DS 39: Resistive Effects I

Time: Thursday 9:30–11:00 Location: H8

DS 39.1 Thu 9:30 H8

Investigation of oxygen vacancy formation and migration in HfO_2 from density functional theory — •Marta Gibertini, Daniel Wortmann, Gustav Bihlmayer, and Stefan Blügel — Peter Grünberg Institut (PGI-1) and Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich GmbH and JARA, D-52425 Jülich, Germany

Oxygen vacancies are crucial in the performance of resistive random access memory (ReRAM), one of the most promising device concepts for nonvolatile memory. However, the exact mechanism of switching of a ReRAMs between two states (low and high resistance) is still not clear, especially at the microscopic level. In the formation process of conductive pathways, the vacancy formation and migration play an important role. Therefore, we present a density functional theory (DFT) study of the formation energy and the diffusion barrier of oxygen vacancies in HfO_2. Different structures (cubic, tetragonal, monoclinic), different charge states of the vacancy and different pathways are considered. The role of electronic correlations is investigated in the DFT+U model. The calculations are done for different supercell sizes employing the electronic structure code juRS, a real-space finite-difference implementation of the projector augmented wave (PAW) method.

DS 39.2 Thu 9:45 H8

Impact of Cation-Stoichiometry on Switching Speed and Data Retention in $SrTiO_3$ Thin Film Devices — •Nicolas Raab[1], Christoph Bäumer[1], Karsten Fleck[2], Stephan Menzel[1], and Regina Dittmann[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52428 Jülich — [2]Institut für Werkstoffe der Elektrotechnik (IWE-2), RWTH Aachen, 52074 Aachen

$SrTiO_3$ is a model material for resistive switching oxides. Among various proposed switching models, the filamentary switching based on oxygen migration is widely accepted for $SrTiO_3$. It is generally assumed that defects have a strong impact on the resistive switching properties of $SrTiO_3$. However, the correlation between different types of defects present in thin film devices and the resistively switching properties remains elusive.

We fabricated single-crystalline $SrTiO_3$ thin films with different cation ratio to investigate the stoichiometry-related and therefore defect-dependent influence on the resistive switching properties. Beyond a certain degree, non-stoichiometry is accommodated by the formation of extended defects rather than by point defects which are the dominant defect type in the more stoichiometric case. In the devices with either Ti- or Sr-excess a lower current in the pristine state and a higher current in the low resistance state was observed. These non-stoichiometric devices exhibit a larger memory window and a significantly better data retention. We will present a consistent explanation for this modified switching properties in non-stoichiometric thin film devices, supported by an estimation of the filament diameters.

DS 39.3 Thu 10:00 H8

Resistive switching devices with ultrathin graphene top electrodes for in situ spectromicroscopic characterization — •Richard Valenta, Christoph Bäumer, Christoph Schmitz, David Müller, Nicolas Raab, Slavomir Nemsak, Claus Michael Schneider, Rainer Waser, and Regina Dittmann — Peter Grünberg Institut and JARA-Fit, Forschungszentrum Jülich, 52425 Jülich

Resistively switching transition metal oxides are gaining in importance as a promising alternative for future non-volatile memory. Although the switching mechanism is not fully understood, it has been shown that nanoscale redox reactions are responsible for a localized change of the resistance. Spectromicroscopic measurements present a powerful tool to investigate such localized chemical and structural changes and can give a deeper understanding of the switching mechanism.

Here we will present local changes in the electronic structure of $SrTiO_3$-based memristive devices in two different resistance states, utilizing in-operando photoemission electron microscopy measurements (PEEM). Since PEEM is very surface sensitive, ultrathin graphene top electrodes are used to attain spectroscopic information from the active $SrTiO_3$ layer of a functioning device. Localized changes of the work function as well as changes in the O K-edge spectra indicate that the resistance change coincides with redox reactions within confined switching filaments. This finding substantiates the expected filamentary switching of $SrTiO_3$ and confirms that the resistance change is caused by oxygen migration.

DS 39.4 Thu 10:15 H8

Energy-efficient and fast BiFeO3-based artificial synapses with a time window of 25ms to 125μs — •Nan Du[1], Tiangui You[1], Mahdi Kiani[1], Christian Mayr[2], Danilo Bürger[1], Ilona Skorupa[1,3], Oliver G. Schmidt[1,4], and Heidemarie Schmidt[1] — [1]Faculty of Electrical and Information Engineering, TU Chemnitz — [2]Faculty of Electrical Engineering and Information Technology, TU Dresden — [3]Institute of Ion Beam Physics and Materials Research, HZDR — [4]Institute for Integrative Nanosciences, IFW Dresden

Memristive devices can be used to emulate spike-driven synaptic plasticity (STDP) by applying specific voltage waveforms at their two terminals. In this work, we investigate STDP [1] with a simplified single pairing of one presynaptic voltage spike and one postsynaptic voltage spike in a BiFeO3 (BFO)-based memristive device [2-4]. We show that the analog resistive switching of BFO memristors allows to shorten the learning time constant of the STDP function to 125 μs. As the power consumption is a major constraint in neuromorphic circuits, the energy-efficient setting process has also be demonstrated for BFO-based artificial synapse with short and simplified spike sequences (4.5 pJ). [1] C. Mayr, P. Stärke, J. Partzsch, L. Cederstroem, R. Schüffny, Y. Shuai, N. Du, H. Schmidt, Adv. Neural Inf. Process. Syst. 25, 1700-1708 (2012).[2] Y. Shuai et.al., IEEE Elec. Dev. Lett. 34, 54-56 (2013). [3] N. Du et. al., Front. Neurosci. 9, 227 (2015). [4] T. You, Y. Shuai, W. Luo, N. Du, D. Bürger, I. Skorupa, R. Hübner, S. Henker, C. Mayr, R. Schüffny, T. Mikolajick, O. G. Schmidt, H. Schmidt, Adv. Funct. Mater. 24, 3357-3365(2014)

DS 39.5 Thu 10:30 H8

Influence of Stack Order on the Forming and Switching Behavior of HfO_2/TiO_2 Bilayer Cells for ReRAM Applications — •Alexander Hardtdegen, Hehe Zhang, and Susanne Hoffmann-Eifert — Peter Grünberg Institut (PGI-7) and JARA-FIT, Forschungszentrum Jülich, 52425 Jülich, Germany

In this study we investigate the potential of HfO_2/TiO_2 bilayers composed of 3 nm thin ALD films for application in resistive devices. Special focus is on the influence of the stack sequence on the forming and switching behavior of nano crossbar structures of 100 x 100 nm^2 area. The Pt bottom electrode serves as inert layer, while sputtered Ti and Hf are chosen as oxygen exchange layers (OEL), depending on the top layer of the oxide film stack, TiO_2 and HfO_2, respectively.

The stack order and the OEL layer show influences on the forming and switching properties of the cells. Stacks with $Pt/HfO_2/TiO_2/Ti$ exhibit a forming voltage of 2.65 V which is significantly higher as the value of 1.90 V obtained for the stack with $Pt/TiO_2/HfO_2/Hf$, although the thicknesses of the oxide layers are identical. After forming into the ON state and subsequent reset, both cells show stable bipolar resistive switching with SET voltages lower than 1.0 V. A resistance ratio of about 100 is obtained for an operation current of about 300 μA with ON and OFF resistances of 1-5 kΩ and 100-300 kΩ, respectively. For current compliances higher than 500 μA, the devices of both stacks show self-limited switching behavior. Additionally, devices were switched with voltage pulses of about 100 ns. Dependencies of the switching time on the switching voltage and power are discussed.

DS 39.6 Thu 10:45 H8

Hanle magnetoresistance in thin metal films with strong spin-orbit coupling — Saül Vélez[1], •Vitaly Golovach[2,3,4], Amilcar Bedoya-Pinto[1], Miren Isasa[1], Edurne Sagasta[1], Mikel Abadia[2,3], Celia Rogero[2,3], Luis Hueso[1,4], Sebastian Bergeret[2,3], and Fèlix Casanova[1,4] — [1]CIC nanoGUNE, 20018 Donostia-San Sebastián, Basque Country, Spain — [2]Centro de Física de Materiales (CFM-MPC), Centro Mixto CSIC-UPV/EHU, 20018 Donostia-San Sebastián, Basque Country, Spain — [3]Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastián, Basque Country, Spain — [4]IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Basque Country, Spain

The theory of Hanle magnetoresistance is worked out and applied to thin metal films with strong spin-orbit interaction, exhibiting the spin Hall effect. A correction to the resistivity tensor is derived and ana-

lyzed for the case of a classically weak magnetic field. The spin accumulation created at the surfaces of the film by the spin Hall effect decreases with the magnetic field because of the Hanle effect, resulting in an increase of the electrical resistance. The angular dependence of this magnetoresistance resembles the recently discovered spin Hall magnetoresistance in $Pt/Y_3Fe_5O_{12}$ bilayers, although the presence of a ferromagnetic insulator is not required. We show that this Hanle magnetoresistance is an alternative, simple way to quantitatively study the coupling between charge and spin currents in metals with strong spin-orbit coupling. The theory is compared against experiments carried out for Pt and Ta thin films.