TT 75: Multiferroics II (jointly with DF, DS, KR, MA)

Time: Wednesday 15:00–18:50 Location: EB 107

Invited Talk TT 75.1 Wed 15:00 EB 107

Low energy consumption spintronics using multiferroic heterostructures — •Morgan Trassin — ETH Zurich, Zurich, Switzerland

Magnetization reversal in spintronics applications requires either an externally applied magnetic field or a large current density, which is accompanied by significant energy dissipation. A reversal of magnetization induced only by the application of an electric field would lead to low-power devices. Using multiferroics, previous approaches have seen limited success by only achieving rotations of the magnetization or a change in anisotropy by applying an electric field. To pave the way to new low-power devices, the more desirable electric-field driven magnetization reversal must be achieved and read out with a small current. In multiferroic heterostructures, ferromagnetic domains can be moved and switched using different charge states, strain configurations or magnetoelectric coupling. Ferroelectric domain engineering using epitaxial strain is critical towards the achievement of deterministic switchings. A combination of scanning probe microscopy and optical second harmonic generation were used to characterize multiferroic thin films strain state. Using electron microscopy and transport based techniques, a room temperature magnetization reversal of a CoFe thin layer solely induced by the application of a few volts to the heterostructure will be described.

TT 75.2 Wed 15:30 EB 107

Probing ferroic order in thin film heterostructures with optical second harmonic generation — •Gabriele De Luca, Manfred Fiebig, and Morgan Trassin — ETH Zurich, Switzerland

The evidence of the electric field control on the antiferromagnetic ordering in multiferroic bismuth ferrite ($BiFeO_3$) [1] increased interest in low energy consumption logic and memory devices. However, to exploit such functionality for devices it is essential to attain deterministic control of ferromagnetism at the single domain scale. Therefore a ferromagnet/multiferroic heterostructure has been designed based on the combination of magnetoelectric coupling in $BiFeO_3$ (BFO) and exchange coupling between magnetic materials thus offering a new pathway for the electrical control of magnetism [2,3]. Here we show that second harmonic generation (SHG), can detect the distribution of ferroelectric domains in BFO thin films non-invasively and unimpeded by transport properties. We use epitaxial strain for engineering different types of BFO domain patterns that are characterized by SHG, showing a unique relation between the domain distribution and the film symmetry. We then manipulate the BFO film by voltage poling and demonstrate the sensitivity of the SHG process to this manipulation. The concept applied to BFO is transferable to other multiferroics compounds thus indicating the general feasibility of SHG as a characterization technique for heterostructures in which buried ferroelectricity plays a key role in the emergence of magnetoelectric coupling. 1.Zhao et al., Nat. Mat. 5, 823 (2006) 2.Heron et al., Phys. Rev. Lett. 107, 217202 (2011) 3.Trassin et al., Phys. Rev. B 87, 134426 (2013)

TT 75.3 Wed 15:45 EB 107

Investigation of the antiferromagnetic coupling at $SrRuO_3$ / $La_{0.7}Sr_{0.3}MnO_3$ interfaces — •Sujit Das[1,2], Diana Rata[1], Andreas Herklotz[3], Er Jia Guo[4], Robert Roth[1], and Kathrin Dörr[1,2] — [1]Institute for Physics, MLU Halle-Wittenberg, 06099 Halle, Germany — [2]IFW Dresden, Postfach 270116, 01171 Dresden, Germany — [3]Oak Ridge National Lab., Oak Ridge, 37830 TN, USA — [4]Affiliation: Institute for Physics, Johannes-Gutenberg University Mainz, 55128 Mainz, Germany

$La_{0.7}Sr_{0.3}MnO_3/SrRuO_3$ superlattices grown on piezoelectric substrates show large antiferromagnetic coupling of the two ferromagnetic components and a significant strain effect on interfacial coupling [1]. Here we present a systematic investigation of the antiferromagnetic interface coupling in bilayers of $SrRuO_3$ (SRO) and $La_{0.7}Sr_{0.3}MnO_3$ (LSMO), grown by pulsed laser deposition (PLD) on (100)- oriented $SrTiO_3$ substrates. Epitaxial and coherent growth of the bilayers was confirmed by in-situ RHEED and ex-situ x-ray diffraction (XRD). Magnetic characterization was performed by SQUID magnetometry. We observed a strong dependence of the AFM coupling on the layer sequence and the thickness of the individual layers. The bilayers exhibit exchange bias, with the magnitude and sign of the exchange field strongly dependent on cooling field. Results of this study and ongoing work will be discussed. [1] Sujit Das et al, arXiv:1411.0411

TT 75.4 Wed 16:00 EB 107

Massive magnetoelectric modulation of the magnetic anisotropy in an epitaxial $La_{0.7}Sr_{0.3}MnO_3$/PMN-PT heterostructure — •Martin Wahler[1], Sujit Das[1], Kathrin Dörr[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle (Saale), Germany

We use ferromagnetic resonance (FMR) to investigate the strain induced change of the in-plane magnetic anisotropy of an epitaxial ferromagnetic oxide layer on a piezoelectric substrate. The samples consist of 20 nm thick $La_{0.7}Sr_{0.3}MnO_3$ layers on two different substrates, namely $Pb(Mg_{1/3}Nb_{2/3})_{0.72}Ti_{0.28}O_3$ (PMN-PT) (001) and (110) single crystals. The two substrates induce either isotropic or anisotropic in-plane strain, respectively. For $La_{0.7}Sr_{0.3}MnO_3$ on (001) PMN-PT substrate, it has already been demonstrated by SQUID magnetometry that the Curie-temperature and saturation magnetization can be changed by applying an electric field normal to the sample plane [1]. Here we show that for the same substrate orientation there is a small but significant change in FMR resonance fields along the directions of the magnetic easy axes. For the (110) substrate, however, a massive shift of the resonance fields is observed, resulting in a change of the uniaxial anisotropy of more than 0.5 kOe for an applied electric field of 12 kV cm^{-1}. All measurements are carried out at a temperature of 120 K.

[1] C. Thiele et al., Phys. Rev. B, **75** 054408 (2007)

TT 75.5 Wed 16:15 EB 107

Inverse TMR effect in multiferroic tunnel junctions studied from first principles — •Vladislav Borisov[1,2], Sergey Ostanin[2], and Ingrid Mertig[1,2] — [1]Institute of Physics, Martin Luther University Halle-Wittenberg — [2]Max Planck Institute of Microstructure Physics

The spin-polarized electronic transport in multiferroic tunnel junctions (MTJ): Co/PTO/Co and LSMO/PTO/Co was computed from first principles. We confirm that the so-called four-state tunnelling magnetoresistance (TMR) may be detected for each MTJ when its TMR and TER are controlled by the reversible barrier polarization as well as reversible magnetization of the leads. The *ab initio* based results are directly compared to the experimental features of the inverse TMR recently reported for LSMO/PZT/Co [1]. We show how the observed effect originates from the magnetoelectric coupling seen at both interfaces of the MTJ [2]. The role of half-metallic LSMO as well as the effect of Zr substitutes in PTO are analysed in the context of the inversion of the TMR signal [1]. Another important issue of TMR discussed here concerns the functional (insulating) barrier thickness, which is always less than the nominal thickness and which depends on the polarization direction. We found that the functional barrier thickness is systematically reduced when the polarization is directed toward the Co electrode due to charge transfer at the Co/PTO interface.

[1] D. Pantel *et al.*, *Nat. Mater.* **11**, 289 (2012).
[2] V. S. Borisov *et al.*, *Phys. Rev. B* **89**, 054436 (2014).

TT 75.6 Wed 16:30 EB 107

Origin of superstructures in (double) perovskite thin films — •Vikas Shabadi, Marton Major, Philipp Komissinskiy, Aldin Radetinac, Mehran Vafaee, Wolfgang Donner, and Lambert Alff — Institute of Materials Science, Technische Universität Darmstadt, Alarich-Weiss-Strasse 2, 64287 Darmstadt, Germany

We have investigated the origin of superstructure peaks as observed by X-ray diffraction of multiferroic $Bi(Fe_{0.5}Cr_{0.5})O_3$ thin films grown by pulsed laser deposition on single crystal $SrTiO_3$ substrates. The photon energy dependence of the contrast between the atomic scattering factors of Fe and Cr is used to rule out a chemically ordered double perovskite Bi_2FeCrO_6 (BFCO). Structural calculations suggest that the experimentally observed superstructure occurs due to unequal cation displacements along the pseudo-cubic [111] direction that mimic the unit cell of the chemically ordered compound [1]. This result helps to clarify discrepancies in the correlations of structural and magnetic

order reported for Bi_2FeCrO_6. The observation of a superstructure in itself is not a sufficient proof of chemical order in double perovskites.
[1] V. Shabadi, M. Major, P. Komissinskiy, M. Vafaee, A. Radetinac, M. Baghaie Yazdi, W. Donner, and L. Alff, J. Appl. Phys. **116**, 114901 (2014).

TT 75.7 Wed 16:45 EB 107

Using multiferroic systems as a spin filter - an ab initio study — •Stephan Borek[1], Jürgen Braun[1], Hubert Ebert[1], Angelika Chassé[2], Gerd Schönhense[3], Hans-Joachim Elmers[3], Dmytro Kutnyakhov[3], and Ján Minár[1,4] — [1]Ludwig-Maximilians-Universität München — [2]Martin-Luther-Universität Halle-Wittenberg — [3]Johannes-Gutenberg-Universität Mainz — [4]University of West Bohemia, Pilsen

Multiferroic heterostructures such as ultrathin Fe/$BaTiO_3$(001) films are of high interest for technical applications giving the opportunity to control the ferromagnetic state with an electric field or vice versa. In our theoretical study we investigated the effect of changing the electric polarization of the ferroelectric substrate $BaTiO_3$ on the ferromagnetic state of Fe and Co thin films using the method of Spin Polarized Low Energy Electron Diffraction (SPLEED). This method has been shown to be an effective tool for the investigation of surface properties like the determination of surface magnetic moments and the local crystal structure. The possibility of an application of the multiferroic heterostructures Fe/BTO(001) and Co/BTO(001) as a spin filter is discussed. It will be shown that a change of the polarisation of the $BaTiO_3$ results in a significant change of the exchange asymmetry giving the possibility to control the diffraction of electrons using the exchange interaction at the Fe (Co) surface. We focus on the systems of 1 ML, 2 ML and 3 ML Fe (Co) on $BaTiO_3$ because their electronic and magnetic structure as well as the coupling mechanism between the ferroic phases have been intensively discussed in the literature.

20 min coffee break

TT 75.8 Wed 17:20 EB 107

Optical investigation of ferroic domains beyond the resolution limit — •Christoph Wetli, Viktor Wegmayr, Thomas Lottermoser, and Manfred Fiebig — Department of Materials, ETH Zurich, Zurich, Switzerland

In recent years optical second harmonic generation (SHG) has been shown to be a versatile, non-destructive tool to investigate the often complex domain structures of ferroic and multiferroic materials. Ferroic domains vary broadly in structure and size, depending on the nature of the ferroic ordering. So far, however SHG was restricted to domains larger than the optical resolution limit of 1 μm. Here we present a method by applying a numerical model and simulation to overcome this limitation and to analyze ferroic domain structures some orders of magnitude smaller than the optical resolution limit. The method is based on the relation between the orientation of the ferroic order parameter and the phase of the nonlinear optical signal. It gives a relation between domain size and density, optical resolution and the intensity of the SHG signal. To show the reliability of the model, we applied it to several simulated domain structures. The simulation of the domain structures is based on an iterative geometrical algorithm, which allows us to generate complex domain patterns like the ferroelectric vortex structures or the irregular bubble like antiferromagnetic domains in hexagonal $YMnO_3$. The numerical calculations were compared with experimental data and found to be in excellent agreement.

TT 75.9 Wed 17:35 EB 107

Multiferroicity in $DyMnO_3$ thin films — •Chengliang Lu[1,2], Hakan Deniz[2], and Jun-Ming Liu[3] — [1]School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China — [2]Max Planck Institute of Microstructure Physics, Weinberg 2, D-06120 Halle(Saale), Germany — [3]Laboratory of Solid State Microstructures, Nanjing University, Nanjing 210093, China

The mutual control of ferroelectricity and magnetism is stepping towards practical applications proposed for quite a few promising devices in which multiferroic thin films are involved. Although ferroelectricity stemming from specific spiral spin ordering has been reported in highly distorted bulk perovskite manganites, the existence of magnetically induced ferroelectricity in the corresponding thin films remains an unresolved issue, which unfortunately halts this step. Here we report magnetically induced electric polarization and its gigantic response to magnetic field (an enhancement of 800% upon a field of 2 Tesla at 2 K) in $DyMnO_3$ thin films grown on Nb-$SrTiO_3$ substrates. Interestingly, we found a consecutive control of the polarization under a rotating magnetic field by detailed multiferroic response measurements. This is distinct to the standard polarization-flop process which results in a sudden change in polarization in multiferroics with spiral-spin-ordering state. The cooperative action of dual multiferroic mechanisms (the inverse Dzyaloshinskii-Moriya interaction among Mn moments and the exchange striction working between Dy and Mn moments) and phase coexistence associated with a twin-like structure was proposed as the origin of this phenomenon.

TT 75.10 Wed 17:50 EB 107

Observation of direct and converse local magnetoelectric switching at room-temperature in modified single-phase bismuth ferrite — •Leonard Frederic Henrichs[1], Oscar Cespedes[1], James Bennett[1], Joachim Landers[2], Wolfgang Kleemann[2], Heiko Wende[2], Doru Lupascu[2], and Andrew Bell[1] — [1]University of Leeds, Leeds, GB — [2]Universität Duisburg/Essen, Duisburd/Essen, Germany

Multiferroics are promising for applications in sensors and memory. However, no single-phase material with both ferroelectric and ferro- or ferrimagnetic order at room-temperature has been reported to date. Here, we observe very large local magnetoelectric coupling in the novel single-phase multiferroic $(BiFeCo_{0.1}O_3)_{0.4}$-$(K_{1/2}Bi_{1/2}TiO_3)_{0.6}$ at room-temperature. On ceramic samples, both direct and converse magnetoelectric switching was observed using piezoresponse force-microscopy and magnetic force-microscopy respectively. Areas where converse switching occurred, incorporate both a ferroelectric and magnetic domain-like cluster and thus appear to be (relaxor) ferroelectric and ferrimagnetic at room-temperature. The direct coupling-coefficient estimated from the experiments is 1.0×10^{-5} s/m, and thus extremely large. The locally observed converse meangetoelectric effect has a similar of magnitude. we propose that the material can be interpreted as a pseudo-nanocomposite with an ideal strain-mediated coupling due to congruent polar and magnetic nanoregions which are related to the relaxor ferroelectric and superparamagnetic nature of the material.

TT 75.11 Wed 18:05 EB 107

Tiny cause with large effects: the origin of the large magnetoelectric and magnetoelastic effect in $EuTiO_3$ — •Annette Bussmann-Holder — MPI-FKF, Heisenbergstr. 1, D-70569 Stuttgart, Germany

The magnetoelectric coupling in the perovskite $EuTiO_3$ is analyzed within a spin-phonon coupled Hamiltonian. It is shown that the tiny magnetostriction which accompanies the onset of antiferromagnetic order at $T_N = 5.7$ K induces a substantial hardening in the soft optic mode and a drop in the dielectric constant. The reduction of magnetostriction with increasing magnetic field reverses this behavior. While for small fields ferromagnetic order rapidly sets in accompanied by a volume expansion, this is destroyed with increasing fields and a strange paramagnetic state obtained. This exotic observation can be understood as stemming from the interplay between the enhanced oxygen p Ti d dynamical covalency which alters the crystal field at the Eu site and inhibits the virtual transition from $4f7$ to $4f65d$ responsible for ferromagnetic order.

TT 75.12 Wed 18:20 EB 107

First principles calculations on the effect of inner cationic site disorder, single and multiple cation and anion doping on the magnetic properties of $GaFeO_3$ — •Jacqueline Atanelov, Wernfried Mayr-Schmölzer, and Peter Mohn — Institute of Applied Physics - Computational Materials Science, Vienna University of Technology, Austria

$GaFeO_3$ is a promising multiferroic suitable for a wide range of applications in electronic devices. Motivated by that we investigate the influence of single and multiple cation and anion doping on the electronic and magnetic properties of gallium ferrite. Further we consider the well known fact of innner cation site disorder in $GaFeO_3$. In terms of cation doping we replace Ga atoms by Fe atoms and vice versa so that in total a concentration range of $0.9 \leq x \leq 2.0$ in $Ga_2 - xFe_xO_3$ is investigated. In addtion to that we substitute oxygen by B, C, N and S atoms. GFO is also known to show magnetic anisotropy for different cristallographic directions and sublattices. Beside changes in the total net magnetic moment induced by cation and anion doping, the magnetic anisotropy energy (MAE) can be affected as well. Doping

therefore can lead to an enhancement or reduction of the MAE. First principles density functional theory (DFT) calculations performed by the Vienna ab Initio Simulation Package (VASP) are used to predict and analyze the ground state electronic structure of the investigated systems.

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Mechanism of interfacial magnetoelectric coupling in composite multiferroics — Chenglong Jia[1], Tongli Wei[1], Changjun Jiang[1], Desheng Xue[1], •Alexander Sukhov[2], and Jamal Berakdar[2] — [1]Key Laboratory for Magnetism and Magnetic Materials of MOE, Lanzhou University, Lanzhou 730000, China — [2]Institut für Physik, Martin-Luther-Universität, Halle-Wittenberg, 06099 Halle (Saale), Germany

We present a mechanism for the magnetoelectric coupling at ferroelectric/ferromagnetic interfaces based on screening via interfacial spin-rearrangement [1]. We find an electric-polarization-driven, non-collinear spin region extending over the spin-diffusion length in the ferromagnet. The orbital motion of the carriers in the ferromagnet is affected by the gauge field associated with the non-collinear spin order and hence indirectly by the electric polarization. Changing the latter, e.g., via an electric field influences the interfacial magnetic order and hence the spin-orbital coupled motion of the carriers. This allows for tuning the interfacial spin-dependent transport via electric fields. The resulting coupling is robust at room temperature and can be well approximated by a linear polarization- magnetization coupling, whose strength estimate for the composite Co(40 nm)/(tetragonal)$BaTiO_3$ is in line with recent experiments [2].

[1] C.-L. Jia, T.-L. Wei, C.-J. Jiang, D.-S. Xue, A. Sukhov, J. Berakdar, Phys. Rev. B **90**, 054423 (2014). [2] N. Jedrecy, H.J. von Bardeleben, V. Badjeck, D. Demaille, D. Stanescu, H. Magnan, A. Barbier, Phys. Rev. B **88**, 121409(R) (2013).