DS 11: Focus Session: Sensoric Micro and Nano-systems I

One major trend in semiconductor research which was identified by the international technology roadmap for semiconductors (ITRS) is called "More than Moore". This concept explores the variety of physical phenomena which can be obtained by the integration of different technologies and functionalities to basic semiconductor research. Current focus areas comprise signal and information processing as well as the interaction with the environment in a miniaturized system. Such smart systems contain digital and analog electronics, sensors and actuators, radio frequency and high voltage modules or biotechnology. The miniaturization of the components and the utilization of nanotechnology enable new or enhanced functionalities. The topical session aims at presenting recent trendsetting micro- and nano technological concepts which are related to nano electro mechanical sensor systems. Special emphasis will be given to the integration of nanostructures and novel materials as well as the spatial and functional integration of heterogeneous components in micro and nano systems. (Organizers: Dietrich Zahn, TU Chemnitz, Thomas Gessner, Fraunhofer ENAS, Oliver Schmidt, IFW Dresden)

Time: Tuesday 9:30–13:15 Location: CHE 89

Invited Talk DS 11.1 Tue 9:30 CHE 89

Giant magnetoelectric thin film composites — •Andre Piorra, Robert Jahns, Enno Lage, Christine Kirchhof, Erdem Yarar, Volker Röbisch, Dirk Meyners, Reinhard Knöchel, and Eckhard Quandt — Faculty of Engineering, University of Kiel, Kaiserstr. 2, 24143 Kiel, Germany

Magnetoelectric (ME) composite materials show ME coefficients that are larger than that of natural multiferroics by several orders of magnitude. These ME composites have high potential for applications, e.g. as very sensitive ac magnetic field sensors. Special features are their passive nature, their high sensitivity, and their large dynamic range with linear response.

The thin film ME 2-2 composites of this work consist of either AlN or ferroelectric piezoelectrics and different magnetostrictive layers that show extremely high ME coefficient of up to 20 kV/cmOe at mechanical resonance in vacuum (1). However, these composites require in general the presence of an external d.c. magnetic bias field, which is detrimental to their use as sensitive magnetic-field sensors. Composites using exchange biased magnetstrictive layers are used to adjust the shift of the magnetostriction curve in such a way that the maximum magnetoelectric coefficient occurs at zero magnetic bias field (2). In this presentation different thin film composites will be discussed in view of their use as very sensitive magnetic field sensors .

(1) Appl. Phys. Lett. 102, (2013), 232905. (2) Nature Materials 11 (6) (2012), 523-529.

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DS 11.2 Tue 10:00 CHE 89

Rolled-up magnetic nanomembranes: Towards 3D magnetic sensorics — •Denys Makarov[1], Christian Müller[2], Ingolf Mönch[1], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, 01069 Dresden, Germany — [2]Measurement and Sensor Technology, TU Chemnitz, 09126 Chemnitz, Germany

Rolled-up nanotechnology relies on the deterministic release of a strained nanomembrane from a sacrificial layer resulting in formation of a tube of predetermined size and geometry. The approach potentially allows to implement multiple functionalities on diagnostics e.g. electro-chemical, magnetic, optical into a single tubular architecture, thus realizing the Lab-in-a-Tube concept [1].

Here, we report on the realization of the rolled-up magnetic sensor element revealing giant magnetoresistance (GMR), which can be integrated into existing fluidic architectures as a component for the Lab-in-a-Tube [2-4]. The rolled-up tube acts as the fluidic channel guiding the magnetic objects, which can be detected with the integrated magnetic sensor. The performance of the rolled-up sensor was optimized for high sensitivity to weak magnetic fields, as required in biomedical applications, and demonstrated for the in-flow detection of CrO2 nanoparticles embedded in a biocompatible hydrogel shell [2].

[1] E. J. Smith et al., Lab Chip 12, 1917 (2012).
[2] I. Mönch et al., ACS Nano 5, 7436 (2011).
[3] C. Müller et al., Nanoscale 4, 7155 (2012).
[4] C. Müller et al., Appl. Phys. Lett. 100, 022409 (2012).

DS 11.3 Tue 10:15 CHE 89

Integrated MEMS magnetic field sensor based on ΔE-effect — •Sebastian Zabel[1], Robert Jahns[2], Stephan Marauska[3], Björn Gojdka[2], Bernhard Wagner[3], Rainhard Knöchel[1], Rainer Adelung[4], and Franz Faupel[2] — [1]Institute for Materials Science, Multicomponent Materials, Kiel University, Kiel, Germany — [2]Institute of Electrical and Information Engineering , Kiel University — [3]Fraunhofer Institute for Silicon Technology ISIT, Itzehoe, Germany — [4]Institute for Materials Science, Functional Nanomaterials, Kiel University

We present an integrated MEMS magnetic field sensor based on ΔE-effect, which extends our previous approach [Gojdka et al., Appl. Phys. Lett. 99, 223502 (2011); Nature 480, 155 (2011)]. The ΔE-effect describes a change of elastic modulus in magnetostictive materials upon application of a magnetic field. The change of elastic modulus can be measured by the change of resonance frequency of a one side clamped cantilever. The 0.2 x 1 mm SiO2 cantilever is 650 nm thick and coated with a 500 nm thick piezoelectric AlN layer on the bottom and a 2 um thick magnetostrictive FeCoSiB amorphous film on top. The piezoelectric layer is used for excitation of the first resonant bending mode as well as the readout of amplitude and phase. The sensor resonates at 6700 Hz and is encapsulated in a vacuum packing to reduce damping. Using amplitude modulation it is possible to detect small signals of 10 nT at 10 Hz. In order to use the maximal ΔE-effect a bias field of around 1.5 mT has to be applied. The advantage of the sensor concept is the possibility to measure in a broad frequency range down to DC.

DS 11.4 Tue 10:30 CHE 89

Magnetic Domains in Rolled-Up Ferromagnetic Single-Layer Nanomembranes and Magnetically Capped Tubular Architectures — •Robert Streubel[1], Denys Makarov[1], Peter Fischer[2], Rudolf Schäfer[3], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, 01069 Dresden, Germany — [2]CXRO, LBNL, Berkeley CA 94720, USA — [3]Institute for Metallic Materials, IFW Dresden, 01069 Dresden, Germany

Rolled-up magnetic nanomembranes have recently enabled novel sensoric devices and spin-wave filters. Their application potential relies on understanding the modification of magnetic configurations under external stimuli. Due to difficulties in visualizing magnetic domain patterns in these truly 3D structures, the magnetization configuration in cylindrical architectures is usually derived from integral measurements, such as magnetoresistance techniques. Here, we directly visualize magnetic domain patterns in magnetically capped tubes [1] and rolled-up single layer magnetic nanomembranes [2]. By Photoelectron emission and Kerr microscopies magnetic signals from the top part of the tube were recorded whereas magnetic soft X-ray microscopy allowed to probe internal parts of the tube. We demonstrate the possibility to tailor the magnetization orientation from longitudinal for positive magnetostrictive materials over spiral-like to azimuthal for negative ones [2]. These patterns cause distinct magnetoelectronic responses, which is relevant to know for sensoric applications.

[1] R. Streubel et al. Nano Lett. 12, 3961 (2012)
[2] R. Streubel et al., Adv. Mater. 10.1002/adma.201303003

DS 11.5 Tue 10:45 CHE 89

Giant magnetoelectric effect at low frequencies in polymer-based thin film composites — Amit Kulkarni[1], Kerstin Meurisch[1], Robert Jahns[2], Iulian Teliban[2], Andre Piorra[3], •Thomas Strunskus[1], Reinhard Knöchel[2], and Franz Faupel[1] — [1]Chair for Multicomponent Materials, Institute for Materials Science, Christian-Albrechts-University at Kiel, Kaiserstr. 2, 24143 Kiel, Germany — [2]Microwave Laboratory, Institute of Electrical and Information Engineering, Christian-Albrechts-University at Kiel, Kaiserstr. 2, 24143 Kiel, Germany — [3]Chair for Inorganic Functional Materials Institute for Materials Science, Christian-Albrechts-University at Kiel, Kaiserstr. 2, 24143 Kiel, Germany

A new approach for the preparation of polymer based magnetoelectric sensors by spin-coating is presented. Poly(vinylidene fluoride trifluoroethylene)-copolymer 70/30 mol % (PVDF-TrEF) was used as piezo and metallic glass foils as magnetostrictive phase, respectively. The piezoelectric β phase fraction of the polymer layers were optimized by annealing and the films were polarized by contact poling. These films show a saturation polarization of 10 μC/cm^2 and remanent polarization of 8 μC/cm^2. For a prototype single-sided clamped cantilever, a magnetoelectric coefficient as high as 850 V/cmOe is observed at its fundamental bending mode resonance frequency at 27.8 Hz and a detection limit of 10 pT/Hz$^{1/2}$ at its second bending mode resonance frequency at 169.5 Hz. Moreover, this technique allows easy variation of the thickness of the piezoelectric layer and much easier integration into devices.

Coffee break (15 min)

Invited Talk DS 11.6 Tue 11:15 CHE 89

Carbon nanotubes for piezoresistive electro-mechanical transducers incorporating a wafer-level technology — •Sascha Hermann[1], Alexey Shaporin[1], Jens Bonitz[2], Steffen Hartmann[1], Jana Kalbacova[3], Raul D. Rodriguez[3], Dietrich R.T. Zahn[3], Jan Mehner[1], Bernhard Wunderle[1], Stefan E. Schulz[1,2], and Thomas Gessner[1,2] — [1]Technische Universität Chemnitz, Center for Microtechnologies (ZfM), 09126 Chemnitz, Germany — [2]Fraunhofer Institute for Electronic Nano Systems (ENAS), 09126 Chemnitz, Germany — [3]Technische Universität Chemnitz, Institute of Physics, Semiconductor Physics, 09126 Chemnitz, Germany

Single-walled carbon nanotubes (SWCNTs) can exhibit a distinctive intrinsic piezoresistivity exploitable in ultra sensitive displacement and force sensors. Driven by this potential, we present our progress on the integration of suspended SWCNT arrays into microelectromechanical systems (MEMS). Thereby we focus on application oriented wafer-level technologies. Aspects like a reliable electrical/mechanical contact, chirality distribution of SWCNTs, as well defect density and impurities are addressed in this work. Therefore a MEMS test stage is going to be presented which enables an extended electrical and structural characterization of suspended SWCNTs and other 1D nanomaterials under strain, as well as a mechanical reliability test. Furthermore, we investigate the local chiral distribution of SWCNTs as well as the structural and electrical properties of SWCNTs under strain.

DS 11.7 Tue 11:45 CHE 89

Carbon nanotubes under strain: Ab-initio investigations and compact models — •Christian Wagner[1], Vladimir Kolchuzhin[2], Erik Markert[2], Jörg Schuster[3], Jan Mehner[2], and Thomas Gessner[1,3] — [1]Center for Microtechnologies, TU Chemnitz, Germany — [2]Faculty of Electrical Engineering and Information Technology, TU Chemnitz, Germany — [3]Fraunhofer Institute for Electronic Nano Systems (ENAS), Chemnitz, Germany

Carbon nanotubes (CNTs) are not only attracting high interest in research, but also from the application point of view. Their mechanical strength and their outstanding piezoresistive response is one example that makes them suitable for novel sensors. These properties are well-explored for pristine Single-walled CNTs. But there is a lack of quantitative description of realistic CNTs in sensor environments.

Thus, this talk focuses on one hand on ab-initio-results of the electronic structure and transport properties of defective and functionalized CNTs under strain. And on the other hand we want to condense these results in compact models that can be incorporated in large-scale sensor simulations.

The first part concerns the comparison of simplified models to DFT results of strained CNTs [1] and shows its limits. Further, the electronic transport with different simplifications including scattering is elucidated. In the second part, these effective models for all available CNT chiralities will then be used to define compact models for sensor simulations by parametrization of electronic structure results.

[1] Wagner, C. et al., Phys. Stat. Sol. B, 249, 2450 (2012)

DS 11.8 Tue 12:00 CHE 89

Adjustment of carbon nanotube properties for sensor applications using Pd adatoms: An ab-initio study — •Florian Fuchs[1], Christian Wagner[1], Andreas Zienert[1], and Jörg Schuster[2] — [1]Center for Microtechnologies, Technische Universität Chemnitz, Chemnitz, Germany — [2]Fraunhofer Institute for Electronic Nano Systems (ENAS), Chemnitz, Germany

Carbon nanotubes (CNTs) are, thanks to their extraordinary electromechanical properties, suitable for novel sensing devices such as acceleration sensors. For such applications, CNTs with small band gaps are favored. Since type selection of CNTs is still a challenge, methods are required to tune the band gaps in situ. We suggest submonolayer metal coating as a promising approach.

By using density functional theory, we investigate the influence of Pd adatoms on the surface of a semiconducting (8,4) CNT. We show that the adatoms strongly influence the electronic properties and that the band gap can be reduced. This effect can be increased further by using higher amounts of Pd adatoms. When the adatoms finally create a closed chain along the CNT, the band gap is reduced to the desired working range of possible sensor devices. Straining the system in uniaxial direction shows that the sensibility of the band gap and therefore the suitability for strain sensors is conserved. We also vary the position of a single adatom on the CNT surface in order to judge the stability of the adsorption. The resulting energy landscape shows a valley along the tube. Within that valley, energy barriers are small enough to permit thermally activated motion of the adatom.

Invited Talk DS 11.9 Tue 12:15 CHE 89

Integration of individual SWCNTs into field-effect transistor-based sensors — •Miroslav Haluska, Wei Liu, Kiran Chikkadi, Matthias Muoth, Tobias Suss, Stuart Truax, Cosmin Roman, and Chrisofer Hierold — Micro- and Nanosystems, ETH Zurich, Tannenstrasse 3, 8092 Zurich, Switzerland

Sensor demonstrators based on single-walled carbon nanotubes (SWCNTs) have shown very promising performance, including high sensitivity, low detection limits, and ultra-low power consumption. In this presentation, we focus on sensors integrating individual SWCNTs in a field effect transistor (FET). Such carbon nanotube FETs (CNFETs) may be used for different sensor applications, e.g. NO2 gas sensors, pressure sensors, or mechanically resonating transducers. The electrical characteristics of these devices exhibit unpredictable device-to-device variations that cannot be explained solely by the different properties of the incorporated SWCNTs. The device fabrication processes and a choice of materials coming into contact with the SWCNTs can also affect the CNFET characteristics by altering the nanotube and/or the interface properties. To identify and optimize the most critical device fabrication steps, we performed a series of monitoring measurements at different stages of the fabrication process. The results we have obtained from improved nanotube integration processes, including the utilization of a temporary nanotube protection layer, give us optimistic expectations for the utilization of SWCNTs in future sensor devices. The improvements in particular include the decrease of electrical contact resistances and narrowing of Ids-Vg hysteresis widths.

DS 11.10 Tue 12:45 CHE 89

Limitations of signal to noise ratio in Schottky barrier FET based biosensors — •Sebastian Pregl[1,2,3], Larysa Baraban[1], Walter Weber[2], Thomas Mikolajick[4,2,3], and Giovanni Cuniberti[1,3] — [1]Institute for Materials Science and Max Bergmann Center of Biomaterials TU Dresden 01062 Dresden, Germany — [2]Namlab GmbH 01187 Dresden, Germany — [3]Center for Advancing Electronics Dresden (cfaed) TU Dresden 01062 Dresden, Germany — [4]Institute of Semiconductor and Microsystems TU Dresden 01187 Dresden, Germany

In field effect transistor (FET) based biological sensors the presence of the specimen is detected via determination of changes of the electrical potential on the sensor surface. The resolution is limited by the accuracy of the transistor source to drain current measurement. Therefore a high ratio of transconductance to current noise is desired to maximize the signal to noise ratio (SNR). Schottky barrier FETs suffer from a high serial resistance which increases the noise level in transistor regimes beyond the subthreshold. Here, a study is presented reflecting the scaling of important device parameters like threshold voltage, transconductance, current noise and subthreshold slope with respect to the nanowire length. Regarding these dependancies a compromise of transistor size to SNR can be found matching the demands of the particular measurement.

DS 11.11 Tue 13:00 CHE 89

Silicon nanowire based detection of blood proteins — •Andreas Gang[1], Sebastian Pregl[1], Felix Zörgiebel[1], Lotta Römhildt[1], Claudia Pahlke[1], Walter Weber[2,3], Larysa Baraban[1], Lars David Renner[1], Thomas Mikolajick[2,3], and Gianaurelio Cuniberti[1,3] — [1]Institute for Materials Science and Max Bergmann Center of Biomaterials, TU Dresden, 01062 Dresden, Germany — [2]NaMLab GmbH, 01187 Dresden, Germany — [3]Center for Advancing Electronics Dresden (CfAED), TU Dresden, 01062 Dresden, Germany

A fast and reliable detection of viruses and bacteria is crucial for improving our health care system. Compared to the commonly applied enzyme-linked immunosorbent assay (ELISA) method silicon nanowire (SiNW) based bio sensors are able to provide analytical results much quicker and with lower detection limits.

Here, we present our approach towards the assembly of SiNW based sensory devices made from bottom-up grown SiNWs. Introducing well-defined Schottky barrier contacts between electrodes and SiNWs allows on/off current ratios of up to 106 and using parallel arrays of SiNWs enables on currents of over 500 A at a source drain voltage of 0.5 V.

Furthermore, we present the implementation of the SiNW device into a biocompatible micro fluidic setup as well as the immobilization of aptamer bio receptor molecules on the sensor surface to obtain a bio sensor specific for the blood coagulation protein thrombin with a detection limit in the picomolar range.