DF 4: Focused Session on Ferroic Domain Walls I (DF with MA)

Part of the 3-days focus on ferroic domain walls:
Tutorial, Symposium (SYDW), three Focused Sessions, and Poster Session.
Organizers: Elisabeth Soergel (Universität Bonn) and Dennis Meier (ETH Zürich)

Time: Monday 15:00–18:30 Location: EB 107

Topical Talk DF 4.1 Mon 15:00 EB 107
Domain walls and phase boundaries - new nanoscale functional elements in complex oxides — •Jan Seidel — School of Materials Science and Engineering, UNSW Australia, Sydney, Australia

Interfaces and topological boundaries in complex oxide materials, such as domain walls and morphotropic phase boundaries, have recently received increasing attention due to the fact that their properties, which are linked to the inherent order parameters of the material, its structure and symmetry, can be completely different from that of the bulk material [1]. I will present an overview of recent results on electronic and optical properties of ferroelectric phase boundaries, domain walls, and topological defects in multiferroic materials [2, 3, 4, 5, 6]. The origin and nature of the observed confined nanoscale properties is probed using a combination of nanoscale transport measurements based on scanning probe methods, high resolution transmission electron microscopy and first-principles density functional computations. I will also give an outlook on how these special properties can be found in other material systems and discuss possible future applications [7].
1. J. Seidel, et al., Nature Materials 8, 229 (2009) 2. J. Seidel, et al., J. Phys. Chem. Lett. 3, 2905 (2012) 3. J. Seidel, et al., Phase Trans. 86, 53 (2013) 4. J. Seidel, et al., Adv. Mater., 26, 4376 (2014) 5. Y. Heo, et al., Adv. Mater., DOI: 10.1002/adma.201401958 (2014) 6. K.-E. Kim, NPG Asia Mater. 6, e81 (2014) 7. G. Catalan, J. Seidel, R. Ramesh, and J. Scott, Rev. Mod. Phys. 84, 119 (2012)

DF 4.2 Mon 15:30 EB 107
Dielectric properties of multiferroic hexagonal manganites — •Stephan Krohns[1], Eugen Ruff[1], Peter Lunkenheimer[1], Martin Lilienblum[2], Dennis Meier[2], Manfred Fiebig[2], and Alois Loidl[1] — [1]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Germany — [2]Multifunctional Ferroics, Department of Materials, ETH Zurich, Switzerland

Hexagonal manganites exhibit a broad variety of highly interesting features as, e.g., domain-wall structure, geometric improper ferroelectricity and antiferromagnetic ordering. The exact mechanism for ferroelectricity is still under debate as well as the impact of the domain-wall structure to macroscopic quantities (e.g., the dielectric constant). A technique to determine the multiferroic, ferroelectric and domain-wall polarisation phenomena is the measurement of the dielectric response to ac and dc electric fields. Here we thoroughly analyse the dielectric response of $YMnO_3$ single crystals in a broad temperature and frequency range. The crystals were subjected to precisely defined cooling rates from above the ferroelectric transition to vary their domain-wall densities. Two relaxation processes occur at temperatures below 350 K. The major one points to an extrinsic so-called Maxwell-Wagner relaxation, based on a thin insulating layer at the surface of the sample. The second, smaller relaxation seems to be of intrinsic origin. We address the question if the macroscopic dielectric properties are influenced by the ferroelectric domain-wall structure.

DF 4.3 Mon 15:50 EB 107
Domain wall motion in proper and improper ferroelastic materials — •Wilfried Schranz — University of Vienna, Faculty of Physics, Boltzmanngasse 5, Vienna, Austria

Many proper and improper ferroelastic materials display (at low measurement frequncies) a huge elastic softening below Tc. This giant elastic softening is caused by domain wall motion and can be supressed with uniaxial stress. Here we review our results on frequency and temperature dependent elastic measurements of $SrTiO_3$ [1], $KMnF_3$ and $KMn_{1-x}Ca_xF_3$ [2], $PbZrO_3$, $NH_4HC_2O_4 \cdot \frac{1}{2}H_2O$ [3] and $BaFe_2As_2$ [4] and put them into context with data from literature. We also present a model [5] based on Landau-Ginzburg theory to describe superelastic softening observed in some of the perovskite systems (improper ferroelastic) as well as in iron based superconductors (pseudo-proper ferroelastic) and show, how the theory can be extended to describe the effects of domain miniaturization (e.g. near morphotropic phase boundaries) on the macroscopic porperties of materials.

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[1] A.V. Kityk, W. Schranz, P.Sondergeld, D. Havlik, E.K.H. Salje and J.F. Scott, Phys. Rev. B 61, 946 (2000) [2] W. Schranz, P. Sondergeld, A.V. Kityk and E.K.H. Salje, Phys. Rev. B 80, 094110 (2009) [3] W. Schranz, H. Kabelka, A. Sarras and M. Burock, Appl. Phys. Lett. 101, 141913 (2012) [4] A.E. Böhmer, P.Burger, F. Hardy, T. Wolf, T. P. Schweiss, R. Fromknecht, M. Reinecker, W. Schranz and C. Meingast, Phys. Rev. Lett. 112, 047001 (2014) [5] W. Schranz, Phys. Rev. B 83, 094120 (2011)

Topical Talk DF 4.4 Mon 16:10 EB 107
Field-induced hysteresis of chiral vortices in ferroelectric $SrTiO_3$ twin walls. — •Ekhard Salje — University of Cambridge, Cambridge, UK

Resonant piezoelectric spectroscopy shows polar resonances in paraelectric $SrTiO_3$ at temperatures below 80 K. These resonances become strong at $T < 40$ K. This piezoelectric response does not exist in paraelastic $SrTiO_3$ nor at temperatures just below the ferroelastic phase transition. The interpretation of the resonances is related to ferroelastic twin walls which become polar at low temperatures in close analogy with the known behavior of $CaTiO_3$. $SrTiO_3$ is different from $CaTiO_3$, however, because the wall polarity is thermally induced; i.e., there exists a small temperature range well below the ferroelastic transition point at 105 K where polarity appears on cooling. As the walls are atomistically thin, this transition has the hallmarks of a two-dimensional phase transition restrained to the twin boundaries rather than a classic bulk phase transition. Simulations of polar twin walls in $SrTiO_3$ show nanoscopic vortices, which can be switched in orientation under an external electric field. The hysteresis of the vortex polarization inside the twin boundary leads to direct applications in non-volatile memory devices. E.K.H. Salje et al. Domains within Domains and Walls within Walls: Evidence for Polar Domains in Cryogenic $SrTiO_3$, Phys. Rev. Lett. 111, 24, 247603 (2014), Zykova-Timan T and Salje E.K.H. Highly mobile vortex structures inside polar twin boundaries in SrTiO3, APL 104, 082907 (2014).

10 min break

Topical Talk DF 4.5 Mon 16:50 EB 107
Spintronic functionality of $BiFeO_3$ domain walls — Ji Hye Lee[1,3], Ignasi Fina[1,2], Dietrich Hesse[1], and •Marin Alexe[1,2] — [1]Max Planck Institute of Microstructure Physics, 06120 Halle, Germany — [2]University of Warwick, Department of Physics, Coventry CV4 7AL, UK — [3]Division of Quantum Phase and Device, Department of Physics, Konkuk University, Seoul 143-701, Korea

Here we show that the FE domain walls (DWs) in the multiferroic material $BiFeO_3$ (BFO), which are intrinsically two dimensional nanoobjects, are not only conductive, but are also ferromagnetic, showing spin-dependent transport. We will show that the electronic transport across the * FM and FE * domain walls in BFO is modulated by an external magnetic field, resembling the anisotropic magnetoresistance (AMR) in archetypical metallic ferromagnets. The found AMR is accompanied by a visible hysteresis, which is ascribed to the coupling of the FM domain walls to the antiferromagnetic properties of the BFO domains, similar to those found in magnetically coupled FM/AFM structures. Since BFO preserves two switchable electric polarization states, one can manipulate the FE DWs and thus magnetization via an electric field. The electronic transport occurring through the FE DWs in common metal-ferroelectric-metal capacitors has been discriminated from the contribution occurring from the bulk, and the intrinsic conduction mechanism at the DWs is identified.

DF 4.6 Mon 17:20 EB 107
3D-mapping of ferroelectric domain walls by Cherenkov second-harmonic generation — •Thomas Kämpfe[1], Philipp Reichenbach[1], Mathias Schröder[1], Alexander Haussmann[1],

Theo Woike[2], and Lukas M. Eng[1] — [1]Institut für Angewandte Photophysik, Technische Universität Dresden, George-Bähr-Str. 1, 01069 Dresden, Germany — [2]Institut für Strukturphysik, Technische Universität Dresden, Zellescher Weg 16, 01069 Dresden, Germany

Ferroelectric domain walls (DWs) are a novel approach towards nanoelectronic circuitry since providing localized conduction within a fully insulating host matrix. The key factor is the DW inclination angle α with respect to the crystallographic axes determining the amount of polarization charge at the head-to-head DWs. Hence, the conductivity can be considerably tuned via doping concentration and poling conditions. We apply Cherenkov second-harmonic generation (C-SHG) to map such charged DWs in three dimensions throughout a mm-thick Mg:$LiNbO_3$ single crystal [1]. We will present domain wall topologies for different cases, also including surface domains, which are created upon external UV illumination and exhibiting also tail-to-tail DWs. We investigated the domain wall protrusion upon different illumination strengths. Moreover, we will also introduce into an extended version of C-SHG based on interferometric SHG (I-SHG). I-SHG provides several advantages as compared to C-SHG, such as an increased vertical resolution, a larger vertical imaging range, as well as easier imaging conditions.

[1] T. Kämpfe et al., Phys. Rev. B, 89, 035314 (2014).

DF 4.7 Mon 17:40 EB 107

UV-induced AC transport along conductive domain walls in $LiNbO_3$ single crystals — Mathias Schröder[1], Xi Chen[2], •Alexander Haussmann[1], Andreas Thiessen[1], Jan Poppe[3], Dawn A. Bonnell[2], and Lukas M. Eng[1] — [1]Institut für Angewandte Photophysik, Technische Universität Dresden, George-Bähr-Str. 1, D-01069 Dresden, Germany — [2]Materials Science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA — [3]Physikalische Chemie, Technische Universität Dresden, Bergstrasse 66 b, D-01062 Dresden, Germany

The impedance properties of UV-illuminated ($\lambda = 310\,\text{nm}$) conductive domain walls (CDWs) in 5% Mg-doped $LiNbO_3$ single crystals (sc) are investigated both on the nm length scale using nanoimpedance microscopy (NIM), as well as macroscopically by comparing the transport properties of multi- and single domain samples. Similar to the DC transport, we find the CDWs to be highly conductive for AC currents as well, mostly pronounced for $f < 200\,\text{Hz}$ due to the strong influence of the bulk capacitance at higher frequencies. Moreover, simultaneously applying both an AC and DC voltage results in an increased real part of the AC CDW current. Equivalent circuits accurately describing both the domain and CDW contributions hence were developed; as a result we are able to analyze and quantify the complex dielectric conductive behavior of both bulk and CDWs in sc-$LiNbO_3$ within the framework of the mixed conduction model: Hopping of excited charge carriers along the CDWs was identified as the dominant charge transport process.

Topical Talk DF 4.8 Mon 18:00 EB 107

Functional ferroic domain walls - AC & DC transport — •Lukas M. Eng — Institute of Applied Physics, TU Dresden, 01062 Dresden, Germany

Wide band-gap ferroic oxides exhibit both ferroelectric and ferromagnetic properties that promise a novelty of tunable and spectacular applications such as magneto-electric storage devices [1] or metamaterial-based superlensing [2]. We focus here on the domain wall functionality which is clue in order to engineer devices as the ones mentioned above for modern-type applications. Surprisingly, we find such domain walls in $LiNbO_3$ and other single crystals to exhibit a metallic-like conductivity [3] that can even be tuned or switched on and off. Consequently, such charged domain walls allow for both AC [4] and DC [3] electron transport within a nanometer-wide discontinuity that is embedded in a fully insulating matrix. We investigated these novel topologies with a variety of scanning probe techniques, through transport measurements as well as with nonlinear optical methods [5], Since these metallic-like nanocontacts can be engineered on will, they provide a novel and elegant way for exploring nanoscale 2-dimensional transport properties.

[1] R. Streubel et al., Phys. Rev. B 87, 054410 (2013). [2] S.C. Kehr et al., Nature Comm. 2, 249 (2011). [3] M. Schröder et al., Adv. Funct. Mater. 22, 3936 (2012). [4] M. Schröder et al., Mater. Res. Express 1, 035012 (2014). [5] T. Kämpfe et al., Phys. Rev. B 89, 035314 (2014).