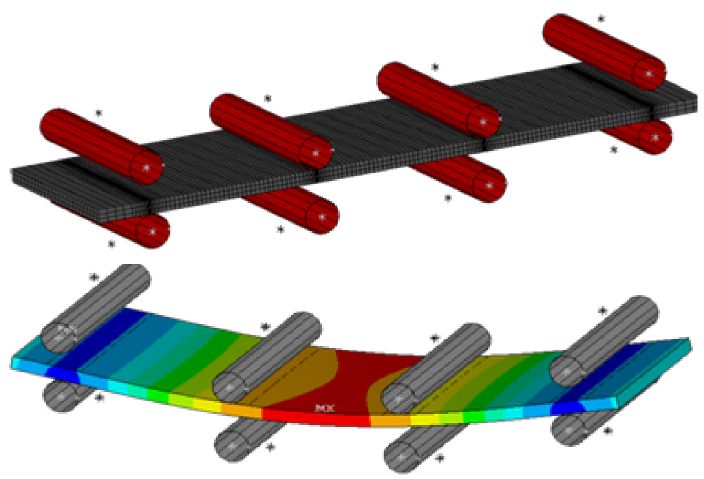
System integration of electromechanical converters

Robert Schulze

By developing novel piezoelectric functional materials and integration strategies, at the Center for Microtechnologies (ZfM) of the Technische Universität Chemnitz in cooperation with the Fraunhofer ENAS innovative concepts are worked out for the use of these materials in micro and nano systems and especially in lightweight structures. This will be a fundamental contribution to combine key technologies for the production of intelligent components.
In addition to designing the components, studies on complete systems are taken up. For this purpose, methods are developed and tested for prediction and characterization of electromechanical converters. These methods are applied to the flagship project C in order to dimension the so-called smart lightweight structures with electromechanical function and to design for specific applications. Relevant loads are especially vibrations or shocks. These mechanical excitations are translated into electrical signals in the sensor by piezoelectric functional polymers, i.e. electromechanical converter and used for switching optical display layers with nanoparticles, so-called quantum dots. To operate these display layers no electronics are necessary, the sensor system operates energy autonomously and spatially resolved. Only precise knowledge of the excitation signals allows the coordination of the converters and therefore of the components in the layer structure, size, shape and material selection.
The activities are complemented by investigations of the behavior of the materials developed in the flagship project C for continuous and limit load as well as by characterization of the electrical, mechanical and electromechanical properties of the materials.



Modeling and FEM simulation of a 4-point bending test on fiber-reinforced plastics
Image: Robert Schulze

Material behavior of polymer-based functional materials

John Brückner

The targeted use of novel polymeric functional materials requires detailed knowledge of the material behavior in order to develop intelligent components to ensure reliable operation. For this, at the Professorship of Materials and Reliability of Microsystems of the Technische Universität Chemnitz materials are investigated for mechanical stresses such as oscillations or deformation as well as the influence of temperature changes and humidity.
The results flow directly back into the development of materials and thus make a significant contribution to the production of smart materials.
The scientific work at the Professorship of Materials and Reliability of Microsystems focuses on an innovative approach in which metrological analyses are used in conjunction with simulations for the assessment of reliability. This methodology leads to a thorough understanding of the load tests, since they are modeled in computational models. Ultimately, with these computer models it is possible to investigate by projections alternative and combined load conditions and to reliably interpret and optimize the components in their shape and material selection.

John Brückner of the workgroup led by Prof. Wunderle testing fiber-reinforced plastics in the 4-point bending test. Photo: Ralph Kunz

As part of the flagship project, among other things, so-called four-point bending tests are performed to determine maximum mechanical load limits of carrier components made of fiber-reinforced plastic. In addition to these macroscopic stress tests micro/nano-load tests are developed in which the micro-tubes produced by the Leibniz Institute IFW can be characterized in their fracture behavior. The task of the Professorship of Materials and Reliability of Microsystems is extended through the development and application of methods for the determination of material parameters that are required for the creation of material and simulation models.

Light from the dwarf world

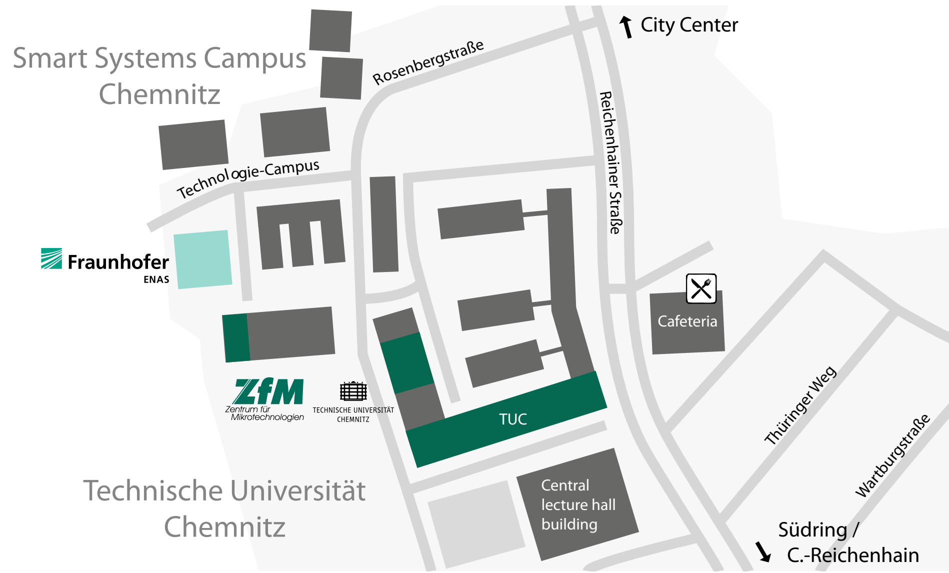
Christian Spudat, Daniel Lehmann

The Nano Physics is one of the fastest growing areas within modern physics; its initial applications have already found their way into new materials and products. For example, using nano effect self-cleaning surfaces can be produced, non-conductive materials made conductive or bacteria combated with nanoparticles.
This new field is described by quantum physics, which takes into account the changing forces of the physical quantities based on small dimensions and is capable of describing even new effects, which are completely unknown to us in our world. The working group for optical nanocomposite-based systems at the Fraunhofer ENAS has therefore taken up this task to make this nano effects useful for new applications and materials, where the focus is on visual effects. Thus, within the joint project nanett new smart materials are to be developed, which can detect load situations and store them if necessary. The load conditions are detected with the help of piezoelectric layers in combination with so-called quantum dots. These quantum dots are virtually artificial atoms, which can be excited by light like natural atoms. The excited state returns to its original state after a certain half-life, where the excess energy is emitted as light.
Now if the quantum dots are earlier excited by electrical current of the piezoelectric layer, they cannot absorb light anymore and remain dark. Such smart material is of interest especially for structure lightweight, aerospace or materials which are operated in the border area.
The Professorship of Semiconductor Physics of the Technische Universität Chemnitz assumes the characterization of materials in the nanometer range. In addition to the determination of thickness and uniformity of the functional layers, also their refractive index and absorption characteristics are determined, which are important for the optical reading of the load or destruction information of sensors.

In addition, the electrical properties are investigated, where the particular focus is on the question as to what electrical stresses must occur in the material system, so that the quantum dots respond to the mechanical load and how long this voltage must be maintained.
In addition to electrical measurements with voltage pulses in the range of microseconds to seconds, especially the Raman spectroscopy can provide interesting insights here. This makes it possible to follow directly in the spectrum, how the quantum dots react to an applied electrical voltage and to draw valuable conclusions that are taken into account in the overall structure of sensors.

Chemical Engineer Dr. Kathleen Heinrich shows a sample body which is layered with quantum dots, i.e. nanoscopic semiconductor particles. When the tiny semiconductor particles are excited with UV light, they begin to fluoresce. What color the emitted light has depends on the size of the particles. If in some places a stress acts on the material, this fluorescence stops. Therefore, the affected areas remain dark when excited by UV light and point to the mechanical load. Photo: Wolfgang Thieme

How to reach us:



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The clean room 1 of the ZfM is located in hall H next to the Weinholdbau on the Smart Systems Campus Chemnitz.

The clean room 2 of the ZfM is located in the building of the Institute of Physics, TU Chemnitz.

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