MA 25: Multiferroics and magnetoelectrics II (joint session MA/KFM)

Time: Wednesday 9:30–12:00 Location: EB 202

MA 25.1 Wed 9:30 EB 202

Magneto-ionic ON/OFF switching of magnetization in FeOx/Fe nanostructures — •Jonas Zehner, Kenny Duschek, Nicolas Peréz, Andreas Petr, Rudolph Schäfer, Kornelius Nielsch, and Karin Leistner — IFW Dresden

A novel route towards low-power voltage-control of magnetism was recently discovered by utilizing voltage-induced ion migration and electrochemical oxidation/reduction in oxide/metal films and denominated magneto-ionic effect [1,2,3]. In all-solid architecture, significant magneto-ionic effects are achieved at elevated temperatures when ion migration is thermally activated. Instead, we present large voltage-induced magnetic changes within several nanometers of FeOx/Fe films at room temperature. The voltage is applied via a liquid alkaline electrolyte [4] (KOH or LiOH solution), which, in comparison to solid oxide gate barrier layers, yields an enhanced electric field and a higher ion mobility at the electrode surface. Nearly complete and reversible voltage-induced ON/OFF switching of magnetization (up to 90 %) is observed in granular FeOx/Fe thin films for a voltage change of 1 V, proven by in situ AHE and in situ FMR. An in situ Kerr microscope set-up has been developed that resolves magnetic domains through a liquid alkaline electrolyte. Thereby, for the first time, the study of the local impact of electrochemical reactions on the magnetic domain characteristics becomes possible for solid/liquid magneto-ionic systems. [1] Song et al., Prog. Mater Sci. 87, 33, 2017, [2] Leistner et al., Phys.Rev. B 87, 224411, 2013, [3] Bauer et al., Nat. Mater. 14, 174, 2015, [4] Duschek et al., APL Mater. 4, 032301, 2016

MA 25.2 Wed 9:45 EB 202

Magnetoelectric memory function with optical readout — Vilmos Kocsis[1,2], Karlo Penc[2,3], Toomas Rõõm[4], Urmas Nagel[4], •Jakub Vít[2,5], Judit Romhányi[6], Yusuke Tokunaga[1], Yasujiro Taguchi[1], Yoshinori Tokura[1], István Kézsmárki[2,7], and Sándor Bordács[2] — [1]RIKEN CEMS, Japan — [2]Budapest University of Technology and Economics, Hungary — [3]HAS, Hungary — [4]NICPB, Estonia — [5]Institute of Physics ASCR, Czech Republic — [6]OISTGU, Japan — [7]EP5, University of Augsburg, Germany

The ultimate goal of multiferroic research is the development of new generation non-volatile memory devices, the so-called magnetoelectric (ME) memories, where magnetic bits are controlled via electric fields without the application of electrical currents, being subject to dissipation. This low-power operation exploits the entanglement of the magnetization and the electric polarization coexisting in multiferroic materials. Here I will demonstrate the optical readout of ME memory states in the antiferromagnetic (AFM) and antiferroelectric (AFE) $LiCoPO_4$, based on the strong absorption difference of THz radiation between its two types of ME domains. [1] This unusual contrast is attributed to the dynamic ME effect of the spin-wave excitations, as confirmed by our microscopic model, which also captures the characteristics of the observed static ME effect. Our proof-of-principle study, demonstrating the control and the optical readout of ME domains in $LiCoPO_4$, lays down the foundation for future ME memory devices based on antiferroelectric-antiferromagnetic insulators.

[1] V. Kocsis *et al.*, arXiv:1711.08124 (2017)

MA 25.3 Wed 10:00 EB 202

On-off switching of magnetism in ultrathin films of $La_{1-x}Sr_xMnO_3$ gated with an ionic liquid — •Alan Molinari, Robert Kruk, and Horst Hahn — Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344, Eggenstein-Leopoldshafen, Germany

Utilization of electric fields instead of conventional dissipative flowing currents to control magnetism may be the key for the realization of a variety of novel low-power microelectronic devices. In our work we addressed the control of the magnetization of ultrathin (about 3 nm) films of $La_{1-x}Sr_xMnO_3$ (LSMO) by means of ionic liquid (IL) gating. The magnetoelectric (ME) coupling[1,2] at the LSMO/IL interface was investigated under various conditions of temperature and applied voltage via in situ synchronized Superconducting Quantum Interference Device magnetometry and Cyclic Voltammetry. Thanks to the high surface-to-volume ratio of the films and the large amounts of surface charge densities attainable with the IL, ferromagnetism could be reversibly suppressed and restored in LSMO by application of just a few volts. Our results intend to bring to attention some appealing functionalities of solid/liquid ME devices.

[1]A. Molinari et al., Nat. Comm. 8, 15339 (2017), doi:10.1038/ncomms15339

[2]A. Molinari et al., Adv. Mater. 1703908 (2017), doi: 10.1002/adma.201703908

MA 25.4 Wed 10:15 EB 202

Domain wall engineering as a route towards room temperature multiferroicity — •Konstantin Z. Rushchanskii, Stefan Blügel, and Marjana Ležaić — Peter Grünberg Institut, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Multiferroics are materials that exhibit two or more ferroic order parameters in a single phase. Their room-temperature functionality as well as the strong coupling of magnetic and electric order parameters are desired for devices of future electronics, such as multistate nonvolatile memory cells, electrically controlled spintronic devices, etc. Isostructural $Ga_{0.6}Fe_{1.4}O_3$ (GFO) [1] and ϵ-Fe_2O_3 (eFO) [2] are of special interest, due to simultaneous presence of ferrimagnetic coupling and a polar structure. Recently reported observation of room-temperature mutiferroic behavior in thin films of these compounds made them prospective materials for practical applications. Unfortunately, ferroelectric properties were experimentally observed only for a limited number of samples, and the conditions to have switchable polarization are still unclear.

We employ Density Functional Theory in combination with an evolutionary algorithm [3] to obtain realistic models of polarization switching in eFO and GFO. We will discuss the conditions, under which the films with maximal, switchable remanent ferroelectric polarization are obtained.

We acknowledge the support by GALIMEO Consortium.

[1] A. Thomasson et al., J. Appl. Phys. **113**, 214101 (2013); [2] M. Gich et al., Adv. Mater., **26**, 4645 (2014); [3] http://uspex.stonybrook.edu

15 minutes break

MA 25.5 Wed 10:45 EB 202

Frustrated magnetism and magnetoelectric switching in RMn2O5 compounds — •Sergey Artyukhin and Louis Ponet — Italian Institute of Technology, Via Morego 30, Genova, Italy

Rare earth manganites RMn2O5 exibit complex magnetism and magnetically induced polarization, with chains of antiferromagnetically coupled Mn ions along a direction geometrically frustrated interchain interactions along b, and the competition of nearest and next-nearest neighbor exchanges along c leading to spiral states in YMn2O5. Here we use Landau theory and model Hamiltonian calculations with parameters obtained from density functional perturbation theory calculations to study magnetoelectric coupling and magnetic switching in these compounds.

MA 25.6 Wed 11:00 EB 202

A theoretical study on the electronic and magnetic excitation spectra of $BiFeO_3$ by dynamical mean-field theory — •Souvik Paul[1,2], Diana Iusan[1], Patrik Thunström[1], Yaroslav Kvashnin[1], Johan Hellsvik[1,3], Manuel Pereiro[1], Anna Delin[1,3], Biplab Sanyal[1], and Olle Eriksson[1] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]Institute of Theoretical Physics and Astrophysics, Christian-Albrechts-Universität zu Kiel, Germany — [3]Department of Materials and Nano Physics, KTH Royal Institute of Technology, Sweden

Using local density approximation plus dynamical mean-field theory (LDA+DMFT), we have computed the electronic and magnetic excitation spectra of one of the popular multiferroic $BiFeO_3$. Our calculated eletronic spectra match very well with the experimental (hard X-ray photoelectron spectroscopy and resonant photoelectron spectroscopy for the Fe 3*d* states) spectra as compared to the commonly used LDA+U method, which fails drastically to produce the general features of the experimental spectra. This indicates the importance of correctly including the dynamical correlation among the Fe 3*d* orbitals to reproduce the experimental spectroscopic data. The LDA+DMFT derived density of states (DOS) exhibit significant amount of Fe 3*d* states at the position of Bi lone-pairs, implying that the latter are not

alone in the spectral scenario. This fact might modify our interpretation about the origin of ferroelectric polarization in this material. Our magnetic excitation spectra computed from the LDA+DMFT results conform well with the inelastic neutron scattering data.

MA 25.7 Wed 11:15 EB 202

Magnetic field control of cycloidal domains and electric polarization in multiferroic $BiFeO_3$ — •Sándor Bordács[1], Dániel Farkas[1], Jonathan White[2], Robert Cubitt[3], Lisa DeBeer-Schmitt[4], Toshimitsu Ito[5], and István Kézsmárki[1,6] — [1]Department of Physics, Budapest University of Technology and Economics and MTA-BME Lendület Magneto-optical Spectroscopy Research Group, Budapest, Hungary — [2]Laboratory for Neutron Scattering and Imaging, PSI, Villigen, Switzerland — [3]Institut Laue-Langevin, Grenoble, France — [4]Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA — [5]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, Japan — [6]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

The magnetic field induced rearrangement of the cycloidal spin structure in ferroelectric monodomain single crystals of the room-temperature multiferroic $BiFeO_3$ is studied using small-angle neutron scattering (SANS). The cycloid propagation vectors are observed to rotate when magnetic fields applied perpendicular to the rhombohedral (polar) axis exceed a pinning threshold value of $\sim$5 T. In light of these experimental results, a phenomenological model is proposed that captures the rearrangement of the cycloidal domains, and we revisit the microscopic origin of the magnetoelectric effect. A new coupling between the magnetic anisotropy and the polarization is proposed that explains the recently discovered magnetoelectric polarization to the rhombohedral axis.

MA 25.8 Wed 11:30 EB 202

Reversible Modulation of Magnetic Anisotropy in $Pb(Zr_{0.2}Ti_{0.8})O_3$ /$La_{0.8}Sr_{0.2}MnO_3$ Multiferroic Heterostructures — •Anil Rajapitamahuni, Lingling Tao, Evgeny Tsymbal, and Xia Hong — Department of Physics and Astronomy,University of Nebraska-Lincoln, Lincoln,NE, 68588

We report a reversible modulation of in-plane magnetic anisotropy energy (MAE) in 4 nm $La_{0.8}Sr_{0.2}MnO_3$ (LSMO) thin films via ferroelectric field effect induced charge doping facilitated by $Pb(Zr_{0.2}Ti_{0.8})O_3$(PZT) top gate. We employed, planar Hall effect measurements (PHE) to characterize the in-plane magnetic anisotropy in PZT/LSMO heterostructures. The magnetic anisotropy in LSMO is found to be biaxial with easy axes along <110> directions for both polarization states. The extracted biaxial anisotropy fields (H1) from PHE measurements, showed an enhancement in H1 in the accumulation state. Assuming a doping level change of 0.1 electron/Mn due to the polarization switching, the estimated anisotropy energy densities are 0.9 x 10^5 erg/cm^3 and 1.17 x 10^5 erg/cm^3 in the depletion and accumulation states respectively. This corresponds to a 30% enhancement of the MAE in the accumulation state when compared to the depletion state values. First principles density functional theory calculations performed for various Sr doping levels also show an increase in the MAE with an increase in the hole doping, agreeing well with our experimental observations. We attribute this enhancement in MAE to the modification of orbital contribution to spin-orbit coupling via ferroelectric field effect in LSMO.

MA 25.9 Wed 11:45 EB 202

Magnetoelectric effect in elastic multiferroic composites — •Yuliya Alekhina[1], Liudmila Makarova[1], Tatiana Rusakova[1], Olga Malyshkina[2], and Nikolai Perov[1] — [1]Lomonosov Moscow State University, Moscow, 11999, Russia — [2]Tver State University, Tver, 170100, Russia

Magnetorheological elastomers (MREs) are a type of "smart materials" changing their properties under the influence of external factors. MREs represent magnetic particles distributed in elastic medium. Under the magnetic field magnetic moments of particles tend to align what can lead to their shifting and rotating. Such ordering leads to several effects which can be observed in MREs, e.g. magnetorheological effect. It was previously shown that in MREs with both iron and graphite particles change of electrical resistance can be induced by magnetic field. In this case shifting of magnetic particles under the magnetic field creates the internal stresses in polymer matrix, which lead to displacements of the conductive graphite particles. Similar effect can be observed if ferroelectric particles are added to the MRE [1]. Those internal stresses can affect the movement of ferroelectric particles forcing to or preventing them from shifting and rotation thus changing the polarization process. The reverse effect is also possible: under the electric field, the magnetization process can be changed. Thereby, a type of multiferroic composite with elastically coupled ferromagnetic iron particles and ferroelectic PZT particles was prepared and investigated in this work. The work was financially supported by Grant RFBR 18-32-00354. [1] L.A. Makarova et al., IEEE Transactions on Magnetics, 2017, 53, 11, pp.7