Symposium Resistive Switching (SYRS)

jointly organized by
the Thin Films Division (DS),
the Dielectric Solids Division (DF),
the Crystallography Division (KR), and
the Semiconductor Physics Division (HL)

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The phenomenon of "resistive switching" relates to the observation that in various materials the electrical resistance is not a material-specific constant, but that it can be modified by applying a voltage or current pulse. This effect is exploited in the resistive random access memory (RRAM) concept to generate highly scalable non-volatile memory elements. With silicon-based CMOS technology reaching the lower limit of scalability according to Moore's law, the RRAM concept has matured to a viable alternative with the potential to further reduce device area and power consumption. Suitable materials range from simple binary metal oxides to the higher chalcogenide based phase change materials.

The symposium will give an overview about the current state of research, the status of device performance and aims to stimulate discussions about the complex details of the underlying physical mechanisms.

Overview of Invited Talks and Sessions

(lecture room H 0105)

Invited Talks

SYRS 1.1	Thu	15:00–15:30	H 0105	**Redox-based resistive memories - recent progress** — •Rainer Waser
SYRS 1.2	Thu	15:30–16:00	H 0105	**Electric Formation of Metal/$SrTiO_3$ Junctions and its Correlation to Multi-Dimensional Defects** — •Dirk C. Meyer, Hartmut Stöcker, Juliane Hanzig, Florian Hanzig, Matthias Zschornak, Barbara Abendroth, Sibylle Gemming
SYRS 1.3	Thu	16:00–16:30	H 0105	**The Connecting between the Properties of Memristive Material Systems and Application Requirements** — •Thomas Mikolajick, Stefan Slesazeck, Hannes Mehne
SYRS 1.4	Thu	16:30–17:00	H 0105	**Mechanism of resistive switching in bipolar transition metal oxides** — •Marcelo Rozenberg
SYRS 1.5	Thu	17:00–17:30	H 0105	**Resistive switching memories: Mechanisms, modeling and scaling** — •Daniele Ielmini

Sessions

SYRS 1.1–1.5	Thu	15:00–17:30	H 0105	**Symposium Resistive Switching (joint symposium organized by DS, DF, KR, HL – Organizers: Gemming, Dittmann)**
SYRS 2.1–2.49	Thu	17:30–19:00	Poster E	**Poster: Resistive switching (jointly organized by DS, DF, KR, HL)**
SYRS 3.1–3.5	Fri	9:30–10:45	H 0111	**Resistive switching I (jointly organized by DS, DF, KR, HL)**
SYRS 4.1–4.6	Fri	11:00–12:30	H 0111	**Resistive switching II (jointly organized by DS, DF, KR, HL)**

SYRS 1: Symposium Resistive Switching (joint symposium organized by DS, DF, KR, HL – Organizers: Gemming, Dittmann)

Time: Thursday 15:00–17:30 Location: H 0105

Invited Talk SYRS 1.1 Thu 15:00 H 0105

Redox-based resistive memories - recent progress — •Rainer Waser — Forschungszentrum Jülich, 52425 Jülich, and IWE2, RWTH Aachen University, 52056 Aachen, Section Fundamentals of Future Information Technology (JARA-FIT), Germany

A potential leap beyond the limits of Flash (with respect to write speed, write energies) and DRAM (with respect to scalability, retention times) emerges from nanoionic redox-based switching effects encountered in metal oxides (ReRAM). A range of systems exist in which ionic transport and redox reactions on the nanoscale provide the essential mechanisms for memristive switching. In two classes, the so-called electrochemical metallization memories, ECM, and the so-called valence change memories, VCM, the electrochemical nature of these memristive effects triggers a bipolar memory operation. In yet another class, the thermochemical effects dominate over the electrochemical effects in metal oxides (so-called thermochemical memories, TCM) which leads to a unipolar switching as known from the phase-change memories. In all systems, the defect structure turned out to be crucial for the switching process. The presentation will cover recent progress in understanding the fundamental principles in terms of microscopic processes, switching kinetics and retention times, as well as device reliability of bipolar ReRAM variants. Despite exciting results obtained in recent years, several challenges have to be met before these physical effects can be turned into a reliable industrial technology.

Invited Talk SYRS 1.2 Thu 15:30 H 0105

Electric Formation of Metal/$SrTiO_3$ Junctions and its Correlation to Multi-Dimensional Defects — •Dirk C. Meyer[1], Hartmut Stöcker[1], Juliane Hanzig[1], Florian Hanzig[1], Matthias Zschornak[1,2], Barbara Abendroth[1], and Sibylle Gemming[2] — [1]TU Bergakademie Freiberg, Institut für Experimentelle Physik, Leipziger Str. 23, 09596 Freiberg — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, Bautzner Landstr. 400, 01328 Dresden

Regarding the successful use of strontium titanate with different doping within resistive switching memory cells, the presence of crystallographic defects seems to be an important prerequisite. Standard explanations for resistive switching rely on the redistribution of oxygen vacancies, however, this motion can be enhanced or prevented by higher-dimensional defects. Intrinsic defects in crystalline $SrTiO_3$ include point defects such as oxygen or strontium vacancies, line defects, stacking faults like Ruddlesden-Popper phases and precipitates (TiO_2, SrO etc.). Electric formation of the metal/oxide/metal cells is widely used as an initial step to enable resistive switching, but the interaction of the multi-dimensional defects during this treatment remains questionable. This talk will present several measurements that were performed in situ, i.e. during the application of an electric field, to investigate the effects of the electric formation on the real structure.

Invited Talk SYRS 1.3 Thu 16:00 H 0105

The Connecting between the Properties of Memristive Material Systems and Application Requirements — •Thomas Mikolajick[1,2], Stefan Slesazeck[1], and Hannes Mehne[1] — [1]NaMLab gGmbH, Nöthnitzer Str. 64, 01187 Dresden — [2]Chair of Nanoelectronic Materials Technische Universitaet Dresden

In the last years large progress has been made to identify switching mechanisms in resistive switching materials and connect these to the materials systems used. The different switching mechanisms result in significantly different I-V characteristics of the switching behavior. As an example the switching can be bipolar or unipolar, abrupt or continuous etc. Additionally parameters like switching power, retention and endurance may show a characteristic fingerprint. In this talk the main mechanisms like thermo-chemical switching, valence change switching or electrochemical switching are compared to the requirements for different types of semiconductor memories like nonvolatile RAM, high density data memories or embedded memories and an assessment of the prospects of the different mechanisms for each system is given. Non-memory applications of memristive switching like xeromorphic circuits will also be taken into consideration.

Invited Talk SYRS 1.4 Thu 16:30 H 0105

Mechanism of resistive switching in bipolar transition metal oxides — •Marcelo Rozenberg — CNRS - LPS, Universite de Paris-Sud, 91405 Orsay, France

Resistive random access memories (RRAM) composed of a transtition metal oxide dielectric in a capacitor-like structure is a candidate technology for next generation non-volatile memory devices. We introduce a model that accounts for the bipolar resistive switching phenomenom observed in many perovskite transition metal oxides. The numerical study of the model predicts that strong electric fields develop in the highly resistive dielectric-electrode interfaces, leading to a spatially inhomogeneous distribution of oxygen vacancies and a concomitant nonvolatile resistance memory effect. The theoretical results of the model are validated by successful comparison with non-trivial resistance hysteresis loops measured in cuprate YBCO and manganite PCLMO samples. Insights from the model simulations are used to propose a novel multi-level and non-volatile memory cell. We shall present results for an implementation of a 6-bit multi-leve memory cell device.

Invited Talk SYRS 1.5 Thu 17:00 H 0105

Resistive switching memories: Mechanisms, modeling and scaling — •Daniele Ielmini — Dipartimento di Elettronica e Informazione and IUNET, Politecnico di Milano, Piazza L. da Vinci 32, 20133 Milano, Italy

Resistive switching memory (RRAM) devices are proposed as next mainstream technology for nonvolatile memories below the 10-nm node. However, to speed up the industrial development of RRAM, the research must still address several open issues, such as identifying a suitable select device, understanding the switching mechanism and predicting the device scalability.

In this talk, I will show experimental results for bipolar RRAM devices based on metal oxides (mostly HfO_x), evidencing that the switching mechanism is a temperature and field-activated ion migration. Based on these experimental evidences, I will provide an analytical model for resistive switching which can be applied to oxide-based RRAM and chalcogenide-based conductive bridge RAM (CBRAM). The model allows for space, time and energy extrapolation for future RRAM generations. The extension of the analytical approach to a self-consistent numerical model for ion migration will be shown. The scaling tradeoff with reliability, e.g. random telegraph noise and data retention, will be finally discussed.

SYRS 2: Poster: Resistive switching (jointly organized by DS, DF, KR, HL)

Time: Thursday 17:30–19:00 Location: Poster E

SYRS 2.1 Thu 17:30 Poster E

Electrical and thermal properties of phase change line cell devices — •Martin Wimmer, Lukas Küpper, and Martin Salinga — 1. Institut of Physics, RWTH Aachen University, Germany

The characteristic electronic properties of phase change materials are the reason for their recent success in electronic data storage devices. While the current versions of phase change memory are used as a replacement of Flash memory, the potential to write information within a nanosecond offers the opportunity to replace even DRAM with this non-volatile technology.

Within this work, electrical and thermal properties of lateral phase change line cells produced by electron beam lithography are studied. This low cost cell design provides excellent scalability down to tens of nanometers. Due to the easy variability of the line cell geometry the threshold and memory switching behaviour, in particular the threshold

field and the scalability of energy consumption, can be systematically investigated.

SYRS 2.2 Thu 17:30 Poster E

Numerical simulations of threshold switching effect in phase change memory devices — •Sascha Cramer, Martin Wimmer, and Martin Salinga — 1. Institut of Physics, RWTH Aachen University, Germany

Phase change materials are one of the most promising candidates for future universal memory technologies. In this class of materials information can be stored by using the huge contrast in electrical resistivity between the amorphous and crystalline phase. While the permanent switching is commonly understood as a structural change between those two phases, there exists another transient switching phenomenon. The latter is observed as a strong non-linearity in the current-voltage characteristic of the amorphous state: At a critical voltage a sudden drop of resistivity is observed, the so-called threshold switching. The physical understanding of this effect is still controversially discussed today. In this work numerical simulations are performed based on two different models (Ielmini*s Poole-Frenkel-model and an alternative generation-recombination-model) and compared with experimental data.

SYRS 2.3 Thu 17:30 Poster E

Resistance drift in amorphous phase change thin films — •Christian Dellen, Martin Wimmer, Rüdiger M. Schmidt, Martin Salinga, and Matthias Wuttig — 1. Institut of Physics, RWTH Aachen University, Germany

While phase change materials have been successfully applied in rewriteable optical data storage, they are also used for novel non-volatile electronic memory devices. The material has the ability to be switched within nanoseconds between two phases, which show large contrast in electrical resistivity. One approach to improve the information density of such a phase change memory device is to store several logic bits in one physical cell by distinguishing between different states of partial crystallization. For this so-called multilevel storage device it is important that the resistance of this device is stable over many orders of magnitude in time. While for the crystalline phase this condition is sufficiently fulfilled, the amorphous phase shows a strong time dependence of the resistance, the so-called resistance drift. In literature this effect is often ascribed to relaxation of mechanical stress or to a change of electronic defects. In this work experimental data of the resistance drift are analyzed for a variety of different phase change materials and compared to models reported in literature.

SYRS 2.4 Thu 17:30 Poster E

Continuum modeling of phase formation in phase change materials — •fatemeh tabatabaei[1], markus apel[2], and efim brener[1] — [1]Peter Grünberg Institut (PGI-2), Forschungszentrum Jülich, 52428 Jülich — [2]Access e.V., RWTH Aachen, 52072 Aachen

Recently, the use of phase change materials (PCM) in non-volatile rewritable memory devices has expanded substantially. For memory applications a stable crystalline and a metastable amorphous state can be utilized for the data recording.To obtain a quantitative understanding of the kinetics of writing and erasing data, gaining insights into the energy transport and phase boundary movement during the phase transformation is aimed. One of the governing parameters for the transformation kinetics is the mobility of the liquid-solid interface. However, only limited knowledge and models for it is available. We carried out phase field modeling as a continuum simulation technique in order to study rapid crystallization processes in AgInSbTe. We performed spatio-temporal simulations of the crystallization of a molten area in a PCM layer stack initiated by a laser pulse. We refined the simulation concerning experimental conditions for the measurement of the crystallization kinetics. Simulations are performed for different substrate temperatures, i. e. for temperatures close to the melting point of AgInSbTe down to the glass temperature when the amorphous state is involved. The effect of the interface mobility on the solidification kinetics is investigated. A non-linear dependence of the interface kinetic coefficient on temperature is necessary to explain the temperature dependent crystallization velocity observed in experiments.

SYRS 2.5 Thu 17:30 Poster E

Thermal Conductivity as sensor for defects in homoepitaxial SrTiO3 — •Thilo Kramer[1], Jonas Lindner[1], Stefanie Wiedigen[1], Manuel Feuchter[2], Marc Kamlah[2], Inga Knorr[1], Cynthia Volkert[1], and Christian Jooss[1] — [1]University of Göttingen, Institute for Materials Physics — [2]Forschungszentrum Karlsruhe, Instiute for Materials Research II

SrTiO3 is a promising material for various future applications in the fields of thermoelectric, oxide electronics or resistive switching, where the control of point defect structure is of high importance. Such defects control the strain and doping level, and, may be involved in resistive switching. Because a direct measurement of defect type and concentrations is difficult, we evaluate whether thermal conductivity can indirectly give access to the desired information via point defect induced phonon scattering. Thin homoepitaxial SrTiO3 films are fabricated with Ion Beam Sputtering. The balance between ion beam induced defect generation and dynamic healing and thus the resulting net defect concentration can be influenced by varying the deposition temperature. The temperature dependence of the thermal conductivity of the thin films is reliably measured by the 3w method in combination with finite element simulations of the thermal conditions. We present systematic study of thermal conductivity as a function of varying preparation conditions. X-ray diffraction, TEM and mechanical measurements allow for detailed insights into the degree of epitaxy and the stress strain state of the films. The combination of all used methods gives evidence that charge neutral Schottky defects are the dominating defect type.

SYRS 2.6 Thu 17:30 Poster E

Pulse length dependence of resistive switching in $Pr_{0.7}Ca_{0.3}MnO_3$ noble metal sandwich structures — •Björn-Uwe Meyer, Malte Scherff, Johannes Maier, Jörg Hoffmann, and Christian Jooss — Institute of Materials Physics, University of Göttingen, Germany

Time-resolved electric transport studies are an important approach for the analysis of the underlying mechanisms of resistive switching. Pulsed voltage experiments of sputtered $Pr_{0.7}Ca_{0.3}MnO_3$ films sandwiched by noble metal electrodes are performed with pulse length variation between 20ns and 1s in a temperature range between 300K and 165K. Due to the interaction of the opposing metal-oxide-interfaces in an asymmetric interface geometry, switching polarity inversion is observed. The inversion and the dependence of the switching amplitude on the pulse length can be used to demonstrate an equivalence of voltage amplitude and pulse duration. Especially, the switching amplitude strongly changes at lower temperature. These results will be compared with other findings such as a variation of electrode materials, device geometry and PCMO deposition parameters. Microstructure and chemical composition before and after switching is characterized for selected samples by transmission electron microscopy.

SYRS 2.7 Thu 17:30 Poster E

Multifunctional oxides and the influence of defects on the ferroic properties — •S. Gemming[1], T. Weissbach[2], M. Zschornak[1,2], H. Stöcker[2], D. C. Meyer[2], T. Leisegang[2,3], I. Ronneberger[1], and K. Potzger[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany. — [2]Institute of Physics, TU Bergakademie Freiberg, Freiberg, Germany. — [3]SAXRAY GmbH i.G., Dresden-Rossendorf, Germany.

Transition metal oxides exhibit many physical phenomena, among them ferroic properties such as ferroelasticity, ferroelectricity and ferromagnetism, or their combination in multiferroics. The stoichiometry of transition metal oxides depends on the oxygen partial pressure and changes conductivity and ferroic properties. Ternary/quaternary oxides are discussed, which correlate local defect-induced structure changes with changes of the elastic, polarization and magnetic properties. The microscopic interactions are determined by density functional theory as basis for more large-scale simulations with effective Hamiltonians. Oxygen vacancies in $SrTiO_3$ accumulate in an external electric field and reduce the hardness. For Sr/O excess $SrO(SrTiO_3)_n$ phases with additional SrO planes occur, which change the X-Ray reflectivity. Ion-irradiation triggers additional point defects which can form stable aggregates. In YMn_2O_5 several antiferromagnetic phases coexist with ferroelectricity; $YFeMnO_5$ exhibits only one commensurable ferrimagnetic phase. Based on spin-polarized DFT calculations a Heisenberg model yields the coupling constants of the two compounds and relates them to crystal-field interactions.

SYRS 2.8 Thu 17:30 Poster E

UHV-compatible setup for alcohol-assisted chemical vapor deposition of metals — •Fedor Strigunov, Volkmar Zielasek, and Marcus Bäumer — Universität Bremen, Institut für Angewandte und Physikalische Chemie, Leobener Str. NW2, 28359 Bremen, Deutschland

Due to the importance of thin metal films in the functionality of magnetic, superconductive, optical and microelectronic devices, there is high interest in chemical vapor deposition (CVD) techniques that fit industry requirements of reliability, sustainability and ease of use. So far, however, metal CVD had often been linked to toxic precursors or low quality of the resulting film.

A recently developed hydrogen-free approach to metal-CVD uses pulsed spray evaporation delivery of simple and commercially available non-toxic metal-organic precursors in alcohols [1]. We will present the design of a CVD reactor for pulsed spray deposition of metal organic precursors and alcohols that is integrated into an UHV system for thin film analysis. Sample transfer between the chambers for thin film preparation and for analysis via XPS, STM, LEED or IR spectroscopy can proceed without breaking vacuum. The results of preliminary experiments on the deposition of Co films on various substrates will be shown. The efficiency of the Co growth process and the quality of the resulting film depend on several parameters such as concentration of the precursors, deposition pressure, carrier gas flow rate, substrate temperature, deposition duration, spray pulse frequency and pulse width.

[1] P. A. Premkumar et al., Chem. Vap. Deposition, 13 (2007) 219.

SYRS 2.9 Thu 17:30 Poster E

Nonvolatile resistive switching in Au/BiFeO3/Pt — •Yao Shuai[1,2], Chuangui Wu[2], Wanli Zhang[2], Shengqiang Zhou[1], Danilo Bürger[1], Stefan Slesazeck[3], Thomas Mikolajick[3], Manfred Helm[1], and Heidemarie Schmidt[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, P. O. Box 510119, Dresden 01314, Germany — [2]State Key Laboratory of Electronic Thin Films and Integrated Devices, — [3]Namlab gGmbH, Nöthnitzer Strasse 64, 01187 Dresden, Germany

Nonvolatile bipolar resistive switching has been observed in an Au/BiFeO3/Pt structure, where a Schottky contact and a quasi-Ohmic contact were formed at the Au/BiFeO3 and BiFeO3/Pt interface, respectively. By changing the polarity of the external voltage, the Au/BiFeO3/Pt is switched between two stable resistance states without an electroforming process. The resistive switching is strongly dependent on the deposition pressure of the BiFeO3 thin films, and the resistive switching property of the Au/BiFeO3/Pt stack has been significantly improved by carefully tuning the oxygen pressure during the growth, and a large switching ratio of ~4500 has been achieved. The deposition pressure modifies the concentration of oxygen vacancies and the rectifying behavior of the Au/BiFeO3 junction, and consequently influences the resistive switching behavior of the whole stack.

SYRS 2.10 Thu 17:30 Poster E

Massive parallelisation in Phonon transport calculations — •Robert Henrich, Michael Czerner, Michael Bachmann, and Christian Heiliger — I. Physikalisches Institut, Justus Liebig University Giessen, D-35392, Germany

In the last years a huge progress was archived in fabrication of nanostructured materials. Typical nano structures are super lattices, quantum dots, and nano tubes. For many applications in such structures the control of the heat flow is an essential issue. The heat flow is carried by electrons and phonons whereas in semi-conductors the phonon contribution dominates. The calculation of the phonon heat flow in nano materials is quite challenging: Although the underlying physics are the same as for bulk systems, the number of simulated atoms are much higher since in nano materials the assumptions of periodic boundary conditions in all directions does not hold. A common tool to calculate phonon transport is the so called atomistic Green's function method [1]. We present a method to calculate phonon transport in systems that contain millions of atoms within a reasonable time. For this task the most time consuming calculations in the atomistic greens function method has to be parallelized with MPI to handle the extreme huge matrices. Furthermore we are using GPU's as a co-processor to gain an enormous speed up for the matrixoperations.

[1], W.Fisher, T.Mingo, N.Numerical Heat Transfer, Part B: 2007, 51, 333

SYRS 2.11 Thu 17:30 Poster E

Semi ab initio phonon tunneling calculations in Au/Slab/Au by using non equilibrium Green's function formalism — •Saeideh Edalati Boostan, Michael Bachmann, Michael Czerner, and Christian Heiliger — I. Physikalisches Institut, Justus Liebig University Giessen, D-35392, Germany

Heat can be conducted across a nanometer-sized vacuum gap something that was deemed impossible until 2010 [1]. In this work we performed ab initio calculations using the abinit package to obtain the interatomic force constants of gold separated by a vacuum slab. These force constants are used in the non equilibrium Green's function formalism to calculate the transmission function and the temperature dependence of the thermal conductivity in the linear ballistic response regime [2, 3]. We analyze the phonon transport across the vacuum slab as a function of the thickness of the vacuum slab.

[1] Igor Altfeder, Andrey A. Voevodin, and Ajit K. Roy, Phys. Rev. Lett. 105, 166101 (2010)

[2] S. Datta, Electronic Transport in Mesoscopic Systems, Cambridge Univeristy Press (1995)

[3] P. E. Hopkins, P. M. Noris, M. S. Tsegaye, and A. W. Ghosh, J. Appl. Phys. 106, 063503 (2009)

SYRS 2.12 Thu 17:30 Poster E

Measurements at a Thermoelectric Nanowire Characterisation Platform (TNCP) — •D. Kojda[1], R. Mitdank[1], Z. Wang[2], M. Kröner[2], P. Woias[2], and S.F. Fischer[1] — [1]Neue Materialien, Humboldt-Universität zu Berlin, D-10099 Berlin — [2]IMTEK, University of Freiburg, D-79110 Freiburg

Nanowires are expected to improve the thermoelectric efficiency [1]. To date, the thermoelectric characterisation of a single nanowire involving the measurements of the Seebeck coefficient, the electrical and the thermal conductivity remains challenging.

For this purpose IMTEK designed the **T**hermoelectric **N**anowire **C**haracterisation **P**latform (**TNCP**), which was established by the means of silicon micromachining [2]. It contains two symmetric Si cantilevers where the nanowire takes place in between. Thin Pt microheaters on each cantilever create a temperature gradient.

Aiming to determine the platforms' characteristics, we measured the specific I-V-curves of the heater and the wire contact points in the temperature range between 5 K and 295 K. We detected the temperature-dependant resistance and the generated temperature difference as a function of power. Starting with a residual resistance of 54 Ω, the heaters resistance increases linearly above 30 K up to 351 Ω at room temperature. Our next investigations will cover the applicability of dielectrophoresis in order to bridge the two cantilevers with a single wire.

[1] K. Nielsch *et al.*, Advanced Energy Materials, October 2011

[2] Z. Wang *et al.*, Transducers Conference, June 2011

SYRS 2.13 Thu 17:30 Poster E

Phase-Change materials as thermoelectrics — •Roland Sittner, Karl Simon Siegert, Felix Lange, and Matthias Wuttig — 1.Physikalisches Institut IA, RWTH Aachen, 52064 Aachen

Phase-change materials (PCMs) offer a unique combination of physical properties. They possess a high contrast in optical reflectivity and electrical resistivity and in addition a nanosecond switching capability between the amorphous and the crystalline state [1]. These properties make PCMs predestinated for the technological application in the field of data storage. Here they are already used as an active layer in rewritable optical data storage media (e.g. DVD±RW) and are promising candidates for the next generation of non-volatile electrical data storage applications (PRAM). Another potential field of application for PCMs are thermoelectrics (TEs). PCMs are close to common TE materials in their atomic composition and offer favourable low thermal conductivities in combination with high electrical conductivity values.

This work focuses on the potential of PCMs for thermoelectric applications by evaluating their figure of merit ZT. Several PC thin films were created by sputter deposition. The related physical properties κ, σ and S are measured with the 3ω method, the van der Pauw method and a self-made setup for determining the Seebeck coefficient. Special focus is set on the measurement of the thermal conductivity.

[1] Bruns et al., Appl. Phys. Lett. 95, 043108 (2009)

SYRS 2.14 Thu 17:30 Poster E

Thermal conductance of ballistic point contacts — •Alina Tittel, Thorben Bartsch, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik, Jungiusstr. 11, D-20355 Hamburg, Germany

We study the thermal conductance of ballistic point contacts that are realized as few nanometer long pillars. The pillars were fabricated using molecular beam epitaxy, with a combination of in situ local droplet etching and ex situ selective chemical wet-etching of a sacrificial layer [1]. They have typical length between 2 nm and 8 nm and diameters of about 100 nm. Because of the short pillar length, which is significantly

smaller than the phonon mean free path up to room temperature, the thermal conductance is dominated by ballistic thermal transport. [2] The fabrication technique allows for control of composition, geometry and density of the pillars. Here we present investigations of the influence of such modifications on the thermal conductance. The measurements were performed with the 3w method.

[1] Ch. Heyn et al., Appl. Phys. Lett. 98, 033105 (2011). [2] Th. Bartsch et al. submitted , published on arXive: http://arxiv.org/abs/1111.1164

SYRS 2.15 Thu 17:30 Poster E

Magnesium- and fluorine co-doping of vanadium dioxide films — •Marc K. Dietrich, Andreas Laufer, Angelika Polity, and Bruno K. Meyer — I. Physics Institute, Justus-Liebig-University Gießen, Heinrich-Buff-Ring 16, 35392 Gießen, Germany

Thermochromic Mg- and F-doped VO_2 thin films, which enable new possibilities as an intelligent window coating, were deposited by rf sputtering. The appliance of VO_2 for energy efficient fenestration is so far limited by some properties of the bulk material. The alternation of luminous transmittance of bulk VO_2, which is caused by a reversible metal-semiconductor phase transition, will appear at temperatures about 68°C. By doping with Mg or F this transition temperature can be decreased to practical values. Furthermore, the Mg-doping level is associated with a blue shift of the band gap energy and is connected with an increase of luminous transmittance.

SYRS 2.16 Thu 17:30 Poster E

Doped Amorphous Si/Ge Nanostructured Thin Films via Glancing Angle Deposition — •Jens Bauer, Christoph Grüner, and Bernd Rauschenbach — Leibniz-Institut für Oberflächenmodifizierung, Permoserstrasse 15, D-04318 Leipzig, Germany

The preparation of efficient thermoelectric nanomaterials is a big challenge in modern material science. Key research fields are the defined adjustment of structure geometry, size and orientation on one hand and the structural material optimization on the other hand. For this purpose we present PVD investigations on self-organized a-Si and a-Ge nanostructures by a recent nanofabrication technique, the glancing angle deposition (GLAD). Nanostructure shape and distribution can be controlled via the geometrical deposition parameters, i.e. the polar and azimuthal particle incidence angle. Multicomponent nanomaterials as up-right nanocolumns with incorporated axial Si/Ge multiheterojunctions are realized by sequential deposition and a fast azimuthal rotation speed. For structural material customization the amorphous materials were passivated by atomic hydrogen. The hydrogen incorporation was verified via effusion tests, X-ray reflection, SIMS and FTIR measurements. Furthermore, in situ B and Sb doping was investigated. SIMS analyses showed high doping levels up to the solid solubility limits. Hydrogen effusion experiments revealed no difference between continuous films and GLAD nanostructures. However, B doping was found to strongly enhance the hydrogen release. Since hydrogen effusion started at temperatures >320℃ in a-Si without doping, with B doping hydrogen released already above room temperature.

SYRS 2.17 Thu 17:30 Poster E

Thermoelectric transport coefficients of bismuth compound nanomaterials — •Daniel Huzel[1,2], Heiko Reith[1,2], Matthias C Schmitt[1,2], Friedemann Völklein[1], and Michael Huth[2] — [1]IMtech, Hochschule RheinMain, Am Brückweg 26, D-65428 Rüsselsheim — [2]Physikalisches Institut, Goethe-Universität, Max-von-Laue-Str. 1, D-60438 Frankfurt am Main

Thermoelectric transport properties show a strong dependency on composition, crystallinity and geometric structure of a sample. With a decrease in size and dimensionality the conductivity decreases, therefore nanostructures are a promising field for materials / structures aiming at a high thermoelectric figure of merit (ZT).

Our work focuses on the determination of the thermoelectric transport coefficients of bismuth and bismuth compound nanowires. We present the Z-Chip, a platform for the combined measurement of Seebeck-coefficient, thermal and electrical conductivity on a single thermoelectric nanowire which allows the characterization of ZT of the wire. Results of bismuth telluride nanowires are shown but the measurement platform can be used for different nanostructures as well.

Additionally, a setup for the steady-state measurement of cross-plane thermal conductivity for embedded nanowires is demonstrated. Results obtained by this method are presented as well.

With regard to future applications, stability and reliability results on bismuth antimonide films are also shown.

SYRS 2.18 Thu 17:30 Poster E

In-plane thermal conductivity measurements of ZnO-, ZnS-, and YSZ thin-films on glass substrates — •David Hartung, Florian Gather, Achim Kronenberger, Florian Kuhl, Bruno K. Meyer, and Peter J. Klar — I. Physikalisches Institut, Justus-Liebig-University, Heinrich-Buff-Ring 16, 35392 Giessen

In this work we present in-plane thermal conductivity measurements of ZnO-, ZnS-, and YSZ thin-films. Borosilicate glass with a thickness of 50 microns and low thermal conductivity for improving the signal to noise ratio was used as substrate material. The above different films are deposited by rf-sputtering and have a thickness of about 1 micron. Our approach is a steady-state measurement. A wide metal wire on the film is used as a heater and two parallel lying narrow wires at distances of 100 microns and 200 microns from the heater wire, respectively, serve as the temperature sensors. The wire structure design is transfered on to the thin films by photolithography and metal evaporation. Measurements of the in-plane thermal conductivities of the above mentioned materials are presented and compared with corresponding results in the literature.

SYRS 2.19 Thu 17:30 Poster E

Investigation of the thermal conductivity of $ZnO_{1-x}S_x$ thin films — •Florian Gather, Achim Kronenberger, Peter J. Klar, and Bruno K. Meyer — I. Physikalisches Institut, Justus-Liebig-University, Heinrich-Buff-Ring 16, 35392 Giessen

We investigated the thermal conductivity κ of rf-sputtered $ZnO_{1-x}S_x$ thin films. For a reliable measurement of the thermal conductivity of thin films, the 3ω-method is supposed to yield the best results. Measurements, performed using a self-constructed 3ω measurement system, show a reduced κ of the $ZnO_{1-x}S_x$ samples compared to bulk crystals. Using Raman spectroscopy we found indications for local phonon modes of oxygen in zinc-sulfide and sulphur in zinc-oxide, respectively. Presumably these local phonon modes cause the reduction of κ observed in the experiments.

SYRS 2.20 Thu 17:30 Poster E

Fabrication of a CuO/ZnO thin film thermoelectric generator — •Tobias Lind, Gert Homm, Peter J. Klar, Bruno K. Meyer, Achim Kronenberger, Torsten Henning, Daniel Reppin, and Stefan Lautenschlaeger — I. Physikalisches Institut, Justus Liebig University, Heinrich-Buff-Ring 16, 35392 Giessen

Cuprous oxide and zinc oxide are promising candidates for thermoelectric applications as an alternative to the well known Te-based thermoelectric materials, since they are stable up to high temperatures, environmentally friendly and available in abundance. A further advantage is their processability down to the micrometer range. Thin films of about 400 nm thickness were either CVD grown on MgO substrates or sputtered on glass substrates. These films were microfabricated by photolithography and wet chemical etching to create the p-type legs of a thermoelectric generator (TEG). In a second lithography and sputter depostion step the n-type legs of the TEG, created from 400 nm of ZnO, were placed in between the CuO legs to create the desired p-n-leg structure of the thermoelectric generator. The legs were connected by metallic microcontacts made from Ti/Au on ZnO or Au on CuO, respectively. First measurements of the thermoelectric voltage and the output power of the generator are presented.

SYRS 2.21 Thu 17:30 Poster E

Optimizing thermoelectric Properties: Microstructure Analysis of $Ag_{1-x}Pb_{18}Sb_{1+y}Te_{20}$ — •Susanne Perlt[1], Thomas Höche[2], Jayaram Dadda[3], and Eckhard Müller[3] — [1]Leibniz Institute of Surface Modification, Leipzig — [2]Fraunhofer Institute for Mechanics of Materials, Halle — [3]German Aerospace Center, Institute of Materials Research, Köln

The feasible recovery of waste-heat energy as it is generated by industrial and vehicle engines has led to increasing research interest in thermoelectrics (TE). In order to get TE materials with high performance, i.e. with a large figure of merit ZT, one needs to tune electronic and phononic properties. A promising candidate is the quaternary compound $Ag_{1-x}Pb_{18}Sb_{1+y}Te_{20}$ (Lead-Antimony-Silver-Tellurium, LAST) for applications in the mid-temperature range. While the self-organized nanostructures assumed to act as phonon scatterers decrease the lattice thermal conductivity κ_L, the volume fraction of Sb and Ag and their ratio in the matrix have a significant influence on the electronic properties of the material. This study reports microstructure investigations at the micrometer and nanome-

ter scale regarding SEM and TEM analysis, as well as measurements concerning TE properties. An attempt is made to derive a structure-property relationship.

SYRS 2.22 Thu 17:30 Poster E

Investigations on the $Ti_{0.5}Zr_{0.25}Hf_{0.25}NiSn_{1-x}Sb_x$ system. — •Michael Schwall and Benjamin Balke — Institute of Inorganic Chemistry and Analytical Chemistry, Johannes Gutenberg - University, Mainz

Heusler compounds with $C1_b$ structure were reported from several groups in Asia and the USA as suitable for thermoelectric applications. Thereby, is the best published Figure of Merit $ZT = 1.5$ for a n-type material was found in the $Ti_{0.5}Zr_{0.25}Hf_{0.25}NiSn_{1-x}Sb_x$ system and presented by Toschiba and Toyota already in 2005. Since then, nobody was able o reproduce these results. Now, we were able to - almost - reach their high ZT values. In this study, we investigated the reasons for this outstanding thermoelectric properties in the $Ti_{0.5}Zr_{0.25}Hf_{0.25}NiSn_{1-x}Sb_x$ system. The effect of the microstructure on the transport properties will be described in details. The authors gratefully acknowledge the financial support by the "thermoHeusler" Project (Project No. 0327876D) of the German Federal Ministry of Economics and Technology (BMWi).

SYRS 2.23 Thu 17:30 Poster E

Nano structuring of XCoSb based Heusler compounds with $C1_b$ structure as thermoelectric materials. — •Elisabeth Rausch, Michael Schwall, and Benjamin Balke — Institute of Inorganic Chemistry and Analytical Chemistry, Johannes Gutenberg - University, Mainz

This work reports on the experimental investigations of XCoSb (X= Ti, Zr or Hf) based Heusler compounds discussed as potential p-type thermoelectic materials. A lot of n-type materials are known and exhibt high ZT values (ZT_{max}=1.5), but there are only a few p-type materials which can achieve ZT values above 0.5. We tried to improve the thermoelectric properties by nano structring the materials. The samples were mechanical alloyed by means of a high energy ball mill. The thermoelectric properties could be enhanced due to the nano structuring of the material. We will present structural and physical properties of the synthized coumpounds including a complete high temperature thermoelectric characterisation. The authors gratefully acknowledge the financial support by the "thermoHeusler" Project (Project No. 0327876D) of the German Federal Ministry of Economics and Technology (BMWi).

SYRS 2.24 Thu 17:30 Poster E

Evolution of Si surface topography during ion beam erosion at high incidence angles — •Marc Teichmann, Jan Lorbeer, Frank Frost und Bernd Rauschenbach — Leibniz-Institut für Oberflächenmodifizierung e. V., Permoserstr. 15, D-04318 Leipzig

The self-organized pattern formation on Si(001) by low-energy ion beam sputtering at high incidence angels ($\alpha \geq 65$ deg) with and without sample rotation is studied.

At ion incidence angles between 65 deg and 85 deg, ripple patterns oriented perpendicular to ion beam direction evolve at low fluences. However, after a certain erosion time, isolated protuberances oriented parallel to the beam direction and with higher amplitude were formed. At a certain fluence the ripple structures vanish with increasing angle of incidence. The amplitude of these protuberances, or columnar structures increases continuously in the fluence range analyzed, i. e. up to $1.3 \times 10^{19}\,\mathrm{cm}^2$. These facets are suppressed if the samples are rotated where dot-like structures evolve. The height and size of the dots decreases with increasing rotational speed.

These observations suggest that the angle-dependent sputter yield Y is responsible for the formation of these columnar structures, that is also supported by TRIM.SP [1] calculations. At high angles the slope of the sputter yield curve is much larger than for small angles, i. e. small variations in the surface gradient produce large changes of Y and hence in the local erosion rate.

Support by DFG through FOR 845 is gratefully acknowledged.

[1] J. P. Biersack, W. Eckstein, Appl. Phys. A **34**, 73 (1984).

SYRS 2.25 Thu 17:30 Poster E

Pattern formation on ion beam eroded quartz glass surfaces — •Jan Lorbeer, Marc Teichmann, Frank Frost, and Bernd Rauschenbach — Leibniz-Institut für Oberflächenmodifizierung e. V., Permoserstr. 15, D-04318 Leipzig

The surface evolution quartz glass by low-energy ion beam erosion with and without simultaneous sample rotation is investigated. In detail the influence of the ion incidence angle ($\theta = 0-85$ deg), ion energy ($E_{ion} = 800 - 2000$ eV), ion species, fluence ($\Phi \approx 2 \times 10^{18} - 1.5 \times 10^{19}$ cm^{-2}) and speed of rotation ($N = 1/60 - 30$ rpm) were evaluated.

For the non-rotating samples ripple pattern starts to form at ion incidence angles between 40 and 50 deg. For increasing erosion times the ripple structures reveal a distinct faceting and coarsening. The faceting can be explained by gradient dependent sputtering as an important topography evolution mechanism on fused silica [1]. The observed surface coarsening is explained by the contribution of reflected ions resulting in an incessantly vanishing of smaller facets [2].

These experiments where repeated with substrate rotation. It is shown, that the size of the emerging surface features decreases with increasing speed of rotation. The correlation between the speed of rotation and the emerging pattern allows an insight to the associated time scale of the underlying mechanism and the growth kinetics.

Support by Deutsche Forschungsgemeinschaft through Forschergruppe 845 is gratefully acknowledged.

[1] J. Völlner et. al., J. Appl. Phys. **109**, 043501 (2011)
[2] W. Hauffe, Phys Status Solidi A **35**, K93 (1976)

SYRS 2.26 Thu 17:30 Poster E

Optical investigation of Au coated nanostructured surfaces — •Tammo Böntgen[1], Jan Lorbeer[2], Marc Teichmann[2], Frank Frost[2], Rüdiger Schmidt-Grund[1], Michael Lorenz[1], and Marius Grundmann[1] — [1]Universtät Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, Germany — [2]Leibniz-Institut für Oberflächenmodifizierung e.V., Permoserstr. 15, Leipzig, Germany

Nanoscale ripple pattern on SiO_2 and Al_2O_3 surfaces were formed with low-energy ion beam erosion ($E_{ion} < 2$ keV) at oblique ion incidence angles. Depending on process parameters (ion species, erosion time, ion energy,) ripple pattern with different wavelengths and amplitudes are formed. Using spectroscopic ellipsometry an anisotropy in the structures optical response was found. This anisotropy is only visible if the wavelength of the light is on the same scale as the periodicity of the pattern. By coating the surface with a thin gold film, the present plasmon resonances transfer the structural anisotropy to a dielectric anisotropy. This manifests in a shift of the resonance frequency depending on the in-plane orientation of the sample. For Au plasmonic structures deposited on patterned surfaces we found a distinct resonance frequency for k parallel and perpendicular to the ripple pattern. The wavelength of the pattern also affects the strength of the anisotropy. For structures with a wavelength of ≈100 nm only a very weak anisotropy is observed whereas the anisotropy is much stronger for structures with a shorter wavelength.

SYRS 2.27 Thu 17:30 Poster E

Saturation of Plastic Deformation by Swift Heavy Ion Irradiation: Ion Hammering vs. Surface Effects — •Redi Ferhati[1], Knut Dautel[1], Monika Fritzsche[2], and Wolfgang Bolse[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart — [2]Helmholtz-Zentrum Dresden-Rossendorf

Swift heavy ion (SHI) induced plastic deformation is a subject of current research and scientific discussion. This *Ion Hammering* phenomenon was first observed 30 years ago in amorphous materials like metallic glasses [1]. About 10 years ago, Feyh et al. [2] have shown that stress generation and *Ion Hammering* result in self-organization of thin NiO-films on Si-wafers into a sub-micron lamellae-like structure under grazing angle irradiation. The growth of the lamellae was found to saturate as soon as they have reached a thickness of a few hundreds of nm. Here we will show our latest results on the restructuring of pre-patterned thin oxide films by SHI under various irradiation conditions. The experiments were performed by employing (in-situ) scanning electron microscopy [3], and were complemented by (in-situ) energy dispersive x-ray analysis and atomic force microscopy. As we will show, the saturation behavior can be understood as a competition of *Ion Hammering* and surface energy effects, while the unexpected fact, that the initially crystalline films undergo *Ion Hammering* can possibly be attributed to oxygen loss and thus amorphization during irradiation. [1] S.Klaumünzer et al., Phys. Rev. Lett. 51 (1983), [2] W. Bolse et al., Appl. Phys. A77 (2003), [3] S. Amirthapandian et al., Rev. Sci. Instr. 81 (2010)

SYRS 2.28 Thu 17:30 Poster E

Manipulating the aspect ratio of Si surface nanopattern with low energy ion sputtering and reactive ion etching —

Hans Hofsäss, •Kun Zhang, Ulrich Vetter, Omar Bobes, and Christoph Brüsewitz — II. Physikalisches Institut, Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

A periodic self-forming surface nanostructure can be produced with low energy ion sputtering. The wavelength of such nanopattern can be controlled very well, by varying the energy and the incident angle of ion-beam. A low energy $N_2{}^+$ ion beam produces not only nanoripples on Si surface, but also forms a thin silicon nitride layer on the ridges of the ripples. This thin silicon nitride layer has a thickness from some nm to 20 nm (depending on the ion energy and the incident angle) and acts as an inert nanomask for reactive ion etching process, resulting in formation of deep grooves [1]. The depth of the grooves depends on the etching time. By combining the low energy $N_2{}^+$ ion beam sputtering and reactive ion etching, the formation of surface nanopattern with controllable average values of wavelength, ridge width and groove depth on Si surface can be realized. This surface nanostructured silicon with controllable features could be widely used in nanotechnology, including so-called black silicon for solar cells. Here, we will report on the formation of nanoripple patterns by low energy $N_2{}^+$ ion beam ($\leq$ 10keV), and the modification of these nanopatterns by reactive ion etching. In addition, the optical properties of the nanostructured silicon surfaces will be discussed. [1] V. K. Smirnov et al., Nanotechnology 14 (2003)709.

SYRS 2.29 Thu 17:30 Poster E

Ripple pattern formation on single crystalline magnesium oxide. — •Omar Bobes, Hans Hofsäss, and Kun Zhang — II. Physikalisches Institut, Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Magnesium oxide MgO is a highly ionic bound crystal with cubic rock salt structure. Because of its high ionicity MgO is almost impossible to amorphize by ion irradiation. MgO could therefore act as a model system to investigate pattern formation by ion beam erosion on a crystalline substrate. Furthermore, the sputter yield is quite low and therefore MgO could be also a model system to investigate the role of sputtering itself for pattern formation. We have irradiated single crystalline MgO samples at 60° incidence angle with 1 keV Ar^+- and O_2^+-ions at room temperature. The sputter yield under these conditions is 3.5 for oxygen and 4.2 for magnesium. The maximum projected ion range is only about 3 nm. The as grown samples were flat with rms roughness $<$ 0.7 nm. Only μm wide weak wavy structures could be seen in AFM. After irradiation with fluence of 1*10^{18} Ar/cm^2 a complex ripple structure with rms roughness of 5.3 nm and maximum ripple amplitudes of 10-20 nm are observed. The pattern consists of ripples with up to 400 nm in length oriented perpendicular to the projected ion beam direction. The width of the ripples varies between about 30 nm and 100 nm. For O_2^+-irradiation, dot-pattern appears at the ion fluence of 1*10^{18} Ar/cm^2. With increasing the ion fluence, these dots tend to orient along the direction perpendicular to ion-beam. The pattern formation is discussed based on existing models.

SYRS 2.30 Thu 17:30 Poster E

Influence of Phase Separation for Surfactant Driven Pattern Formation during Ion Beam Erosion — Hans Hofsäss, •Kun Zhang, Ulrich Vetter, Omar Bobes, Andre Pape, Hans-Gregor Gehrke, and Marc Brötzmann — II. Phys. Institut, Uni Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

We will present results on metal surfactant driven self-organized pattern formation on surfaces by ion beam erosion, with a focus on the role of phase separation for the initial steps of pattern formation. Si substrates were irradiated with 5 keV Xe ions at normal incidence and ion fluences up to 5*10^{17} Xe/cm^2 under continuous deposition of surfactant atoms. In the absence of such surfactants uniform flat surfaces are obtained, while in the presence of Fe and Mo surfactants pronounced patterns like dots, combinations of dots and ripples with wavelengths around 100 nm are generated [1]. The surfactant coverage and deposition direction determine the pattern type and the pattern orientation, respectively. A critical steady-state coverage for onset of dot formation and onset of ripple formation is in the range of 10^{15} and 5*10^{15} /cm^2. The steady-state surface region consists of a thin amorphous metal silicide layer with high metal concentration in the ripple and dot regions. Pattern formation is explained by ion induced diffusion and phase separation of the initially flat amorphous silicide layer and subsequent ion beam erosion with composition dependent sputter yield. To investigate the role of initial phase separation we additionally compare the pattern formation for different other metal surfactants. [1] H. Hofsäss et al., New J. Phys. 13 (2011) 013033

SYRS 2.31 Thu 17:30 Poster E

Transport anisotropy of $LaAlO_3/SrTiO_3$ interfaces on chemically patterned $SrTiO_3$ — •Michael Foerster[1], Romain Bachelet[1], Vladimir Laukhin[1,2], Josep Fontcuberta[1], Gervasi Herranz[1], and Florencio Sanchez[1] — [1]Institut de Ciència de Materials de Barcelona ICMAB-CSIC, Campus de la UAB, 08193 Bellaterra, Catalonia, Spain — [2]Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Catalonia, Spain

A few years ago high mobility electronic transport was found at the interface between the wide bandgap insulators $SrTiO_3$ and $LaAlO_3$ [1]. This conductive layer is confined to a few unit cells around the interface and it appears when $LaAlO_3$ layers with thickness above 3-4 unit cells are grown on $SrTiO_3$. It is known that TiO_2/LaO interfaces are conductive, while SrO/AlO_2 interfaces are insulating.

Here we exploited this way to control the interface properties to produce large scale functional nanostructures. TiO_2/AlO - SrO /LaO_2 modulated interfaces have been prepared using thermally treated $SrTiO_3$ surfaces with self-organized patterned chemical termination. The interface transport properties are found to be controlled according to these interface patterns. While the influence of the interface topology, e.g. terrace steps, is negligible, a strong transport anisotropy is observed when large-scale well oriented chemical patterns are realized. Our results show that bottom-up engineering of the interface chemical composition is a suitable strategy to influence the transport properties on large scales.

References [1] A. Ohtomo and H.Y. Hwang, Nature 427, 423 (2004).

SYRS 2.32 Thu 17:30 Poster E

Deposition of ZnO on Micro-structured Electrodes for the Characterization as a Field Effect Transistor — •Martina Stumpp, Christopher Keil, and Derck Schlettwein — Justus-Liebig-Universität Gießen, Institut für Angewandte Physik, Heinrich-Buff-Ring 16, D-35392 Gießen

Zinc oxide (ZnO) films were electrodeposited in pulses of controlled current on micro-structured silver and gold electrodes on insulating SiO_2 on Si wafers using aqueous solutions of 0.1 M $Zn(NO_3)_2$. The growth of ZnO crystals on top of the metal fingers and between the fingers on the SiO_2 was analyzed. In some cases the film deposited between the fingers was conductive enough to even induce deposition on neighboring fingers which were not connected to the potentiostat. Depending on the applied current density, a different concentration profile of the precursors in solution was established leading to ZnO films with different surface morphologies. The deposited ZnO within the gaps of the microstructures formed a thin semiconducting film which subsequent to the deposition served as active layer of a field-effect transistor (FET). Electrical measurements were performed in different environments, in order to characterize the efficiency of the ZnO layer as a transistor channel.

SYRS 2.33 Thu 17:30 Poster E

Diffusion-controlled Electrochemical Growth of Porous ZnO on μ-structures — •Christian Lupo and Derck Schlettwein — Justus-Liebig-Universität Gießen, Institut für Angewandte Physik, Heinrich-Buff-Ring 16, D-35392 Gießen

Porous ZnO films were prepared by electrochemical deposition on interdigitated microstructures of gold-, silver- or platinum band electrodes. The electrodeposition was realized at a constant electrode potential of a rotating electrode from an aqueous $ZnCl_2$ solution in the presence of the xanthene dye $EosinY$. The deposition conditions were kept constant, except the deposition time and the rotation speed. The interdigital electrode size, gap width and the number of electrode bands were varied. The growth of ZnO was characterized by the observed deposition current and by scanning electron microscopy. The comparison with a model of spherical diffusion reveals limitations of mass transport towards the edges of the bands during extended growth. Application of this model to the process of electrochemical deposition provides useful contributions to the further development towards a controlled growth of semiconducting oxide films on microelectrodes. Additional options and limitations of the model in this respect will be discussed.

SYRS 2.34 Thu 17:30 Poster E

Plasma functionalization of self-organized Polystyrene Nanospheres — •Lienhard Wegewitz[1], Alexandra Prowald[2], Sebastian Dahle[1], Oliver Höfft[2], Frank Endres[2], and Wolf-

gang Maus-Friedrichs[1] — [1]Institut für Energieforschung und Physikalische Technologien, TU Clausthal, Leibnizstr. 4, 38678 Clausthal-Zellerfeld, Germany — [2]Institut für Mechanische Verfahrenstechnik, TU Clausthal, Arnold-Sommerfeld-Str. 6, 38678 Clausthal-Zellerfeld, Germany

Polystyrene nanospheres are currently under investigation as litography masks and templates for the production of hollow inorganic spheres which have promising applications in catalysis and energy storage. In this regard the chemical functionalization and stabilization of the polystyrene framework is crucial.

Thin films of ordered polystyrene nanospheres with diameters of about 600 nm have been exposed to dielectric barrier discharges in different atmospheres and were subsequently chemically treatet in DMDCS and OMCTS. For the investigation of each treatment X-Ray Photoelectron Spectroscopy (XPS) and Atomic Force Microscopy (AFM) are applied. The plasma treatment of the spheres in oxygen yields a significant increase of carbon-oxygen bonds at the surface whereas a silane-plasma covers the spheres with a closed silicon nitride layer. After the wet chemical treatment silicon dioxide is detectable at the surface. Furthermore first experiments of electrochemical deposition with modified nanospheres as substrate will be shown.

SYRS 2.35 Thu 17:30 Poster E

Nanopatterning by molecular polygons — •Stefan-Sven Jester, Eva Sigmund, and Sigurd Höger — Rheinische Friedrich-Wilhelms-Universität Bonn, Kekulé-Institut für Organische Chemie und Biochemie, Gerhard-Domagk-Str. 1, 53121 Bonn, Germany

Self-assembled monolayers of shape-persistent macrocycles at the solid/liquid interface (here: 1,2,4-trichlorobenzene/HOPG) are investigated by scanning tunneling microscopy. The macrocycles are accessible from cyclooligomerization of the respective half-rings and subsequent separation of the respective crude product. The chemical structure includes dithiophene corner units connected via linear phenylene-ethynylene-butadiynylene rod units. The resulting cyclooligomers (of oligomerization degree n = 3-6) can be viewed as equilateral two-dimensional polygons with three to six sides and diameters in the range of 2-5 nm. The distinct shapes allow the formation of predictable surface patterns with lateral periodicities of up to 19 nm. The results include the 2D crystallization of molecular pentagons as well as the formation of binary mixtures of triangles and hexagons and thus provide an insight into how the symmetry of molecules is translated into periodic structures. [1] S.-S. Jester, E. Sigmund, S. Höger, *J. Am. Chem. Soc.* **2011**, *133*, 11062.

SYRS 2.36 Thu 17:30 Poster E

Phase Change of Tetrahedral Amorphous-Carbon by Low Energy Electrons in a Scanning Tunnelling Microscope — •Frederik Klein and Thomas Mühl — Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden

Low energy electron-based energy deposition in tetrahedral amorphous-carbon thin films by a scanning tunnelling microscope leads to a local phase change of the carbon. Both the mass density and the electrical resistivity are reduced indicating a graphitization. We expose nano-sized surface areas to field emitted low energy electrons under high vacuum conditions and investigate the temperature and electron energy dependence of the carbon phase change process. Supplementary topography measurements are performed by atomic force microscopy.

SYRS 2.37 Thu 17:30 Poster E

Deep X-Ray Lithography at DELTA — •Thorsten Brenner, Daniela Lietz, Michael Paulus, Christian Sternemann, and Metin Tolan — Technische Universität Dortmund/DELTA, 44221 Dortmund, Germany

DELTA (Dortmund, Germany) is a synchrotron light source with a electron energy of 1.5 GeV and a maximum current of 130 mA. DELTA beamline BL-1 is dedicated to deep x-ray lithography (DXRL). DXRL is a method to produce various microstructures with a height up to several millimeters. Microstructures are applied in optics, micro mechanics, fluidic, or medical devices. It is possible to reach a high aspect ratio of about 100 and a lateral resolution up to 2 μm for microstructures using DXRL [1]. A well-established process for production of microstructures using lithography is the LIGA process. It includes the process steps (xray) lithography, electroplating, and molding. The aim is to produce microparts with high quality. For that reason silicon wafers with SU-8 photoresist are exposed and chemically developed. Here, process parameters (x-ray spectrum, mask types, dose, post exposure bake) are tuned for optimization of exposure process. SEM images are made to determine aspect ratio, roughness of surfaces and walls and adhesion between substrate and resist. Furthermore, a new endstation for BL-1 at DELTA is under construction. Here, improvements for the exposure process are of central interest.

[1] V. Saile, U. Wallrabe, O. Tabata, J.G. Korvink, O. Brand, G.K. Fedder, C. Hierold (Eds.):, LIGA and its applications, Wiley-VCH (2009).

SYRS 2.38 Thu 17:30 Poster E

Simulation-free determination of structural grating parameters with GISAXS — •Jan Wernecke, Michael Krumrey, and Frank Scholze — Physikalisch-Technische Bundesanstalt (PTB), Abbestr. 2-12, D-10587 Berlin

New technologies such as next-generation semiconductor and lithography techniques rely on complex surface structures with characteristic dimensions in the nanometre range. The functionality of such structures depends greatly on their feature size, thus, dimensional nanometrology is essential for precise control of nanostructured devices. Grazing Incidence Small Angle X-ray Scattering (GISAXS) is a tool for non-destructive length measurement in the nanometre range. Structure parameter retrieval from GISAXS scattering data generally requires simulation of the morphology due to the loss of phase information during image acquisition. Here we present an approach to obtain dimensional parameters of highly ordered surface structures directly from the scattering data without the need of simulation. Line gratings have been investigated with GISAXS and important parameters such as line and groove width, etching depth and period length can be obtained from scattering images by Fourier transformation. The analysis method was applied to different test grating structures as well as to simulated scattering patterns for validation. The experiments were performed at the Four-Crystal Monochromator (FCM) beamline in the PTB laboratory at the electron storage ring BESSY II using the SAXS setup of the Helmholtz-Zentrum Berlin (HZB).

SYRS 2.39 Thu 17:30 Poster E

Hierarchical Fabrication of Gecko-Mimicking Nano- and Microstructures by Hot Embossing and Hot Pulling — •Guénola Etienne, Michael Röhrig, Farid Oulhadj, Marc Schneider, Matthias Worgull, and Hendrik Hölscher — Karlsruher Institut für Technologie, Institut für Mikrostrukturtechnik, Postfach 3640, 76021 Karlsruhe, Deutschland

Hierarchical dry adhesives have been fabricated by hot embossing and hot pulling. Three levels of hierarchy mimic the gecko*s tiny tilted hairs which ramify into smaller structures covering its toes. Gecko-like adhesives offer a large amount of interesting applications, like pick-and-place systems or adhesive bandages inside the human body. However, such products have to be cost-effectively fabricated on large areas. This can be achieved by three-fold hierarchical dry adhesives, fabricated by hot embossing and hot pulling. These techniques enable the large-area fabrication of delicate polymer fibrils with high aspect ratios and diameters in the nanometer range. The fabricated structures are very compliant and achieve a high real contact area even to rough substrates. This causes high adhesion originating from van-der-Waals forces.

SYRS 2.40 Thu 17:30 Poster E

Laser thinning of titanium foils — •Regina Moser, Adrian Zacherle, Gerhard Heise, and Heinz Huber — Munich University of Applied Sciences, Lothstrasse 34, 80335 Munich, Germany

Electron beam guns with powers of approximately 100 kW are used for drying printing colors. The exit window for the electron beam consists of a 10 um thin titan foil. By thinning this window, electron transmission can be increased reducing the required acceleration voltage and power consumption for the electron gun. In fact, the minimal achievable thickness in an industrial rolling process is about 10 um. To keep the thin foils vacuum proof and to retain their mechanical stability, we are reducing the foils thickness locally using ultra short pulse laser ablation. For this purpose, different overlap values, fluencies and structuring strategies as well as sample mounting methods are examined to reduce foil thickness maintaining optimal surface quality and suppressing the observed foil benching.

SYRS 2.41 Thu 17:30 Poster E

Towards nanofocusing of attosecond XUV pulses — •Christian Späth[1], Alexander Guggenmos[2], Soo Hoon Chew[1],

Kellie Pearce[1], Michael Hofstetter[2], Jürgen Schmidt[1], and Ulf Kleineberg[1] — [1]Ludwig-Maximilians-Universität München, Fakultät Physik, 85748 Garching — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching

Attosecond pulses are finding more and more applications in measuring electron dynamics in atoms and molecules as well as electronic phenomena at surfaces and nanostructures. Nanofocusing of such pulses, for intensity enhancing at the sample position or for microscopic investigations, has not been successfully performed yet. We report on first towards diffractive polychromatic nanofocusing optics for XUV pulses at 90 eV photon energy.

Circular and elliptical zone plate structures have been written by advanced e-beam lithography in different resists (PMMA and HSQ) on ultrathin Si3N4 membrane windows.

Combining diffractive with refractive lenses on the same element results in increased usable bandwidth as required for focusing of sub femtosecond pulses. We will discuss the capabilities and limitations of these new optics and report first steps towards their experimental fabrication.

SYRS 2.42 Thu 17:30 Poster E

Damage formation in SiC ion implanted at 625 K — Elke Wendler[1], •Philipp Schöppe[1], Thomas Bierschenk[1], Steffen Milz[1], Werner Wesch[1], Nick G. van der Berg[2], Erich Friedland[2], and Johan B. Malherbe[2] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Physics Department, University of Pretoria, 0002 Pretoria, South Africa

Damage formation in 4H-SiC during ion implantation at 625 K is studied applying Rutherford backscattering spectrometry (RBS) in channeling configuration. For comparison two selected samples are analysed by cross section transmission electron microscopy (TEM). The results for dual implantation of the self-ions Si and C with the ratio 1:1 are compared with those obtained for Ag ion implantation. It is found that the evolution of damage as a function of the number of displacements per lattice atom proceeds in two steps and is almost independent of the ion species implanted. The second significant increase of the damage concentration starts obviously when the relative volume increase introduced by the implanted ions exceeds a critical value of about $6 \cdot 10^{-3}$. The damage produced at high ion fluences consists of point defect clusters and, probably, extended defects.

SYRS 2.43 Thu 17:30 Poster E

Ion beam induced density changes and plastic phenomena — Tobias Steinbach, •Emanuel Schmidt, Aaron Reupert, Mathias Schmidt, and Werner Wesch — Institute of Solid State Physics, Friedrich Schiller University Jena

Conventional ion irradiation is a well-established standard doping method in semiconductor processing for effective modification of electrical, mechanical, optical and chemical properties. However, in the low energy range the ions are stopped mainly by elastic scattering with the lattice atoms, which results in the displacement of target atoms and consequently in lattice damage. This ion beam induced damaging and amorphization process is accompanied by three different radiation-induced deformation phenomena: densification, radiation enhanced viscous flow and anisotropic deformation. The change of stress associated with these effects can be investigated during irradiation by observing the bending of freestanding thin crystalline samples by means of an in situ scanning laser reflection technique, which was recently established at the FSU Jena. We present ion beam induced stress evolution as a function of fluence for the irradiation of semiconductors (Ge and Si) as well as for insulators ($LiNbO_3$). In case of Ge and Si, the formation and relaxation of stress will be discussed as a function of fluence, nuclear energy deposition, projected ion range and irradiation temperature. In addition, the significant stress increase during beam interruption will be explained. In $LiNbO_3$, the observed stress evolution depends on the crystallographic orientation and will be discussed based on the preferential rearrangement of displaced lattice atoms.

SYRS 2.44 Thu 17:30 Poster E

Ion beam nano-patterned surfaces as biomaterials — •Falk Wyrwa, Steffanie Kosan, Jessica Hönig, Raphael Niepelt, Jana Sommerfeld, and Carsten Ronning — Institute of solid state physics, Friedrich Schiller University of Jena, Helmholtzweg 3, 07743 Jena

We prepared wave-like ripple structures in the nanometer scale on silicon and titanium dioxide substrates using low energy sputtering with nobel gas ions. The ions were accelerated up to 20 keV hitting the target with a specific angle about 70° to the surface normal. Different ripple wavelengths and amplitudes could be achieved by varying the acceleration energy and the erosion time, which will lead to new surface characteristics without changing the chemical stoichiometry. Especially a different adsorbent behavior for protein molecules was established, which also depends on the substrate material itself. Motivated by the many possibilities to apply silicon and titanium dioxide in the biomedical field, we investigated their interaction with the biological environment, which will be presented in this contribution.

SYRS 2.45 Thu 17:30 Poster E

Scanning ion irradiation of polyimide films — •Stefan Lücken, Yuri Koval, and Paul Müller — Department of Physics and Interdisciplinary Center for Molecular Materials (ICMM), Universität Erlangen-Nürnberg

Recently we found, that the surface of nearly any polymer can be converted into conductive material by low energy ion irradiation. The graphitized layer consists of nanometer sized graphene and graphite flakes [1]. In order to enhance the conductivity and to increase the size of the flakes we applied a novel method of scanning irradiation [2]. We investigated the influence of various irradiation parameters on the conductivity of the graphitized layer. We show, that the conductance vs. temperature can be described in terms of weak Anderson localization. At approximately 70 K, a crossover occurs from 2-dimensional to 3-dimensional behavior. This can be explained by a decrease of the Thouless length with increasing temperature. The crossover temperature can be used to estimate the thickness of the graphitized layer.

[1] I. Lazareva, Y. Koval, M. Alam, S. Strömsdörfer, P. Müller, Appl. Phys. Lett. 90, 262108 (2007)

[2] S. Lücken Scanning irradiation of polyimide by low-energy Ar ions Diplomarbeit, Erlangen (2011)

SYRS 2.46 Thu 17:30 Poster E

Modification of diamond-like carbon by ion irradiation — •Hanna Bukowska[1], Benedict Kleine Bussmann[1], Dirk Walecki[1], Florian Meinerzhagen[1], Marc Brötzmann[2], Hans-Gregor Gehrke[2], Hans Hofsäss[2], and Marika Schleberger[1] — [1]Universität Duisburg-Essen, Fakultät für Physik, Lotherstraße 1, 47057 Duisburg, Germany — [2]Universität Göttingen, Fakultät für Physik, Bunsenstraße 13, 37073 Göttingen, Germany

Diamond-like carbon (DLC) films were irradiated with swift heavy ion beams of varying energy and angles of incidence. The irradiation created electrically conducting tracks in the DLC-films by transforming sp^3 into sp^2 bonds. The DLC-films were analyzed by conductive atomic force microscopy. The images were used to identify ion impact sites, and I-V-Spectroscopy was applied to determine the conductivity of the tracks. High energy ions (2,2 GeV, Au^{25+}) created tracks with ohmic conductivity in the case of perpendicular bombardment, whereas grazing irradiation results in tracks that show mainly tunneling behavior. Low energy ions (100 MeV, Xe^{23+}) created tracks which exhibit tunneling behaviour after perpendicular incidence irradiation, but irradiation under 1° did not result in conductive tracks.

SYRS 2.47 Thu 17:30 Poster E

Monte Carlo Simulations of Silicon Sputtering by Argon Ions and an Approach for Comparison with Molecular Dynamic Results — René Feder, Frank Frost, Stefan G. Mayr, Horst Neumann, and •Carsten Bundesmann — Leibniz-Institut für Oberflächenmodifizierung e.V., Permoserstr. 15, 04318 Leipzig, Germany

Ion beam sputter processes deliver some intrinsic features influencing the growing film properties. Utilisation of these features needs to know how primary ion properties and geometrical process conditions influence the energy and spatial distribution of the sputtered and scattered particles. Beside complex experiments simulations are helpful to explain the correlation between primary parameters and thin film properties.

The paper presents first results of two simulation codes with completely different approaches: Monte Carlo (MC) calculations with help of the well known TRIM.SP code [1] and Molecular Dynamics calculations with an in-house developed code. First results of both simulation principles are compared for Argon ion bombardment on a Silicon target. Furthermore, a special experimental setup is outlined for validation of modelling. The setup allows the variation of ion beam parameters (ion species, ion energy, ion incidence angle on the target) and the

measurement of the properties of sputtered and scattered particles.

Financial support by DFG within project BU2625/1-1 is gratefully acknowledged.

[1] J. P. Biersack, W. Eckstein, Appl. Phys. A 34, 73 (1984)

SYRS 2.48 Thu 17:30 Poster E

Tuning the conductivity of vanadium dioxide films by swift heavy ion irradiation — •Paul Ehrhardt[1], Hans Hofsäss[1], Hans-Gregor Gehrke[1], Johann Krauser[2], Christina Trautmann[3], and Shriram Ramanathan[4] — [1]II. Physikalisches Institut, Fakultät für Physik, Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Hochschule Harz, University of Applied Sciences, Friedrichstraße 57-59, 38855 Wernigerode, Germany — [3]Gesellschaft für Schwerionenforschung, Planckstrasse 1, 64291 Darmstadt, Germany — [4]Harvard School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

We demonstrate the generation of a persistent conductivity increase in vanadium dioxide thin films by irradiation with swift heavy ions at room temperature. VO2 undergoes a temperature driven metal-insulator-transition (MIT) at 67 °C. After the ion irradiation the conductivity of the films we observe a strong increase in conductivity below the transition temperature proportional to the ion fluence. This change in conductivity is persistent and remains after several cycles of heating. Low temperature measurements down to 15 K show no further MIT below room temperature. Although the conductivity increase after irradiation at such low fluences is due to single ion track effects, atomic force microscopy (AFM) measurements do not show surface hillocks, which are characteristic for ion tracks in other materials. AFM measurements with conducting tip give no evidence for conducting ion tracks but indicate the existence of conducting regions around poorly conducting ion tracks, possible due to stress generation.

SYRS 2.49 Thu 17:30 Poster E

Ion beam assisted deposition of nano-structured C:Ni films — G. Abrasonis[1], M. Krause[1,2], A. Mücklich[1], R. Heller[1], K.-H. Heinig[1], •S. Gemming[1], and W. Möller[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany. — [2]Institute of Physics,TU Dresden, Dresden, Germany.

Nanostructures influence material properties dramatically due to size, shape and interface effects. Thus the control of the structure at the nanoscale is a key issue in nanomaterials science. The interaction of hyperthermal ions with solids is confined to the nanometer scale. Thus, it can be used to control the morphology evolution during multiphase film deposition. Ion-induced displacements occur in a thin surface layer of the growing film where they increase the atomic mobility for the phase separation. Here the growth-structure relationship of C:Ni (~15 at.%) nanocomposite films grown by oblique incidence (~45°) ion beam assisted deposition is reported. The influences of the flux of an assisting Ar+ ion beam (0-140 eV) as well as of an elevated substrate temperature have been studied. The formation of elongated nickel nanoparticles is strongly promoted by the ion beam assistance. Moreover, the metal nanocolumns no longer align with the advancing surface, but with the incoming ions. A window of conditions is established within which the ion assistance leads to the formation of regular composition modulations with a well defined periodicity and tilt. As the dominating driving force for the pattern formation is of physical origin, this approach might be applicable to other immiscible systems.

SYRS 3: Resistive switching I (jointly organized by DS, DF, KR, HL)

Time: Friday 9:30–10:45 Location: H 0111

SYRS 3.1 Fri 9:30 H 0111

Ab-initio studies of metal-insulator transitions in defective perovskites — •Gustav Bihlmayer and Kourosh Rahmanizadeh — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Resistive switching in perovskite materials can be triggered by a variety of external stimuli, like electric fields or oxygen partial pressure. While the role of oxygen defects for the electronic transport is in many cases established, the nature of the metal-insulator transition has still to be explored. Density functional theory calculations including strong correlation effects on a model level can help to gain an understanding here.

We investigate the transition between an insulating state of a correlated, localized level and a partially filled conductive band as function of electron concentration. The band filling can be controlled in a chemical way or via electric fields. A ferroelectric polarization can screen or enhance the effects at the boundaries of a ferroelectric material. We study the localization of defect states in model systems of structurally simple perovskites like $SrTiO_3$ or $PbTiO_3$ to gain a coherent picture of the conductive states that are manipulated in the resistive switching process.

Financial support of the EU grant NMP3-LA-2010-246102 (IFOX) is gratefully acknowledged.

SYRS 3.2 Fri 9:45 H 0111

Elucidation of the resistive switching in $SrTiO_3$ MIM-structures by μXANES — •Christian Lenser[1,2], Alexei Kuzmin[3], Alexandr Kalinko[3], Juris Purans[3], Rainer Waser[1,2,4], and Regina Dittmann[1,2] — [1]Peter Grünberg Institut 7, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich-Aachen Research Alliance, Section Fundamentals of Future Information Technology (JARA-FIT), Germany — [3]Institute of Solid State Physics, University of Latvia, Kengaraga Street 8, LV- 1063 Riga, Latvia — [4]Institut für Werkstoffe der Elektrotechnik, RWTH Aachen, 52056 Aachen, Germany

The resistive switching effect in Fe-doped $SrTiO_3$ thin films is investigated on 100 μm^2 metal-insulator-metal (MIM) structures by chemical mapping in the μm regime. X-ray absorption fine structure (XAFS) - measured at beamline ID03, ESRF - with a x-ray beam focused to several μm provides information about the absorption fine structure modulations at the Fe K-edge. The increase of pre-edge intensity characteristic of oxygen vacancies in the first coordination shell of the transition metal dopant shows the films to be highly oxygen deficient after growth. In addition to an increase of the Fe-$V_O^{\bullet\bullet}$ concentration over the whole electrode area after electroforming, μm-sized mapping of a MIM-structure reveals the location of the conducting filament by a strong local change in the absorption edge, which is localized to a size of the order of 1 μm. The change of the absorption characteristics is interpreted with full multiple-scattering XANES simulations, suggesting oxygen vacancy clustering around Fe as the likely explanation.

SYRS 3.3 Fri 10:00 H 0111

A ferroelectric switchable tunnel junction: $KNbO_3/SrTiO_3$ — •Kourosh Rahmanizadeh, Gustav Bihlmayer, Daniel Wortmann, and Stefan Blügel — Peter Grünberg Institut (PGI-1) & Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The properties of thin oxide films and multilayers are strongly influenced by defects and, therefore, can be controllably tuned by the defect concentration at the interface. For example, due to the charge discontinuity at the $SrTiO_3$/KO-$KNbO_3$-NbO_2/$SrTiO_3$ interface only one direction of polarization in $KNbO_3$ film is stable. A switchable polarization in $KNbO_3$ can be realized by creating (oxygen) defects at the interfaces.

We carried out density functional theory (DFT) calculations based on the full potential linearized augmented planewave (FLAPW) method as implemented in the `FLEUR` code [1] for studying the polar interface $SrTiO_3/KNbO_3$ and a $SrRuO_3/SrTiO_3/KNbO_3$ tunnel junction. The electronic transport properties of the switchable multiferroic $SrRuO_3/SrTiO_3$/KO-$KNbO_3$-$NbO_3/SrTiO_3/SrRuO_3$ heterostructure have been investigated using an embedded Green-function approach [2]. A strong dependence of the (magneto electric) transport properties on the polarization is observed. The work was conducted under the auspices of the IFOX consortia under grant agreement NMP3-LA-2010-246102.

[1] http://www.flapw.de

[2] D. Wortmann, H. Ishida, and S. Blügel, PRB **66**, 075113 (2002)

SYRS 3.4 Fri 10:15 H 0111

Resistive switching in different forming states of Ti/$Pr_{0.48}Ca_{0.52}MnO_3$ junctions — •Chanwoo Park[1], Anja

Herpers[1], Rainer Bruchhaus[1], Johan Verbeeck[2], Ricardo Egoavil[2], Francesco Borgatti[3], Giancarlo Panaccione[4], Francesco Offi[5], and Regina Dittmann[1] — [1]PGI-7, FZ Jülich — [2]EMAT, University of Antwerp, Belgium — [3]ISMN-CNR, Bologna, Italy — [4]Laboratorio Nazionale TASC-INFM-CNR, Trieste, Italy — [5]CNISM and Dipartimento di Fisica, Università Roma Tre, Rome, Italy

We investigated the resistive switching (RS) characteristics of $Ti/Pr_{0.48}Ca_{0.52}MnO_3$ (PCMO) junctions. RS characteristics were observed after a first forming (1stF) procedure, which changes the initial resistance state to a high resistance state (HRS) which shows a clear area dependence. By performing Hard X-ray Photoelectron Spectroscopy for different resistive states, we found a change of the Ti2p peak intensity after the 1stF which is associated with the formation of TiO_2 at the interface. Moreover, the shape and position of the Mn2p peak hints on the reduction of Mn. The formation of TiO_x at the Ti/PCMO interface after the 1stF was confirmed by cross-sectional Transmission Electron Microscope investigations. The results indicate that the 1stF step is related to a redox process at the Ti/PCMO interface. Moreover, we were able to perform a second forming step which changes the HRS to the low resistance. The area dependence disappeared after the second forming. This implies that conducting filaments might form at the Ti/PCMO interface.

SYRS 3.5 Fri 10:30 H 0111

Remanent resistance changes in metal- PrCaMnO-metal sandwich structures — •Malte Scherff, Bjoern Meyer, Julius Scholz, Joerg Hoffmann, and Christian Jooss — Institute of Materials Physics, University of Goettingen, Germany

The non-volatile electric pulse induced resistance change (EPIR) seems to be a rather common feature of oxides sandwiched by electrodes. However, microscopic mechanisms are discussed controversially. We present electrical transport measurements of sputtered $Pr_{0.7}Ca_{0.3}MnO_3$ films sandwiched by metallic electrodes with variation of electrode materials, device geometry and PCMO deposition parameters. Cross-plane transport measurements have been performed as function of temperature and magnetic field. Specifically, the transition from dynamic resistance changes due to non-linear transport to remanent switching is analyzed. By analyzing changes of magnetoresistance at low temperatures in different resistance states we aim for separation between interface and film contributions to switching. Comparing switching behavior in symmetric and asymmetric electrode configuration allows for identification of the active, single interface in the switching process and the origin of an observed switching polarity inversion[1]. The influence of excitation field and power on the switching characteristics of different noble metal electrodes is discussed. Samples from macroscopic devices and in situ stimulated sandwich structures were studied in a transmission electron microscope in order to investigate the induced structural, chemical and electronic changes. [1] M. Scherff et al, J.Appl.Phys. 110, 043718 (2011)

SYRS 4: Resistive switching II (jointly organized by DS, DF, KR, HL)

Time: Friday 11:00–12:30 Location: H 0111

SYRS 4.1 Fri 11:00 H 0111

Resistive switching mechanism of $Ti/HfO_2/TiN$ RRAM cells studied by nondestructive hard x-ray photoelectron spectroscopy — •Małgorzata Sowińska[1], Thomas Bertaud[1], Damian Walczyk[1], Christian Walczyk[1], Sebastian Thiess[2], Wolfgang Drube[2], and Thomas Schroeder[1] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt/Oder, Germany — [2]DESY, Notkestrasse 85, 22607 Hamburg, Germany

A variety of different metal-insulator-metal (MIM) multilayered structures reveal reversible changes in resistance upon applying bias voltages across the layers. The physical mechanism of this resistive switching effect in such MIM cells is mostly unknown up to nowadays, although different models depending on the switching behaviour (unipolar or bipolar) and the conducting path type (filamentary or interface) have been proposed. In order to identify whether the resistance variation in the $Ti/HfO_2/TiN$ system is related to local changes in the chemistry or to charge distribution we performed ex-situ and in-situ hard x-ray photoelectron spectroscopy (HAXPES) studies. This technique is well suited for investigating the buried interface of our resistive random access memory (RRAM) cell in a nondestructive way. In result, spectral differences observed between as-deposited and electrically switched devices lead us to the conclusion that the Ti/HfO_2 interface was modified, which can be associated with an interface-type model. Furthermore, we have also better revealed the impact of the current compliance on the HAXPES spectra of our device.

SYRS 4.2 Fri 11:15 H 0111

Pulse-induced resistive switching of CMOS embedded HfO_2-based 1T1R cells — •damian walczyk, christian walczyk, thomas bertaud, małgorzata sowińska, mindaugas lukosius, steffen kubotsch, thomas schroeder, and christian wenger — IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany.

Low-cost embedded nonvolatile memories (eNVMs) with high-density, high-speed, and low-power are of interest for many different system applications in Si-based CMOS technologies, including consumer electronics, high-end and mobile computing, various sensor and medical health care devices. The rising importance of embedded NVM technologies in recent years has pushed Resistance change Random Access Memory (RRAM) into the spotlight. However, despite numerous integration efforts, the driving mechanism for the resistive switching effect of HfO_2-based RRAM is still under debate [1]. Progress in the development has mainly been delayed due to the lack of control over the switching parameters. To achieve an application relevant endurance, the capability to control the resistance by an access device is addressed in this talk. Moreover, this work considers the pulse-induced resistive switching of memory cells with an area down to $1 \times 1\ \mu m^2$. It is observed that the pulse width range for the set process is between 60 ns and 80 ns while the reset encompasses a pulse width range of 10-30 μs. Due to the intrinsic current compliance of the access transistor, low set currents of 10 μA and reset currents of 1 μA are obtained.

[1] C. Walczyk et al., IEEE Trans. Electron. Devices, vol. 58, no. 9, pp. 3124-3131 (2011).

SYRS 4.3 Fri 11:30 H 0111

Resistive switching on HfO_2-based metal-insulator-metal structures: effects of the top metal electrode and the oxygen partial pressure — •Thomas Bertaud[1], Damian Walczyk[1], Christian Walczyk[1], Steffen Kubotsch[1], Malgorzata Sowinska[1], Thomas Schroeder[1], Christophe Vallée[2], Vincent Jousseaume[3], and Christian Wenger[1] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt Oder, Germany — [2]LTM Université Joseph Fourier, 17 Rue des Martyrs 38054 Grenoble, France — [3]CEA-LETI Minatec, 17 Rue des Martyrs 38054 Grenoble, France

Embedded nonvolatile memories (eNVM) are attractive for a growing number of applications. One promising candidate for next-generation eNVM is based on the electrically switchable resistance change between a high and a low resistive state of a metal-insulator-metal (MIM) structure, called resistance random access memory (RRAM). Due to the cost effectivity and BEOL compatibility with (Bi)CMOS technologies, this approach is highly attractive. In this talk, the resistive switching on HfO_2/bottom TiN based devices will be demonstrated. The work is focused on the impact of the top metal electrode on the switching behavior of the RRAM devices: Al, Hf and Ti (reactive non-blocking), and Cu, Pt and Au (non-reactive blocking) are used and lead to bipolar or unipolar switching, respectively [1]. The current and capacitance characteristics of the MIM diodes are studied by voltage sweeps and retention measurements under different gas ambient in order to highlight the effect of the oxygen partial pressure for a better understanding of the mechanism. [1] T. Bertaud et al., Thin Solid Films (2011).

SYRS 4.4 Fri 11:45 H 0111

A model for a non-volatile memory material: First principles study of Cu diffusion in α-cristobalite and α-quartz — •Martin Zelený[1], Jozsef Hegedüs[1], Adam. S. Foster[2], David. A. Drabold[3], Stephen. R. Elliott[4], and Risto. M. Nieminen[1] — [1]COMP/Dept. of Applied Physics, Aalto University School of Science, Espoo, Finland — [2]Dept. of Physics, Tampere University of Technology, Tampere, Finland — [3]Dept. of Physics and Astronomy, Ohio University, Athens, USA — [4]Dept. of Chemistry, University of

Cambridge, Cambridge, UK

The switching mechanism of a new type of non-volatile memories can be based on electrochemical metallization occurring due to the migration of Ag or Cu ions in oxide glasses as for example SiO_2. In order to clarify this mechanism, we have performed simulations of Cu diffusion in the different modifications of SiO_2. All calculations in our study were carried out based on first-principles density-functional theory using the Vienna Ab initio Simulation Package (VASP).

We present a total-energy calculation of the barrier along a diffusion path of Cu between two equivalent interstitial positions in α-cristobalite and α-quartz. Our results for α-cristobalite show that the shape of the path strongly depends on the charge of the system, but the height of the migration barrier stays between 0.15-0.2 eV. On the other hand, the height of the barrier in α-quartz varies between 0.1 and 0.6 eV and depends on the directions of Cu motion. We also present results of molecular dynamics simulations of the drift of a Cu atom driven by an external electric field.

SYRS 4.5 Fri 12:00 H 0111

Transient Processes in Response to Electronic Excitation of Phase Change Materials — •Martin Salinga and Martin Wimmer — 1. Institut of Physics, RWTH Aachen University, Germany

In recent years a strong interest in phase change materials has been aroused by their potential for being utilized as the core element of a promising novel electronic memory technology. For such an application it is crucial to understand the characteristic switching mechanisms. Especially the electronic properties of the amorphous phase are of paramount importance. Thus, the strong non-linearity in the current-voltage-dependence of the amorphous phase, often referred to as threshold-switching, has drawn much attention.

In this work the transient current response of vertical Ge2Sb2Te5 devices to controlled voltage excitations is experimentally studied down to a time-scale of a few nanoseconds and analyzed with a particular focus on the delay-time before threshold switching and its dependence on the applied voltage. The results are compared to both experimental and theoretical studies in the literature and their implications for this field of research are discussed.

SYRS 4.6 Fri 12:15 H 0111

Nonvolatile resistive switching in Au/BiFeO3 rectifying junction — •Yao Shuai[1,2], Chuangui Wu[2], Wanli Zhang[2], Shengqiang Zhou[1], Danilo Bürger[1], Stefan Slesazeck[3], Thomas Mikolajick[3], Manfred Helm[1], and Heidemarie Schmidt[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, P. O. Box 510119, Dresden 01314, Germany — [2]State Key Laboratory of Electronic Thin Films and Integrated Devices, Chengdu, China — [3]Namlab gGmbH, Nöthnitzer Strasse 64, 01187 Dresden, Germany

BiFeO3 thin films have been grown on Pt/Ti/SiO2/Si substrates with pulsed laser deposition. RF sputtered Au has been used for the top electrode. The transport properties of the BiFeO3 thin films have been previously demonstrated to be sensitive to the interface [1]. In the present work, an interface-related resistive switching behavior with large switching ratio up to 4500 has been observed in the Au/BiFeO3/Pt structure [2]. The different polarities of the external voltage induce an electron trapping or detrapping process, and consequently change the depletion layer width below the Au Schottky contact, which is revealed by capacitance-voltage measurements and by long-term low/high resistance state capacitance transient measurements at zero bias [3]. [1] Y. Shuai et al., Appl. Phys. Lett., 98, 232901 (2011). [2] Y. Shuai et al., Appl. Phys. Express. 4, 095802 (2011). [3] Y. Shuai et al., J. Appl. Phys. 109, 124117 (2011).