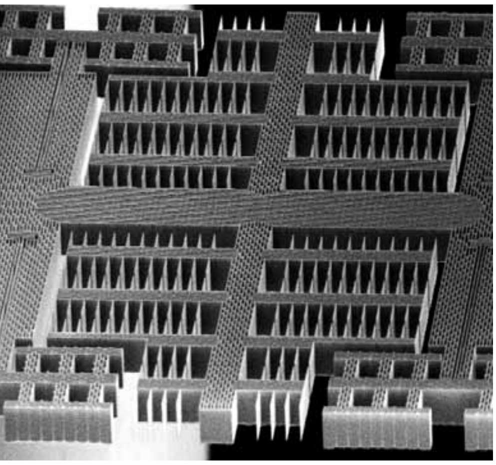
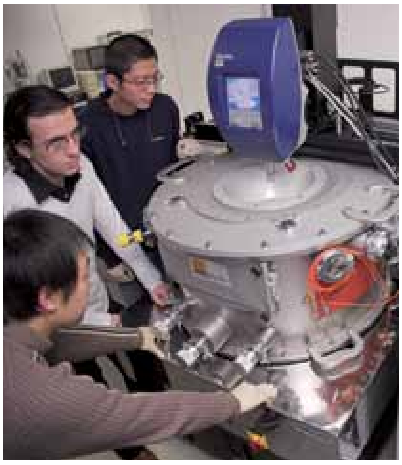
Center for Microtechnologies

Faculty for Electrical Engineering and Information Technology
Chemnitz University of Technology





ZfM
Zentrum für Mikrotechnologien

CHEMNITZ UNIVERSITY OF TECHNOLOGY
1836-2011
175 Years

Annual Report 2010

Contents

Center for Microtechnologies

The Center for Microtechnologies (ZfM), founded in 1991, belongs to the department of Electrical Engineering and Information Technology of the Chemnitz University of Technology (CUT). 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 CUT departments.

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 Chemnitz University of Technology has a tradition and experience for more than 30 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

- Chair Microtechnology – Prof. Dr. Thomas Gessner
- Chair Microsystems and Precision Engineering – Prof. Dr. Jan Mehner
- Chair Circuit and System Design – Prof. Dr. Ulrich Heinkel
- Chair Electronic Devices of Micro and Nano Technique – Prof. Dr. John Thomas Horstmann
- Chair Electrical Measurement and Sensor Technology – Prof. Dr. Olfa Kanoun
- Chair Power Electronics and Electromagnetic Compatibility – Prof. Dr. Josef Lutz
- Chair Materials and Reliability of Microsystems – Prof. Dr. Bernhard 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 cleanroom class ISO 4. Modern equipment was installed for processing of 4 inch, 6 inch and 8 inch 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 microsystems and nanosystems (sensors, actuators, arrays, back-end of line)
- Design of components and systems
- Nanotechnologies, nano components and ultrathin 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/

President of the Board
Prof. Dr. Thomas Gessner

Deputy of the President
Dr. Karla Hiller

ORGANIZATION

Highlights of the last 20 years

1991

Foundation of the Center for Microtechnologies out of the Technikum Mikroelektronik

Scientific Highlights:

- Anodic bonding, Silicon fusion bonding
- Simulation of orientation dependent silicon wet etching
- One dimensional electrostatic operated micromechanical torsional mirrors
- High precision acceleration sensor in bulk technology

1992

Scientific Highlights:

- Advanced sputtering of highly reflecting films
- PECVD on thin membranes with reduced mechanical stress

1993

Appointment of Prof. T. Geßner (Chair Microtechnology), Prof. W. Doetzel (Chair Microsystems and Precision Engineering), Prof. G. Ebest (Chair Electronic Devices)

Retirement of Prof. H. Lippmann (Chair Opto and Solid State and Electronics)

First common annual report

Since 1990, 14 millions DM have been invested into clean room technology and equipment

Finalization of the plans for reconstruction of clean room facilities

1994

Appointment of Prof. C. Radehaus (Chair Opto and Solid State Electronics)

Reconstruction of the clean room facilities starts

1995

Reconstruction of clean room is still ongoing

Start of the collaborative research center SFB 379 "Arrays of micromechanical sensors and actuators" on January 1st

ZfM is the organizer of the conference MAM '95: Materials for Advanced Metallization, held from March 19th to March 22nd, 1995, with participants from 16 countries

Integration of the working group Materials of electrical engineering/electronics, head Dr. J. Fruehauf

Scientific Highlight:

- High temperature stable metallization systems

1996

Ceremonial inauguration of the clean rooms of the ZfM by the ministers of the state Saxony, Prof. Hans-Joachim Meyer and Prof. Georg Milbradt, on August 15th, nearly 250 guests

Processing of test structures as well as sensors and actuators based on silicon is possible within the ZfM

1997

Positive evaluation of the collaborative research center SFB 379 "Arrays of micromechanical sensors and actuators"

Set-up of 6 inch wafer processing, especially for research activities in the field of interconnect technologies of micro electronics

Scientific Highlights:

- A copper technology by using PVD or CVD deposition methods and RIE was demonstrated for 0.3 µm lines
- Strip arrays for scanning application were developed up to resonant frequencies of about 200 kHz
- First prototype of a high precision angular rate sensor
- First fine line patterning with dimensions less then 50 nm was realized

1998

Integration of Prof. D. Mueller (Chair Circuit and System Design) and Prof. V. Krozer (Chair Radio Frequency Technique) within the board of directors of ZfM

Scientific Highlights:

- Within a Joint Develpoment Programme with Applied Materials a Cu-RIE equipment (Centura mainframe) was installed at the ZfM and the copper-line patterning of 0.25 µm by using RIE was demonstrated
- New methods and tools for MEMS design as well as microelectronics design were investigated and developed
- Scanning actuators were developed for an insitu-modular measurement system for MEMS testing
- A low k-CF-dielectric material based on a CVD-technology was fabricated (k = 2.2...2.5, annealing stability up to 420° C)

Foundation of the department Micro Devices and Equipment of the Fraunhofer Institute for Reliability and Micro Integration Berlin in Chemnitz

1999

ZfM becomes an active member of the network "Ultrathin Functional Films"

Scientific Highlights:

- The CVD process of copper has been optimized, especially the adhesion properties on underlaying materials
- New application fields for several microactuators were demonstrated
- A novel gas sensor device was developed and tested for high temperature applications

2000

Positive evaluation of the collaborative research center SFB 379 "Arrays of micromechanical sensors and actuators"

Scientific Highlights:

- The copper CVD process has been successfully applied to vertical chip integration
- Metal oxide gas sensor for higher temperatures has been applied in a car exhaust
- Demonstration of a monolithic integration of Silicon resonator MEMS device with standard CMOS

2001

10th anniversary of the Center for Microtechnologies on November 22nd, 2001

2002

Prof. V.Krozer (Chair Radio Frequency Technique) left the board of directors of ZfM

Scientific Highlights:

- Testing of nanoporous SiO_2 and CF-polymers as low-k material within damascene process modules (including copper and CMP)
- Application of a new barrier materials and processes for copper bases technologies
- A novel high aspect ratio technology for MEMS fabrication using standard silicon wafers was developed
- A high aspect ratio vertical FET sensor for motion detection has been tested successfully
- New methodologies and tools for order reduction of finite element models to provide links between component and system design for microsystems were developed and applied
- New approaches for wafer bonding technologies were established

2003

Positive evaluation of the collaborative research center SFB 379 “Arrays of micromechanical sensors and actuators”

Scientific Highlights:

- A new method for MEMS capping by low temperature and selective adhesion bonding has been developed and verified
- Verification of the AIM technology by fabrication of inclinometer prototypes and successful functional testing by industrial partner
- Tunable infrared filter have been tested successfully
- Miniaturized NIR/MIR spectrometer based on micro mechanical scanners with integrated gratings appropriate for substance analysis in gaseous, liquid and solid state has been developed
- Measurement and comparison of the thermal conductivity of a variety of low-k and ULK dielectrics as well as thermal modeling of low-k material containing interconnect schemes
- Development of an ultrathin, amorphous PECVD W-N diffusion barrier for copper damascene metallization with a thermal stability of up to 600° C

2004

Professor J. Lutz (Chair Power Electronics and Electromagnetic Compatibility) has been integrated into the board of directors of ZfM

Scientific Highlights:

- Silicon gyroscope chips from Chemnitz have been successfully implemented and tested within a miniaturized LITEF demonstrator for avionic applications
- System integration of frequency selective sensor arrays for vibration monitoring at cutting tools
- Within the frame of projects NanoCMOS and Skalar the in-house multi-purpose simulation environment T2 has been extended to multiscale simulation of thin film deposition using advanced PVD and of planarization of oxide films for Shallow Trench Isolation (STI)
- Development of a low-k compatible H_2-based resist stripping process

2005

Retirement of Prof. D. Mueller (Chair Circuit and System Design)

Appointment of Prof. U. Heinkel (Chair Circuit and System Design), integration of Prof. U. Heinkel within the board of directors of ZfM

Intensification of the international contacts especially to China and Japan

2006

New research topic: Smart Systems Integration

Collaborative Research Center No. 379 “Arrays of micromechanical sensors and actuators” ends after 12 years of successful research

Start of the international research training group “Materials and concepts of advanced interconnects“, Fraunhofer IZM, TU Berlin, Fudan University Shanghai and Jiao Tong University Shanghai are partner

Start of the construction of the new clean room facilities within the new building of the institute of physics at the Smart Systems Campus Chemnitz

2007

Retirement of Prof. W. Doetzel (Chair Microsystems and Precision Engineering) und Prof. G. Ebest (Chair Electronic Devices)

Appointment of Prof. J. Mehner as Chair Microsystems and Precision Engineering and appointment of Prof. J.-T. Horstmann as Chair Electronic Devices of Micro and Nano Technique

Both chairs are integrated within the board of directors of ZfM

Mrs. Dr. K. Hiller is the deputy director of the Center for Microtechnologies

In December 2007, the clean room (clean room class 10) is finished within the new building of the institute of physics at the Smart Systems Campus

2008

Appointment of Mrs Prof. O. Kanoun as Chair of Electrical Measurements and Sensor Technology

Integration of Prof. Kanoun within the board of directors of ZfM

Retirement of Prof. C. Radehaus (Chair Opto and Solid State Electronics)

Appointment of Dr. G. Herrmann as adjunct professor and appointment of Dr. T. Otto as Honorary Professor for Optoelectronic Systems as well as Dr. S. E. Schulz as Honorary Professor for Nanoelectronics Technologies

2009

Retirement of Prof. J. Fruehauf

Appointment of Prof. B. Wunderle as Chair Materials and Reliability of Microsystems

Integration of Prof. B. Wunderle within the board of directors of ZfM

Center of Competences ”Nano Systems Integration” is one of the successful initiatives of the “Spitzenforschung und Innovation in den Neuen Ländern”

2010

The honorary professors Prof. T. Otto and Prof. S. E. Schulz are integrated within the ZfM

Successful evaluation of the international research training group, new topic: “Materials and concepts for advanced interconnects and nanosystems”

2011

Successful evaluation of the research group “Sensoric micro and nano systems“

Chair Microtechnology

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Main working fields:

- Development of new materials and processes for metallization systems in micro and nano-electronics
- Simulation and modeling of equipment and processes for micro and nanoelectronics as well as nano materials and nano structures
- Development of nanotechnologies, nano components and ultra-thin functional films
- Development of plasma processes for photovoltaics
- Development of technologies and components for microsystems and nanosystems (sensors, actuators and arrays)
- Processes and technology for integration of electronics and micro as well as nanosystem components
- Prototype fabrication of sensors, actuators and arrays
- Processing services for customer applications

Special attention is paid to Si-based MEMS technologies:

- Bulk technology
- High aspect ratio technologies, e.g. air gap insulated microstructures (AIM technology)
- Encapsulation by wafer bonding
- Encapsulation by thin film technology

Several high aspect ratio MEMS technologies, such as the patented AIM technology or the BDRIE (Bonding and Deep RIE) technology, have been established in order to fabricate high precision inertial sensors, e.g. acceleration, vibration and inclination sensors as well as gyroscopes. Furthermore, RF switches and RF resonators are presently under development. The performance of such sensors and actuators using the capacitive working principle is highly influenced by the capacitance gradient due to an electrode movement. However, fabrication restrictions limit the minimum size of the spacing between the electrodes. The reduction of the trench width after patterning of the microstructures down to the sub-µm-range can overcome these restrictions and hereby contribute to higher sensitivity of inertial sensors, decrease of the switching time for RF switches, increase the tuning range of varactors and decrease the motional impedance for RF resonators.

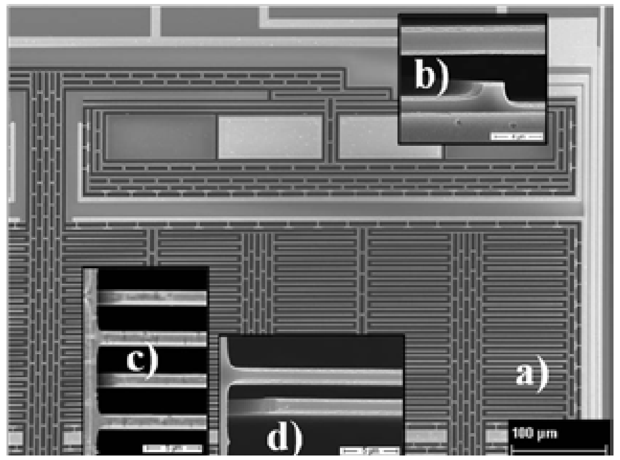

Fig. 1: SEM photographs – a) fabricated test structure, b) detailed view of a micro welding pad, c) detailed view of the initial gap separation and d) the reduced gap separation between fixed and movable electrodes.

A post process gap reduction approach based on electrostatically actuated gap reduction mechanism in combination with micro welding of Si for permanent fixation of the gap size has been demonstrated successfully with an AIM structure. Figure 1 shows a top view on part of the structure with detail of micro welding pad, and capacitor before and after gap reduction. Figure 2 is a SEM picture of the micro welding contact after gap reduction sequence, clearly indicating the welded material. The welding is obtained by an electrical discharge of a capacitor. At a certain voltage (usually above 100 V) a short current flow between the welding pad and the movable structure can be observed. The silicon melts and a firmly bonded connection is created. The residual gap size has been reduced from originally 4.5 µm down to about 400 nm, hereby increasing the aspect ratio from 12 to about 150. The reliability of the bonded connections in a switching device is confirmed by more than 10^9 switching cycles during a lifetime test.

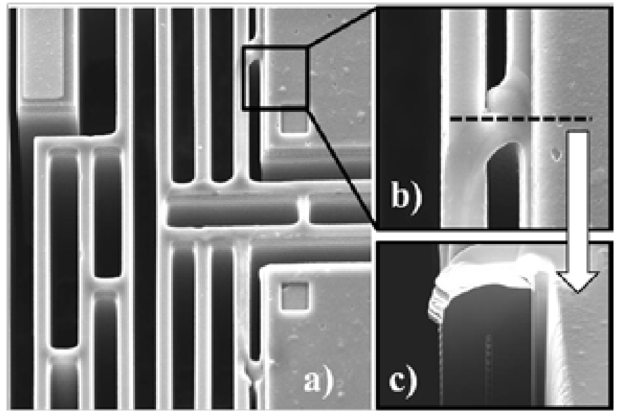

Fig. 2: SEM photographs – a) gap reduction area after the gap reduction sequence has been done, b) top view of a micro welding pad and c) cross section of a micro welding pad after FIB preparation.

Micromachined Fabry-Perot filters for the NIR range (3...5 µm) for spectral analysis of gases have been fabricated for several years. Recently, in joint projects with Fraunhofer ENAS, InfraTec Dresden, Jenoptik LOC and IOM Leipzig, further improvement could be demonstrated, e.g. extension of the measuring range to the 8...11 µm window and achievement of dual band characteristics by integration of new optical materials (Fig. 3). Besides distributed bragg layers, nanostructures are under investigation.

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 micro electronic devices, as intermediate layers for packaging processes or protective coatings for micro machines or even as functional films in optical components like gratings or interferometers.

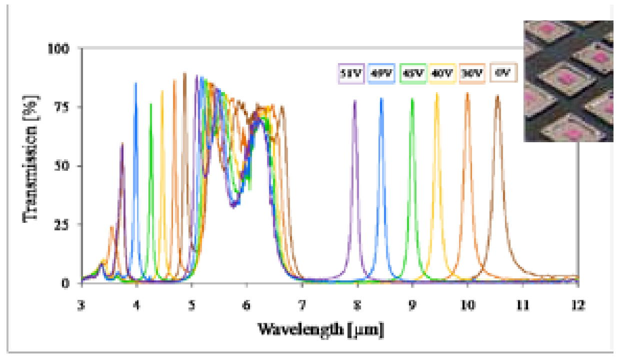

Fig. 3: Transmission characteristics of a dual band IR filter with regards to drive voltage, by courtesy of InfraTec GmbH Dresden.

Selected publications:

Nowack, M.; Reuter, D.; Bertz, A.; Kuechler, M.; Aurich, T.; Dittrich, C.; Gessner, T.: **A Novel Three-Axis AIM Vibration Sensor for High Accuracy Condition Monitoring.** IEEE Sensors 2010 Conference, Waikoloa (USA), Nov 1 – 4, 2010, Proceedings, pp. 879 – 884 (ISBN 978-1-4244-8168-2).

Kurth S., Leidich,S.; Bertz, A.; Nowack, M.; Kaufmann, C.; Faust, W.; Gessner, T.; Akira, A.; Ikeda, K.: **Reliability enhancement of Ohmic RF MEMS switches**. Proc. SPIE Vol. 7928-11 (2011), SPIE Photonics West, San Francisco, USA, January 22 – 27, 2011.

Meinig, M.; Kurth, S.; Hiller, K.; Neumann, N.; Ebermann, M.; Gittler, E.; Gessner, T.: **Tunable mid-infrared filter based on Fabry-Pérot interferometer with two movable reflectors**. Proc. of SPIE Vol. 7930-18 (2011).

Waechtler, T.: **Thin Films of Copper Oxide and Copper Grown by Atomic Layer Deposition for Applications in Metallization Systems of Microelectronic Devices**. published by Universitätsverlag Chemnitz, 2010 (ISBN 978-3-941003-17-0).

Hofmann, L.; Braeuer, J.; Baum, M.; Schulz, S.E.; Gessner, T.: **Electrochemical deposition of reactive nanoscale metallization systems for low temperature bonding in 3D integration**. AMC, Baltimore (USA), October 13 – 15, 2009; Proceeding of the Advanced Metallization Conference 2009, pp. 241-251 (ISBN 987-1-60511-218-3).

Hofmann, L.; Ecke, R.; Schulz, S.E.; Gessner, T.: **Pulse Reverse Electroplating for TSV Filling in 3D Integration**. Smart Systems Integration, Como (Italy), Mar 23 – 24, 2010, Proceedings (ISBN 978-3-8007-3081-0).

Hermann, S.; Fiedler, H.; Waechtler, T.; Falke, M.; Ecke, R.; Schulz, S.E.; Gessner, T.: **Approaches for Fabrication of Carbon Nanotube Vias**. Nanoelectronic Days 2010, Aachen (Germany), Oct 4 – 7, 2010; Poster presentation.

Chair Microsystems and Precision Engineering

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

Main working fields:

- Modeling and simulation of physical domains and their interactions
- Experimental characterization and measurement methodologies
- Sensor and actuator development
- Wireless communication and energy scavenging

Microsystems 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 (e.g. Fraunhofer Institutes, IPHT Jena, Freescale...).

One of the most advanced topics in the field of design is the challenge to establish fast and precise behavioral models for microsystems. Parametric reduced order modeling (ROM) technique, Figure 1, is the most promising approach to this. The parametric ROM macromodels capture the complex nonlinear dynamics inherent in 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 MEMS components in order to export macromodels for external system simulators.

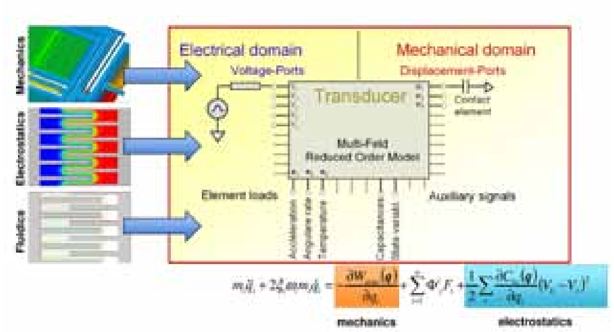

Fig. 1: Reduced order modeling for microsystems design.

This advanced design technique is successfully used for instance for the design of the vibrational sensor shown in Figure 2.

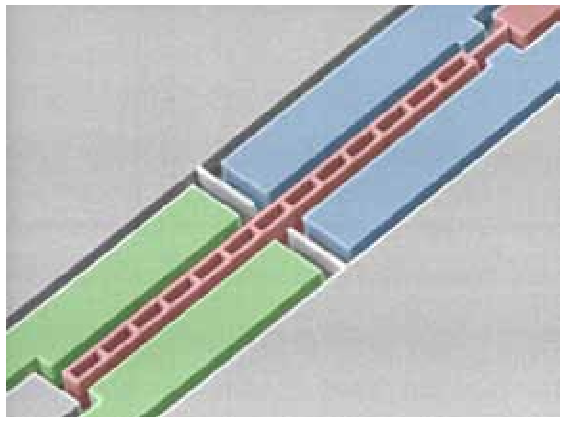

Fig. 2: Zoomed and colored view of a vibration sensor for machine noise detection

The Chair of Microsystems and Precision 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. Figure 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.

Fig. 3: PVM-200 vacuum wafer prober and microsystem analyzer.

One of the current medical related projects is the research on a pressure measurement catheter for the human esophagus with high resolution regarding pressure and position. Figure 4 shows the working principle of this fiber bragg grating (FBG) based sensing system. A wideband light source is selectively reflected by an array FBGs with stepped reflection wavelength. In case of the presented pressure sensor catheter the FBGs are sensitive to pressure and the characteristic wavelengths can be allocated to the place of applied pressure. The advantages are the absence of electrical components, the feasibility of long time measurements, the non-bulky interrogation systems which allow the manometry in rather natural situations and the homogeneous surface which enables easy cleaning and disinfection.

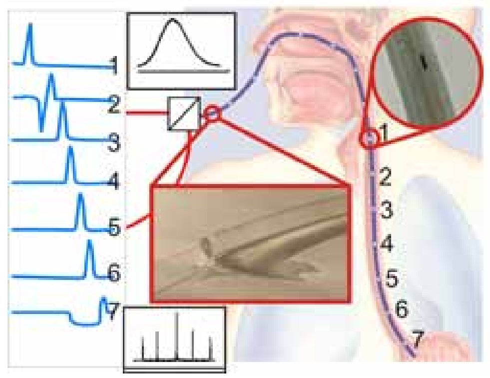

Fig. 4: Working principle of a medical pressure sensor catheter for esophageal diagnosis.

Other current research projects:

- Development of a parametric ROM technique for precise and fast simulation of microsystems
- Design and characterization of microsystems for acoustic emission and vibration detection
- Development of test structures based characterization technique for the extraction of critical technological parameters for microsystems on wafer level
- Development of vibrational energy harvester
- Development of a friction vacuum gauge with an extended measurement range
- Pressure Sensor for human bladder

Selected Publications:

Voigt, S.; Rothhardt, M. ; Becker, M. ; Lüpke, T. ; Thieroff, C.; Teubner, A. ; Mehner, J.: **Homogeneous catheter for esophagus high-resolution manometry using fiber Bragg gratings**. SPIE Photonics West, Proc. SPIE 7559, 75590B (2010).

Mehner, J.; Kolchuzhin, V.; Schmadlak, I.; Hauck, T.; Li, G.; Lin, D.; Miller, T. F.: **The influence of packaging technologies on the performance of inertial MEMS sensors**. Proceedings of 15. Intern. Conf. on Solid State Sensors, Actuators and Microsystems, Transducers' 09, (2009) pp. 1885 – 1888.

Shaporin, A.; Streit, P.; Specht, H.; Dötzel, W.; Mehner, J.: **Novel test-structures for characterization of microsystems parameters at wafer level**. SPIE – Photonics West, Proc. SPIE 7206 (2009) pp. 72060E-1-12.

Naumann, M.; Koury, D.; Lin, D.; Oi, H.; Miller, T.F.; Mehner, J.: **Characterisation of sticking effects by surface micromachined test structures**. Chemnitzer Fachtagung Mikrosystemtechnik, Tagungsband, (2009). S. 103 – 107.

Forke, R.; Scheibner, D.; Dötzel, W.; Mehner, J.: **Measurement unit for tunable low frequency vibration detection with MEMS force coupled oscillators**. Sensors and Actuators A: Physical, 156, 1 (2009) pp. 59 – 65 (ISSN 0924-4247).

Kolchuzhin, V.; Forke, R.; Dötzel, W.; Mehner, J.: High Order Derivatives Technology in Advanced MEMS Modeling. Smart Systems Integration 2009, Proceedings (2009) pp. 472 – 475 (ISBN 978-3-89838-616-6).

Chair Circuit and System Design

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Main working fields:

- 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, analogue 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)

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 microsystems in cooperation with the Chair of Microsystems and Precision Engineering and 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, controlling of projection 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)
- Design of control circuits for medical applications

Although many projects have been processed through the years, there is still a lot of work ahead.

Recently, the chair has 28 employees, most of them working on application specific industrial research projects. Some of those projects, for example, are:

- BMBF-project Innoprofile „Generalisierte Plattform zur Sensordaten-Verarbeitung GPSV“

Fig. 1: Daniel Kriesten presenting a prototype of an on-board unit, developed within the project „Generalisierte Plattform zur Sensordaten-Verarbeitung GPSV“.

- Joint project (BMBF): Kompetenznetzwerk für Nanosystemintegration: subproject: NEMS/MEMS-Elektronik-Integration für energieeffiziente Sensorknoten
- BMBF-project ForMaT2: Faserkunststoffverbunde mit integrierter Zustandsüberwachung in Echtzeit (FIZ-E)
- Joint project (DLR): SEIS: subproject: Entwurf und Bewertung eingebetteter IP-basierter Netze
- ZiM-AiF-project: “ProTecT - Progressive Techniques for Testing Embedded Systems“
- ZiM-AiF-project: “Entwicklung eines therapeutischen Reizstrombodys“

Selected Publications:

Kriesten, D.; Pankalla, V.; Heinkel, U.: **An Application Example of a Run-time Reconfigurable Embedded System**. Accepted for publication in the Proceedings of the International Conference on ReConFigurable Computing and FPGAs (ReConFig’10). IEEE Computer Society. Mexiko, 13. – 15. Dezember 2010 .

Markert, E.; Billich, E.; Tischendorf, C.; Proß, U.; Leibelt, T.; Knäblein, J.; Schneider, A.; Heinkel, U.: **An In-band Reconfigurable Network Node based on a heterogeneous Platform**. Conference on Design and Architectures for Signal and Image Processing DASIP), 26. – 28. Oktober 2010, Edinburgh, Schottland, ISBN 978-1-4244-8734-9.

Shende, M. A.; Wolf, P.; Markert, E.; Herrmann, G.; Heinkel, U.: **Modeling of electrical resistance strain gauge using VHDL- AMS for the realtime structural heath monitoring of wind turbines**. 10. Chemnitzer Fachtagung Mikrosystemtechnik - Mikromechanik & Mikroelektronik, Chemnitz, 20. – 21. Oktober 2010, Chemnitz, ISBN 978-3-00-032052-1.

Froß, D.; Langer, J.; Froß, A.; Heinkel, U.: **Hardware-Implementierung eines Partikelfilters zur Positionsbestimmung**. DASS 2010 Dresdner Arbeitstagung Schaltungs- und Systementwurf, 18. – 19. Mai 2010, ISBN 978-3-8396-0126-6.

Knäblein, J.; Tischendorf, C.; Markert, E.; Heinkel, U.: **Technology Independent, Embedded Logic Cores – Utilizing synthesizable embedded FPGA-cores for ASIC design validation**. ReCoSoC’2010, Karlsruhe, 17. – 19. Mai 2010, ISBN 978-3- 86644-515-4.

Roßberg, C.; Froß, A; Froß, D; Heinkel, U.: **Beacon Frame based Network Simulation using TrueTime Network Simulator**. SIMUTools 2010, Torremolinos, Spanien, 15. – 19. März 2010, ISBN 978-963-9799-87-5.

Proß, U.; Goller, S.; Markert, E.; Jüttner, M; Langer, J.; Knäblein, J.; Schneider, A.; Heinkel, U.: **Demonstration of an in-band reconfiguration data distribution and network node reconfiguration**. Proceedings DATE conference 2010, Dresden, Germany, March 8 – 12, 2010, ISBN 978-3-9810801-6-2 .

Langer, J.; Pepelyasehv, D.; Heinkel, U.: **Determinierung von Automaten bei der High-Level-Synthese von Operationseigenschaften**. 13. Workshop “Methoden und Beschreibungssprachen zur Modellierung und Verifikation von Schaltungen und Systemen”, 22. – 24. Februar 2010, Fraunhofer IIS, EAS Dresden, Tagungsband zum Workshop pp. 31 – 40, Fraunhofer Verlag, ISBN 978-3-8396-0103-7.

Billich, E.; Rößler, M.; Heinkel, U.: **Effiziente Auslastung der heterogenen Ressourcen eines Systems durch domainübergreifendes Multithreading**. 13. Workshop “Methoden und Beschreibungssprachen zur Modellierung und Verifikation von Schaltungen und Systemen”, 22. – 24. Februar 2010, Fraunhofer IIS, EAS Dresden, Tagungsband zum Workshop pp. 127 – 136, Fraunhofer Verlag, ISBN 978-3-8396-0103-7.

Chair Electronic Devices of Micro and Nano Technique

Contact: **Prof. Dr. John Thomas Horstmann**

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Main working fields:

- Layout and verification of analog- and mixed-signal circuit designs for microsystem technology

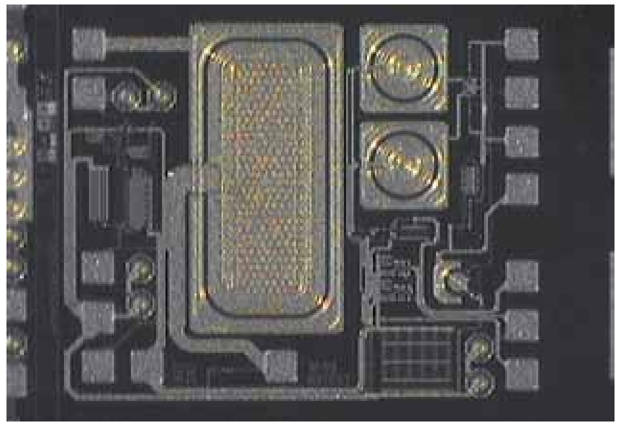

Fig. 1: Example for an electronic microsystem.

- Sensor signal evaluation and actuator control of discrete and integrated microsystems
- 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 nano electronic devices

The main research topics at the Chair of Electronic Devices of Micro and Nano technique are:

- Development of new circuit concepts for nano electronic 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

Fig. 2: SEM-picture of the gate electrode of a sub-50nm-MOS-transistor.

- Characterization and simulation of sub-50nm-MOS-transistors
- Analysis of physical mechanisms of micro and nano electronic devices
- Evolution of measurement methods for analysis of the electrical parameters of next generation nano electronic devices
- Invention of new materials in the CMOS-process for next generation nano devices

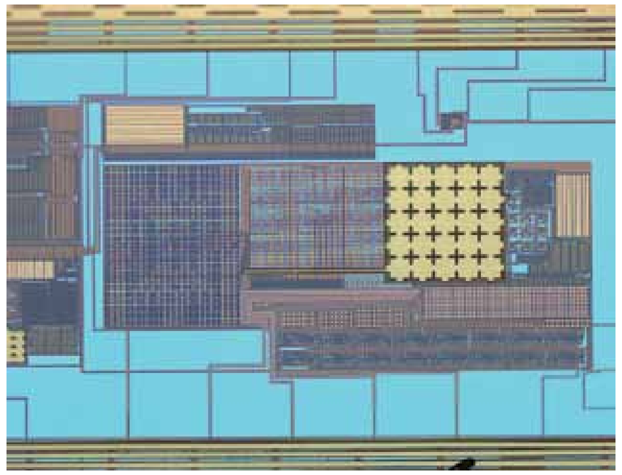

Fig. 3: Layout of an electronic micro device.

Main areas of responsibility in the research activities of the “Microsystem Electronics” working group at the Chair of Electronic Devices of Micro and Nano Technique are the development of integrated electronic microsystems and electronic micro and nano devices and the solution of customer-oriented problems.

The current research projects are:

- 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
- 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 like 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 nano technologies
- 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

Example for the results of research at the characterization of the trench insulation:

For the fabrication of deep trenches for device insulation in a high-voltage process in thick SOI have been examinatet different manufacturing technologies. The trenches have been investigated by current-voltage characteristics. In comparison to conventional produced trenches alternatively produced samples obtain a remarkable increase of the breakdown voltages. A trench fabrication method has been selected which enables the manufacturing of single trenches suitable for operating voltages up to 650 V. The new trench will be implied as SITRIS module in XD10 X-FAB process.

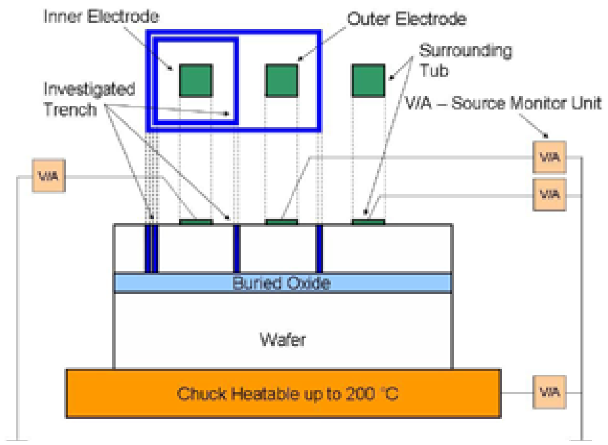

Fig. 4: Test configuration of the trench characterization.

Chair Electrical Measurment and Sensor Technology

Contact: **Prof. Dr. Olfa Kanoun**

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Email: **olfa.kanoun@etit.tu-chemnitz.de**

Main research focus:

- Sensors and Measurement systems
- Energy storage for mobile and stationary applications
- Energy autonomous system

Measurement and sensor technologies are gaining importance in technical systems because of continuous ever-increasing of the demand for automation, quality assurance, safety and comfort. The research activities at the Chair for Measurement and Sensor Technology (MST) have a strategic focus on measurement methods, sensor technology, impedance spectroscopy, design of sensor systems and model-based signal processing.

Impedance spectroscopy is a powerful measurement method used in many application fields such as electro chemistry and material science. The research activities of MST in this field include several methodological contributions involving the main aspects of measurement techniques, physical-chemical modeling and signal processing. One example can be given by research projects dealing with diagnosis of Li-Ion batteries.

Energy storage is gaining increasingly more importance because of its key role in the sectors electro mobility, energy and entertainment electronic. Long term stability, suitable charging and discharging processes and behavior prediction are decisive factors demanding the development of novel technologies and management systems. Smart battery management systems can be developed using impedance based methods in combination with suitable models (Fig. 1).

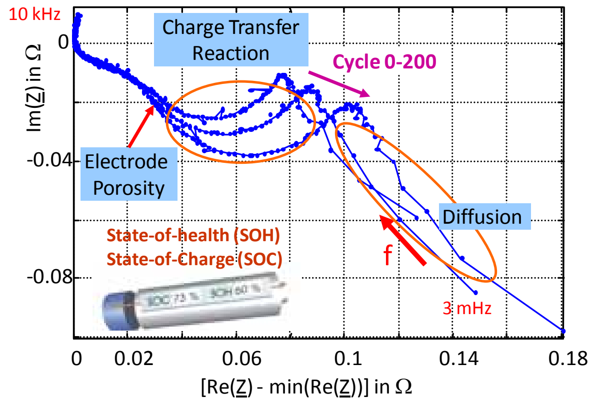

Fig. 1: Diagnosis of Li-Ion batteries by impedance spectroscopy.

The use of ambient energy to power small electronic devices allows the realization of autonomous systems having reduced installation and maintenance costs. A variety of energy conversion principles and technologies can be nowadays adopted to convert temperature differences, vibration (Fig. 2) or electrostatic energy. In order to bridge low energy availability, system should be capable to accumulate energy and to manage energy flows between converter, storage unit and application. The limited efficiency of energy converter, the heavy fluctuations of energy availability changing environmental conditions and the limited capacity of storage units are challenging aspects for the system design. Novel energy harvesting solutions have been developed for specific application requirements. Sophisticated energy management concepts have been developed considering high fluctuations of energy availability.

Fig. 2: Electro magnetic vibration harvester .

The technological progress in the field of micro and nano technology allows promising possibilities for new sensors and sensing principles. Novel sensors with outstanding performance can be realized using multi-walled and single-walled CNTs in different technologies and allowing the measurement of versatile measurement quantities. Different activities are in progress aiming to demonstrate the benefits of CNTs for sensors particularly for mechanical quantities. For example, CNT thin films have been realized for use as strain gauges (Fig. 3). Homogeneous CNT-films have been manufactured with different methods and in different forms. They are self-adhesive and show a high sensitivity and a big measurement range in comparison with metallic strain gauges.

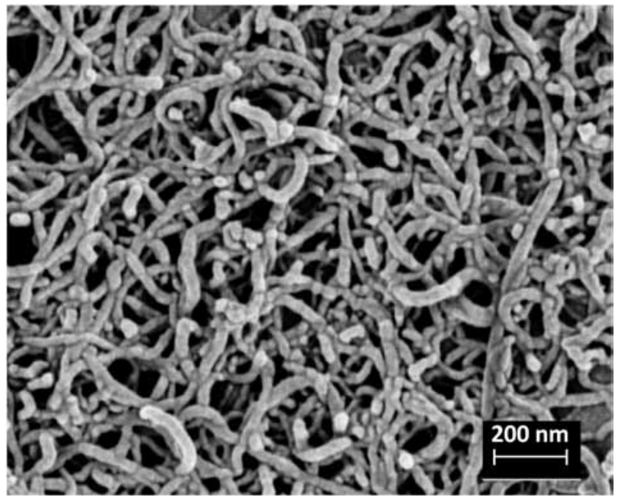

Fig. 3: CNT-films manufactured by spin coating.

Current research projects focus on:

- Energy storage for mobile and stationary applications
- Battery diagnosis (state of charge, state of health, state of function)
- Simulation of batteries and behavior prediction
- Material testing by impedance spectroscopy
- Meat quality assessment by impedance spectroscopy
- Cable fault detection and localization
- Availability and conversion of ambient energy
- Experimental evaluation of thermo electrical converters
- Design of energy autonomous systems
- Energy conversion from electrostatic field
- Smart energy management
- Strain gauges based on carbon nanotubes

Selected Publications:

Kanoun, O.; Tröltzsch, U.; Tränkler, H.-R.: **Benefits of Evolutionary Strategy in Modeling of Impedance Spectra**. Electrochimica Acta 51 (2006), Elsevier, S. 1453 – 1461.

Tröltzsch, U.; Kanoun, O.; Arnold, M.; Stöckel, C.: **Untersuchungen zur Machbarkeit von Fleischqualitätsbewertung mit Impedanzspektroskopie**. Sensoren und Messsysteme, 18. – 19. Mai 2010, Nürnberg.

Kanoun, O.; Wallascheck, J.: **Energy Harvesting**. Expert-Verlag, 2007, ISBN 978-3-8169-2789-1.

Ben Amor, N.; Kanoun, O.: **Availability of Vibration Energy for Supply of Hearing Aids**. Article in press, Transactions on Systems, Signals & Devices, Vol. 4, No. 4, 2009.

Dinh, N. T.; Kanoun, O.; Arreba, A.; Blaudeck, T.; Sowade, E.; Belau, R.; Baumann, R. R.: **Performance of Liquid-Deposited Multiwalled Carbon Nanotube Films under Strain**. Proceedings of Smart Systems Integration 2011, March 22 – 23, 2011. Dresden, VDE VERLAG GMBH, 2011.

Chair Power Electronics and Electromagnetic Compatibility

Contact: **Prof. Dr. Josef Lutz**

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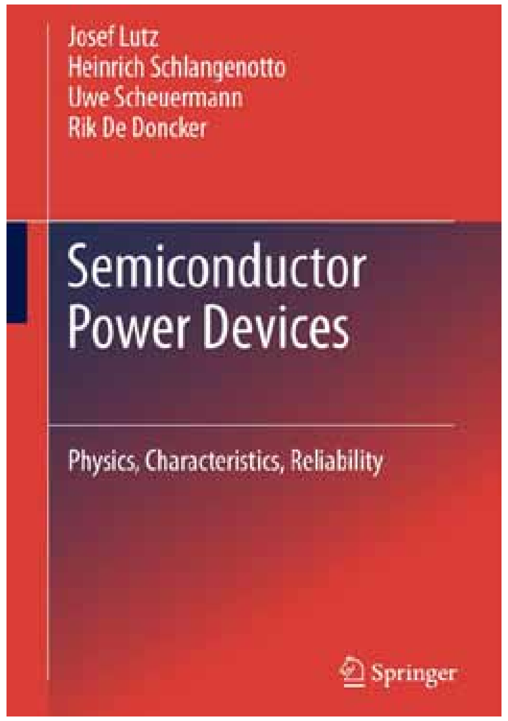
The education covers power devices, thermo-mechanical problems of power electronic systems, power circuits and electromagnetic compatibility. The lecture on "Semiconductor Power Devices" is given in English.



The focus of research is on power devices, especially their reliability. The main fields of research are:

- Dynamic avalanche and ruggedness: At high stress conditions in dynamic avalanche, current tubes or filaments occur. Of most importance is the nn⁺-junction. Designs with improved ruggedness are deduced.
- Surge current capability of power diodes in Si and SiC. Figure 1 shows the new "Inverse Dependency of Emitter Efficiency" Diode.

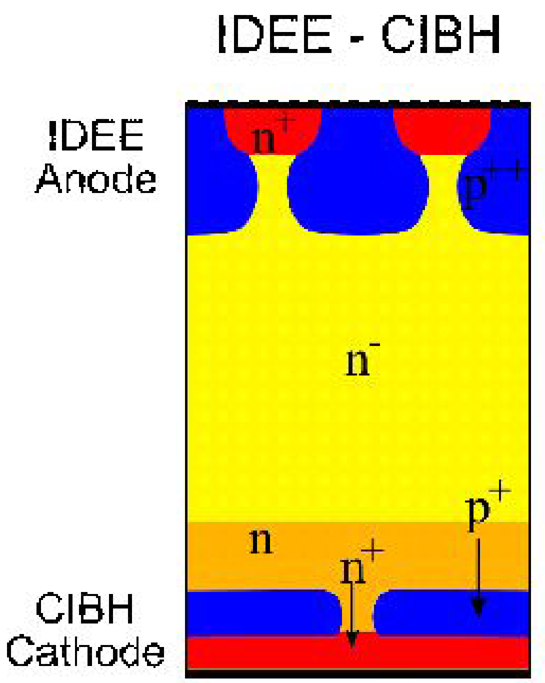


Fig. 1: Inverse Dependency of Emitter Efficiency (IDEE) Diode. Usually, the emitter efficiency decreases at high current density. For the IDEE diode, it is increasing.

- Short circuit capability of high-voltage IGBTs: Power devices must be capable to withstand extreme high loads at fault conditions.

- Long term blocking stability of power devices: A hot reverse test station, DC 2500V, T_j up to 200° C, has been built and is running.
- Reliability of packaging technologies: The focus is on power cycling. Seven self-build power cycling stations are running. A new 2000A station is in construction.
- Simulation of thermal-mechanical stress in power devices: The analysis shows the local mechanical stresses and strains in the package, which result from the mismatch in the thermal expansion of the material layers.
- Failure analysis: Electrical measurements, opening of power modules, inspection, if necessary REM analysis etc., failure reports including evaluation.

Important research projects:

- Electric components for active gears – EfA: joint project 2006 – 2011 for increased energy density of the electric components in the power train of a hybrid vehicle

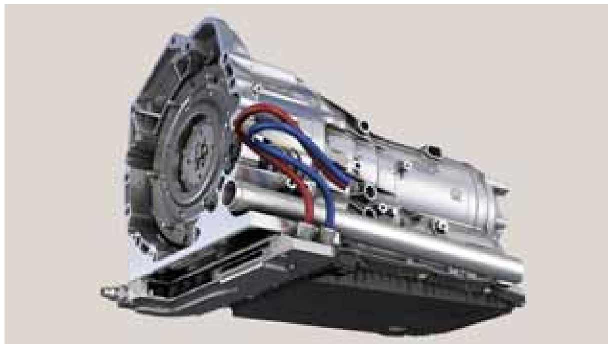


Fig. 2: Active gear for hybrid vehicles with integrated power electronics. (figure from ZF AG, Friedrichshafen).

- Investigation of a power module design for high thermal stress applications in automotive, aerospace and space – HiT-Modul. Joint project supported by BMBF.
- High power converters for offshore applications, joint project with NTNU Trondheim and SINTEF Norway. Power cycling capability and design rules for long lifetime of high-power converters for future large offshore wind parks.
- Reliability and lifetime of Converter – Energy-storage – Systems: subproject of ESF- and SAB-funded junior research group 'Intelligent on-site energy storage systems'.
- Robustness of high-voltage IGBTs with special consideration of gate drive conditions – industry project.

Selected publications:

Lutz, J.; Schlangenotto, H.; Scheuermann, U.; De Doncker, R.: **Semiconductor Power Devices**. Physics, Characteristics, Reliability; Springer 2011.

Baburske, R.; Lutz, J.; Schulze, H.-J.; Siemieniec, R.; Felsl, H.-P.: **A new diode structure with inverse injection dependency of emitter efficiency (IDEE)**. Proc. IEEE International Symposium on Power Semiconductor Devices & ICs, Hiroshima, Japan, 2010.

Poller, T.; Lutz, J.: **Comparison of the Mechanical Load in Solder Joints Using SiC and Si Chips**. Proc. International Seminar on Power Semiconductors, 1 – 3 September 2010, Prague: CTU, 2010, S. 217 – 222.

Lutz, J.; Baburske, R.: **Dynamic Avalanche in Bipolar Power Devices**. Proc. International Seminar on Power Semiconductors, 1 – 3 September 2010, Prague: CTU, 2010.

Baburske, R.; Lutz, J.; Heinze, B.: **Effects of Negative Differential Resistance in High Power Devices and some Relations to DMOS Structures**. Proc. Interational Reliability Physics Symposium, Anaheim, California, IEEE, 2010.

Hensler, A.; Lutz, J.; Thoben, M.; Guth, K.: **First Power Cycling Results of Improved Packaging Technologies for Hybrid Electrical Vehicle Applications**. Proc. 6th International Conference on Integrated Power Electronics Systems (CIPS) 2010.

Chair Materials and Reliability of Microsystems

Contact: **Prof. Dr. Bernhard Wunderle**

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The chair "Materials and Reliability of Microsystems" has been held by Bernhard Wunderle since July 2009. Currently the research group consists of seven full time employees, six of them are academic research staff.

Lectures:

The professorship is responsible for the scientific education in the field of material science for students of electrical engineering and microelectronics and focuses on the reliability assessment and prediction for micro and nano systems for graduate students, including the new international master's program in micro and nano systems.

Research:

Reliability as a scientific discipline is concerned with the analysis, assessment and prediction of the lifetime of microelectronic systems (e.g. of interconnects and interfaces of standard and advanced packages, BEOL-layers, MEMS, 3D-architectures, SIP, etc.).

The main challenges involved therein are the handling of the complexity of microsystems (system reliability), the correlation of degradation to the nanostructure of the materials (nano reliability) and the generation of lifetime models for the transferability between field and lab testing conditions (definition of accelerated and combined tests).

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 microsystems 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").

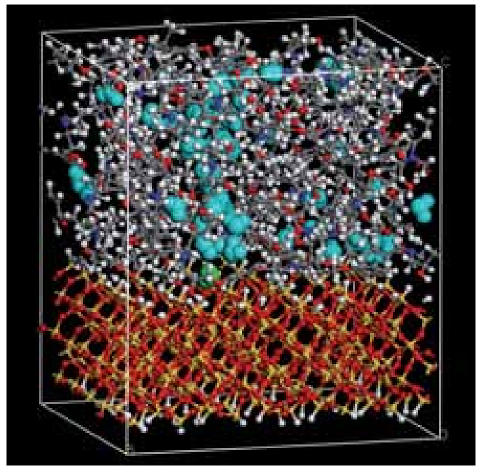

Fig. 1: Molecular dynamics simulation of cross-linked epoxy resin on SiO_2 with H_2O molecules to study moisture diffusion and adhesive properties under different temperature and pressure boundary conditions to obtain structure-property correlations.

The following fields of competence are being built up in a close collaboration with the Fraunhofer ENAS and Fraunhofer IZM:

Material characterization:

- Thermal and mechanical characterization of materials and compounds of microsystems under typical, application-relevant loading conditions such as temperature, moisture and vibration.
- Characterization of cracks in materials and interfaces by means of fracture-mechanical methods considering also process influences on the materials.

Simulation:

- Calculation of failure parameters as a function of external loading conditions.
- Multi-physics approaches to couple e.g. thermal, mechanical and fluidic fields (Finite Element simulations, Computational Fluid Dynamics) for system simulation.
- Multi-scale approaches (e.g. Molecular Dynamics simulation) to obtain structure-property correlations between the nano-scale and the continuum.

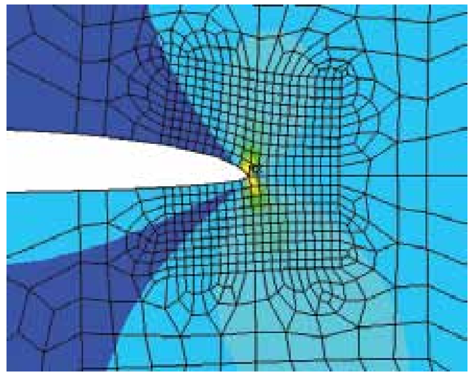

Fig. 2: Finite Element simulation of (asymmetric) crack tip: stress field to investigate mixed mode crack growth at the interface between silica-filled epoxy resin and a copper surface.

Experimental analytics:

- Modern non-contact deformation analysis to verify simulation results on various length scales, in this vein degradation and cracks can be observed in-situ in the micro and nano domain (e.g. nm-resolution by microDAC 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.

Prof. Wunderle is a member of the European Centre for Micro and Nano Reliability (EUCEMAN) and participates in a joint initiative with Fraunhofer ENAS and industrial partners to establish a keylab for micro-reliability in Chemnitz. There is also a close collaboration with Fraunhofer IZM in Berlin.

Current Projects:

- EU-IP eBRAINS: Ambient intelligent nano sensor systems: 3D-SiP architectures in Silicon
- DFG Research Group "Sensoric Micro and Nanosystems": Design of sensors based on nanostructures
- VW Foundation: Integration and Reliability of CNTs into sensor structures
- EU-IP Smartpower: Smart integration of GaN & SiC high power electronics

Selected Publications:

Wunderle, B.; Michel, B.: **Lifetime Modeling for Microsystems Integration – from Nano to Systems**. J. of Microsystem Technologies, Vol. 15, No. 6, pp. 799 – 813, 2009.

Wunderle, B.; Dermitzaki, E.; Hölck, O.; Bauer, J.; Walter, H.; Shaik, Q.; Rätzke, K.; Faupel, F.; Michel, B.; Reichl; H.: **Molecular Dynamics Approach to Structure-Property Correlation in Epoxy Resins for Thermo-Mechanical Lifetime Modeling**. J. Microelectronics Reliability, Vol. 50, pp. 900 – 909, 2010.

Brunschwiler, T.; Paredes, S.; Drechsler, U.; Michel, B.; Wunderle, B.; Reichl, H.: **Angle-of-attack investigation of pin fin arrays in non-unifrom heat-removal cavities for Interlayer cooled chip stacks**. Proc. Semitherm Conf., San Jose, USA, March 20 – 24, 2011.

Hölck, O.; Bauer, J.; Wittler, O.; Lang, K. D.; Michel, B.; Wunderle, B.: Experimental Contact Angle Determination and Characterisation of Interfacial Energies by Molecular Modeling of Chip to Epoxy Interfaces. Proc. 61st ECTC Conf. Orlando, Fl., USA, May 30 – June 3, 2011.

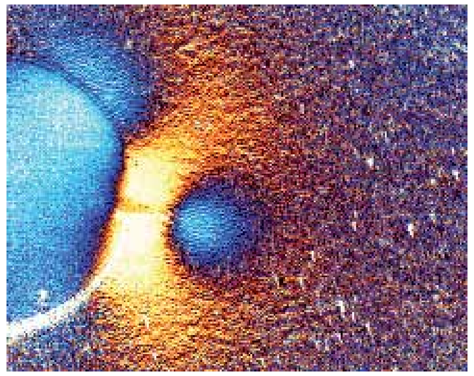

Fig. 3: IR phase image of a mK-temperature field generated during subcritical periodic loading of a crack in PMMA allowing e.g. precise determination of the crack tip position

Honorary Professor for Nanoelectronics Technologies

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The most advanced technologies within micro and nanoelectronics have achieved minimum pattern widths smaller than 30 nm for transistors and metallization. Further shrinking (More Moore) will meet scientifically-technological as well as economical limits within a foreseeable future. Thus, an ongoing development of well-known technologies is no longer the only answer. The necessity for the introduction of nano-scale materials and functional layers gets more and more emphasis in order to cope with the physical and technological challenges. Moreover, radical technology changes (Beyond CMOS) will become necessary.

The research group of the professorship is working on process and material development including modeling and simulation to overcome present technology challenges driven by miniaturization. On the other hand, new technology concepts as well as new approaches within materials area are part of research for future electronic devices. This is done in close collaboration with the Center for Microtechnologies at Chemnitz University of Technology as well as the Fraunhofer Institute for Electronic Nano Systems ENAS.

Main working fields:

Process and material development for advanced interconnect systems: Miniaturization leads to faster operating speed for transistors, but rises signal delays (RC-product) in the interconnect system due to smaller structures and increased complexity. Thus, research emphasis is on reduction of RC-product and associated parasitic effects. For that purpose the application of materials with a low dielectric constant (low-k and ULK dielectrics) is examined. Due to their specific properties like low mechanical strength and inherent porosity, integration of those materials into the entire technology flow is of special importance. Damage-poor patterning and cleaning methods as well as development of repair processes are investigated. As new and alternative technology approach the Air-Gap-technology is considered here.

Carbon nanotubes (CNT) for interconnect applications as a new technology approach for replacement of copper in vias. The deposition of high-quality CNTs by low-temperature CVD with different catalyst materials, structural and electrical characterization of CNTs, and process integration into the complete technology flow of an interconnect system are research topics in that field (see to article „CNTs for interconnect and sensor applications").

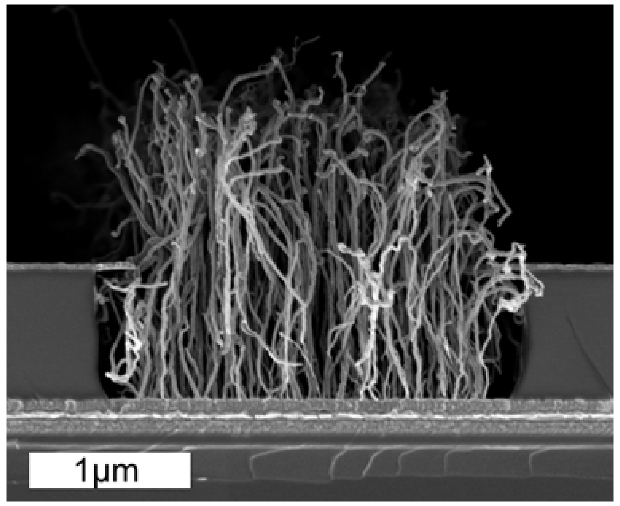

Fig. 1: Selective CNT growth in a via structure.

Development of thin films with high tensions (Stressors) for the increase of the carrier mobility in MOS-transistors in combination with simulation and modeling of stress fields in MOS-transistor structures and their influence on the transistor characteristics (see to article „Stressor films for enhanced transistor performance ").

Concepts and metallization processes for the integration of electronics and micro/nanosystem components: Development of integration schemes (3D-Integration) using Through Silicone Vias (TSV) considering the special requirements of micro/nanosystem components. TSV metallization using copper-CVD and ECD in order to achieve good step coverage and defective-free filling of TSVs with high aspect ratios (AR $\geq$ 4).

Atomic layer deposition of metal and metal oxide layers: Process development based on metal-organic precursors, evaluation of new precursors and integration of the processes and materials into the technology flow for the manufacturing of interconnect systems or sensor applications (e.g. GMR sensors or functionalization of CNTs).

Materials and metallization for NEMS: Synergy with micro and nanosystem technology arises from materials which are applicable for sensor functions. Examples are CNTs with selected characteristics and exact positioning by Dielectrophoresis, thin film deposition and patterning processes for device production (e.g. metallization processes, ALD layers, dry etching of multi-layer systems for spintronic applications).

Simulation and modeling of devices, processes and equipment: The development of new materials and technologies requires new or optimized processes and equipment. Advanced models and simulation tools support the development of improved process conditions, tool configurations and film properties. Of special importance is the development of quantum-mechanical simulation models for the description of nano-scale devices and their integration in continuum-based device simulators; e.g. simulation of the transportation characteristics in CNTs and transition to metallic contacts.

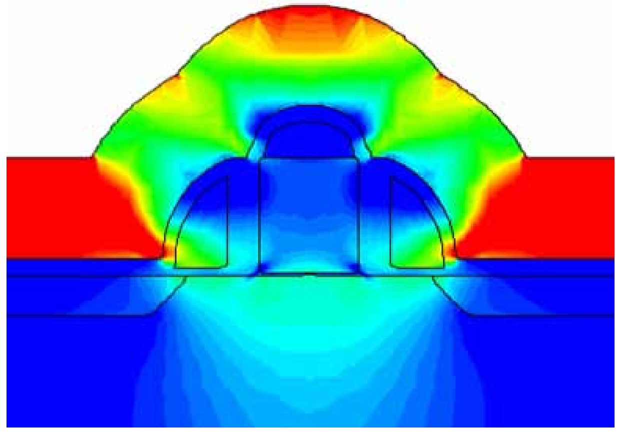

Fig. 2: Stress σ_{xx}, nFET, tensile 2 GPa

Selected publications in 2010:

Ahner, N.; Zimmermann, S.; Schaller, M.; Schulz, S.E.**: Optimized wetting behavior of water-based cleaning solutions for plasma etch residue removal by application of surfactants**. 10th International Symposium on Ultra Clean Processing of Semiconductor Surfaces, Os-tende (Belgium), 2010 Sep 20 – 22; Proceedings, pp. 48 – 49.

Fischer, T.; Ahner, N.; Zimmermann, S.; Schaller, M.; Schulz, S.E.**: Influence of thermal cycles on the silylation process for recovering k-value and chemical structure of plasma damaged ultra-low-k materials (Talk)**. Advanced Metallization Conference, Albany, NY (USA), Oct 5 – 7, 2010.

Zimmermann, S.; Ahner, N.; Blaschta, F.; Schaller, M.; Zimmermann, H.; Ruelke, H.; Lang, N.; Roepcke, J.; Schulz, S.E.; Gessner, T.**: Etch processes for dense and porous SiCOH materials: plasma states and process results**. 3rd International Workshop Plasma Etch and Strip in Microelectronics, PESM 2010, Grenoble (France), 4 – 5 March, 2010.

Schulze, K.; Jaschinsky, P.; Erben, J.; Gutsch, M.; Blaschta, F.; Freitag, M.; Schulz, S.E.; Steidel, K.; Hohle, .; Gessner, T.; Kuecher, P.**: Variable-Shaped E-Beam lithography enabling process development for future copper Damascene technology (Poster)**. 36th International Conference on Micro- and Nanoengineering (MNE), Genoa (Italy), Sept 19 – 22, 2010.

Hermann, S.; Fiedler, H.; Waechtler, T.; Falke, M.; Ecke, R.; Schulz, S.E.; Gessner, T.**: Approaches for Fabrication of Carbon Nanotube Vias**. Nanoelectronic Days 2010, Aachen (Germany), Oct 4 – 7, 2010; Poster presentation.

Hofmann, L.; Ecke, R.; Schulz, S.E.; Gessner, T.**: Pulse Reverse Electroplating for TSV Filling in 3D Integration**. Smart Systems Integration, Como (Italy), Mar 23 – 24, 2010; Pro-ceed-ings (ISBN 978-3-8007-3081-0).

Waechtler, T.; Ding, S.-F.; Hofmann, L.; Mothes, R.; Xie; Oswald; Detavernier, C.; Schulz, S.E.; Qu, X.-P.; Lang, H.; Gessner,T.**: ALD-grown seed layers for electrochemical copper deposition integrated with different diffusion barrier systems**. Materials for Advanced Metallization (MAM), Mechelen (Belgium), Mar 7 – 10, 2010.

Wolf, H.; Streiter, R.; Friedemann, M.; Belsky, P.; Bakaeva, O.; Letz, T.; Gessner, T.**: Simulation of TaNx deposition by Reactive PVD**. Microelectronic Eng., 87 (2010) pp. 1907 – 1913 (ISSN 0167-9317).

Zienert, A.; Schuster, J.; Streiter, R.; Gessner, T.**: Transport in carbon nanotubes: Contact models and size effects**. IWEPNM, Kirchberg (Austria), Mar 6 – 13, 2010; phys. stat. sol. (b), 247 (2010) pp. 3002 – 3005.

Honorary Professor for Opto Electronic Systems

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Email: **thomas.otto@enas.fraunhofer.de**

Main technology fields:

- 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 micro fluidic systems for different Lab-on-Chip systems
- Prototype service of components and systems

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 nanoeffects (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.

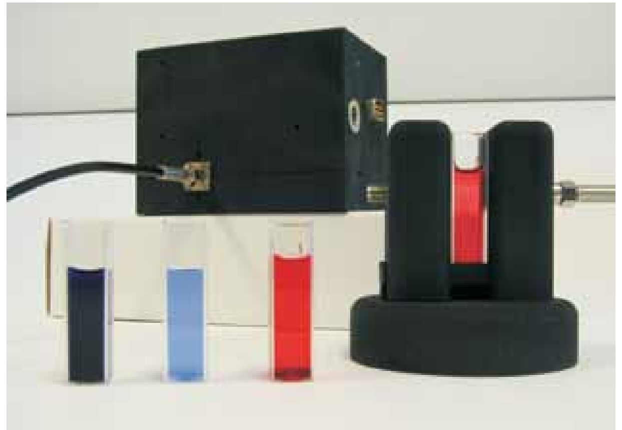

Fig. 1: NIR/MIR MEMS Spectrometer

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 microsystems, 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.

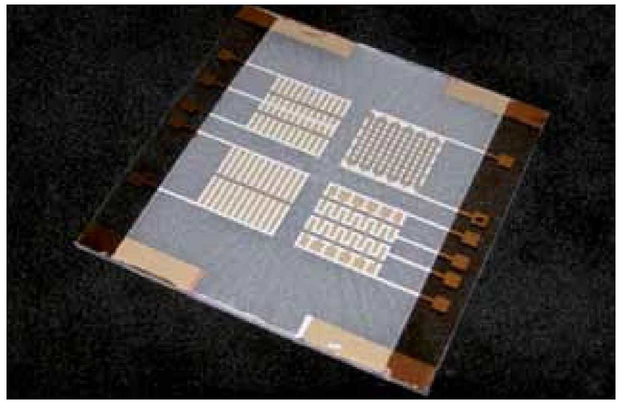

Fig. 2: Humidity sensor based on nanocomposites

Selected publications:

Martin, J.; Schwittlinsky, M.; Piasta, D.; Streit, P.; Billep, D.; Otto, T.; Gessner, T.**: Thermoelectric generators based on polymers and nanocomposites**. Smart System Integration, Como (Italy), Mar 23 – 24, 2010; Proceedings (CD-ROM), Paper 80, VDE Verlag GmbH 2010. ISBN 978-3-8007-3208-1.

Nestler, J.; Morschhauser, A.; Hiller, K.; Otto, T.; Bigot, S.; Auerswald, J.; Knapp, H.F.; Gavillet, J.; Gessner, T.**: Polymer Lab-on-Chip systems with integrated electrochemical pumps suitable for large scale fabrication**. Int. J. Adv. Manuf. Technol., 47, 1 (2010) pp. 137 – 145 (ISSN 0268-3768).

Otto, T.; Saupe, R.; Weiss, A.; Stock, V.; Throl, O.; Graehlert, W.; Kaskel, S.; Schreck, H.; Gessner, T.**: MEMS Analyzer for fast determination of mixed gases**. MEMS/MOEMS Conference, San Jose, Proceedings of SPIE (2009).

Scientific Reports of Chairs of the Center for Microtechnologies

Integration of Dielectrophoretic Deposited Carbon Nanotubes and Their Reliability in Mechanical Sensor Systems

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The outstanding electrical and mechanical properties of carbon nanotubes (CNTs) promise fundamental advancements for a variety of applications in nanoelectromechanical systems (NEMS). Beside the extreme mechanical properties and the nanometer dimensions CNTs show excellent sensitivity to electrical, optical or mechanical influences, which make them suitable for different sensor principles. CNTs offer clear advantages to other technologies like classic piezoresistive or capacitive sensor principles. The high piezoresistive gauge factor and nanometer dimension promise a higher signal to noise ratio and sensitivity.

The aim of this project is the development of a mechanical sensor based on the piezoresistive effect of semiconducting single-walled carbon nanotubes (SWCNTs) which are arranged between a movable mass and a fixed frame. If acceleration is acting on the mass, a strain is applied on the CNTs which results in a resistance change. A schematic is shown in figure 1.

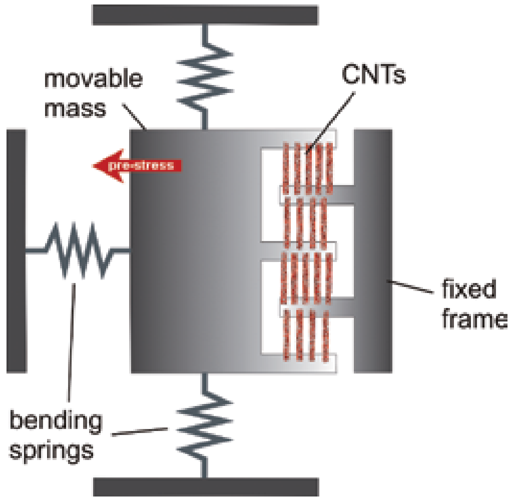

Fig. 1: Principle illustration of a mechanical structure with CNTs

A MEMS test system (Fig. 2) with integrated reliability testing and monitoring techniques to investigate physical properties of CNTs such as piezoresistive behavior, the stress-strain-relationship and the impedance spectrum should provide information about CNT behavior which is relevant for the sensor application. The reliability investigations focus on probable failure modes of the CNTs upon tensile loading, supported by FEM simulations for mechanical fracture evaluation.

The full integration of SWCNTs in NEMS structures, the formation of mechanical, electrical resilient contacts and the selection of appropriate SWCNTs with scalable approaches are main issues of the project.

This work is founded by the "Volkswagenstiftung" within the funding initiative "Integration of Molecular Components in Functional Macroscopic Systems". The cooperation between the Center for Microtechnologies and the chairs Microsystems and Precision Engineering and Materials and Reliability of Microsystems combine experiences in CNT deposition and integration in MEMS, design and modeling as well as reliability of microsystems.

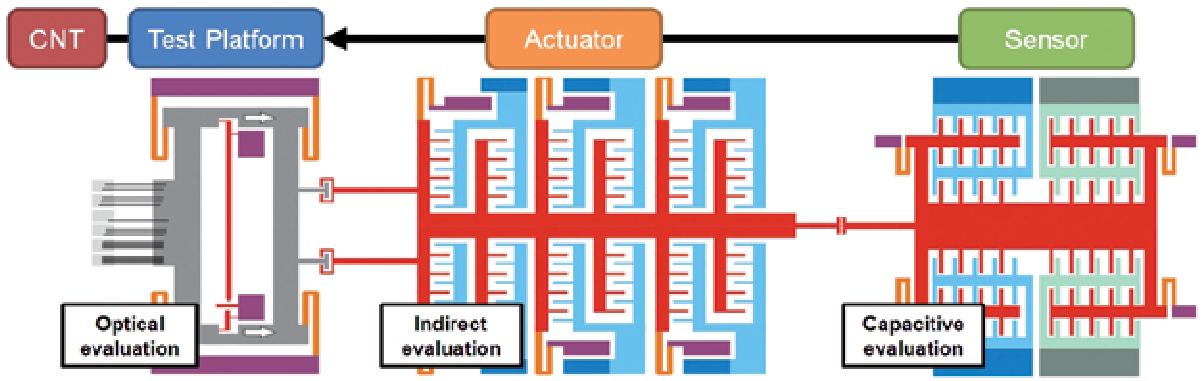

Fig. 2: MEMS test system for CNT investigations with optical, indirect and capacitive information about load on the CNTs

Integration of Nanostructures in Micromachined Optical Filters

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Tunable IR filters utilizing thick reflector carriers and distributed bragg reflectors (DBR) have been developed at InfraTec, Fraunhofer ENAS and ZfM for several years. However the stress of the layer stacks may be a source of warping and tilting of the reflector surfaces, resulting in reduced finesse of the filters. In order to replace such DBR layers, periodically arranged sub-wavelength structures are presently under investigation [1]. Arrays of aluminum ring resonators on thin Si_3N_4 membranes and etalons formed by two reflectors with a fixed cavity in between have been designed and their transmission characteristics were analyzed using the Finite Difference Method (FDM).

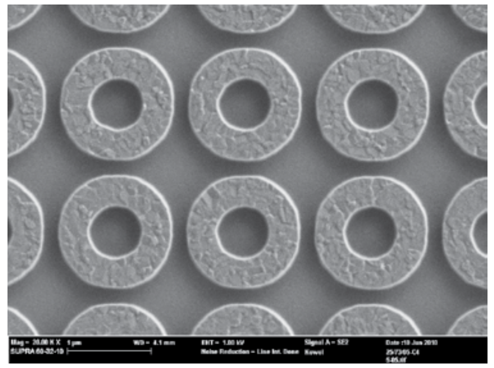

Fig. 1: Al ring resonators on Si_3N_4 membrane (pitch: 1,5 µm, critical dimension: 150 nm)

The nanostructures were fabricated on 300 µm thick Si wafers by e-beam lithography (Leibnitz IOM Leipzig and IAP Jena) and dry etching of Al. Figure 1 shows a SEM picture of the ring array. Afterwards, membranes were formed by dry etching of Si, the etalons were mounted using SU-8 as a bonding and spacer material, and finally the membranes were released by SiO_2 buffer layer removal (Fig. 2). The measurement results (using a FTIR spectrometer) are in perfect accordance with the simulation, when the real geometry parameters are taken (Fig. 3). A maximum transmittance of 60 % and a bandwidth of about 200 nm are comparable with DBR results. Further options are higher order filters and extension of the wavelength range by changing the ring geometry. Further projects will focus on nanostructure integration into tunable filters.

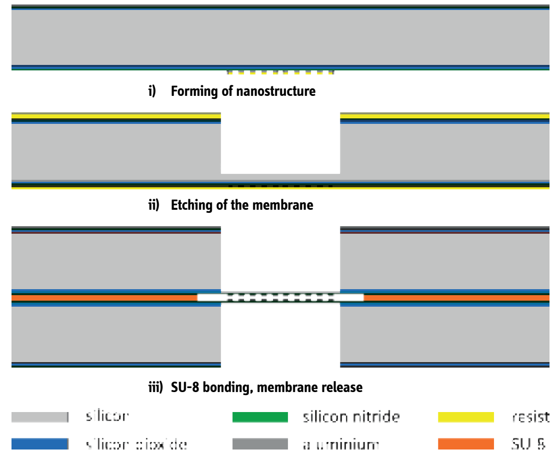

Fig. 2: Technology flow of the etalons

The authors would like to thank Mr. Zajadacz (IOM Leipzig) and Mr. Kley (IAP Jena) for providing e-beam lithography. The project was supported by the Saxon State Ministry for Science and the Arts, contract number 12976/2016.

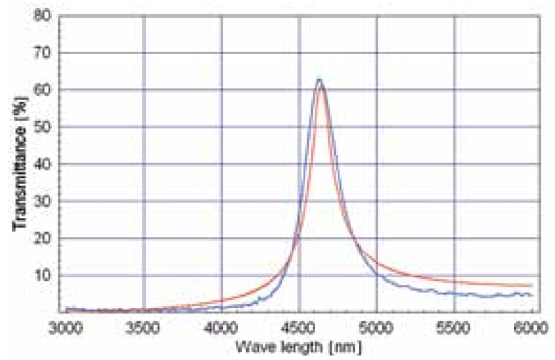

Fig. 3: Comparison of measured (blue) and calculated (red) transmission characteristics

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Silicon as Mechanical Material for Mechanical Watches

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Introduction

The fabrication of mechanical watches uses a mature technology, which fundamentals are well known since decades or even centuries. Nevertheless, there is still room for substantial improvement regarding demands for higher precision, lower wear and increased maintenance interval. With the advent of cheap and precise quartz watches a strong competition arose to mechanical watches leading to the survival of only high class models, which are perceived as a piece of jewellery and gratify aesthetic demands.

Monocrystalline silicon as a mechanical material [1] shows excellent linear behavior of elasticity up to its high ultimate strength. It is antimagnetic and therefore insensitive to the terrestrial magnetic field. Silicon can be processed using micromechanical techniques originating from microelectronics processing. One of the long-term objectives is the manufacturing of an oil-free mechanical watch.

Fig. 1: Silicon anchor as one part of the lever escapement

DRIE tool as workbench in the engineering workshop

Deep reactive ion etching (DRIE) is a powerful tool for precise silicon machining. However, the design pattern provides two degrees of freedom only – the two dimensions of pattern area. The third dimension is limited to the adjusted etch depth, comparable to a stamped or extruded workpiece. Steps towards true three-dimensional shaping are multi-level etch techniques [2], smart utilization of aspect dependent etching [3] (ARDE) and the combination of anisotropic and isotropic etch processes.

Separation of the shaped parts

A reliable temperature control of the silicon to be etched is one of the important constraints in the course of anisotropic etching. Therefore the watch parts have to be connected thermally to the bulk of the silicon wafer. A thin but stiff supporting layer connects the fabricated parts during etch through and beyond. This layer has to take up the mechanical forces induced by the helium back-side cooling of the wafer inside the etch tool. Separation of components takes place by removing the supporting layer either by means of dry or wet etching.

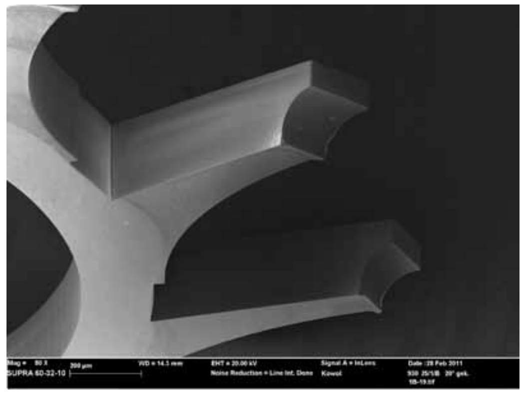

Fig. 2: SEM image of an escape wheel showing the rounded bevel

Fabrication of escape wheel and pallet lever

Within the research project 'SiMec' funded by the Sächsische Aufbaubank a process technology was developed for the production of mechanical watch parts. The suitability of this process flow was demonstrated by fabrication of escape wheel and anchor, which were successfully used in an existing movement.

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Plasma-Chemical Texturing of (Multi) Crystalline Silicon for High-Efficiency Solar Cells – an Example for Green Processing

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[2] Fraunhofer Institute for Electronic Nano Systems ENAS, Departement Back-end of Line (BEOL), Chemnitz, Germany

1 Motivation

Renewable energies are worldwide one of the most important and discussed topics of our society. Photovoltaic represents an environmental friendly and promising kind of energy harvesting. For this there are continuous worldwide efforts for an increase in electrical efficiency on the one hand and cost reduction on the other. An enhancement in efficiency can be achieved by a decrease of surface reflection associated with a higher quantum yield. Beside the today default anti reflex coating (ARC) which is typically realized by SiN there are more and more ambitions for a structured silicon surface. State of the art in photovoltaic industry is wet chemical processing. This wet generated texture helps to reduce the weighted (AM 1.5) average reflection from about 36 % to nearly 13 % [1]. Our aim is to develop a mask-less plasma based process which is clearly able to improve the existing textures.

2 Results of the process development

The ZfM of the Chemnitz University of Technology and the Fraunhofer ENAS have in cooperation developed a new plasma chemical etch process for advanced texturing of mono- and polycrystalline silicon wafers. The research was done with our new (purchased in the middle of 2010) versatile usable plasma etch tool AK 1000 RIE from the manufacturer Roth & Rau Microsystems, as shown in figure 1. It is equipped with six linear microwave sources and a radio frequency (RF) generator. We used square polycrystalline solar silicon substrates which are p-doped with the dimension 156 x 156 mm² and a thickness of 200 µm. The carrier takes up to nine such wafers at once – it is comparable with industrial machines.

The requirements for such a process are very high. Apart from the reduction of the reflection coefficient preferably over the whole spectral range of the sun the procedure has to be sustainably. Therefore it was not possible to make recourse of already known and published texturing techniques by use of reactive ion etching (RIE) with the reactive gases SF_6 und O_2 [2]. One reason is the extremely high global warming potential (GWP) of SF_6 which is about

Fig. 1: Our new versatile usable plasma etch tool – a Roth & Rau Microsystems AK 1000 RIE.

23,900 [3], it is one of the most harmful known gases. Another one is the surface reflectance of roughly 5 % which is still slightly too high.

Therefore we were looking for a completely different solution without using any greenhouse gas: a microwave supported RF-RIE process with chlorine (GWP free) and oxygen as reactive gases. After intensive studies of the silicon removal mechanism and the application of modern DOE (design of experiments) methods the requested surface texture could be attested. Following process parameters are important for structure type and quality:

- microwave power
- RF power resp. bias voltage
- Cl_2:O_2 ratio
- total flow rate
- working pressure and
- temperature of the substrate.

Fig. 2: Photographs of different kind (various process parameters) textured polycrystalline silicon wafer.

Some photographs are shown in figure 2 to illustrate the visual impression. These wafers were processed by different parameters and result in multiple degree of reflection. The degree of reflectance and etching rate can be scaled through a careful choice of process parameters. With the best texture the reflective coefficient undershot a mark of one percent in the spectral range. In this case we scored an etching rate about 125 nm/min. The requested texture depth can be controlled by process time. There is a linear correlation between etch duration and structure depth up to 2 µm (peak-valley). This so prepared texture has the shape of inverted pyramids as shown in the following SEM image (Fig. 3).

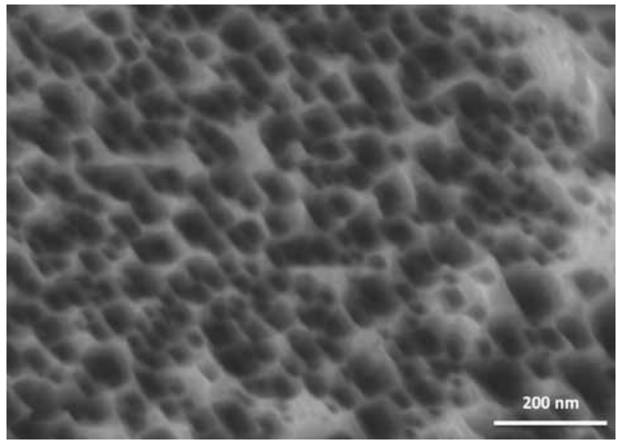

Fig. 3: SEM image (surface @100k magnification) of a plasma-chemical textured polycrystalline silicon wafer as an example.

Based on first solar cell preparations by the business partner a weighted reflectance lowered up to 2 % was detected for these textured wafers. It is demonstrable that a good electrical performance of solar cells can only reached by an optimal adaptation of all process steps. So it is absolutely necessary to customize several technological stages causing the significantly changed surface topology of the textured wafer. Corresponding investigations will be done currently. Nevertheless, first results indicate already a significant rise of solar cell efficiency.

3 Summary

The photovoltaic group of the ZfM succeeded to design a sustainably plasma based process for texturing crystalline silicon which is superior with respect to any known wet chemically process. So the degree of surface reflection could be decreased up to 2 % in dependence of process parameters and etching time. This texture looks like inverted pyramids with a structure depth (peak-valley) in a range from 0.5 to 1.5 µm. While the principle benefit of dry texturing is already shown, the future work (together with our industry partner) will focus on the optimal adaption of all process steps for a better cell efficiency.

4 Acknowledgement

The results which are described in this publication were part of a R&D project with the Roth & Rau AG, Hohenstein-Ernstthal, Germany.

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Modeling of Aerodynamic Effects of Wind Turbine for Development of a Strain Gauge Sensor using VHDL-AMS

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Chemnitz University of Technology, Chair for Circuit and System Design

Abstract

Introduction of the wind turbine Structural Health Monitoring System (SHMS) in the market has significantly caught up. At present several SHM systems based on different sensor technologies and different signal evaluation schemes are available in the market. SHMS offers many advantages towards the safety of the wind turbine. The work presented in this paper is supportive to the project under which a SHM system is being developed for a wind turbine. Through this paper, an attempt has been made to model and to analyze the in-plane forces acting on the wind turbine rotor blade and to model an electrical resistance strain gauge sensor using a mixed signal multi-domain hardware description language VHDL-AMS. It has been shown that the stresses occurred in the wind turbine blade in the normal operating conditions are periodic in nature and depend upon various design parameters of the blade.

1 Nomenclature

ρ	air density	(kg/m^3)
u	Linear velocity	(m/s)
v	wind velocity	(m/s)
w	relative wind velocity	(m/s)
n	rotations per second	(rps)
r	radial distance	(m)
A_b	area of the blade element	(m^2)
F_R	radial force	(N)
F_G	gravitational force	(N)
F_L	lift force	(N)
F_D	drag force	(N)
F_M	moment producing force	(N)
F_T	thrust force	(N)
F	resultant force	(N)
C_D	drag coefficient	(-)
C_L	lift coefficient	(-)

2 Introduction

Since the wind turbines have been installed at the remote locations, it is often difficult to reach them for periodic and preventive maintenances. SHM systems offer the solution to this problem. As a result, a great deal of research has been focused on the development of the real time SHM systems for wind turbine safety.

The real time SHM systems available in the market are either lacking in functionality, reliability, accuracy or the cost effectiveness. Under the project titled 'FiZ-E', a real time SHMS is being developed. It mainly consists of a set of electrical strain gauge sensors, micro-machined acoustic emission sensors and an intelligent system, which is capable of analyzing the real time data and generates appropriate control signals.

VHDL-AMS is the IEEE standard modeling language (standard 1076.1) created to model, simulate, analyze, and optimize the modern analog mixed-signal, multi-domain designs. In the presented strain gauge model electrical and mechanical domains are used. Though the complete model is based on analog signals, for the sophisticated output signal processing mixed signal modeling constructs can also be used. As per the best of authors' knowledge this is the first ever modeling attempt of the wind turbine and the related sensor system using VHDL-AMS.

3 Basic Concepts of Wind Turbine Aerodynamics

Wind turbines are subjected to very specific loads and stresses. As the nature of the wind is highly variable, so are the loads acting on the wind turbine. Varying loads are far more difficult to analyze than the static loads because of the material aging and fatigue. Large wind turbines are inevitably elastic and the varying loads thus create a complex aeroelastic interplay that induces vibrations and resonances and can produce high dynamic load components [4]. The sources of all the forces acting on the rotor can be categorized as follows:

- aerodynamic loads
- gravitational loads
- inertial loads (including centrifugal and gyroscopic loads) and
- operational loads arising from actions of the control system

Since the strain gauge sensor modeled in this paper has been developed to sense the stresses, which get generated in the plane of rotation of the rotor disc, only these forces are discussed in the next subsections.

3.1 Aerodynamic loads

BEM[1] theory is the most frequently used mathematical model to design a rotor blade and to evaluate various loads acting on the rotor disc. The theory is based on the assumption that the flow at a given annulus does not affect the flow at adjacent annuli [2]. This allows the rotor blade to be analyzed in sections, where the individual forces over different sections are summed up to get the resultant force acting on the rotor. Figure 1 shows the cross section of the modeled blade. For the analysis the blade is divided into five sections. The direction of FM depicts the direction of rotation of the rotor, here anti-clockwise. The linear velocity associated with a blade element is given by:

$$u = 2\pi \cdot r \cdot n$$

Figure 2 shows the vector diagram representation of various aerodynamic components acting on an airfoil. The lift force F_L and the drag force F_D are given by the following equations [6]:

$$F_L = \frac{1}{2}\cdot \rho \cdot A_b \cdot w^2 \cdot C_L$$

$$F_D = \frac{1}{2}\cdot \rho \cdot A_b \cdot w^2 \cdot C_D$$

It can be also seen in figure 2 that F can be resolved in horizontal component F_T and vertical component F_M. These forces are given as per the following equations:

$$F_T = F_L \cos(I) + F_D \sin(I)$$
$$F_M = F_L \sin(I) - F_D \cos(I)$$

3.2 Gravitational loads

Gravity loading on the blade results in a sinusoidally varying edgewise bending moment which reaches a maximum when the blade is horizontal, and which changes it is sign from one horizontal position to the other. It is thus a major source of fatigue loading [1]. Total gravitational loading is equal to the total weight of the blade.

[1] Boundary Element Method

3.3 Centrifugal loads

For a rigid blade rotating with its axis perpendicular to the axis of rotation, the centrifugal force also known as radial force generates a simple tensile load in the blade. In the case of small size wind turbines (diameter < 10 m), centrifugal force largely contributes to the net forces acting on the rotor blade as compared to the medium and large size wind turbines due to their higher rated speeds. For a blade element with mass M, the radial force F_R is given by [7]:

$$F_R = M \cdot r \cdot (2\pi n)^2$$

4 VHDL-AMS Model of Blade Element

The blade element model is divided into four main components as shown in Figure 3: blade element model, stiffness model, strain gauge sensor model and Wheatstone bridge model. Four separate models are designed using behavioral modeling approach and then the connections between them are defined using structural modeling approach.

Listing 1 presents the VHDL-AMS model of the blade element. It is purely a mechanical system model and based on the equations discussion in the previous section.

5 VHDL-AMS Model of a Strain Gauge

The behavioral VHDL-AMS model of a strain gauge developed according to the equations given in the previous section, is shown in listing 2. The model is based on mechanical and electrical domains. The mechanical domain deals with the geometry of the conductor and displacement of one end of the conductor with respect to the other end. The electrical domain deals with the resistance change in response to the geometrical changes in the conductor. Quantity 'x' defines the displacement across the conductor end.

6 Simulation Results

The complete VHDL-AMS model of the blade has been tested using Mentor Graphics's ADVance-MS 2007 simulation tool. In figure 4 wave forms associated with element one are shown. From the waveforms, it can be seen that the net force acting on the blade element is cyclic in nature and is in the range of 25 N, which generates oscillation in the range of 6 nanometers in the strain gauge element. In figure 5 the comparison of the radial force and the moment producing forces is done. From the figure it can be seen that the contribution of the radial force to the net force is much higher than the other two constituent

parts which are moment producing force and gravitational force. The results obtained from the VHDL-AMS blade model are in close proximity to the mathematical estimations.

7 Conclusion

The use of strain gauge for the estimation of periodic stresses occurred in the wind turbine rotor has been discussed. The VHDL-AMS models of a strain gauge and a blade element and a rotor blade have been presented. From the simulation results, the nature of the loads was shown. Further detailed modeling of strain gauge and periodic stresses will be the part of future work. A sophisticated signal processing system is needed to analyze the sensor output.

8 Acknowledgement

The project 'FiZ-E' is funded by BMBF under the program For-MaT.

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```
ARCHITECTURE blade_element_behv OF blade_element_
ent IS

CONSTANT v2  : real := (2.0/3.0)*(v1);  -- wind velocity
CONSTANT rps : real := rpm/60.0;        -- rps
QUANTITY s ACROSS F_sine THROUGH trans TO trans-
lational_ref;
QUANTITY u    : real; -- linear velocity of blade element
QUANTITY w    : real;               -- relative wind velocity
QUANTITY A    : real;                    -- elemental areas
QUANTITY I    : real;                              -- angle
QUANTITY beta : real;                              -- angle
QUANTITY FM   : real;         -- moment producing force
QUANTITY FR   : real;                       -- radial force
QUANTITY FG   : real;                -- gravitational force
QUANTITY FL   : real;       --lift force acting at element
QUANTITY FD   : real;   --drag force acting at element
QUANTITY FM_sine : real;  -- sinusoidal moment force
QUANTITY FR_sine : real;      -- sinusoidal radial force
QUANTITY F_net  : real;

BEGIN  -- blade_model_behv

u    == math_2_pi*r*rps;              -- linear velocity (m/s)
A    == r*chl;                        -- elemental area (m^2)
I    == arctan(v2/u)*57.29577951;    -- angle I (deg)
beta == I-alpha;                      -- angle of attack (deg)
w    == u/cos(I*math_pi/180.0);     -- relative wind w (m/s)
FL   == 0.5*rho*A*w**2*CL;            -- lift force (newton)
FD   == 0.5*rho*A*w**2*CD;           -- drag force (newton)
FM    == (FL*sin(I*math_pi/180.0))-(FD*cos(I*math_
pi/180.0));
FR   == (blade_weight/9.81)*r*(math_2_pi*rps)**2;  --
radial force (N)
FG   == blade_weight;               -- gravitational force (N)

-- calculation of sinusoidal forces
FR_sine  ==  FR  *  sin(math_2_pi*4.0*now);   --
FR*sin(omega*t + theta)
FM_sine == FM * sin((math_2_pi*4.0*now) - math_pi/2.0);
F_sine == (sqrt(FR**2+FM**2))*sin((math_2_pi*4.0*now)-
arctan(FM/FR));

-- calculaction of net forc
F_net == sqrt((sqrt(FR**2+FM**2))**2*(cos(math_2_
pi*4.0*now)) **2
+(sqrt(FR**2+FM**2))**2*(sin(math_2_
pi*4.0*now))**2-2.0*
(sqrt(FR**2+FM**2))*FG*sin(math_2_
pi*4.0*now)+FG**2)*
sin((math_2_pi*4.0*now)-arctan(FM/FR));

END blade_element_behv;
```

Listing 1: VHDL-AMS model of a blade element

```
ARCHITECTURE strain_res_behv OF strain_res_ent IS

CONSTANT a : real := math_pi*r**2;  -- cross sectional
area QUANTITY u ACROSS i THROUGH p TO n;
QUANTITY x ACROSS t1 TO t2;
QUANTITY del_l   : real;  -- change in length
QUANTITY del_a   : real;  -- change in area
QUANTITY del_r   : real;  -- change in radious
QUANTITY del_res : real;  -- change in resistance
QUANTITY res_new : real;  -- new value of resistance

BEGIN  -- strain_res_behv

del_l == x*24.0;           -- change in length
del_r == -(neu*r*del_l)/l;  -- change in radious,
del_a == -(2.0*neu*del_l*a)/l;  -- change in area
del_res/res ==  ((1.0+2.0*neu)*del_l/l)+(0.2040e-6);
i == u/(res+del_res);  -- calculation for change in voltage
Res_new ==  res + del_res;

END strain_res_behv;
```

Listing 2: VHDL-AMS model of the strain gauge

```
ENTITY blade_model_ent IS

  PORT (
    TERMINAL t1                       : translational;
    TERMINAL a1, b1, c1, d1         : electrical;
    -- similar port declaration for component 2 to 5 );

END blade_model_ent;

ARCHITECTURE blade_model_behv OF blade_model_ent IS
  TERMINAL t2, t3, t4, t5, t6         : translational;

BEGIN
element_1 : ENTITY element_model_ent(element_mod-
el_behv)
    PORT MAP (  trans1 => t1,
      trans2 => t2,
      a      => a1,
      b      => b1,
      c      => c1,
      d      => d1);

  element_1a : ENTITY blade_element_ent(be_behv)
    GENERIC MAP (
      rpm          => rpm,
      rho          => rho,
      v1           => v1,
      blade_weight  => wt1,
      element_width => element_width,
      alpha         => alpha,
      TSR           => TSR,
      r             => r1,
      chl           => chl1,
      CL            => CL1,
      CD            => CD1)
    PORT MAP (
      trans => t2);
-- similar component instantiation for element 2 to 5

END blade_model_behv;
```

Listing 3: VHDL-AMS model of the wind turbine blade with the strain gauge sensor

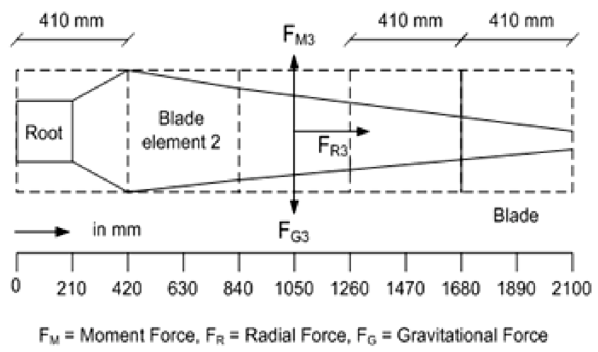

Fig. 1: Various forces acting in the plane of rotation on the rotor blade

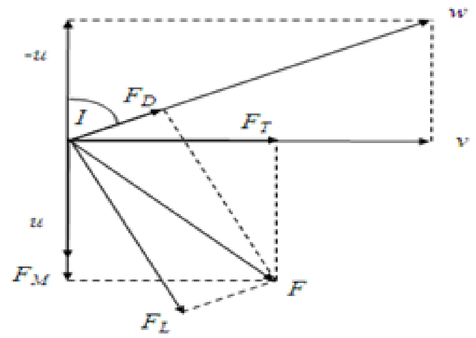

Fig. 2: Velocities and forces associated with an airfoil

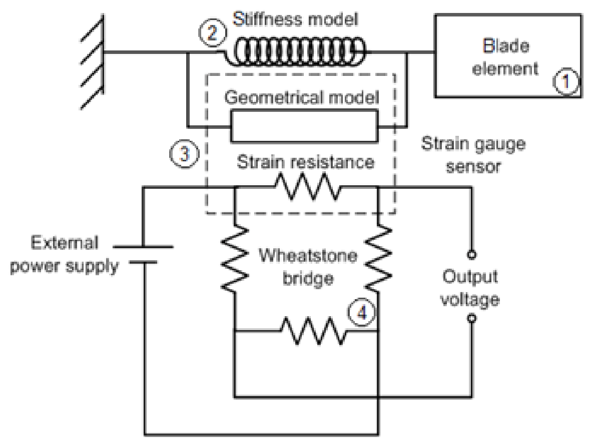

Fig. 3: Schematic model of a wind turbine blade element

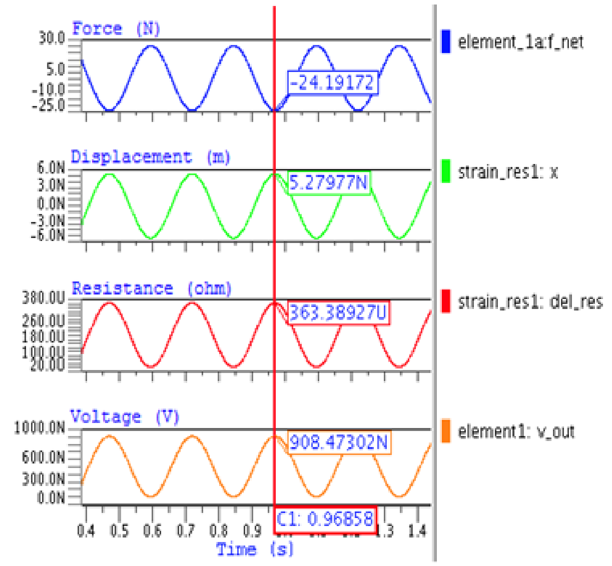

Fig. 4: Results obtained from the VHDL-AMS model of the first element of the blade

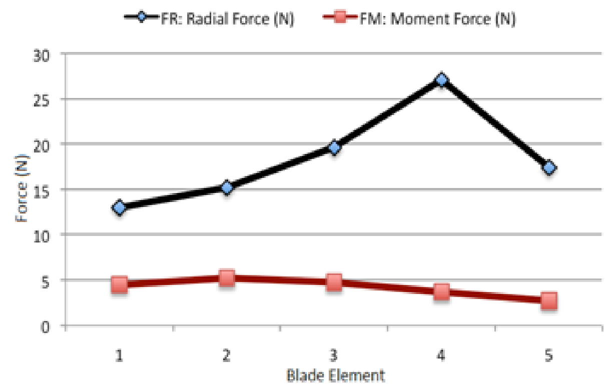

Fig. 5: Comparison of radial forces and moment producing forces

Strain Dependency of Carbon Nanotube Films

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1 Introduction

Strain sensors based on carbon nanotubes (CNTs) have a higher sensitivity than traditional metallic strain gauges and a higher flexibility than semiconductor strain gauges [1]. The piezoresistivity of a CNT network is determined by band gap change of deformed CNTs and by the variation of the conductive paths within the network, such as loss of contact between the fillers and tunneling effect to neighbouring CNTs [1].

2 Manufacturing of CNT films

For manufacturing CNT films different possibilities can be adopted having influence on the properties of the film in terms of homogeneity, sensitivity and costs of realisation. We compare between a low cost method which is drop casting and inkjet printing which is able to realise structured CNT films.

To produce CNT films by inkjet and drop-casting CNTs are first brought into a solution. As CNTs are hydrophobic, sodium dodecyl sulfate (SDS) was used as surfactant to form micelles on the surface of CNTs. Thereby surface tension is reduced so that CNTs can be dispersed in deionised water. CNTs were mixed with SDS solution and then dispersed by using an ultrasonic homogeniser. A pulse mode of the ultrasonic device was chosen to prevent overheating [2]. The CNT dispersions were optimised considering sonication time and SDS concentration in order to avoid agglomeration of CNTs and to get a low resistance value of CNT films. The used multi walled CNTs (MWCNT) were about 10 - 30 nm in outer diameter, 1 - 2 µm in length and have more than 95 % of purity [2, 3].

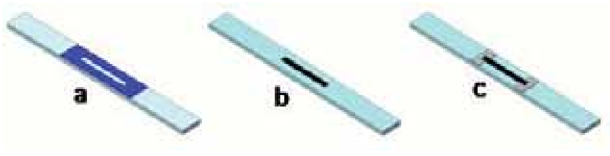

Fig. 1: Drop-casting process

CNT films were manufactured using drop-casting [2] and by inkjet printing [3]. For drop-casting a controlled volume of MWCNT-SDS-dispersion was dripped onto a polyester substrate by using a plastic-film mask to get the wanted film geometry which is shown in figure 1. After 24 h evaporation the mask was removed and the film was electrically contacted. For inkjet technology the MWCNT-SDS-dispersion was applied on polyester substrate using drop on demand process [4]. For inkjet printing no printing plate or mask is necessary, but the nozzle diameter defines the suitable CNT geometry and agglomerate size. In figure 2 the print result of one drop CNT-SDS-dispersion is shown.

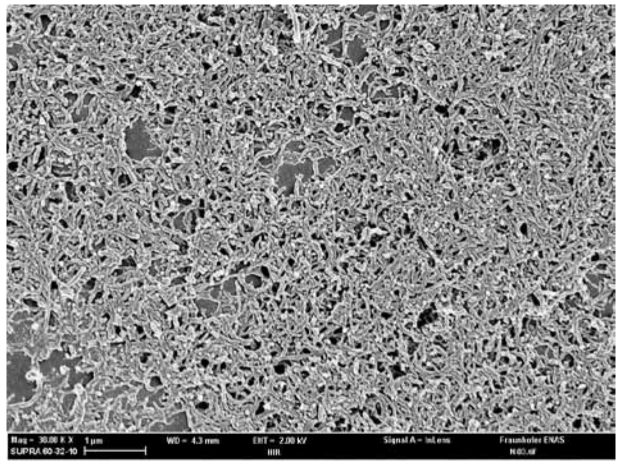

Fig. 2: CNT network printed by inkjet method

3 Experimental investigations

To characterise the piezoresistive properties by tensile test the drop-casted and inkjet fabricated CNT films on polyester substrate were evaluated using a Wheatstone bridge with an AC voltage using a lock-in amplifier. The sinusoidal signal had an effective voltage value set to 1 V and the frequency set to 300 Hz. The deformation of the CNT film was measured directly on the CNT film using an extensometer.

The initial resistance of the strained drop-casted film shown in figure 3 was 926 Ω. The initial length was 50 mm. It can be seen that under the first part of stretching the resistance change under strain is non-linear up to a tensile strain of 0.1 %. This can be explained by the firstly randomly distributed CNT network, where CNTs partially get aligned along strain direction. Furthermore this characteristic occurs due to the curvature of CNTs at the beginning of the loading process which get straighter under tensile strain. After the partially alignment of the CNTs along strain direction the change of resistance becomes linear. In the linear range sensitivity is 5 which is more than twice as high as that of classical metal strain gauges which have only a sensitivity of 2 [1].

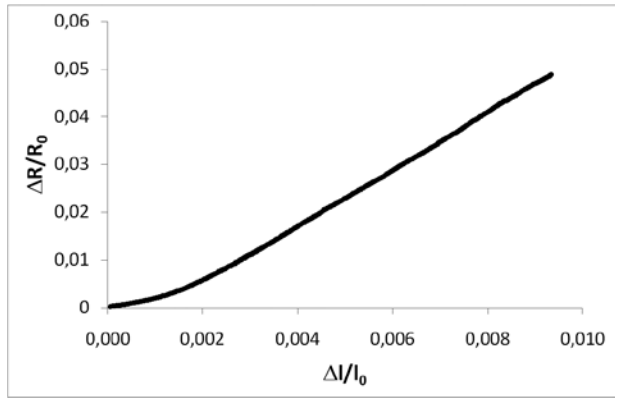

Fig. 3: Resistance change of a drop-casted MWCNT film under tensile strain

The same strain dependent resistance behaviour could be obtained for the strained sample shown in figure 4 manufactured by inkjet printing. Initial resistance of the film was 773 kΩ and the initial length was 30 mm.

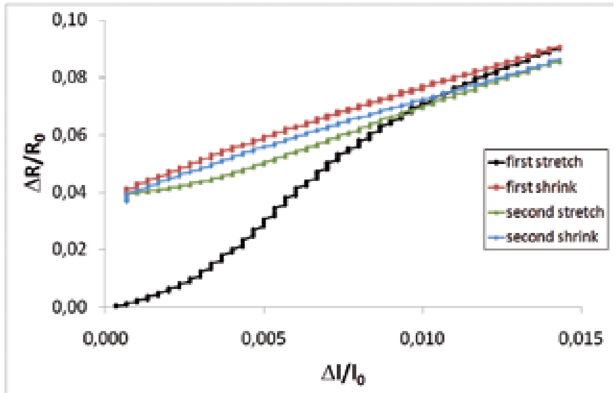

Fig. 4: Resistance change of a printed three layer MWCNT film with inkjet under tensile strain

It can be seen that the resistance change is much higher for the first stretch than for the subsequent shrink and stretch processes. During the first stretch sensitivity varies between 3.5 and 6. For subsequent cycles the sensitivity becomes more stable at about 3.6. During the first stretch process the CNTs tend to become ordered. Therefore initially non-directional CNTs become aligned along the stretching direction [5]. All samples composed of 3, 5 and 8 layers showed the same behaviour for the first stretching and the subsequent load cycles.

4 Conclusions

Strain sensitive films based on MWCNT-SDS-dispersions were manufactured by drop-casting method and inkjet technology. Strain dependent resistance behaviour was investigated for both application methods. During the first stretching cycle the resistance change is non-linear at the beginning, which is caused by the alignment of CNTs along strain direction and by the straightening of the initially curved CNTs. For subsequent load cycles strain dependent resistance behaves linear since CNTs stay aligned. The strain dependent electrical behaviour was shown to be similar for drop-casted and inkjet printed films. The sensitivities of the manufactured CNT films were at least twice as high as that of classical metal strain gauges.

5 Acknowledgement

This research is supported by "Sächsische Landesstipendien". The authors would like to acknowledge Enrico Sowade (TU Chemnitz), René Belau (TU Chemnitz), Tino Grunert (TU Chemnitz) and Roland Liebold (TU Chemnitz) for cooperation.

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Energy Harvesting from the Electric Field of a Power Line

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1 Introduction

The amount of energy transported on overhead power lines depends on the current load of the grid and on environmental conditions like temperature and wind. Additionally, the power distribution of newly developed renewable energy resources, for example offshore wind farms, is becoming more challenging for grid operator companies. Also regarding extreme weather phenomena especially in wintertimes, a power line monitoring system is necessary.

Therefore, several critical parameters must be monitored in time directly at the power line to guarantee their availability and operability. In order to obtain low installation and maintenance effort, an autonomous wireless sensor network is aspired within the BMBF-project ASTROSE. The basic idea of this wireless monitoring system incorporates sensors to measure temperature, the inclination of the power lines and their current load. The sensor nodes are directly mounted onto the conductor rope and the measured data is transmitted wireless to a base station. For the power supply of the wireless nodes, an approach for energy harvesting from the electric field is proposed in this paper.

2 Theoretical investigation

Compared to AC current, AC voltage is a stable and reliable energy source for the conversion of electrical energy independent of the conductor's current load. The theoretical fundamentals were discussed in [1]. In this paper we focus on the energy availability regarding the structure of the energy harvester and the load impedance.

Figure 1 (a) shows the principle structure of the energy harvester, which comprises a tube with the radius r_2, the axial length l, the dielectric material ε_r between the conductor and harvester electrode and the height d to the ground. Consequently, two capacitances are formed from the wire to the ground because of the cylindrical harvester electrode. The two capacitances are shown in fig. 1 (b): C_{WE} (Wire to Electrode) and C_{EG} (Electrode to Ground). Due to this electrical model it is possible to evaluate the theoretical available energy from the electric field around the conductor regarding all parameters of the harvester structure.

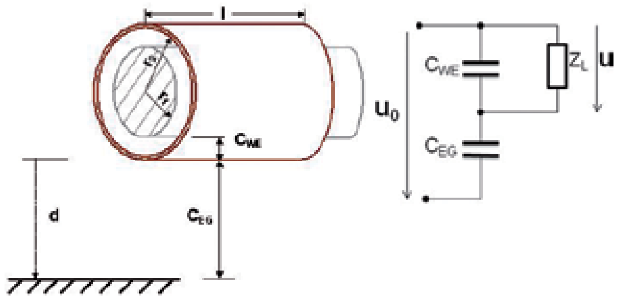

Fig. 1: Structure (a) and equivalent circuit (b) of the cylindrical harvester

The two capacitors, which are connected in series, can be seen as a capacitive voltage divider, as shown in fig. 1 (b), with the high voltage u_0 on the conductor and the load impedance Z_L. The voltage at the load is u.

The maximal power P_{max} can be calculated by [2]

$$P_{\max} = P\left(Z_{L\_opt}\right) = \frac{\left(\omega m u_0\right)^2 \cdot Z_{L\_opt}}{n^2 + \left(\omega q Z_{L\_opt}\right)^2} \quad (1)$$

with the load impedance

$$Z_{L\_opt} = \frac{n}{q \cdot \omega} \quad (2)$$

and substituted parameters

$$\begin{cases} m = 2\pi\varepsilon_0 l \cdot \ln\left(\dfrac{r_2}{r_1}\right) \\ n = \ln\left(\dfrac{r_2}{r_1}\right) \cdot \cosh^{-1}\left(\dfrac{d}{r_2}\right) \\ q = 2\pi\varepsilon_0 l \cdot \left[\ln\left(\dfrac{r_2}{r_1}\right) + \varepsilon_r \cdot \cosh^{-1}\left(\dfrac{d}{r_2}\right)\right]. \end{cases} \quad (3)$$

In the ideal case, the maximal power can be obtained when the condition $Z_L = Z_{L\_opt}$ is satisfied. Figure 2 (a) shows the maximal available power P_{max} concerning the nominal voltage u_0. The power is continuously increasing with conductor voltage u_0. Figure 2 (b) shows the relation between the available power and the load. For the determined conditions in figure 2 (b) the maximal available power can be achieved at the load resistance of about 300 MΩ.

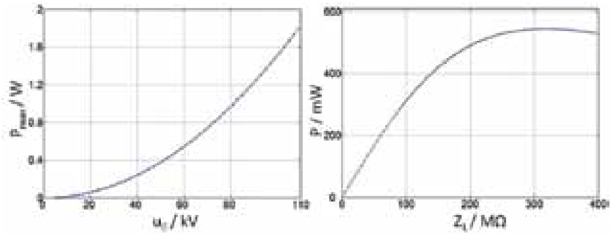

Fig. 2: Dependency of the maximal available power at the nominal voltage (a). The conditions are: d=90cm, r_1=1cm, r_2=5cm, l=20cm, Z_L=Z_{L_opt}. Dependency of the available power at the load (b). The conditions are: d=90cm, r_1=1cm, r_2=5cm, l=20cm, u_0=60kV.

Figure 3 shows the theoretical available energy concerning the harvester's dimensions for one specific load impedance. The available power can be achieved by increasing the length l and radial distance r_2 of the cylindrical electrode. Meanwhile, in order to achieve more power from the harvester the impedance on the load must be increased as much as possible. In this paper, one solution using a specific transformer configuration was investigated, because of the functionality of impedance and voltage transformation. The nominal voltage u_0 can be converted to low voltage. In addition, the resistance for ZL can also be transformed from the resistance of terminal application as

$$Z_L \approx n^2 \cdot R_L \quad (4)$$

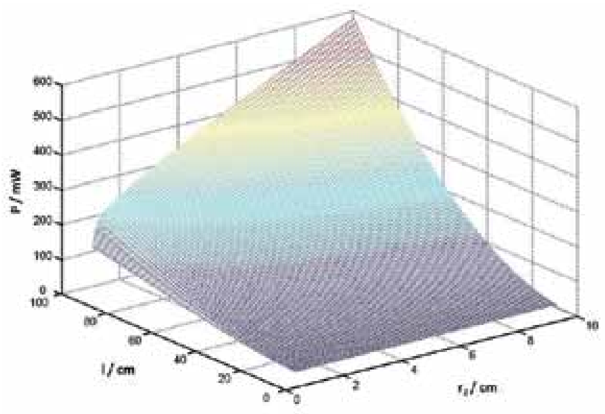

Fig. 3: Energy availability concerning harvester parameter. The conditions are: d=90cm, r_1=1cm, Z_L=4.4MΩ.

Besides this method for a voltage conversion other principles had been discussed, for example switched transformers and capacitive DC/DC converter. The solution using switching transformer had to transform the DC-voltage under high resonant frequency. Due to this the complexity of the energy management system increases obviously and it consumes more energy to control additional components. Also the capacitor DC/DC converter cannot realize an impedance matching to achieve a higher efficiency in comparison to the presented transformer solution.

3 Performance test of the prototype

Figure 4 shows the basic measurement setup. A transformer (ratio n = 120) was proposed to realize voltage and impedance transformation, which transforms high voltage of the harvester tube to lower voltage for the power management circuit and the low impedance of the load to a higher level on the primary side for effective energy absorption.

Fig. 4: Measurement setup

For a first field test prototypes were realized. Figure 5 shows the block diagram of the power module which comprises a surge/overvoltage protection, rectifier, power matching, logical controller and double layer capacitors to store the harvested energy. To enable full functionality of the wireless sensor node without high voltage at the power lines primary batteries are used for the field tests.

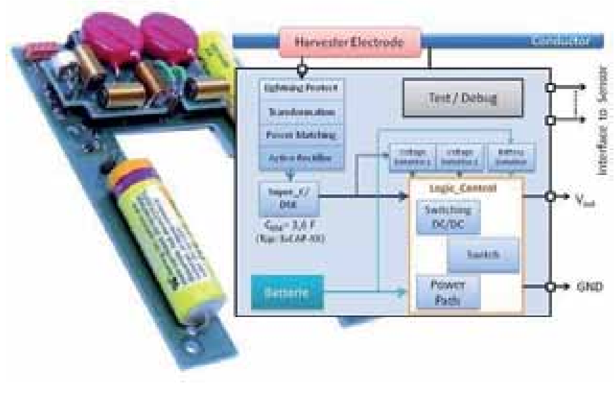

Fig. 5: Prototype (a) and block diagram (b) of the power module

For the first prototype three double layer capacitors were connected in parallel to obtain a large capacitance of 3.6 F at a terminal voltage of 5.5 V. These supercapacitors are characterized by ultra-low self-leakage current and equivalent series resistance (ESR), high temperature tolerance up to 85° C and thin form factor. High current peak or high pulsed power can benefit from the low ESR of the capacitors, which is very important for the application of wireless transmission. To achieve an operating voltage of 5.5 V two capacitors are connected in series. To avoid over voltage damage of single capacitors due to parameter tolerances and different leakage currents, a balancing method is necessary. An active balance circuit using an ultra-low current rail-rail op-amp to balance the voltage between the two capacitors is used for this purpose.

The primary battery is a Lithium-thionyl Chloride battery ($Li-SOCl_2$). Its key features are large capacitance (2.7 Ah), high temperature tolerance up to 85° C, low self discharge rate and high continuous current of 40 mA. A maximum continuous current of 120 mA can be achieved with three batteries connect in parallel, which is enough to power the wireless transceiver.

The test/debug block in figure 5 (b) is used for testing the controller. For example, the power module can be set that only the primary battery powers the module. In this operating mode the power generated by the harvester can be measured. Therefore an interface between the power module and microprocessor was defined to match all control demands.

The scavenged energy is stored in the supercapacitor and can be calculated by

$$W_e = \frac{1}{2} \cdot CU^2 \quad (5)$$

Then, the power can be calculated by

$$P = \frac{W_{e\_2} - W_{e\_1}}{t_2 - t_1} = \frac{\frac{1}{2} \cdot CU_2^2 - \frac{1}{2} \cdot CU_1^2}{t_2 - t_1} \quad (6)$$

where the time interval between two measurement points is known.

The experimental setup is shown in fig. 6. Measurements were carried out in a high voltage laboratory using a functional prototype of the cylindrical harvester electrode.

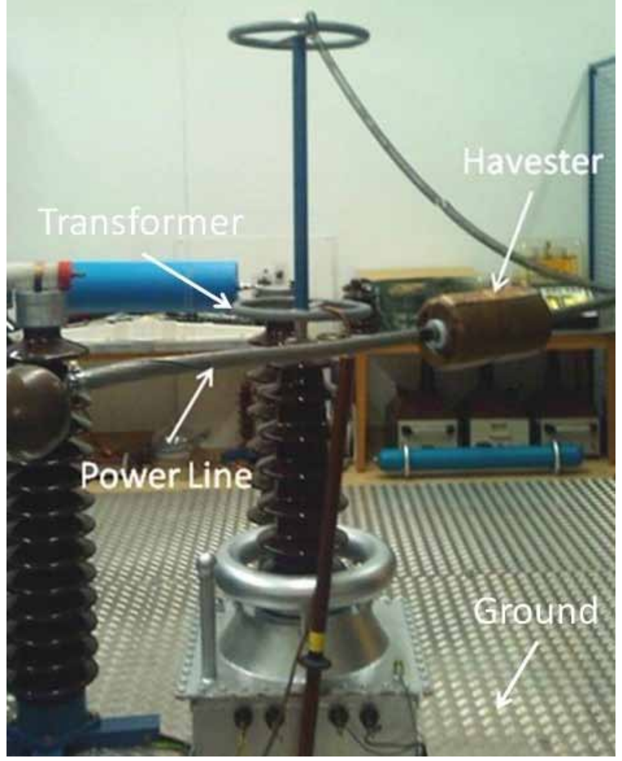

Fig. 6: Measurement setup in the high-voltage laboratory

Figure 7 shows the time dependent voltage level of the supercapacitor during a charging process. Furthermore, the energy in the storage device can be calculated by equation (6). Its dependency on the charging time is displayed in fig 8. The power in fig. 8 was calculated for the marked periods of constant energy slope.

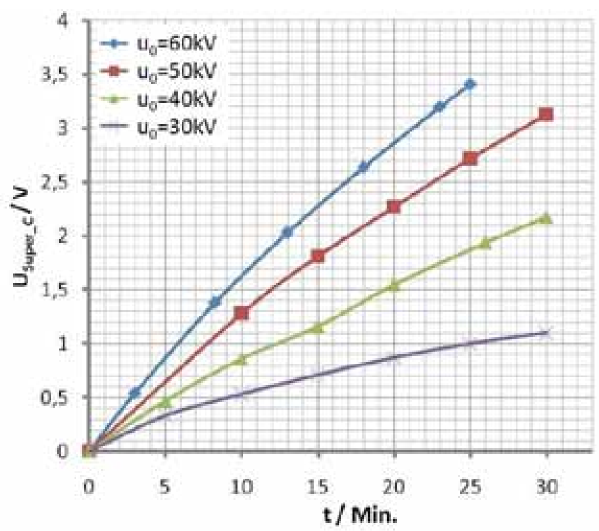

Fig. 7: Time dependent voltage level of the supercapacitor

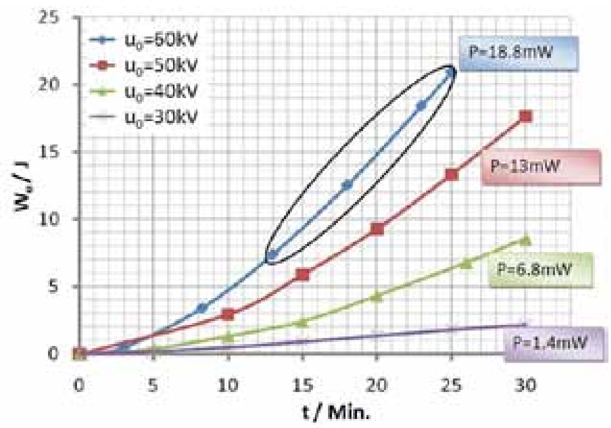

Fig. 8: Time dependent energy stored in the supercapacitors

From the two figures it is clear, that the power is constantly increasing with the increase of the nominal high voltage u_0. A power level of about 18.8 mW is obtained at a nominal voltage of 60 kV. The power can be further increased by increasing the high voltage u_0, increasing the active harvester area (larger diameter or length of the harvester) or optimal design of the energy management such as power matching between the source and the terminal application.

Here, a larger transformation ratio n = 140 is used to increase the output power by 0.7 mW to 19.5 mW. The transformer is a special high-voltage transformer with maximum rating voltage of 3000 kV and a comparatively low rated power of 0.5 W.

4 Conclusion

This paper presents theoretical and experimental investigations on energy scavenging from the electric field of a high-voltage power line. Simulations based on the harvester model confirm the feasibility of this energy harvesting topology. Finally, experimental results obtained in a high-voltage laboratory prove that energy scavenging from the electric field can provide sufficient energy for wireless sensor nodes.

5 Acknowledgement

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Thermal Impedance Spectroscopy as Method to determine Ageing of Power Modules

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1 Abstract

Thermal impedance spectroscopy significantly simplifies the failure analysis of power modules. It enables online observation of degradation within the cooling path with detailed information about failure mechanisms. The degradation of certain layers within the power module is detected by observation of Z_{th} parameters. Several test results are compared with analysis of the scanning acoustic microscopy.

2 Introduction

The reliability of power modules at power cycling load is determined besides bond wire lift-off by deterioration of different layers within heat flow path (Fig. 1). In order to detect this failure during reliability tests, today the thermal resistance in quasi steady state between junction and heat sink or coolant is monitored. This measurement, however, delivers no information which layer of the power module degraded. Thus for detailed information about specific failure mechanism, subsequent time consuming and often destructive failure analyses are needed, e.g. metallographic preparation. Thermal impedance spectroscopy of power modules promises a simpler and faster method for localizing failures.

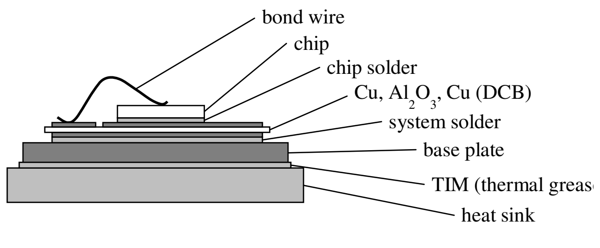

Fig. 1: Typical power module with base plate

3 Method Description

a) Definition of Thermal Impedance Spectrum

The transient thermal behavior of power modules is usually given between the junction and a reference temperature T_{ref} (case, heat sink or ambient) and is determined by means of a step response. The power device is exposed to an active power pulse P_V generated by the load current. After the steady state is reached, the load current is switched off and the cooling behavior is measured until the junction temperature equals the reference temperature. From this the Z_{th} function is extracted (Eq. 1).

$$Z_{th} = \frac{T_j - T_{ref}}{P_V} \qquad (1) \qquad (1)$$

In applications this function is used to estimate the junction temperature of the power device depending on power losses and pulse time. This Zth function is appro imated with an equivalent Foster network as shown in Fig. 2. The mathematical description is given in Eq. 2.

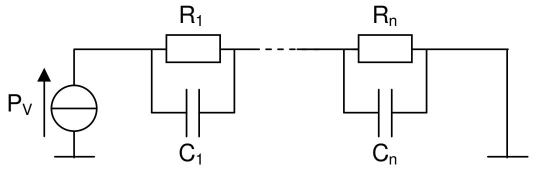

Fig. 2: Equivalent Foster network

$$Z_{th}(t) = \sum_{i=1}^{n} R_i \left(1 - e^{-\frac{t}{\tau_i}}\right); \; \tau_i = R_i \cdot C_i \qquad (2)$$

In most cases few RC elements are sufficient to describe the thermal system properly. E.g. in data sheet for the thermal impedance between junction and case (bottom side of the base plate) four elements are used. For direct liquid-cooled power modules the approximation with five elements is standard.

For further considerations the correlation of Eq. (2) is defined as the thermal impedance spectrum. Time constants τ_i are on the x-coordinate, magnitudes R_i are on the y-coordinate. For example the thermal impedance spectrum of a power module is depicted in Fig. 3. This spectrum describes the thermal impedance between junction and case (Z_{thjc}).

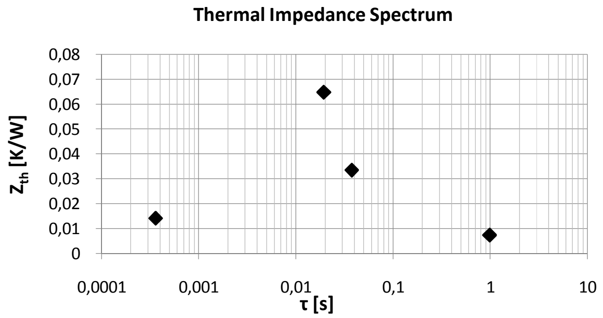

Fig. 3: Thermal impedance spectrum of a power module

4 Approach for Failure Localization

It is assumed that different failures within the heat flow path of the power module lead to different change of the thermal impedance spectrum. Partial thermal resistances R_i with corresponding low time constant τ_i represent the heat flow area near to the chip. An increase is expected in this R_i part, if the chip solder layer degradation determines the increase of the thermal resistance. RC elements with higher time constants describe the material layers which are further away from the chip.

For this simplified approach the failure localization is implemented with the following schedule:

- Periodical measurement of the $Z_{th}(t)$ function during power cycling test
- Extraction of the equivalent FOSTER network with an approximation method (e.g. [1])
- Comparison of the thermal impedance spectrum with the initial state

5 Experimental Application

a) Separation of chip solder degradation from thermal grease effect

First verification of the thermal impedance spectroscopy was performed during a power cycling test. The device under test was a standard power module of Infineon Technologies AG, Fig. 4.

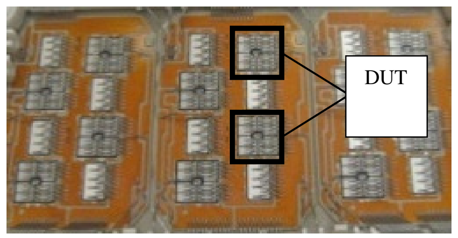

Fig. 4: DUT (IGBT of standard power module)

During the reliability test the DUT was loaded with active thermal cycles induced by cycling direct current. The temperature cycle of the junction is depicted in Fig. 5.

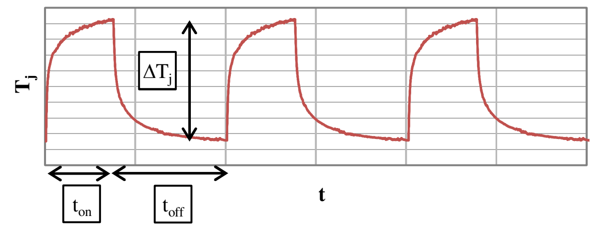

Fig. 5: Junction temperature during power cycling test

Test parameters in detail:

I_{Load} = 400 A; t_{on} = 0.6 s; t_{off} = 3.1 s; T_{jmax} = 175° C, ΔT_j = 105 K, P_V = 340/cm²

The steady state thermal resistance R_{thja} between junction and coolant was measured corresponding to the conventional method of the aging monitoring. The trend of the R_{th} is shown in Fig. 6. In the beginning of the test there is a significant decrease of the R_{thja} and in the range of 30,000 cycles a low increase. Thereby the failure criterion (20 % increase of the initial value) was not reached.

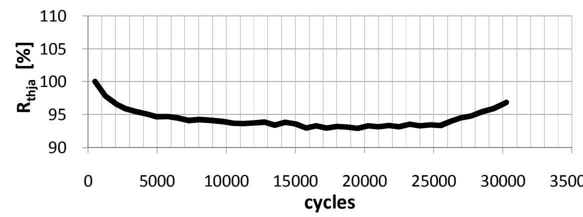

Fig. 6: Trend of steady state thermal resistance R_{thja}

Parallel to the conventional method the thermal impedance spectrum was monitored. The $Z_{thja}(t)$ was measured every 250 cycles. For this measurement the cycling test was interrupted. After that a load pulse was applied with 250 A load current, 40 s heating and 40 s cooling time. The $Z_{thja}(t)$ was recorded during the cooling phase.

With the thermal impedance spectroscopy different effects can be separated. In Fig. 7 the change of the spectrum at 30,000 cycles is shown in comparison to the initial state.

As shown in Fig. 7 the R_i parts of RC elements with higher time constants decrease. It should be the influence of the thermal grease. The partial R_i corresponding to the l constant show a significant increase. The RC elements in the middle of the spectrum show no change. According

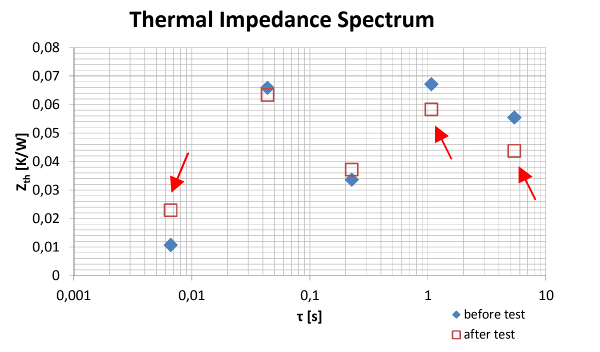

Fig. 7: Thermal impedance spectrum before and after test

to the simplified approach for the failure localization first RC element should indicate chip solder layer failure, elements with time constants greater than 1s show thermal grease effect and elements in-between contain the influence of the system solder layer. The trend of the thermal impedance spectrum of Fig. 7 is shown in Fig. 8.

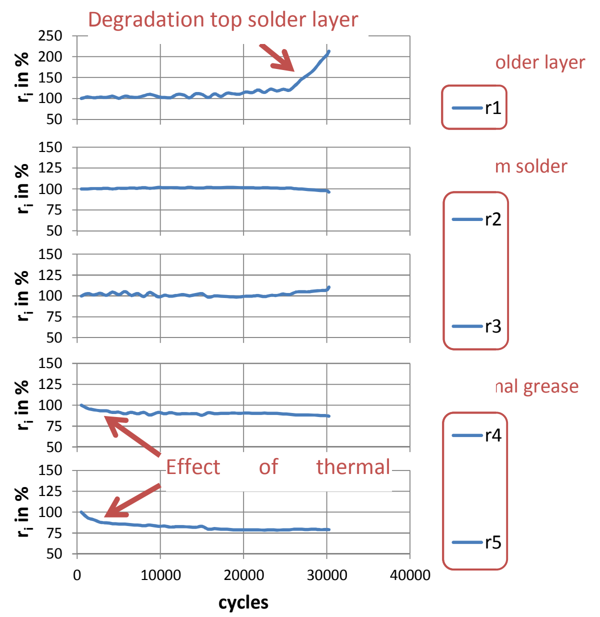

Fig. 8: Trend of thermal impedance spectrum

Corresponding to this analysis the power module should have degradation within the chip solder layer and no degradation within the system solder layer. It was verified with scanning acoustic microscopy. The analysis is shown in Fig. 9. In the middle image bright regions of the chip solder layer show clearly the degraded chip solder layer, whereas the system solder layer has no degradations. It is conform to the result of the thermal impedance spectroscopy.

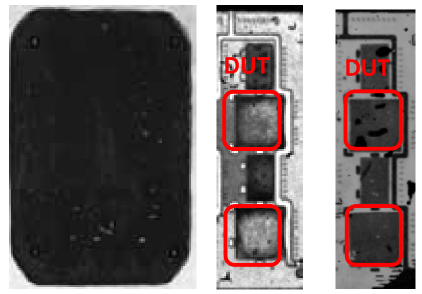

Fig. 9: left: system solder layer after test without degradation, middle: degraded chip solder layer after test, right: unstressed chip solder layer

b) Localization of system solder layer failure

For the verification of this method for system solder layer failure, a superimposed power cycling test was performed. The DUT was the power module type "HybridPACK1" as well.

The power module was mounted on a liquid sink. With an external heating/cooling station the power module was heated and cooled passively. During the heating phase power, cycles were superimposed. trend is shown in Fig. 10 Test parameters are listed in These test parameters were chosen to activate the system solder layer degradation.

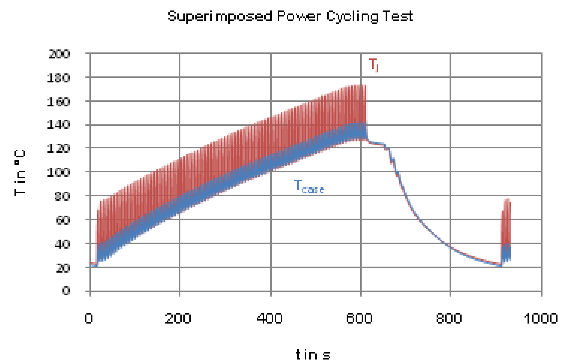

Fig. 10: Temperature trend of superimposed power cycling test

Table1: Test parameters of superimposed power cycling test

$T_{coolant\_min}$	22°C
$T_{coolant\_max}$	122°C
$t_{heating}$ (passive cycle)	10min
$t_{cooling}$ (passive cycle)	5min
I_{Load}	220A
t_{on} (power cycling)	2s
t_{off} (power cycling)	4s
P_V	140 W/cm²
Power cycles per passive cycle	100
T_{jmax}	175°C
ΔTj (power cycling)	53K

The thermal impedance was measured periodically 20 passive cycles. For this measurement the cycling test was interrupted at the lowest coolant temperature at the end of the cooling phase. After that a load pulse was applied with 250 A load current, 20 s heating and 20 s cooling time. During the cooling phase the Z_{th} was measured between junction and case.

The thermal impedance spectrum localization of the failure mechanism. The partial thermal resistances are shown in Fig. 12. In this power cycling test the parameter r2 has a significant increase. It indicates the system solder layer degradation. The effect of the thermal grease is shown in the parameter r4 and can be clearly separated from other failure mechanisms.

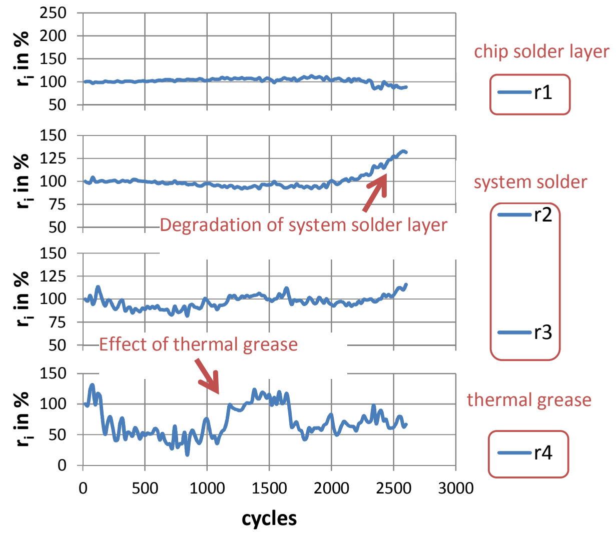

Fig. 11: Trend of thermal impedance spectrum

The subsequent failure analysis with the scanning acoustic microscopy confirmed the failure of the system solder layer. Bright region beneath the chip is the delaminated solder area, which caused the increase of the thermal resistance.

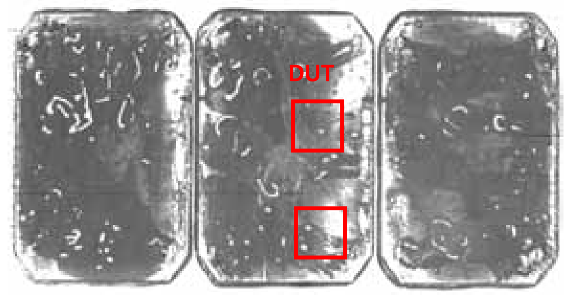

Fig. 12: System solder layer after superimposed power cycling test

6 Conclusion

The thermal impedance spectroscopy is an appropriate non-destructive failure analysis method for power modules. This method provides the separation of partial thermal resistances and enables an online monitoring of different failures. With this method typical failures can be clearly identified in power cycling tests. With experimental tests the degradation of the chip solder layer, the failure of the system solder and the effect of the thermal grease could be distinguished and localized.

An experimental proof for power modules is published here for the first time. A further improvement of this method is conceivable corresponding to the high resolution evaluation method described in [2]. Also the recursively rapid Foster-Cauer circuit transformation described in [3] is a further tool for more detailed conclusions from thermal impedance spectra. This is the subject for further investigations.

7 Acknowledgement

The work was supported by grants of the Federal Ministry of Economics and Technology (BMWi).

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Stressor Films for Enhanced Transistor Performance

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1 Introduction

Straining the silicon in the transistor channel by applying mechanical stress is one of the key technologies to improve the transistor performance, namely the computing power per watt consumed electrical power. In current technology nodes, strained nitride liners are used to strain the gate area of the transistor including the conductive channel. We present recent results on improving the nitride liners, searching for alternative liner materials and on simulation of metallization process integration which are the outcome of a joint research effort between GLOBALFOUNDRIES Dresden and the Center for Microtechnologies at CUT within the CoolTrans project.

2 Improved tensile stress levels in silicon nitride liners by UV cure processes

High tensile strained silicon nitride films are one approach for stressor cap liners to improve NMOS transistor performance. A post deposition treatment under ultraviolet radiation is one way for increasing the tensile stress. This so-called UV cure leads to desorption of hydrogen and to an enhanced cross-linking due to the high energetic ultraviolet waves. As a result of this process, films are shrinking and thus have a higher density along with a higher tensile stress. In our investigations we focused on the impact of UV curing on the chemical bonding characteristics and changes in stress of differently PECVD deposited silicon nitride films. To analyze structural changes, especially modifications in Si-H and N-H bonding characteristics we used an advanced Fourier Transform Infrared Spectroscopy (FTIR) analysis.

It could be shown, that thermal assisted UV curing changes the bonding structure differently, dependent on the chemical network after deposition. With these advanced techniques films of 50 nm thickness and a tensile stress of up to 1.4 GPa could be produced.

3 Diamond-like carbon (DLC) as a new compressive stress liner material

Another approach for performance improvement is the deposition of high compressive strained diamond like carbon (DLC) on top of PMOS transistor structures. These materials are usually used as hard coatings, but up to now not in microelectronic applications. Naturally these films are a compound of sp^3 (Diamond) and sp^2 (Graphite) bonded carbon with some amount of hydrogen and stand for high compressive intrinsic stress.

In our studies we investigated a parallel plate plasma enhanced CVD process with two different precursors and mixtures of them. Within our experiments we were able to produce films with an intrinsic stress of -3.5 GPa.

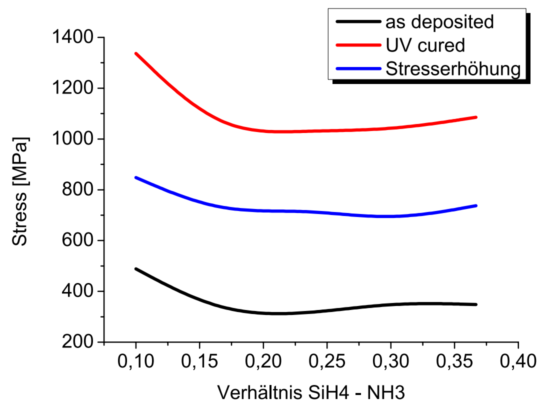

Fig. 1: Stress of UV cured silicon nitride films produced by varying the SiH_4 to NH_3 ratio.

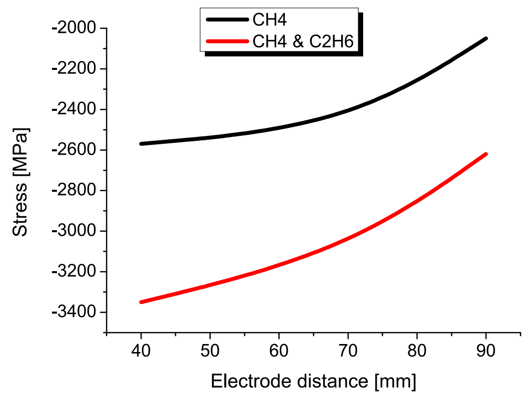

Fig. 2: Stress of DLC films deposited with different electrode distances for different gas mixtures.

4 Simulation of the impact of strained contacts on stress liner performance

Stress induced by so-called stress liner materials, currently being silicon nitride, is only one of many contributions to the total stress accumulated in the transistor channel. Since direct strain measurements in the channel are still a scientific challenge, at the moment simulations are the only way to study, how stress from different sources will enter into the channel.

Contact materials such as tungsten are known to show high levels of tensile strain. In addition, processes for metallization of the source, drain and gate contacts include etching of the nitride liner and thus the stress in the liner will be relaxed in these areas. Due to the close proximity of the contacts to the transistor channel, all these effects will have a drastic influence on the stress level in the channel and thus on electron or hole mobility.

Simulations of strained transistors have been performed using Synopsys Sentaurus TCAD. Simulated process steps follow data provided by GLOBALFOUNDRIES (45 nm node). Full transistor structures including all processes involving stress formation, such as nitride liner deposition and metallization are modeled using Synopsys Sentaurus Process. Device simulations using Synopsys Sentaurus Device were used to compute current changes in the channel.

Figure 3 shows the model system consisting of 45 nm transistors including tungsten contacts in the source/drain area. The structure is derived from TEM cross sections of real 45 nm transistors provided by GLOBALFOUNDRIES. In the present study we focus on the role of the different stress contributions from the liner and from the strained contact metal. The contact stress was varied while the liner stress was fixed and vice versa. Results are shown in figure 4. While for the NMOS structure (Fig. 4a) the two contributions act in reverse direction, for the PMOS structure (Fig. 4b) the effect of the two stress sources will add up. In conclusion, best electron mobility is given for tensile strain in the contact. Hole mobility is optimum for an unstrained contact. The reason for the different behavior of electrons and holes is given by a different response of their mobility to strain, where electron mobility is improved by compressive strain in the channel, while the hole mobility favors from tensile strain.

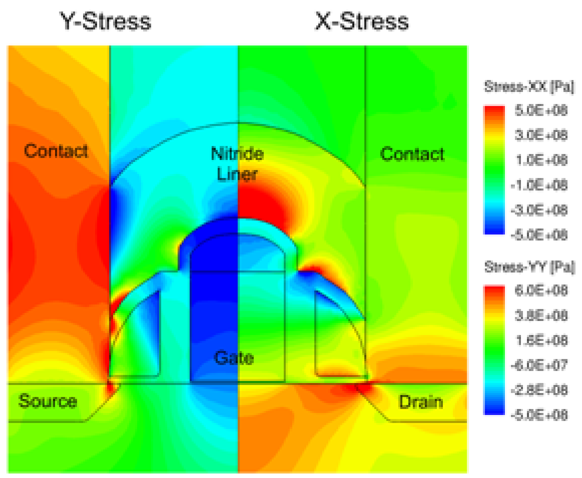

Fig. 3: Distribution of the stress components along (X-Stress) and perpendicular (Y-Stress) to the transistor channel. The distance of the transistors is 180 nm, contact width is 60 nm. Nominal stress levels are 1.6 GPa for the contact metal and 2 GPa for the liner.

5 Acknowledgement

We acknowledge financial support from the Sächsische Aufbaubank (SAB) for the CoolTrans project and fruitful discussions with our project partners from GLOBALFOUNDRIES.

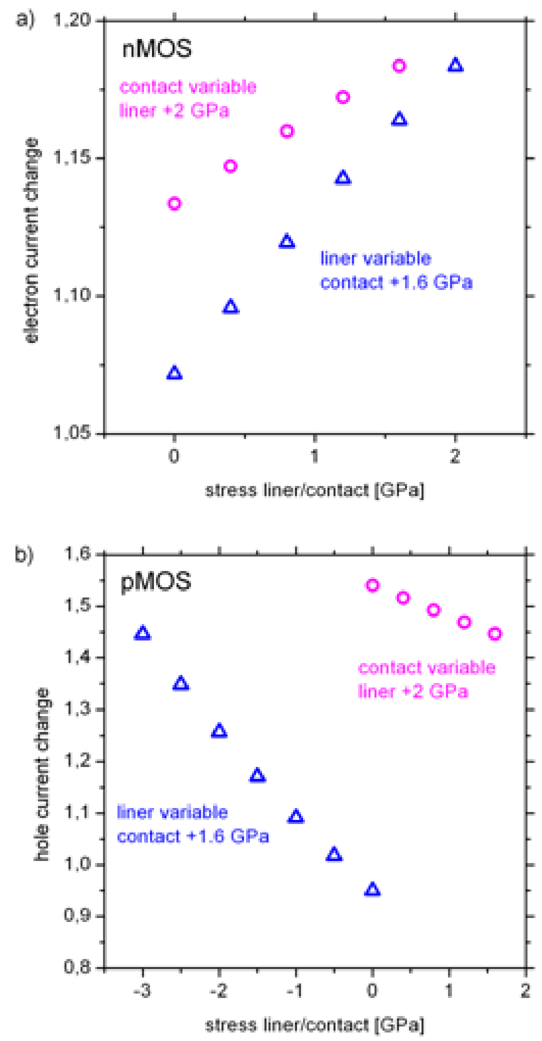

Fig. 4: Comparison of the effects of strained liner and strained contacts on the carrier mobility for 45 nm transistors; a) NMOS b) PMOS.

Integration of Carbon Nanotubes in Interconnect Systems and Sensors

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1 Introduction

Carbon nanotubes (CNTs) attracted huge interest in the field of nanoelectronics and sensors due to their outstanding physical properties. In interconnect systems of ultra-large scale integrated (ULSI) circuits, where metals are increasingly confronted with electromigration, heat dissipation as well as fabrication issues due to continuous downscaling, CNTs are seen as a promising alternative interconnect material. Besides, CNTs facilitate a wide range of different sensors with new functionalities and high sensitivity. However, despite a huge progress in research on CNTs, complete integration of CNTs in different applications with scalable and reproducible technologies remains challenging.

2 CNT interconnects

In our group one field of activity is concerned with technological developments on CNT based vertical interconnects (vias) in ULSI circuits (Figure 1).

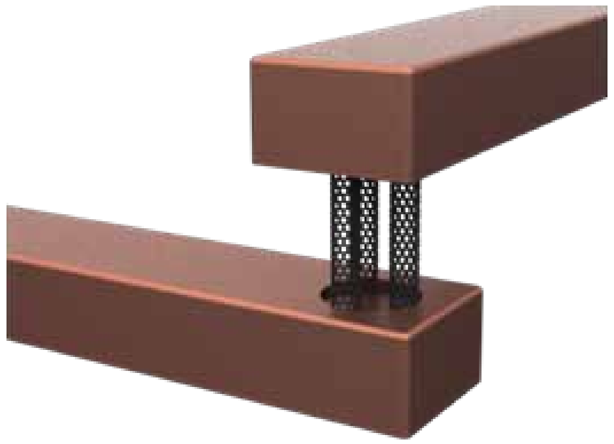

Fig. 1: Schematic of vertical CNTs in a CNT/metal hybrid interconnect system

Therefore systematic studies on CVD processes were conducted aiming growth of dense and vertically aligned multi-walled CNTs (MWCNTs). Those experiments were performed in a home-made vertical CVD reactor capable to process wafers up to 4 inch. Especially the role of the catalyst supporting layer was investigated [1]. Key results are CNT growth processes with adjustable growth mode and growth inhibition through adjustment of the support/catalyst system and the process (Figure 2 a, b). In the scope of those investigations a novel CNT film structure was obtained which was defined as interlayer CNT (ICNT) structure. Those films are characterized by a high homogeneity of CNT height and a continuous metallic catalyst layer system carried on the CNTs. The special structure enables an improved and simplified integration technology for CNTs in interconnect systems and a variety of other applications, which are currently under investigation. Additionally, CNT via structures were fabricated as shown in Figure 2 c. A homogeneous filling of via holes with vertically aligned MWCNTs was demonstrated on 4 inch wafers. Equally we were able to lower the growth temperatures down to 400° C, which demonstrates CMOS compatibility.

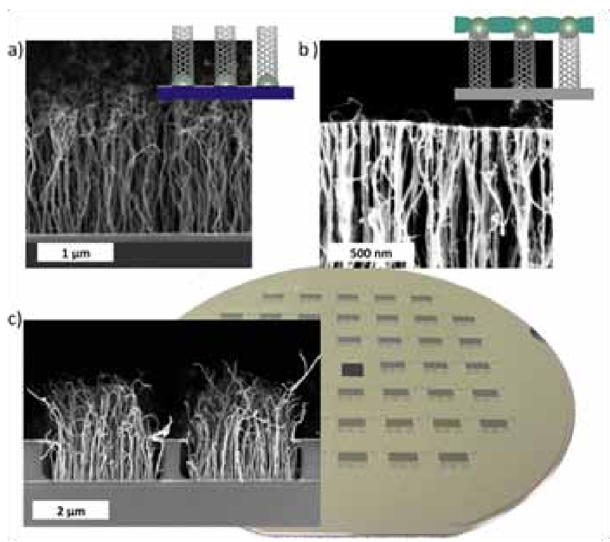

Fig. 2: Vertically aligned MWCNTs grown in root growth mode (a), novel interlayer CNT film structure (b), CNT via interconnect test structure (c), and 4" wafer after CNT process (background).

Ongoing developments focus on the fabrication of CNT/low-k interconnect structures with optimized interfaces between CNTs and the metallization to improve electrical and thermal properties. Those studies are supported by ab-initio modeling of the CNT/metal interface based on quantum mechanics. Furthermore, structural and electrical characterizations of CNT vias are underway.

3 CNT based sensors

Another emerging field is the application of CNTs in different sensors. In the focus there are electro-mechanical transducers with a high signal-to-noise ratio and high operation frequency. Envisaged applications are inertial, deformation, and high frequency vibration sensors. To detect very small relative movements especially the outstanding piezoresistive effect of single-walled CNTs (SWCNTs) is of interest. However, fundamental as well as technological challenges thwart realization of those sensors so far. Major issues are large scale assembly of specific SWCNTs, good metal/SWCNT interfaces, and complete integration solutions accommodating scalability and high reproducibility.

In our group systematic investigations and developments on the integration of SWCNTs and MWCNTs in sensor test structures are in progress. For the dielectrophoretic (DEP) assembly of CNTs from dispersions extensive preliminary studies on the preparation and characterization of different CNT dispersions have been conducted. Methods and routines have been compiled to prepare high quality CNT dispersions with a high reproducibility. Effects of preparation parameters like sonification power and time have been systematically studies as exemplarily presented in Figure 3. Furthermore, issues like strong length and quality variation of CNT raw material are addressed with centrifugal separation.

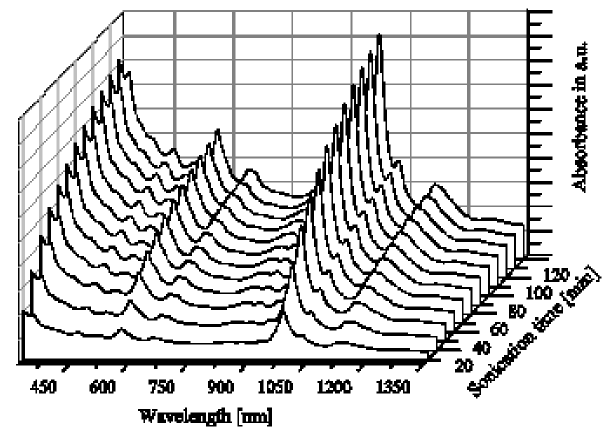

Fig. 3: UV-Vis spectra of SWCNT dispersions treated with different sonification times.

For the dielectrophoretic assembly of CNTs removable microfluidic channels are used to locate the dispersion flow only at electrode sites. There CNTs are deposited in an inhomogeneous electric field at high frequencies. Processes for the deposition of CNT films with aligned CNTs have been developed. Likewise good progress has been made towards aligned single-CNT assembly (Figure 4). Another important aspect is the optimization of the CNT/metal interface. Therefore different technologies are under development facilitating for instance the defined contacting of CNTs with Pd. Furthermore, equipment and process developments for large scale integration of CNTs are in progress. Thereby homogeneous assembly of CNTs on wafers up to 6 inch has already been demonstrated.

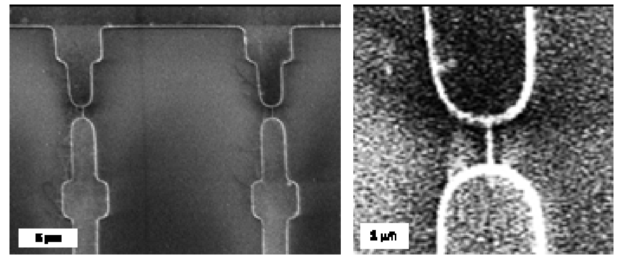

Fig. 4: Aligned SWCNTs between finger electrodes.

Ongoing developments include the fabrication of test structures in FET configuration adapted to the specific requirements of transducers based on the piezoresistive effect of SWCNTs. Special emphasize is paid to type selection of certain semiconducting SWCNTs, modification of SWCNT properties through functionalization, self-limited deposition, and interface engineering for resilient electrical/mechanical contacts. Besides, CVD processes for the growth of semiconducting SWCNTs are under development using a new processing system equipped with advanced in-situ analytics.

4 Acknowledgement

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Condition Monitoring of Greases in Rolling Bearings

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1 Introduction

Approximately 95 % of all rolling bearings are lubricated with grease. The grease forms a lubricant film on the contact surfaces that is sufficiently capable of supporting loads and is thus intended to prevent premature fatigue of the bearing. Reliable information about the condition of the grease in the rolling bearing is therefore of major significance. Around three quarters of all rolling bearing failures thus occur in conjunction with the lubricant, for example, due to insufficient lubrication, lubricant contamination or ageing of the lubricant (see Fig. 1).

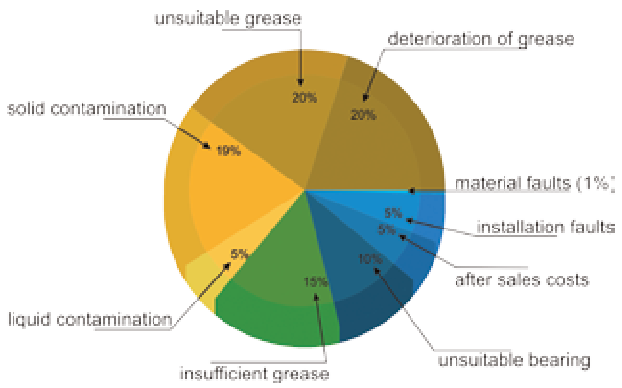

Fig. 1: Causes of rolling bearing failures [1]

Up until now, it has not been possible to analyse greases in rolling bearings during operation. It is for this reason that greases are usually replaced long before the end of their operating life as part of preventive maintenance in order to prevent damage to the rolling bearings and therefore prevent expensive downtime and failure of ma-chinery and plant. Alternatively, an incorrect concept of safety leads to overgreasing, which can have a negative effect on the function and operating life of the bearing. In jointly cooperation with the Schaeffler Technologies GmbH & Co. KG, Freudenberg Sealing Technologies GmbH & Co. KG and the lubricants expert Klüber Lubrication München KG, a grease sensor has developed that can be used to analyse the condition of the grease in the rolling bearing during ongoing operation. As a result, grease changes can be made in future on the basis of actual requirements.

2 Disadvantages of previous methods

Many bearing failures can be attributed to old grease. It is now possible by means of condition monitoring, such as analysis of vibrations, to detect defects in machines at an early stage. This, in turn, enables maintenance measures to be precisely scheduled, thereby preventing secondary damage to bearings and transmission components. The disadvantage of this method is that damage must already be present in the machine in order for a signal to be detected. As a result, at least one component must be replaced during the next maintenance operation. The advance warning time until actual failure of the machine will vary depending on the signal recorded (see Fig. 2).

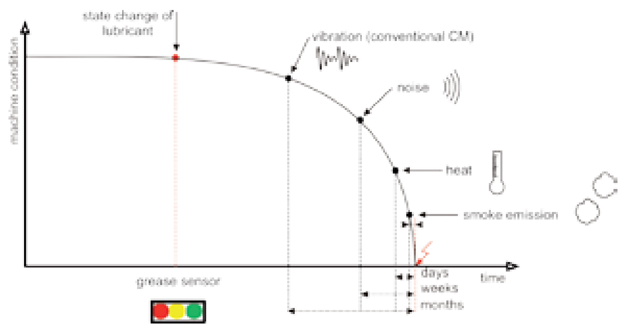

Fig. 2: Indications of rolling bearing failures at different times

With the aid of the newly developed grease sensor and the associated electronic evaluation system, it is now possible to detect changes in the condition of the grease long before any damage to the rolling bearing occurs. This means that replacement of the grease can be precisely planned, whereby the user can decide at which point in the condition of the grease (from 100 per cent for as-new to a theoretical 0 per cent for unusable) relubrication or a grease change should be carried out. With the new grease sensor, relubrication is changed from time-based to demand-based.

3 Design and function of the grease sensor

It became clear that optical infrared reflection was the ideal method for determining the condition of the lubricant during ongoing operation of the rolling bearing.

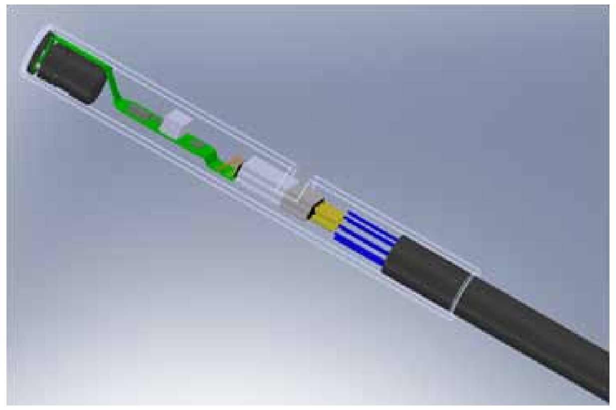

Fig. 3: Basic design and function of the grease sensor

The sensor head (see Fig. 3) is embedded in the lubricant. At the same time, a reference system exists that undergoes ageing in parallel is subjected to the same temperature but does not have any contact with the grease. The measured signal is compared with this reference system. The penetration depth of the signal extends from the surface of the sapphire glass on which the lubricant is located to a few millimetres into the lubricant. The optimum measurement point varies from application to application. In this connection, it is advisable to draw on the know-how of the Schaeffler Group application engineers, who can specify precisely where the sensor should be positioned in the specific application. During the validation phase, precise analysis was carried out to determine the influence of individual contaminants in greases on the signal. The sensor can be used to determine four parameters relating to the lubricant:

- opacity,
- wear (mechanical, thermal),
- water content,
- temperature.

The electronic evaluation system processes these parameters to generate an analogue signal (4 – 20 mA) from which the customer can quickly and easily see the condition of the grease. In addition, it is also possible by setting a trigger threshold (limit value) to generate a digital signal that indicates whether the grease condition is good or poor (see Fig. 4).

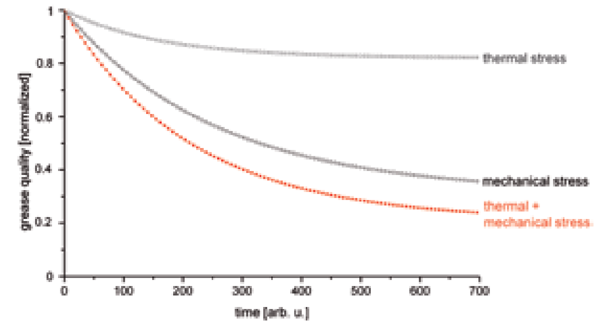

Fig. 4: Measured grease quality over time

4 Conclusion

Due to the intensive partnership work, a sensor suitable for practical use together with an electronic evaluation system was developed that can be used to determine the quality of grease in a rolling bearing during operation for a very wide range of greases. Ongoing analysis of the lubricant makes it possible to detect any changes in the grease at an early stage. This means that the lubricant can be replaced when a specific lubricant quality defined by the customer is reached before damage occurs to the rolling bearing due to inadequate lubrication. As a result, it is no longer necessary to carry out time-based relubrication with its many disadvantages. The demand-based relubrication that can be realised with the grease sensor allows grease to be used with optimised costs and improved environmental benefit. Further advantages of the new grease sensor include possibilities for optimization of rolling bearings and bearing positions, since it is possible to assess from the behaviour of the lubricant quality whether, for example, a rolling bearing has been overdimensioned. If there is a sudden, critical failure as a result of water ingress into the rolling bearing, for example, an emergency shutdown can be initiated. This can reduce the risk of damage to other components. The sensor is positioned directly in the rolling bearing.

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Smart Integrated Lab-on-a-Chip Systems

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1 Introduction

Since about 15 years, microfluidic R&D has been focussing on the development of tiny systems for the analysis of small amounts of liquids e.g. for diagnostic applications. Such systems are called "Lab-on-a-chip" systems as they aim to integrate the functionality of a laboratory analysis into a chip. For a long time, a key issue has been the delivery of liquid volumes in the range of several microliters inside the microchannels. To address this problem, the Center for Microtechnologies (ZfM) had started to develop a low-cost, fully-integrated liquid handling technology based on an electrochemical reaction inside a hydrogel already in 2005. While the technology has significantly advanced during the last years, it was licensed also to applied research at Fraunhofer ENAS [1] and recently even been commercialized [2].

Additional efforts have been taken to further increase the level of integration and to miniaturize the components and the whole device. Current research is dealing with the integration of means for plasma separation from whole blood [3], cell collection from samples, and transferring the pumping technology to a real chipcard-like format.

2 Towards a real "lab-in-a-chipcard"

The ZfM pumping the technology was described previously [5,6]. In short, a gas is generated by an electrochemical reaction inside a hydrogel. The resulting gas pressure deflects a membrane into a liquid reservoir on top of it, driving the liquid out of the reservoir. This technology has applied already to several immunoassays and is available in a microscope slide format also for R&D purposes (e.g. sensor integration and bioassay miniaturization) [2].

To increase the level of integration, current developments at ZfM focus on the use of real chipcard technologies to establish a diagnostic platform in a chipcard format. In such a chipcard, not only micropumps are integrated, but also microvalves, liquid reservoirs, means for sample preparation and a control ASIC. So far, first prototypes have been developed and fabricated to demonstrate the feasibility of valve integration based on the same technology as used for the micropumps (Fig. 1).

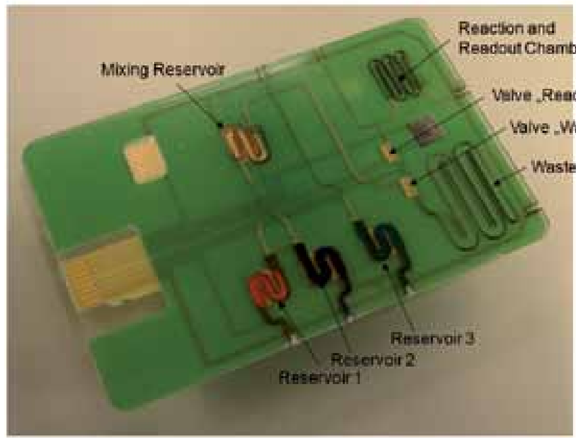

Fig. 1: Chipcard prototype with integrated reservoirs, micropumps and microvalves

In the chipcard shown in Fig. 1, a gel-based micropump is situated below each of the reservoirs 1 to 3 as well as below the mixing reservoir. The pumps 1 and 2 are electrically connected in series to allow their emptying at the same time for mixing. The two valves are used to direct the liquid either to the waste reservoir or to the reaction and readout chamber: when the valve "Readout" is slightly closed, the liquid is delivered in the waste chamber; when subsequently the valve "Waste" is closed stronger than the first valve, the liquid will be transferred in the reaction and readout chamber (Fig. 2).

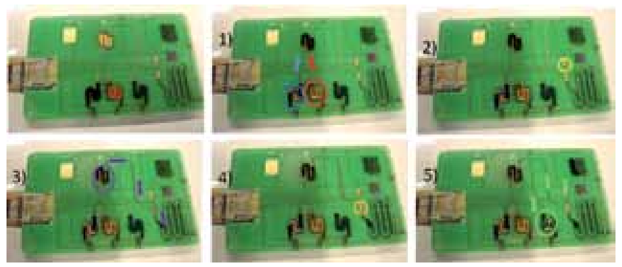

Fig. 2: Pumping and valving sequence: 1) pumping the liquids of reservoirs 1 and 2 to the mixing reservoir 2) Closing of the valve "Readout", 3) Pumping of the mixed liquid out of the mixing reservoir towards the waste reservoir, 4) Closing the valve "Waste", 5) Pumping the liquid out of Reservoir 3 towards the Sensing Reservoir

3 Integrated plasma separation

A process often required for integrated sample preparation is the separation of plasma from whole blood. While there is a large variety of solutions available for large sample volumes, only few approaches are known for whole blood volumes in the microliter range.

For a first easy-to-integrate proof of concept, microfluidic structures for filtration have been directly fabricated using picosecond laser micromaching in a glass substrate. These channels had a length of about 1mm and a height of only 500 nm (Fig. 3b). The structured glass substrate was then bonded by plasma activation to silicone chip (Sygard 184, Dow Corning) incorporating larger channels and reservoirs (Fig. 3a). This silicone chip was fabricated by casting of Sylgard 184 using a silicon wafer with SU-8 (a negative photo resist) negative structures as master. Figure 3c shows a close-up view of such a filtration system after successfully separating plasma from EDTA-treated whole blood.

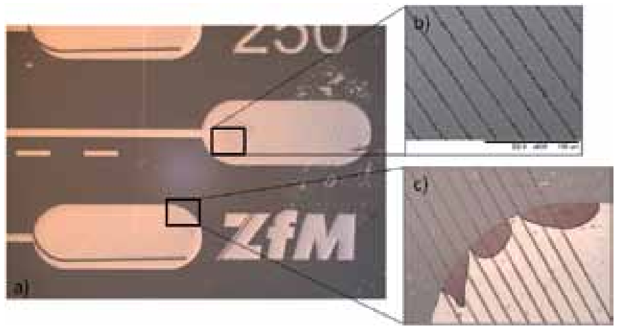

Fig. 3: a) Filtration chip with microchannels, b) SEM image of the laser structured filtration channels in glass, c) Close-up of the filtration channels at the plasma collecting reservoir after separation

4 On-chip cell traps

The extraction of rare cells from a liquid solution is topic of numerous publications [7-10]. In this paper, a 3D cell trap structure for large numbers of large cells produced by soft lithography is presented, which could easily be adapted to different cell sizes. The performance was studied using fluorescence labeled yeast cells.

The proposed trap structure consists of an U-shaped compartment with additional pillars on the opposing walls (Fig. 4). These pillars define a small gap (1 – 3 µm), which enables the flow of the solution through the trap but keeps the cells in the compartment. With rising cell number the hydrodynamic diameter of the trap reduces until the flow mainly runs beside the trap. Thus, an even distribution of the cell number in the trap array is reached.

The cell traps were produced in two different technologies: soft lithography and deep reactive ion etching of silicon. For the soft lithography a two-layer negative structure of SU-8 was fabricated by photolithography. By tuning the thickness of both layers the properties (trap height and channel height) of the cell trap could easily be adapted to different cells or particles. The master structures were replicated in silicone (Sylgard 184) and bonded to glass carriers with prepared fluidic connectors by nitrogen plasma exposition. For the realization in silicon 4 inch wafers were etched in a two step DRIE process, diced and bonded to silicon-coated glass carriers using nitrogen plasma.

First experiments on trapping performance were carried out using fluorescein labeled yeast cells. Yeast represents a well known cell culture with good availability. To reach a higher contrast the yeast cells were immersed in fluorescein-water-ethanol solution for one hour and then rinsed several times in deionized water to remove unbound fluorescein. Shortly before experiments the yeast solution was homogenized by ultrasonication.

Different layouts of the cell traps were fabricated to compare the performance with respect to the principle layout. Figure 5 shows the result of an extraction experiment with optimized structures: As it can be seen, an even distribution of yeast cells over the array was reached.

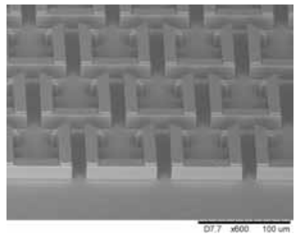

Fig. 4: SEM picture of a cell traps fabricated by DRIE

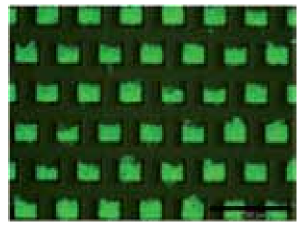

Fig. 5: Fluorescence image of trap array with labeled yeast cells

Further experiments will be carried out using different cell types like red and white blood cells.

5 Conclusion

The integration of a valving functionality based on ZfM's low-cost pumping technology was successfully demonstrated inside chipcard-like microfluidic devices. Current research is targeting the integration of additional functionalities such as cell trapping and on-chip plasma separation.

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Department Lithography/Etch/Mask

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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
- 4 inch and 6 inch wafers can be 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, a 20 years experience exists within the e-beam lithography field. In combination with about 10 dry etch tools, 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 .

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. Another example of successful technology research is the development of a new thin film encapsulation procedure in order to reduce the package size and costs of the devices.

Fig. 1: Wafer inspection within the lithography clean room

Department Layer Deposition

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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 provides 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:

Fig. 1: Equipment for Electron Beam Evaporation and Sputter Deposition

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 (materials: Ag, Al, Au, Co, Cr, MoNi, MoFe, Ti, TiN)
- R&D sputtering system FHR MS 150 x 4-AE-B (materials: Al, Al-Alloys, Hf, Pyrex)
- R&D Electron-Beam-Evaporation (materials: Al, Cu, Pd, Pt ...)

Chemical Vapor Deposition (MO-CVD, PE-CVD, LP-CVD):
- MO-CVD R&D system Varian Gartek (materials: Cu, TiN)
- PE-CVD system Precision 5000 Mark II Applied Materials (materials: SiO_2, Si_3N_4, $Si_xO_yN_z$, SiCOH, SiCH)
- PE-CVD system Plasmalab Plasma Technology (materials: SiO_2, Si_3N_4)
- PE-CVD system Microsys 400 Roth & Rau (material: Diamond-like Carbon)
- LP-CVD system LP-Thermtech (materials: SiO_2, Si_3N_4, polysilicon)

High temperature processes (diffusion / thermal oxidation / annealing / RTP):

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 Alpha step 500
- 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).

Equipment and Service Offers

Fig. 1: View into the new clean room facilities, equipment for depositing foto resist

The ZfM facilities include 1000 m² of clean rooms (300 m² of them class ISO 4). Modern equipments were installed for processing of 4 inch, 6 inch and 8 inch wafers as well as design and testing laboratories providing the basis for the following processes:

Design

- MEMS/NEMS,
- IC, ASICs and FPGAs
- low power and low noise, analog-mixed signal integrated circuits
- integrated high-voltage circuits
- Design support
- Optimization by means of novel approaches, methodologies and dedicated design tools
- Design for reliability

Modelling and Simulation

- Equipment and processes for micro and nano-electronics
- Physical domains and their interaction
- Thermal simulation
- Electronic devices
- Defects and their influence

Mask fabrication

- 3 inch ... 7 inch mask size
- Electron beam lithography
- Proximity and contact double-side lithography

Fig. 2: P5000 used for deposition of Copper

Processes

- High temperature processes: Diffusion / thermal oxidation / annealing / RTP
- Physical Vapour Deposition PVD
- Sputtering
- Electron beam evaporation
- Chemical Vapor Deposition CVD
- Plasma enhanced CVD (PE-CVD)
- Low-Pressure CVD (LP-CVD)
- Metall-Organic CVD (MOCVD)
- Electroplating: Cu, Ni, Au
- Etching (dry: Plasma- and RIE-mode & wet: isotropic / anisotropic)
- Dry etching (Si, SiO_2, Si_3N_4, Polysilicon, Silicides, Al, refr. metals, TiN, Cr, DLC, low k dielectrics)
- Wet etching (SiO_2, Si_3N_4, Si, Polysilicon, Al, Cr, Au, Pt, Cu, Ti, W)
- Wafer lithography / Electron beam lithography
- Chemical Mechanical Polishing CMP (Copper, Silicon, SiO_2)

Characterization and Test

- MEMS/NEMS
- Nanoelectronic devices
- Parametric testing: Waferprober, HP Testsystem
- Characterization of analog-mixed signal circuits up to 500 MHz
- Characterization and modeling of devices from low-voltage and high-voltage micro technologies

Analytics

- Scanning electron microscopy SEM / EDX
- Atomic force microscopy AFM
- Variable angle spectroscopic ellipsometry
- Laser profilometry (UBM, TENCOR FLX-2900)
- Surface profilometer
- US-Microscope
- Tension/Compression testing machine Zwick 4660 universal
- Perkin-Elmer DMA 7e dynamic mechanical analyser
- Micromechanical testing instrument
- Lifetime scanner

Fig. 3: Wafer inspection at the microscope

Lectures 2010

Chair Microtechnology

Process and Equipment Simulation
Lecturers: Prof. Dr. T. Gessner, Dr. R. Streiter

Advanced Integrated Circuit Technology
Lecturers: Prof. Dr. S. E. Schulz, Dr. R. Streiter

Microelectronics Technology
Lecturers: Prof. Dr. T. Gessner, Prof. Dr. S. E. Schulz,

Micro Technology
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller, Dr. A. Bertz

Microoptical systems
Lecturer: Prof. Dr. T. Otto

Technology of Micro and Nanosystems
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller

Micro and Nano Technology
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller

Lectures of International Research Training Group
Lecturer: Prof. Dr. S.E. Schulz

Chair Microsystems and Precision Engineering

Mikro- und Feingerätetechnik
Lecturer: Prof. Dr. J. Mehner

Gerätekonstruktion
Lecturer: Prof. Dr. J. Mehner

Mikro- und Nanosysteme
Lecturer: Prof. Dr. J. Mehner

CAD
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Mikromechanische Komponenten
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Microsystems Design
Lecturer: Prof. Dr. J. Mehner

Mikrosystementwurf
Lecturer: Prof. Dr. J. Mehner

Mess- und Prüftechnik in MST
Lecturers: Dr. J. Markert, Dr. S. Kurth

Prüftechnik/MST
Lecturers: Dr. J. Markert, Dr. S. Kurth

Gerätetechnik
Lecturer: Prof. Dr. J. Mehner

Klein- und Mikroantriebe
Lecturer: Dr. R. Kienscherf

Gerätetechnische Antriebe
Lecturer: Dr. R. Kienscherf

Angewandte Optik
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Grundlagen der Medizin
Lecturer: Dr. A. Müller

Spezielle Aspekte der Medizintechnik
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Chair Circuit and System Design

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Lecturers: Prof. Dr. U. Heinkel, Prof. Dr. G. Herrmann, Dr.-Ing. E. Markert

System Design
Lecturer: Prof. Dr. U. Heinkel

EDA-Tools
Lecturer: Prof. Dr. U. Heinkel

Rapid Prototyping
Lecturer: Prof. Dr. U. Heinkel

ASIC Design
Lecturer: Prof. Dr. G. Herrmann

Components and Architectures
Lecturer: Prof. Dr. G. Herrmann

Microprocessor Systems
Lecturer: Prof. Dr. G. Herrmann

Design of heterogeneous Systems
Lecturer: Dr.-Ing. E. Markert

Design for Testability für Circuits and Systems
Lecturers: Prof. Dr. G. Herrmann, Dipl.-Ing. J. Schmid, Dr.-Ing. E. Markert

Micro Production Technologies (BTU Cottbus)
Lecturer: Prof. Dr. G. Herrmann

Micro Systems (BTU Cottbus)
Lecturer: Prof. Dr. G. Herrmann

Chair Electronic Devices of Micro and Nano Technique

Electronic Devices and Circuits
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Electronic Devices
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Physical and Electrical IC Design
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Microelectronics
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Devices of Micro- and Nano Technique
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Lecturer: Prof. Dr.-Ing. J. Horstmann

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Lithography for Nano Systems
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Integrated Circuit Design
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Semiconductor Power Devices (English)
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Industrial Electronics
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Simulation of Electroenergetic Systems
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Electric Measurement Technology
Lecturers: Prof. Dr. O. Kanoun, Prof. Dr. N. Kroemer

Electronic Measurement Technology
Lecturer: Prof. Dr. O. Kanoun

Smart Sensor Systems
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Sensor Signal Processing
Lecturer: Prof. Dr. O. Kanoun

Sensors and Actuators
Lecturer: Prof. Dr. O. Kanoun

Automotive Sensors
Lecturer: Prof. Dr. O. Kanoun

Praxis Seminar Measurement and Sensor Technology
Lecturer: Prof. Dr. O. Kanoun

Fundamentals of Technical Optics
Lecturer: Dr. M. Arnold

Optoelectronic
Lecturer: Dr. M. Arnold

Photonics
ecturer: Dr. M. Arnold

Chair for Materials and Reliability of Microsystems

Reliability of Micro and Nanosystems
Lecturer: Prof. Dr. B. Wunderle

Materials of Microsystems and Precision Engineering
Lecturer: Prof. Dr. J. Fruehauf

Materials of Electrical Engineering and Electronics
Lecturer: Prof. Dr. J. Fruehauf

Materials of Micro Technology
Lecturer: Prof. Dr. J. Fruehauf

Interdisciplinary Cooperation

Interdisciplinary cooperation is the key for success. Since 1998 a strong cooperation exists between the Center for Microtechnologies ZfM and the Fraunhofer Institute for Electronic Nano Systems ENAS developed out of the former Chemnitz branch of Fraunhofer IZM. The cooperation aims at generating synergies between the basic research conducted at the Chemnitz University of Technology (CUT) and the more application-oriented research at the Fraunhofer ENAS. The Fraunhofer ENAS focuses on smart systems integration by using micro and nano technologies.

In order to ensure a longterm scientific and economic success Fraunhofer ENAS has defined three business units:

- Micro and Nano Systems,
- Micro and Nano Electronics / Back-End of Line as well as
- Green and Wireless Systems.

They address different markets and different customers.

The core competences are an indicator for the specific technological know-how of the Fraunhofer Institute for Electronic Nano Systems. Fraunhofer ENAS accesses on a broad variety of technologies and methods for smart systems integration. There have been defined seven core competences:

- Design and Test of Components and Systems
- Silicon Based Technologies for Micro and Nano Systems
- Polymer Based Technologies for Micro and Nano Systems
- Printing Technologies for Functional Layers and Components
- Interconnect Technologies
- System Integration Technologies
- Reliability of Components and Systems

They are the inner structure of the technology portfolio of Fraunhofer ENAS. These competences are of course supported by the cooperation with the Center for Microtechnologies ZfM of Chemnitz University of Technology, the Chair Digital Printing and Imaging Technology of the faculty of mechanical engineering of Chemnitz University of Technology and the Chair Sensor Systems of the faculty of electrical engineering of University Paderborn.

Moreover, the ZfM maintains a close contact with numerous universities, research institutes and industry via participation in projects and European technology platforms. In Asia, long-term cooperation exists with the Tohoku University in Sendai, the Fudan-University Shanghai and the Shanghai Jiao Tong University.

Both, the Center for Microtechnologies and the Fraunhofer ENAS belong to 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 the entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close integration of science, applied research and industry is there an everyday reality and reflects a strategy that is being fulfilled.

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, CWM GmbH, AMIC GmbH, Amitronics GmbH, SEDEMAT GmbH, Clean Technologies Campus GmbH
- Memsfab, common lab with Leibniz IFW
- EDC Electronic Design Chemnitz GmbH
- LSE Lightweigth Structures Engineering GmbH
- SiMetrics GmbH
- saXXocon GmbH
- BiFlow Systems GmbH

The business park allows expanding companies to set up in business in the very neighbourhood. The first company in the park is the 3D-Micromac AG which develops and manufactures highly efficient and innovative machines for laser micro machining.

Networks

Networking is our formula for success. The Center for Microtechnologies is working in several national and international networks.

Silicon Saxony

Silicon Saxony e.V. is Europe's largest trade association for the microelectronic industry.

It was founded in 2000 as a network for the semiconductor, electronic and micro system industry. The association connects manufacturers, suppliers, service providers, colleges, research institutes and public institutions in the economic location of Saxony. The current number of members has risen to 270. The member companies employ about 35,000 people and the total turnover of the companies is 4 billion € per year. The ZfM belongs to the foundation members.

13 working groups are working within the network. The working group "Smart Integrated Systems" has been founded 2007. It is leaded by Prof. Thomas Gessner.

In 2009 Prof. Thomas Gessner became a member of Silicon Saxony Board.

IVAM

As international association of companies and institutes in the field of micro technology, nano technology and advanced materials, IVAM's priorities are to create competitive advantages for our members. Nearly 300 member companies and institutes from 20 countries open up new markets and set standards with the support of IVAM. Companies, institutes, products, services and contact persons are listed here online as well as in the printed IVAM directory. The Center for Microtechnologies is a member of the IVAM network since 2005.

Within 2007 Prof. Gessner became a member of IVAM Advisory Council. The IVAM Advisory Council helps impulses from application oriented science to be integrated into the work of the association. Apart from their consulting function, the members of the IVAM Advisory Council also represent IVAM in public.

Nanotechnology Center of Competence "Ultrathin Functional Films"

The Center of Competence "Ultrathin Functional Films" (CC-UFF) is coordinated by Fraunhofer IWS Dresden. It joins 51 enterprises, 10 university institutes, 22 research institutes, and 5 corporations into a common network. Activities within the frame of Nano-CC-UFF are subdivided into 6 working groups, each of them is administered and coordinated by one member.

WG 1: Advanced CMOS

WG 2: Novel components

WG 3: Biomolecular films for medical and technological purposes

WG 4: Mechanical and protective film applications

WG 5: Ultrathin films for optics and photonics

WG 6: Nano-size actuators and sensors

Working group 1 is headed by Prof. Thomas Gessner and working group 2 by Prof. Christian Radehaus (former member of the board of directors of the Center for Microtechnologies of Chemnitz University of Technology).

DFG Research Unit 1713 „Sensoric Micro and Nano Systems“

The German Research Foundation (DFG) has established the research unit 1713 “Sensoric Micro and Nano Systems” at the Chemnitz University of Technology for a period of three years, starting in March 2011. Besides the professorships of the Center for Microtechnologies from the Faculty of Electrical Engineering and Information Technology , also the Faculty of Natural Sciences, the Fraunhofer Institute for Electronic Nano Systems (Fraunhofer ENAS) and the Leibniz Institute for Solid State and Materials Research (IFW Dresden) are involved in the Research Unit. Speaker of the Research Unit is Prof. Thomas Geßner.

Smart System Integration – the integration of intelligent systems – is a shared research focus for the Chemnitz University of Technology and the Fraunhofer ENAS. It follows the trend towards miniaturized multifunctional assemblies and systems, which is named “More than Moore” in the International Technology Roadmap for Semiconductors (ITRS). Smart System Integration aims on the interaction of the system with the analog environment via different domains and the integration of heterogeneous systems, for example in a System-in-Package (SIP). These systems join powerful components enabling complex system functions at smallest volume.

The scientific goal of the Research Unit is the integration of nano structures and novel materials, as well as the spatial and functional integration of heterogeneous components in micro and nano systems. Especially for the integration of nanotechnologies and the development of novel materials the collaboration between the Center for Microtechnologies and the Institutes of Physics and Chemistry are of great concern. Together with the Fraunhofer ENAS and the IFW Dresden the competences in the areas of design, fabrication, characterization and reliability of micro and nano structures and of integration and packaging technologies will be combined for working on the complex scientific tasks arising from the development of multifunctional micro and nano systems.

The realization of the research goals in the first funding period of the Research Unit 1713 is based on three independent technological routes:

- Silicon nano sensors
- Modelling and integration of nanotubes
- Novel materials and technologies for sensor applications

Within the technological route “Silicon nano sensors”, nano structures based on state of the art MEMS technologies will be integrated in Microsystems for utilizing nano effects in transducers. The use of nano structures as transducer elements needs new pathways for interconnecting the signal processing with the sensor element, since signal to noise ratios are getting smaller. Furthermore, new concepts for the design and the packaging of nano systems have to be developed. Especially for heterogeneous systems technological flexibility and interactions between different components are essential.

The second technological route “Modeling and integration of nanotubes” covers the whole bandwidth from atomistic modeling of carbon nanotubes (CNTs), over process development for deposition and integration of nanotubes, characterization by scanning probe techniques up to the application in sensor systems. Until now, nanotubes, especially CNTs, were considered as ideal elements. For application oriented and technology driven simulations structural defects, contact properties as well as contaminations by subsequent processes have to be taken into account. The evaluation of realistic models with the reality requires highly accurate characterization methods, therefore analytics with a spatial resolution in the nanometer range for a multitude of material parameters are necessary. The requirements on the integration processes will be investigated for the planned applications of nanotubes microfluidic systems and resonators.

Syntheses, patterning and integration of magnetic materials is in the focus of the third technological route “Novel materials and technologies for sensor applications”. Novel geometric configurations like nano particle arrays will be reproducible processed and studied fundamentally by self assembly and rolling up of thin film systems as well as studied fundamentally. Connecting both methods enables the fabrication of completely new hetero structures, consisting of coated particle mono layers and film membranes with a defined switching behavior of these structures in a magnetic field.

Further information:

http://www.zfm.tu-chemnitz.de/for1713/

Fig. 1: Research cooperation at the Smart Systems Campus Chemnitz: Location for the Chemnitz University of Technology with the Center for Microtechnologies, the Faculty of Electrical Engineering and Information Technology, the Faculty of Natural Sciences, as well as the Fraunhofer Institute for Electronic Nano Systems ENAS and the Chemnitz research group of the Leibniz IFW Dresden

Nanett - Nano System Integration Network of Exellence

The research consortium nanett „nano system integration network of excellence" 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 (BMBF). Under the direction of the Chemnitz University of Technology and the Fraunhofer Institute for Electronic Nano Systems ENAS this multi disciplinary network of nine partners was formed to bring together their different competences in the field of applied nanotechnologies. Using the approach of combining the capabilities of several renowned scientific institutions enables international and domestic top level research on a competitive basis. The grant of the BMBF for the whole R&D joint venture amounts 14 million Euros. The project started in November 2009 with a funding period of five years.

Nano System Integration means the technological utilization of already known as well as new-found effects resulting from nano scale elements integrated in a material, a chip, an assembly or a complete system. The strategic direction of the network is the connection of fundamental with application oriented research in the promising domains of nanotechnology and system integration technology with the aims of transferring science into applications and being an attractive, competent and solid partner for the industry. To suit the scientific requirements of these highly interdisciplinary fields and due to huge invest costs for production and test equipment in the field of micro and nanotechnologies it is essential to use synergies created by collaborative work of different renowned research centers for successfully conducting competitive research and development.

As a basis for these activities important technological questions and application constraints have been identified and summarized in three areas of competence. From these areas of competence three flagship projects have been created which are illustrated in the picture below together with the project partners. In the first three years period, the research is focused on the integration of component level within the areas of competence. On the basis of concrete technological problems superordinate approaches will be investigated. In the second two year period, the flagship projects will be merged in order to create application orientes projects with focus on system level integration.

The three areas of competence with their research topics are:

Processes and technologies for nano scale material systems

- Application of quantum mechanical phenomena and effects of nano structures
- Patterning of nano structures in unconventional materials
- Characterization of magnetic properties

Micro-nano-integration

- Integration of nano structures with electromechanical functionalities
- System design and architecture of energy efficient sensor networks
- Technologies for autonomous sensor nodes

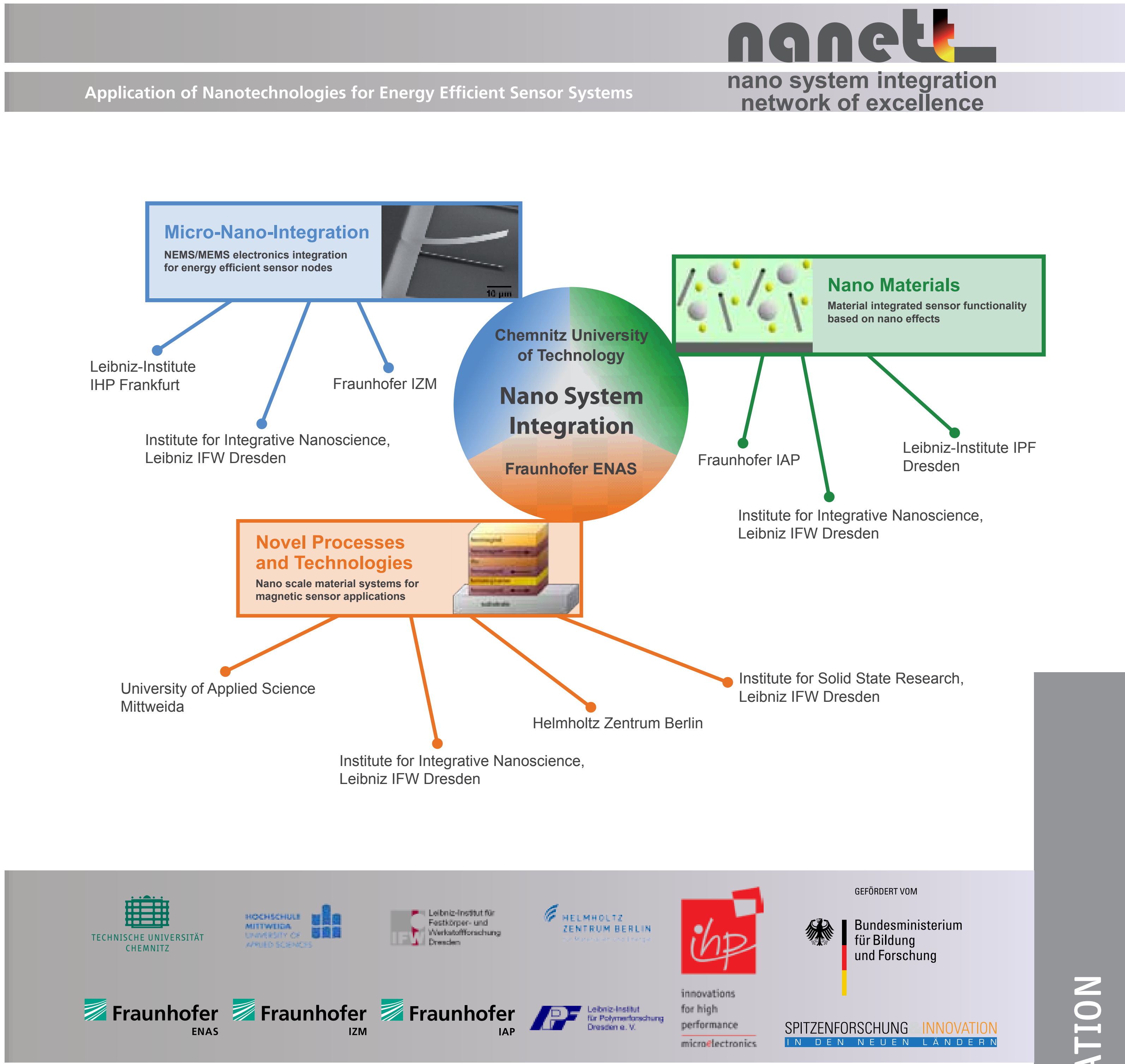
Nano materials

- Fabrication of functional nano composite materials
- Material integrated sensor functionality in lightweight structures
- Reliability of functional materials

The Center for Microtechnologies takes part with six Professorships in all three areas of competence within the following research topics: patterning of nano structures in unconventional materials, integration of nano structures with electromechanical functionalities, system design and architecture of energy efficient sensor networks, technologies for autonomous sensor nodes and Reliability of functional materials.

For more information please visit our website:

http://www.nanett.org/



COOPERATION

International Research Training Group

At a Glance

Since April 2006, the International Research Training Group (Internationales Graduiertenkolleg 1215) “Materials and Concepts for Advanced Interconnects”, jointly sponsored by the German Research Foundation (DFG) and the Chinese Ministry of Education, has been established for 4.5 years between the following institutions:

- Chemnitz University of Technology
- Institute of Physics
- Institute of Chemistry
- Center for Microtechnologies
- Fraunhofer Institute for Electronic Nano Systems ENAS
- Fraunhofer Institute for Reliability and Microintegration IZM
- Technische Universität Berlin
- Fudan University, Shanghai
- Shanghai Jiao Tong University

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”.

This International Research Training Group (IRTG) is the first of its kind at Chemnitz University of Technology. It is led by Prof. Ran Liu of Fudan University as the coordinator on the Chinese side and Prof. Thomas Gessner on the German side. A graduate school like this offers brilliant young PhD students the unique opportunity to complete their PhD work within 2.5 to 3 years in a multidisciplinary environment. Up to 14 PhD students of the German and 20 of the Chinese partner institutions, as well as a post-doctoral researcher at the Center for Microtechnologies are involved in the current program. The different individual backgrounds of the project partners bring together electrical and microelectronics engineers, materials scientists, physicists, and chemists. In particular, the IRTG is working to develop novel materials and processes as well as new concepts for connecting the devices within integrated microelectronic circuits. Smaller contributions are being made in the field of device packaging and silicides for device fabrication. In this sense, the IRTG project is helping to solve problems currently encountered on the way to nanoelectronics.

Therefore, the research program of the IRTG concentrates on both applied and fundamental aspects, and treats the mid- and long-term issues of microelectronics metallization. Atomic layer deposition (ALD) of metals, new precursors for metal-organic chemical vapor deposition (MOCVD), ultra low-k dielectrics and their mechanical and optical characterization together with inspection techniques on the nanoscale are considered. New and innovative concepts for future microelectronics such as carbon nanotube interconnects or molecular electronics along with silicides to form links to front-end of line processes are of interest, as well as the evaluation of manufacturing-worthy advanced materials. Moreover, the research program addresses reliability and packaging issues of micro devices. Highlighting links between fundamental materials properties, their characteristics on the nanoscale, technological aspects of materials and their applications to microelectronic devices is the main objective of the program.

Nevertheless, the principal idea of the IRTG is four-fold: The research program defines the framework of the activities and the topics of the PhD theses. This is accompanied by a specially tailored study program including lectures, seminars and laboratory courses to provide comprehensive special knowledge in the field of the IRTG. The third part of the program comprises annual schools held either in China or Germany, bringing together all participants of the IRTG and leading to vivid discussions during the presentation of the research results. Moreover, an exchange period of 3 to 6 months for every PhD student at one of the foreign partner institutions is another essential component. Besides special knowledge in the scientific field, these activities will provide intercultural competencies that cannot easily be gained otherwise.

Summer School 2010

The 5th summer school of the IRTG 1215 was held from 26th March to 1st April 2010 in Chemnitz. This event was organized by the German partners under the direction of Prof. Thomas Gessner.

The summer school started with a social event. A guided sight seeing tour was planned to Freiberg, Saxony, for all members of the IRTG program. The Professors, tutors and PhD students visited the historic center of Freiberg and the Freiberg Cathedral “St. Marien”. After lunch all participants attended “A mineralogical Journey around the World”, which is the theme of the “Terra Mineralia”, one of the largest mineral collections in the world provided by the Technische Universität Bergakademie Freiberg. Due to earlier exchanges (Mobility Period) of several PhD students between the Chinese and the German side, the event was accompanied by an active communication of all members.

On March 29th and 30th, 18 talks and 32 scientific posters were presented by the German and Chinese PhD students to show their status and progress of their diversified scientific work. Each oral presentation closed-up by questions from the audience. Moreover, the communication between the international participants was improved by the discussions at the posters and during tea breaks and meals on both days.

Finally, the summer school closed with the evaluation meeting on March 31st for all participants.

Evaluation meeting on March 31st

The proposal for the second period of the IRTG program was submitted to the German Research Foundation (DFG) in October 2009 including a detailed report of the first period. The new topic “Materials and Concepts for Advanced Interconnects and Nanostructures” combines both, activities related to “More Moore” as well as “More than Moore”, correlating to the current trends in micro- and nanoelectronics. The proposal included 9 subprojects on the German and 11 subprojects on the Chinese side.

On May 31st the evaluation of the first period of the IRTG program took place at Chemnitz University of Technology. The members of the IRTG welcomed six evaluators from German universities and research institutions, two evaluators of the Chinese Ministry of Education (MoE) and four representatives of the German Research Foundation in Chemnitz.

The event was opened by Prof. Thomas Gessner, speaker of the International Research Training Group. He presented the activities and progress in the scientific program within the first four years. An overview of all Chinese activities as well as the Chinese scientific environment was given by Prof. Ran LIU from Fudan University in Shanghai and Prof. Di CHEN of Shanghai Jia Tong University. Additionally, two PhD students from each partner side presented their scientific work in detail. Moreover, a poster session was held, including 34 PhD presentations of all involved PhD students and postdocs. The second part of the day was reserved for extensive discussions of the evaluators and all members of the IRTG. The day ended with a reception in the hotel “Chemnitzer Hof” for all participants.

As the first period of the IRTG program achieved an “excellent research” rating and in July 2010 the second period of the IRTG program was approved by the German Research Foundation.

Statistics of the 1st IRTG period 04/2006 – 09/2010

Even though this program is the first of its kind at the Chemnitz University of Technology, it was quickly well-established and successfully operating since April 2006.

Within 4.5 years of the first period, one autumn and four summer schools of several days duration were held in Germany and China. More than 20 PhD students were exchanged from the German to the Chinese side and vice versa for about 3 months each. As a result of the strong collaboration of all partner institutions, round about 10 joint publications and more than 150 publications in total resulted from the scientific work in the IRTG. On the German side, 10 PhD students finished their PhD or submitted their thesis within the first period. The over-all gender ratio of the German PhD students was about 35 % female.

For further information please visit our webpage: http://www.zfm.tu-chemnitz.de/irtg/

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