

TT 28: Poster Session on Ferroic Domain Walls - Multiferroics (jointly with DF, KR, MA)

Sponsored by NT-MDT

Part of the 3-days focus on ferroic domain walls:
Tutorial, Symposium (SYDW), and three Focused Sessions.

The goal of the poster session is to present the state of the art of the research on magnetic, ferroelectric, and multiferroic domain walls bringing interested scientist together in a stimulating environment in order to stimulate vivid topical discussions.

Time: Monday 19:00–21:00

Location: Poster C

TT 28.1 Mon 19:00 Poster C

Superdomains in $K_{0.9}Na_{0.1}NbO_3$ thin films on $NdScO_3$ substrates — •JUTTA SCHWARZKOPF¹, MARTIN SCHMIDBAUER¹, DOROTHEE BRAUN¹, ALBERT KWASNIEWSKI¹, JAN SELLMANN¹, and MICHAEL HANKE² — ¹Leibniz Institute for Crystal Growth, Berlin, Germany — ²Paul-Drude-Institut für Festkörperelektronik, Berlin, GermanyIncorporation of lattice strain in thin films gives rise to the creation of controlled arrays of domains and can lead to very complex domain structures. Understanding of strain induced domain formation will open the possibility to selectively influence film properties. Due to its orthorhombic symmetry (K_xNa_x) NbO_3 films offer a large variety of ferroelectric and ferroelastic domain types. In this study $K_{0.9}Na_{0.1}NbO_3$ thin films were grown under slight compressive lattice strain on $NdScO_3$ substrates by MOCVD. Lateral PFM images of the (100) oriented films reveal bundles of ferroelectric domains along the [001] substrate direction and a width of 100-200 nm which are superimposed by ferroelastic domains forming regularly arranged herringbone patterns with a periodicity of 30 nm. The domain walls within the domain bundles are tilted alternately by +15° and -15° with respect to the [110] orientation of the substrate. Grazing incidence x-ray diffraction experiments have shown that adjacent superdomain bands exhibit an in-plane monoclinic lattice distortion of 0.12°. We conclude that the hierarchical structure leads to a domain formation on two scales, which effectively release the misfit strain in the film induced by the substrate.

TT 28.2 Mon 19:00 Poster C

Advanced characterization of functional ferroelectric domain walls by X-ray photoelectron emission microscopy — •JAKOB SCHAAB¹, INGO P. KRUG^{2,3}, ZEWU YAN⁴, EDITH BOURRET⁴, CLAUDIA M. SCHNEIDER³, RAMAMOORTHY RAMESH^{4,5}, MANFRED FIEBIG¹, and DENNIS MEIER¹ — ¹Department of Materials, ETH Zürich — ²Institut für Optik und Atomare Physik, TU Berlin — ³Forschungszentrum Jülich, PGI-6 — ⁴Materials Science Division, LBNL Berkeley — ⁵Department of Materials Science and Engineering, UC Berkeley

The observation of anomalous electronic transport at ferroelectric domain walls and its significance for nano-electronics triggered tremendous scientific interest. To date, the transport behavior and potential barriers at domain walls have been predominantly scrutinized by scanning probes. This, however, convolutes the intrinsic electronic properties with contact resistance and inhomogeneous probe fields, so that the detailed origin of the behavior remains obscured.

Here, we report on the capability of high-resolution X-ray photoemission electron microscopy (X-PEEM) to image and characterize ferroelectric domain walls contact-free and with nanometer resolution. In the ferroelectric semiconductor $ErMnO_3$, we visualize ferroelectric domain walls by exploiting photo-induced charging effects and generate an electronic conduction map by analyzing the kinetic energy of photoelectrons. With this we open a pathway for non-destructive and element-specific studies of electronic and chemical domain-wall structures bypassing previous experimental limitations and significantly expanding the accessible parameter space.

TT 28.3 Mon 19:00 Poster C

Strain-induced defect-polarization coupling in $SrMnO_3$ films — •CARSTEN BECHER¹, LAURA MAUREL², ULRICH ASCHAUER¹, MARTIN LILIENBLUM¹, CESAR MAGEN², DENNIS MEIER¹, ERIC LANGENBERG², MORGAN TRASSIN¹, JAVIER BLASCO³, INGO KRUG⁴, PEDRO ALGARABEL³, NICOLA SPALDIN¹, JOSE PARDO², and MANFRED FIEBIG¹ — ¹ETH Zürich, Zürich, Switzerland — ²Instituto de Nanociencia de Aragon, Zaragoza, Spain — ³Departamento deFísica de la Materia Condensada, Zaragoza, Spain — ⁴Institut für Optik und Atomare Physik, Berlin, GermanyEpitaxial strain can stabilize new matter phases in thin films and is thus a degree of freedom to increase functionality. Here we demonstrate a novel polar phase in 20 nm $SrMnO_3$ films that are epitaxially grown under tensile strains by pulsed laser deposition. High resolution X-Ray diffraction and transmission electron microscopy confirm the crystalline quality of the tetragonal films. We use nonlinear optics to prove that strain induces polarity, and density functional theory to show that it simultaneously increases the concentration of oxygen vacancies. These vacancies accumulate at the polar domain walls where they establish an electrostatic barrier to electron migration. As a consequence, scanning probe microscopy shows that the electrical conductance is structured into isolated "nanocapacitors" which can be charged individually.

TT 28.4 Mon 19:00 Poster C

Raman spectroscopy for the characterization of ferroelectric materials: An Overview — •MICHAEL RÜSING¹, PETER MACKWITZ¹, GERHARD BERTH^{1,2}, and ARTUR ZRENNER^{1,2} — ¹Department Physik, Universität Paderborn, 33098 Paderborn, Germany — ²Center of Optoelectronics and Photonics Paderborn (CeOPP), 33098 Paderborn, Germany

Nonlinear ferroelectrics are a key material class for application in integrated optics from the high power to the single photon level. The exploitable properties range from the electro-optic effect, to large nonlinear susceptibilities and the possibility to achieve quasi-phase matching by periodic poling. But design and fabrication of devices requires an extensive knowledge on the limiting factors, such as intrinsic and extrinsic defects. Here Raman spectroscopy offers a versatile tool for characterization of material properties due to its sensitivity to a wide range of effects. This work provides an overview on performed Raman studies in various ferroelectrics, including Lithium-Niobate-Tantalate mixed crystals and KTP. Determined properties include the relative scattering tensor strengths, material composition in mixed crystals and dielectric properties. Of particular interest is the study of ferroelectric domain structures, whose behavior influenced by the presence of defects.

TT 28.5 Mon 19:00 Poster C

Laser induced poling inhibition of $LiNbO_3$ using an amorphous Si absorber — GRIGORIS ZISIS¹, GREGORIO MARTINEZ-JIMENEZ¹, YOHANN FRANZ¹, NOEL HELAY¹, DAVID GRECH², HAROLD CHONG², ELISABETH SOERGEL³, ANNA PEACOCK¹, and •SAKELLARIS MAILIS¹ — ¹Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, SO17 1BJ, U.K. — ²School of Electronic and Computer Science, University of Southampton, Highfield, Southampton SO17 1BJ, U.K. — ³Institute of Physics, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany

Here we demonstrate laser-induced inhibition of poling in lithium niobate by irradiating a thin absorbing layer of amorphous Si, deposited on the surface of the crystal. The absorption of a-Si in the visible range is sufficiently high to produce significant temperature gradients in the substrate causing a local change in the stoichiometry of the crystal, which in turn modifies the coercive field locally.

This arrangement enables domain engineering using readily available visible laser sources instead of costly and power limiting UV lasers which were previously used to obtain inhibition of poling in this material.

Examination of the topography and piezoresponse of the PI domains, which are formed using this laser assisted method shown a "soft" domain boundary where the domain wall is not sharp but rather consists

of isolated nano-domains whose density and size is a function of the distance from the centre of the laser irradiated track.

TT 28.6 Mon 19:00 Poster C

Raman Spectroscopy and Spin-Phonon-Coupling of Multiferroic $\text{Eu}_{1-x}\text{Ho}_x\text{MnO}_3$ — •SEBASTIAN ELSÄSSER¹, JEAN GEURTS¹, VLADIMIR V. GLUSHKOV², and ANATOLY M. BALBASHOV² — ¹Exp. Phys. III, University of Würzburg, Germany — ²Prokhorov GPI, Russian Academy of Sciences, Moscow, Russia

The revival of studies on magneto-electric (ME) effects has led to rich insights in the physics of charge and spin degrees of freedom and their mutual interaction via ME coupling [1]. One of the most extensively studied effects is the inverse Dzyaloshinskii-Moriya interaction. Hereby, the ordering of the magnetic moments leads to a lattice distortion which, in turn, can induce in a permanent electric polarization. This manifests itself in the perovskite-like rare-earth manganites RMnO_3 . Here, the average size of the rare-earth ions R^{3+} directly influences the octahedron tilting angle. This can be used to tune the coupling between the magnetic Mn sites yielding model system for the interplay of crystalline distortion, magnetic frustration and electric polarization. In this study, $\text{R} = \text{Eu}^{3+}$ ions are partially replaced with Ho^{3+} (<30%) to achieve the multiferroic phase. Spin-phonon-coupling (SPC) is probed by temperature-dependent Raman spectroscopy. We identify the elusive peak at 650cm^{-1} to be the $\text{B}_{3g}(1)$ mode. Upon cooling renormalisation of phonon energies due to SPC-effects starts already well above T_N . We observe that the SPC-shift is mode-specific, being strongest (up to 1%) for the $\text{B}_{2g}(1)$ and $\text{B}_{3g}(1)$, which are both octahedron breathing modes.

[1] M. Fiebig, Journal of Physics D-Applied Physics **38**, 8 (2005)

TT 28.7 Mon 19:00 Poster C

Domain walls in lithium niobate investigated by Raman spectroscopy and density functional theory — •SERGEJ NEUFELD¹, MICHAEL RÜSING², GERHARD BERTH², ARTUR ZRENNER², WOLF GERO SCHMIDT¹, and SIMONE SANNA¹ — ¹Lehrstuhl für Theoretische Physik, Universität Paderborn — ²Department Physik, Universität Paderborn

The intensity of the Raman signal associated to different phonon modes of LiNbO_3 is strongly modified by the presence of ferroelectric domain boundaries [1]. The intensity modulation can be exploited to map domain structures, thus using Raman spectroscopy as a non-destructive imaging tool for the investigation of polarization-domains and domain walls [2]. Unfortunately, the origin of the modifications in the Raman signal is currently unknown. In an attempt to understand the mechanisms leading to the modification of the measured intensity, we have modeled Raman scattering efficiencies from first-principles. Thereby the Raman susceptibility tensor is calculated within the density functional theory following the approach proposed by Ghosez and co-workers [3]. The approach is validated with the TO bulk phonon modes of A_1 and E symmetry and then applied to domain boundaries. The bulk Raman intensities calculated for all possible combinations of the polarization of incoming and scattered photons are in good agreement with the measured spectra. Results for simplified domain wall models are presented and discussed. [1]P. S. Zelenovskiy et. al., Appl. Phys. A **99**, 741 (2010). [2]G. Berth et al., Ferroelectrics **420**, 44 (2011). [3]M. Veithen et al., Phys. Rev. B **71**, 125107 (2005).

TT 28.8 Mon 19:00 Poster C

Evolution of ferroelectric domain patterns in BaTiO_3 at the orthorhombic \leftrightarrow tetragonal phase transition — •THORSTEN LIMBÖCK and ELISABETH SOERGEL — Institute of Physics, University of Bonn, Nussallee 12, 53115 Bonn, Germany

Domain patterns in barium titanate (BTO) were investigated by piezoresponse force microscopy (PFM) using a variable-temperature scanning force microscope. By analyzing the vertical and the lateral PFM images, the directions of polarization of the individual domains, i.e. 6 directions for the tetragonal and 12 for the orthorhombic phase, could be identified. The change of a domain pattern when submitting the crystal to a temperature ramp between $+20^\circ$ and -20° synchronized to the PFM scanning process, was directly monitored. Finally, the possible conversions between specific domain orientations upon heating/cooling the crystal across the phase transition were experimentally confirmed.

TT 28.9 Mon 19:00 Poster C

Domain wall conductivity in gold-patterned single-crystal bulk samples using c-AFM — •THORSTEN ADOLPHS and ELIS-

ABETH SOERGEL — Physikalisches Institut, Universität Bonn, Wegelerstrasse 8, 53115 Bonn

Domain wall conductivity is generally measured by c-AFM, thereby applying moderate voltages between the tip and a large-area back electrode. This technique being very attractive because of its ease of use it has, however, a couple of drawbacks: (i) the voltage applied to the tip leads to electric fields at the tip apex locally exceeding E_c . Since the displacement of a domain wall is energetically favorable (when compared to the creation of new domains), local poling predominantly takes place at the domain walls, leading to a local poling current which is also seen by c-AFM; (ii) the electrical connection between the tip and the domain wall is not reliable; and (iii) different materials of the tip and the back electrode might lead to Schottky-barrier behavior of the domain-wall current. In order to overcome these drawbacks, we propose the use of small, some μm^2 -sized gold-patterns evaporated on top of the sample surface, partially connecting to the domain walls. We will present first experimental results obtained with bulk, single crystalline samples prepared for c-AFM in such a way.

TT 28.10 Mon 19:00 Poster C

Local poling at domain walls in LiNbO_3 crystals in connection with c-AFM measurements — •JAKOB FROHNHAUS and ELISABETH SOERGEL — Physikalisches Institut, Universität Bonn, Wegelerstrasse 8, 53115 Bonn

An electrical current localized at ferroelectric domain walls recorded by means of conductive atomic force microscopy (c-AFM) can basically have two origins: electrical conductivity of the domain wall or local poling. We show that also local poling leads to c-AFM images which cannot straightforwardly be distinguished from those c-AFM images displaying the electrical conductivity of the domain wall.

TT 28.11 Mon 19:00 Poster C

Signature of domain walls in PFM measurements — •TIM FLATTEN and ELISABETH SOERGEL — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Piezoresponse force microscopy (PFM) is at present the technique the most used for mapping ferroelectric domain patterns. However, the unambiguous determination of the direction of polarization of the individual domains based on PFM-images is generally not straightforward. Not only the careful analysis of a set of vertical- and lateral-PFM images are required, but possibly also a set of images after the rotation of the sample by 90° are necessary for fully determining the domain pattern. In addition to the PFM-signal obtained on top of the domain faces, on might, however, also make use of the signature of the domain walls (DW) in the PFM-signal. For $\uparrow\downarrow$ domain walls the PFM-signal shows a symmetric, tangent-like transition between the two domains. This transition, however, should exhibit different features depending on the direction of polarization of the domains adjacent to the DW and the inclination angle of the DW relative to the sample surface. Using this additional information, the full determination of the domain pattern should be facilitated.

TT 28.12 Mon 19:00 Poster C

Measurement system for the magnetoelectric effect — •ULRICH STRAUBE and KATHRIN DOERR — Martin-Luther-University Halle, Institute of Physics, FoG, Von-Danckelmann-Platz 3, 06120 Halle, Germany

Magnetoelectric materials have different and frequency-dependent magnetoelectric effects. The correct determination of these effects is difficult because of various problems including electric and magnetic shielding, sample preparation and pretreatment. A simple measurement arrangement containing a Helmholtz coil, a pair of NdFeB permanent magnets and a special preamplifier is presented. Some results obtained from magnetoelectric ceramic materials are shown.

TT 28.13 Mon 19:00 Poster C

The magnetoelectric effect across scales — •DORU C. LUPASCU¹, HEIKO WENDE², JÖRG SCHRÖDER³, MATTHIAS LABUSCH³, MORAD ETIER¹, AHMADSHAH NAZRABI¹, IRINA ANUSCA¹, HARSH TRIVEDI¹, YANLING GAO¹, MARIANELA ESCOBAR¹, VLADIMIR V. SHVARTSMAN¹, JOACHIM LANDERS², SOMA SALAMON², and CAROLIN SCHMITZ-ANTONIAK⁴ — ¹Materials Science & Center for Nanointegration Duisburg-Essen (CENIDE) — ²Faculty of Physics & CENIDE — ³Institute of Mechanics, all at University of Duisburg-Essen — ⁴Peter-Grünberg-Institut (PGI-6), Forschungszentrum Jülich

Magnetoelectric coupling can arise in intrinsic multiferroics as well

as composites. We will outline how for intrinsic BiFeO₃ nanoparticles yield different magnetoelectric properties at room temperature than larger grains or bulk material. Magnetoelectric nanoscale composites of BaTiO₃ and CoFe₂O₄ display rather poor magnetoelectric coupling macroscopically. Their micron scale counterparts on the other hand yield nice macroscopic response. The mechanical, electrical, and magnetic effects are analyzed using techniques including Mössbauer spectroscopy, magnetic force microscopy, piezoforce microscopy, and macroscopic techniques. It will be shown that microscopic coupling is strong also for (partly) conducting magnetic inclusions and nanosystems while macroscopic properties are highly dependent on good insulation of the samples. Experimental asymmetries in determining the magnetoelectric coupling coefficient are discussed.

Support via FP7 Marie Curie Initial Training Network *Nanomotion* (grant n° 290158) & Forschergruppe 1509 are acknowledged.

TT 28.14 Mon 19:00 Poster C

In situ X-ray studies of mechanical coupling at piezoelectric/magnetostrictive interfaces — ●PHILIPP JORDT¹, STJEPAN HRKAC¹, OLAF M. MAGNUSSEN^{1,2}, and BRIDGET M. MURPHY^{1,2} — ¹Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Germany — ²Ruprecht Haensel Laboratory, Christian-Albrechts-Universität zu Kiel, Germany

To optimize magnetoelectric composites for magnetic sensor applications it is necessary to understand the coupling at the interface between a piezoelectric and a magnetostrictive material. To study the coupling at the interface, we measure the lattice deformation of the piezoelectric substrate *in situ* by grazing incidence X-ray diffraction in an external magnetic field and for different thicknesses of the magnetostrictive layer grown by magnetron sputtering, using the high resolution and high intensity X-ray beam provided by Petra III (P08). We investigate the magnetic field induced strain of (Fe₉₀Co₁₀)₇₈Si₁₂B₁₀ on ZnO and InP substrates. From the Bragg peak positions we determined the interplanar spacings in the substrates and the corresponding strain as a function of the applied magnetic field. We measure the strain for different thicknesses and get a critical thickness for the magnetostrictive layer. We thank the DPG for funding through PAK 902.

TT 28.15 Mon 19:00 Poster C

Influence of piezoelectric induced strain on the Raman spectra of BiFeO₃ films — ●CAMELIU HIMCINSCHI¹, ANDREAS TALKENBERGER¹, JENS KORTUS¹, ALEXANDER SCHMID², ER-JIA GUO^{3,4}, and KATHRIN DÖRR^{3,4} — ¹TU Bergakademie Freiberg, Institute of Theoretical Physics, D-09596 Freiberg, Germany — ²TU Bergakademie Freiberg, Institute of Applied Physics, D-09596 Freiberg, Germany — ³Institute for Physics, Martin-Luther-University Halle-Wittenberg, 06099 Halle, Germany — ⁴Institute for Metallic Materials, IFW Dresden, 01069 Dresden, Germany

BiFeO₃ epitaxial thin films were deposited on piezoelectric 0.72Pb(Mg_{1/3}Nb_{2/3})O₃-0.28PbTiO₃ (PMN-PT) substrates with a conductive buffer layer (La_{0.7}Sr_{0.3}MnO₃, or SrRuO₃) using pulsed laser deposition. The calibration of the strain values induced by the applied voltage on the piezoelectric PMN-PT substrates was realised using X-Ray Diffraction measurements. Raman spectra monitoring as a function of the applied voltage (and hence strain) was performed in resonant conditions, using the 442 nm line of a HeCd laser. The piezoelectric induced strain in the BiFeO₃ films causes shifts in the phonon position. The method of piezoelectrically induced strain allows to obtain a quantitative correlation between strain and the shift of the Raman-active phonons, ruling out the influence of extrinsic factors, as growth conditions, crystalline quality of substrates, or film thickness.

This work is supported by the German Research Foundation DFG HI 1534/1-2.

TT 28.16 Mon 19:00 Poster C

Control of the magnetic properties of magnetostrictive thin films by crossing the phase transition on a Mott insulator — S. FINIZIO¹, A. FANTINI^{1,2}, ●T. LENZ¹, M.V. KHANJANI¹, S. ALTENDORF^{2,3}, D. PASSARELLO², S.S.P. PARKIN², and M. KLÄUI¹ — ¹Institut für Physik, Universität Mainz, Mainz, Germany — ²IBM Almaden Research Center, San Jose, CA, USA — ³Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany

The study of strongly correlated materials such as the Mott insulator VO₂ has recently attracted interest, due to the possibility of manipulating materials properties on ultrafast timescales. VO₂, in particular, has been object of attention as a metal-insulator-transition (MIT) from

an insulating monoclinic phase to a conducting rutile phase occurs at accessible temperatures just above RT. These changes in crystalline order within the MIT induce strain at the interface. Combined with magnetostrictive materials such as Ni, the MIT of VO₂ is exploited to study the dynamics of the magneto-elastic coupling. Here, we present MOKE and SQUID magnetometry studies of the influence of the MIT of VO₂ on the magnetic properties of a Ni thin film. VO₂ thin films were heteroepitaxially deposited by pulsed-laser-deposition on (100) TiO₂ substrates, onto which Ni film were deposited by thermal evaporation. The magnetic properties of the Ni thin films were then determined upon thermally crossing the MIT. Our results show that strong changes in the magnetic anisotropy of the Ni films occur upon crossing the MIT leading to changes in the switching fields and characteristics as needed for ultra-fast strain-induced switching.

TT 28.17 Mon 19:00 Poster C

Structural investigation of erythrosiderites by single crystal X-ray diffraction — ●TOBIAS FRÖHLICH¹, LADISLAV BOHATÝ², PETRA BECKER², and MARKUS BRADEN¹ — ¹II. Physikalisches Institut, Universität zu Köln — ²Institut für Kristallographie, Universität zu Köln

Erythrosiderites A₂[FeX₅(H₂O)], where A stands for an alkali metal or ammonium ion and X for a halide ion, are antiferromagnets with Néel-temperatures ranging from 6 to 23 K [1]. This family of compounds allows to investigate the impact of structural parameters on the magnetoelectric properties by comparing their closely related structures. The compound (NH₄)₂[FeCl₅(H₂O)] was found to be multiferroic with strong magnetoelectric coupling [2]. While most structures of erythrosiderites crystallize in the space group Pnma, Cs₂[FeCl₅(H₂O)] structurally deviates from the other erythrosiderites and crystallizes in space group Cmcm [3]. The structures of (NH₄)₂[FeCl₅(H₂O)] and Cs₂[FeCl₅(H₂O)] are investigated by single-crystal X-ray diffraction. Additionally, the non-magnetic compound (NH₄)₂[InCl₅(H₂O)] is structurally investigated. Irrespective the absence of magnetism, its crystal structure is very similar to that of (NH₄)₂[FeCl₅(H₂O)], therefore it can be used as a reference material to separate magnetoelectric effects.

[1] J. Luzón et al., Physical Review B, **78**, 054414 (2008). [2] M. Ackermann, D. Brüning, T. Lorenz, P. Becker, L. Bohatý, New Journal of Physics **15**, 123001 (2013). [3] M. Ackermann, T. Lorenz, P. Becker, L. Bohatý, J. Phys.: Condens. Matter **26**, 206002 (2014).

TT 28.18 Mon 19:00 Poster C

Multiferroic magnonics: quantum interference, dissipationless energy transport, and Majorana fermions — ●WEI CHEN¹, MANFRED SIGRIST², ANDREAS P. SCHNYDER¹, PETER HORSCH¹, and DIRK MANSKE¹ — ¹Max Planck Institute for Solid State Research, Stuttgart — ²ETH-Zurich, Zurich, Switzerland

We demonstrate the broad applications of multiferroic materials based on their noncollinear magnetic order and magnetoelectric effect. Upon mapping the noncollinear magnetic order into a spin superfluid, the magnetoelectric effect enables the electrically controlled quantum interference of spin superfluid, indicating the possibility of a room temperature SQUID-like quantum interferometer that manifests the flux quantization of electric field. Because the magnetoelectric effect enables changing the noncollinear magnetic order by electric field, we propose that applying an oscillating electric field with frequency as low as household frequency can generate a fast, coherent rotation of the magnetic order that is free from energy loss due to Gilbert damping, and can be used to deliver electricity up to the distance of long range order. At a superconductor/multiferroic interface, the noncollinear magnetic order imprints into the superconductor via *s* – *d* coupling, which can produce Majorana fermions at the edge of the superconductor without the need to adjust chemical potential.

TT 28.19 Mon 19:00 Poster C

Optical properties of Sm-doped BiFeO₃ close to the morphotropic phase boundary — ●FLORIAN BURKERT¹, MICHAELA JANOWSKI¹, XIAOHANG ZHANG², ICHIRO TAKEUCHI², and CHRISTINE KUNTSCHER¹ — ¹Experimentalphysik II, Universität Augsburg, 86159 Augsburg, Germany — ²Department of Materials Science and Engineering, University of Maryland, College Park, Maryland 20742, USA

The perovskite BiFeO₃ is a rare example for a magnetoelectric multiferroic above room temperature. It has been demonstrated on Bi_{1-x}Sm_xFeO₃ thin films that Sm-doping drives BiFeO₃ towards a morphotropic phase boundary with enhanced piezoelectric properties, concomitant with a rhombohedral to pseudo-orthorhombic structural

phase transition [1]. We studied the reflectance of a similar, Sm-doped BiFeO₃ thin film in the far-infrared range at room temperature and ambient pressure by means of FTIR spectroscopy. With increasing Sm doping, we observe changes in the phonon spectrum, especially at Sm content around $x = 0.14$, indicating the occurrence of a structural phase transition in agreement with earlier studies.

[1] I. Takeuchi et al., Appl. Phys. Lett. **92**, 202904 (2008).

TT 28.20 Mon 19:00 Poster C

Inelastic neutron scattering studies on LuFe₂O₄ — ●HAILEY WILLIAMSON¹, PETR ČERMÁK³, JÖRG VOIGT¹, RYOICHI KAJIMOTO⁴, GEETHA BALAKRISHNAN², and MANUEL ANGST¹ — ¹Jülich Centre for Neutron Science JCNS and Peter Grünberg Institut PGI, JARA-FIT, Forschungszentrum Jülich GmbH, Germany. — ²Department of Physics, The University of Warwick, UK. — ³Jülich Centre for Neutron Science JCNS, Forschungszentrum Jülich GmbH, Outstation at MLZ, Germany. — ⁴Neutron Science Section, MLF Division, J-PARC Centre, Japan

Multiferroic oxides, which exhibit a coupling between magnetism and charge order (CO), constitute a strong and competitive avenue of research. The well-known LuFe₂O₄, the first proclaimed multiferroic through CO due to mixed valence Fe^{2+/3+} bilayers separated by Lu monolayers, was initially thought to produce ferroelectricity through polarization, from the specific CO configuration within the bilayers. This fuelled intense investigation, leading to the conclusion through XMCD, bond valence sum analysis of data and macroscopic characterization, that the bilayers are charged and not polar. With much of the static crystallographic and magnetic properties uncovered, it is now essential to elucidate the dynamic properties to understand how the spin and charge are coupled. Here we present quasi-elastic magnetic scattering with a profound temperature dependence, as well as phonon dispersions at higher energies. Finally, we show an indication of a spin gap opening, on cooling through the magnetic ordering temperature.

TT 28.21 Mon 19:00 Poster C

Investigation of low-frequency Raman modes in BiFeO₃ epitaxial thin films with respect to azimuthal orientation — ●ANDREAS TALKENBERGER¹, CAMELIU HIMCINSCHI¹, CHRISTIAN RÖDER¹, IONELA VREJOIU^{2,3}, FLORIAN JOHANN², and JENS KORTUS¹ — ¹TU Bergakademie Freiberg, Institute of Theoretical Physics, Leipziger Str. 23, D-09596 Freiberg — ²Max Planck Institute of Microstructure Physics, Weinberg 2, D-06120 Halle — ³Max Planck Institute for Solid State Research, Heisenbergstr. 1, D-70569 Stuttgart

In this work we present results of highly accurate Raman spectroscopic experiments applied in azimuthal rotation measurements on epitaxial BiFeO₃ thin films grown on different scandate substrates. We observe periodic changes in Raman position, full width at half maximum and intensity for some phonon modes as a function of the azimuthal angle Φ . Further analysis revealed the possibility of the so far controversial assignment of Raman modes at low frequencies ($< 250 \text{ cm}^{-1}$) through rotational Raman measurements, that show high sensitivity towards the mentioned parameters. We successfully simulated the azimuthal behaviour of Raman intensity and position of selected modes offering a symmetry assignment for them. In addition our results support the domain character of the BFO/DSO thin film identified by piezoresponse-force microscopy measurements.

This work is supported by the German Research Foundation DFG HI 1534/1-2.

TT 28.22 Mon 19:00 Poster C

X-ray diffraction on stoichiometric YFe₂O₄ single crystals. — ●THOMAS MÜLLER and MANUEL ANGST — Jülich Centre for Neutron Science JCNS and Peter Grünberg Institut PGI, JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany.

LuFe₂O_{4- δ} was long considered to be the primary example for a charge order multiferroic. YFe₂O_{4- δ} is isostructural, but the ionic radius of Y is much larger compared to Lu, leading to completely different ordering phenomena. We have grown highly stoichiometric single crystals of YFe₂O_{4- δ} by the optical floating zone method, showing for the first time 3D charge ordering in x-ray diffraction at low temperature. The phase at 200 K can be indexed using a propagation vector of $(\frac{1}{7} \frac{1}{7} \frac{9}{7})$ considering 6 twin components and second order. Likewise the 160 K phase can be indexed with $q = (\frac{1}{4} \frac{1}{4} \frac{3}{4})$. While cooling not only the three-fold symmetry but in contrast to LuFe₂O₄ also the mirror plane of the room temperature R $\bar{3}m$ structure of YFe₂O_{4- δ} are lost according to symmetry-analysis.

TT 28.23 Mon 19:00 Poster C

Photoemission electron microscopy study of two-phase Fe/BaTiO₃ multiferroic system — ●ASHIMA ARORA, MATTEO CIALONE, AKIN ÜNAL, SERGIO VALENCIA, and FLORIAN KRONAST — Helmholtz-Zentrum Berlin für Materialien und Energie, Albert-Einstein-Str. 15, 12489 Berlin, Germany

The phenomenon of magneto-electric coupling is of great technological importance in devices such as data storage due to possible electric field control of magnetic properties. However, a single material possessing different ferroic orders which can be exploited practically is difficult to find. Therefore we study a two-phase ferroic system made up of Fe wedge on top of a BaTiO₃ single crystal. Here, we study the magnetization of the ferroelectric film by Photoemission Electron Microscopy (PEEM). The capability of PEEM to be element selective and sensitive to magnetic structure of the sample using the tool of X-Ray Magnetic Circular Dichroism (XMCD) makes it possible to get laterally resolved images of magnetic state for individual element in the sample. We have visualized the magnetic domains on the Fe wedge and observed that they are influenced by the BTO substrate at the bottom. In addition, the spectroscopic information using X-ray Absorption Spectroscopy (XAS) provides a deeper insight on the interplay between the ferroelectric and ferromagnetic properties at the interface of Fe and BaTiO₃ in the multi-ferroic system.

TT 28.24 Mon 19:00 Poster C

Towards an experimental evidence of the linear magnetoelectric coupling — ●ALEXANDER SUKHOV¹, LEVAN CHOTORLISHVILI¹, PAUL P. HORLEY², CHENGLONG JIA³, and JAMAL BERAKDAR¹ — ¹Institut für Physik, Martin-Luther-Universität, Halle-Wittenberg, 06099 Halle (Saale), Germany — ²Centro de Investigacion en Materiales Avanzados (CIMAV S.C.), Chihuahua/Monterrey, 31109 Chihuahua, Mexico — ³Key Laboratory for Magnetism and Magnetic Materials of the MOE, Lanzhou University, Lanzhou 730000, China

We present a theoretical study combining simulations of ferromagnetic resonance (FMR) for interfaces of Co/BaTiO₃ and Fe/BaTiO₃ [1] and calculations of the mean first passage times for a system of single-domain Fe-nanoparticles deposited on a ferroelectric BaTiO₃-substrate [2]. The study is focused on the consequences of the magnetoelectric coupling - which is considered to be linear in polarization and magnetization due to a screening mechanism - on the spectra of absorbed power [1] and the mean switching times of the Fe-nanoparticles [2]. In particular, we demonstrate and discuss how to extract an information on the symmetry and the strength of the magnetoelectric coupling from FMR-experiments, which was recently evidenced in the experiments of Ref. [3] or from eventual telegraph-noise-like experiments.

[1] A. Sukhov, P.P. Horley, C.-L. Jia, J. Berakdar, J. Appl. Phys. **113**, 013908 (2013). [2] A. Sukhov, L. Chotorlishvili, P.P. Horley, C.-L. Jia, S. Mishra, J. Berakdar, J. Phys. D: Appl. Phys. **47**, 155302 (2014). [3] N. Jedrecy *et al.*, Phys. Rev. B **88**, 121409(R) (2013).

TT 28.25 Mon 19:00 Poster C

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 $1 \mu\text{m}$. 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 YMnO₃. The numerical calculations were compared with experimental data and found to be in excellent agreement.

TT 28.26 Mon 19:00 Poster C

Emergence of ferroelectricity in multiferroic h-YMnO₃ — ●MARTIN LILIENBLUM¹, THOMAS LOTTERMOSER¹, SEBASTIAN MANZ¹, SVERRE M. SELBACH², ANDRES CANO³, and MANFRED FIEBIG¹ — ¹Department of Materials, ETH Zurich, Vladimir-Prelog-Weg 4, 8093 Zurich, Switzerland — ²Department of Material Science and Engineering, NTNU, N-7491 Trondheim, Norway — ³CNRS, Université de Bordeaux, ICMCB, UPR 9048, F-33600 Pessac, France

Universal scaling laws, interfacial nano-electronics, and topological defects are currently studied using hexagonal manganites $R\text{MnO}_3$ ($R = \text{Sc}, \text{Y}, \text{Dy-Lu}$) as model system. In spite of the remarkably broad interest in the system, surprisingly little is known about the origin of the ferroelectric state. Here we solve the controversy about the emergence of the spontaneous polarization and its coupling to the underlying structural distortion by applying scanning probe microscopy (SPM) and optical second harmonic generation (SHG). We trace the spontaneous polarization by SHG from 100 K to 1450 K directly and contact-free. We find that only a single transition exists in which the polarization arises slower than expected as by-product of the structural distortion. By thermal treatments close to the structural transition and subsequent SPM scans, we show that the exceptionally robust ferroelectric domain pattern is determined only by the structural distortion. In summary we reveal that the ferroelectric order results from an interplay of electric polarization, topological effects, and temperature.

TT 28.27 Mon 19:00 Poster C

Strain-induced defect-polarization coupling in SrMnO₃ films — ●CARSTEN BECHER¹, LAURA MAUREL², ULRICH ASCHAUER¹, MARTIN LILIENBLUM¹, CESAR MAGEN², DENNIS MEIER¹, ERIC LANGENBERG², MORGAN TRASSIN¹, JAVIER BLASCO³, INGO KRUG⁴, PEDRO ALGARABEL³, NICOLA SPALDIN¹, JOSE PARDO², and MANFRED FIEBIG¹ — ¹ETH Zürich, Zürich, Switzerland — ²Instituto de Nanociencia de Aragon, Zaragoza, Spain — ³Departamento de Física de la Materia Condensada, Zaragoza, Spain — ⁴Institut für Optik und Atomare Physik, Berlin, Germany

Epitaxial strain can stabilize new matter phases in thin films and is thus a degree of freedom to increase functionality. Here we demonstrate a novel polar phase in 20 nm SrMnO₃ films that are epitaxially grown under tensile strains by pulsed laser deposition. High resolution X-Ray diffraction and transmission electron microscopy confirm the crystalline quality of the tetragonal films. We use nonlinear optics to proof that strain induces polarity, and density functional theory to show that it simultaneously increases the concentration of oxygen vacancies. These vacancies accumulate at the polar domain walls where they establish an electrostatic barrier to electron migration. As a consequence, scanning probe microscopy shows that the electrical conductance is structured into isolated "nanocapacitors" which can be charged individually.

TT 28.28 Mon 19:00 Poster C

Magnetolectric domain control in multiferroic TbMnO₃ — ●SEBASTIAN MANZ¹, MASAKAZU MATSUBARA^{1,2}, MASAHITO MOCHIZUKI^{3,4}, TERESA KUBACKA¹, AYATO IYAMA⁵, NADIR ALIOUANE⁶, TSUYOSHI KIMURA⁵, STEVEN JOHNSON¹, DENNIS MEIER¹, and MANFRED FIEBIG¹ — ¹ETH Zürich — ²Tohoku University — ³Aoyama Gakuin University — ⁴Japan Science and Technology

Agency — ⁵Osaka University — ⁶Paul Scherrer Institute

Spin-spiral multiferroics exhibit a strong coupling between the electric and magnetic subsystems which is of potential interest for technological applications. Although these systems have been investigated for more than a decade, the magnetolectric domain evolution under external fields is still largely unknown. Using optical second harmonic generation we resolve how electric and magnetic fields affect the multiferroic domains in the archetypal spin-spiral multiferroic TbMnO₃. In consecutive electric switching cycles, varying multi-domain patterns emerge before a single-domain state is obtained. This observation reflects that the domain walls can easily move without being pinned by, e.g., structural defects. In striking contrast to the electric-field response, multi-domain patterns persist when the polarization direction is flopped by applied magnetic fields. Here, a uniform polarization rotation is observed within all domains, which incorporates a transformation of neutral into nominally charged domain walls. Our results are explained based on numerical Landau-Lifshitz-Gilbert simulations and provide first evidence for the scalability of macroscopic magneto-electric properties onto the level of domains.

TT 28.29 Mon 19:00 Poster C

Ab initio expression of magneto-electric coupling coefficients in terms of current response function — ●RONALD STARKE¹ and GIULIO SCHOBER² — ¹Institut f. Theo. Physik, Bergakademie Freiberg — ²Institut f. Theo. Physik, Uni Heidelberg

Based on the Functional Approach to electrodynamics of media, we show that the Maxwell equations imply closed, analytical expressions of the magneto-electric coupling coefficients in terms of the current response functions. On the linear level, these expressions include all effects of inhomogeneity, anisotropy and relativistic retardation. Moreover, we relate the 36 component functions of the constitutive tensor used in the context of bi-anisotropic media to only 9 causal response functions which specify the current response to an external vector potential.

TT 28.30 Mon 19:00 Poster C

First-principles study of magnetic properties of BaFeO_{3-δ} — ●IGOR MAZNICHENKO¹, SERGEY OSTANIN², ARTHUR ERNST², and INGRID MERTIG^{1,2} — ¹Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle, Germany — ²Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany

Oxides with a perovskite atomic structure are ideally suited to grow two-component multiferroics, in which a ferroelectric oxide barrier is sandwiched between magnetic electrodes. For example, the perovskites ATiO₃ ($A = \text{Ba}, \text{Pb}$) can be used as ferroelectric barrier, while ferromagnetic perovskites (La,Sr)MnO₃ or SrRuO₃ can serve as ferromagnetic electrodes. Oxide materials are preferable in such a tunnel junction because of their compatibility and growth. Since the number of ferromagnetic conducting oxides is restricted, a search of new suitable oxide electrodes is highly desirable. Recently, the perovskite BaFeO₃ was reported to be ferromagnetic in bulk and as thin film [1]. Here, using a first-principles Green function method within the density functional theory, we present a study on magnetic and electronic properties of bulk BaFeO₃ especially focusing on the impact of structural deformations and intrinsic defects.

[1] S. Chakraverty et al., Applied Physics Letters 103, 142416 (2013).