DS 56: Focussed Session: Resistive Effects II

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. Within a microelectronic context this effect allows a resistive random access memory 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, such 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. In a broader context the resistive property also renders a system reprogrammable and hence able to adapt to changing environments. In addition to the obvious potential for sensing applications this property is characteristic for systems which can be trained or learn. Thus, resistive elements have successfully been introduced into neural networks, which artificially mimic learning in the human brain.

Organizers: Sibylle Gemming (HZ Dresden-Rossendorf) and Peter Zahn (HZ Dresden-Rossendorf)

Time: Friday 9:30–11:45 Location: H11

Topical Talk DS 56.1 Fri 9:30 H11

Processes at the nanoscale: Recent progress in understandings on ReRAMs — •Ilia Valov — Forschungszentrum Jülich, PGI-7, 52425 Jülich, Germany

Since their re-discovery roughly 20 years ago the resistive switching memories (RRAM) turned out into one of the most exciting, innovative and multidisciplinary scientific field with a greatest potential for application in the nanoelectronics and information technology. Relating these systems to the missing memristor and pointing out the possible functionalities such as neuromorphic computing, non-volatile memories etc., pushed this topic to one of the highest priorities not only for the academic research but also for the nanoelectronics industry.

The present talk will focus on the processes at the nanoscale in memristive devices emphasizing the importance of understanding nanosize effects in order to design and control thin film device at the atomic scale. The recent achievements in the microscopic understandings of the physicochemical processes will be presented. The mobility of cations in VCM devices will be discussed in the light of bridging ECM and VCM mechanisms. The importance of interface dynamics, local charge concentration and distribution, the effects of moisture and in general the generic relevance of the counter charges will be highlighted. The nanobattery effect and its implications on both memristors theory and device stability and performance will be outlined on theoretical and experimental level.

The topic will be discussed in a more fundamental context of microscopic description of electrochemical processes at the atomic scale.

Topical Talk DS 56.2 Fri 10:00 H11

Tunnel junction based memristors as artificial synapses — •Andy Thomas — Leibniz Institute of Solid State and Materials Research (IFW Dresden), Institute for Metallic Materials, Dresden, Germany

The synapse is a crucial element in biological neural networks, but a simple electronic equivalent has been absent. This complicates the development of hardware that imitates biological architectures in the nervous system. Now, the recent progress in the experimental realization of memristive devices has renewed interest in artificial neural networks. The resistance of a memristive system depends on its past states and exactly this functionality can be used to mimic the synaptic connections in a (human) brain [1].

We prepared magnesia, tantalum oxide and barium titanate based junction structures and investigated their memristive properties. We increased the amplitude of the resistance change from 10% up to 100%. Utilizing the memristive properties, we looked into the use of the junction structures as artificial synapses. We observed analogs of long-term potentiation, long-term depression and spike-time dependent plasticity in these simple two terminal devices [2]. Finally, we prepared these junctions on top of an integrated neuromorphic circuit to store analog synaptic weights and and support the implementation of biologically plausible learning mechanisms in the future.

[1] A. Thomas, J. Phys. D: Apple. Phys. 46 (2013) 093001
[2] A. Thomas et al., Frontiers in neuroscience 9 (2015) 241

15 min. break.

DS 56.3 Fri 10:45 H11

Metastable states of HfO_2 suboxides and resistive switching — •Konstantin Z. Rushchanskii, Stefan Blügel, and Marjana Ležaić — Peter Grünberg Institut, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Resistive random access memories (RRAM) are considered the next generation of memory devices, which combine the operation speed of volatile DRAM and the nonvolatile ability of flash technology in one device with good scalability. Materials used for RRAM should be compatible with silicon technology. One of these materials is hafnia (HfO_2), thin films of which have valence change memory properties. With the aim of shining light on the filamentary initial state of the memory cell after electroforming we will present results of a study of the Hf-O system combining an evolutionary-algorithm [1] for structure prediction with density functional theory. The main focus is given to suboxides in close vicinity of the HfO_2 ground state, in order to search for possible metastable structures in oxygen deficient conditions. We find metastable crystalline structures, which could occur in the electroforming process and allow for a reversible resistive switching. The obtained structures favor ionic conductivity of oxygen. We characterise electronic and vibrational properties of these phases in order to compare them with experimental data.

We acknowledge financial support by the Helmholtz Young Investigators Group Programme VH-NG-409 and by the DFG through the SFB917 (Nanoswitches).

[1] http://uspex.stonybrook.edu

DS 56.4 Fri 11:00 H11

Avalanche-discharge-induced electrical forming in Ta_2O_5 based MIM structures — •Katharina Skaja[1], Christoph Bäumer[1], Oliver Peters[1], Stephan Menzel[1], Marco Moors[1], Hongshu Du[1,2], Manuel Bornhöfft[1,2,3], Chun-Lin Jia[1,2], Joachim Mayer[2,3], Rainer Waser[1,4], and Regina Dittmann[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich , Germany — [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich , Germany — [3]Central Facility for Electron Microscopy, RWTH Aachen University, 52056 Aachen , Germany — [4]Institute of Materials in Electrical Engineering and Information Technology II, RWTH Aachen University, 52056 Aachen , Germany

We investigated the resistive switching characteristics of Pt/ Ta_2O_5/Ta cells prepared by sputtering. Structural changes in the top electrode develops during the electrical forming process, which can be correlated to the formation of a dendrite-like conductive structure, which is induced by an avalanche discharge between the top electrode and the Ta_2O_5 layer, which occurs instead of a local breakdown between top and bottom electrode. The dendrite-like structure evolves primarily at structures with a pronounced interface adsorbate layer. Local conductive atomic force microscopy reveals that the entire dendrite region becomes conductive. We demonstrate by in-situ spectromicroscopy that the subsequent switching is caused by a valence change between Ta^{4+} and Ta^{5+}, which takes place over the entire former Pt/ Ta_2O_5 interface of the dendrite-like structure.

DS 56.5 Fri 11:15 H11

KKRnano: A Massively Parallel KKR Green's Function

Code for Large Scale Systems — •Marcel Bornemann, Rudolf Zeller, Roman Kovacik, and Stefan Blügel — Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The advent of exascale supercomputers may enable researchers to perform electronic structure calculations for systems that exceed the realm of conventional solid state physics and reach deep into the field of material sciences. In Jülich, we developed the KKRnano code [1] to facilitate the research of systems containing up to 10000 atoms and beyond. This ability is crucial to the study of effects of chemical and structural disorder, doping, single and line defects in various materials which are, from a theoretical point of view, insufficiently understood so far. In KKRnano we apply the Korringa-Kohn-Rostocker Green's function method that is already widely used in computer programs aiming at smaller system sizes. By extending its theoretical framework we were able to come up with a code whose requirements for computational resources, e.g. memory and CPU time, scale linearly with system size. In the past we have applied KKRnano 1.0 to phase change materials [2]. Currently we are developing KKRnano 2.0 that we plan to apply to oxide systems in conjunction with the understanding of the switching behavior of VCM type ReRAM.

This work is supported by the DFG via SFB 917.

References: [1] A. Thiess et al., Phys. Rev. B 85 , 235103 (2012), [2] W. Zhang et al., Nature Materials 11, 952 (2012)

DS 56.6 Fri 11:30 H11

Bipolar resistive switching of p-$YMnO_3$/n-$SrTiO_3$:Nb junctions — •Agnieszka Bogusz[1,2], Daniel Blaschke[1], Barbara Abendroth[3], Ilona Skorupa[1], Danilo Bürger[2], Oliver G. Schmidt[2,4], and Heidemarie Schmidt[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Material Systems for Nanoelectronics, Chemnitz University of Technology, 09107 Chemnitz, Germany — [3]Institute for Experimental Physics, TU Bergakademie Freiberg, 09596 Freiberg, Germany — [4]Institute for Integrative Nanosciences, IFW-Dresden, 01069 Dresden, Germany

Resistive switching (RS) phenomena of oxides in metal-insulator-metal structures have been widely investigated due to promising applications as a non-volatile memory and in neuromorphic circuits. In our previous works, we have demonstrated unipolar RS of $YMnO_3$-based structures [1]. This work investigates the non-volatile RS switching in Au/$YMnO_3$/Nb:$SrTiO_3$/Al structures with (p-$YMnO_3$)-(n-Nb:$SrTiO_3$) junctions. The $YMnO_3$ films are deposited by pulsed laser deposition on the (100)-$SrTiO_3$ doped with 0.5 wt.% of Nb substrates and exhibit bipolar RS. Observed RS behavior is assigned to the coupled electronic and ionic processes which depend on the depletion layer extension in the p-n junction. Exploitation of RS in p-n junctions offers additional functionalities of memristive devices, e.g. related to their optical properties.

[1]A. Bogusz et al., AIP Advances 4 (2014), A. Bogusz et al., Adv. Mater. Res. 1101 (2015).