DF 7: Focus Session: Ferroic Domain Walls I

Fascinating correlation physics, such as superconductivity and magnetoelectric coupling, occur at domain walls in complex oxides even when forbidden in the surrounding bulk. These unusual interface phenomena and their hypersensitivity to external stimuli are of great academic and technological interest, and are currently intensively studied. This session focuses on recent and future developments in the rapidly growing field of domain and domain-wall engineering, related functionality, key concepts and materials, as well as advanced characterization methods. In total, the session consists of three parts (DF7, DF9, DF11) and one poster session (DF12)

Organized by Elisabeth Soergel and Dennis Meier

Time: Tuesday 9:30–13:00 Location: H25

Invited Talk DF 7.1 Tue 9:30 H25

Spin and charge transport in multiferroic domain walls — •Ramamoorthy Ramesh — University of California, Berkeley

Complex perovskite oxides exhibit a rich spectrum of functional responses, including magnetism, ferroelectricity, highly correlated electron behavior, superconductivity, etc. The basic materials physics of such materials provide the ideal playground for interdisciplinary scientific exploration. Among the large number of materials systems, there exists a small set of materials which exhibit multiple order parameters; these are known as multiferroics. Domain walls may play an important role in future electronic devices, given their small size as well as the fact that their location can be controlled. We reported the observation of room-temperature electronic conductivity at ferroelectric domain walls in the insulating multiferroic BiFeO3. The origin and nature of the observed conductivity were probed using a combination of conductive atomic force microscopy, high-resolution transmission electron microscopy and first-principles density functional computations. Our analyses indicate that the conductivity correlates with structurally driven changes in both the electrostatic potential and the local electronic structure, which shows a decrease in the bandgap at the domain wall. Subsequent work in our program has demonstrated several key features of domain wall transport in manganites. Of course, one dream is to be able to create *metallic* walls in a ferroelectric matrix. I will describe our efforts in this direction.

DF 7.2 Tue 10:10 H25

Roughness, dynamics and conduction at domain walls in $Pb(Zr_{0.2}Ti_{0.8})O_3$ thin films — •Philippe Tückmantel[1], Iaroslav Gaponenko[1], Benedikt Ziegler[1], Joshua Agar[2], Lane Martin[2], and Patrycja Paruch[1] — [1]DQMP, University of Geneva — [2]MSE, University of Berkeley

Defects and electrostatic boundary conditions greatly impact the geometry and growth dynamics of polarization domains in ferroelectric thin films. In PZT we have shown that defect pinning and screening by surface water determine the roughness and creep dynamics of 180° domain walls. Surface adsorbates and defects can also reversibly control domain wall conduction. However, there has not been a detailed study considering specifically the interrelation of domain wall roughness and local conductance variations.

Here, we present our results on PZT thin films grown simultaneously on STO, DSO, GSO, and LSAT substrates to address this. Substrate choice provides control over the defect density, while ultra-high vacuum (UHV) thermal annealing allows removal of surface adsorbates, thus providing an opportunity to study the role of defects and adsorbates on the functional and fundamental ferroelectric domain walls.

Using piezoresponse force microscopy at ambient conditions as well as in UHV, we study the effect of the substrate and surface adsorbates on the roughness and growth dynamics of domains as well as on the conduction behaviour of the domain walls, thus providing insight into the effect of the substrate on the intrinsic defect configuration of the overlying films.

DF 7.3 Tue 10:30 H25

Variable arrangement of domain walls in monoclinic $K_{0.9}Na_{0.1}NbO_3$ epitaxial films on $NdScO_3$ substrates — •Jutta Schwarzkopf[1], Dorothee Braun[1], Toni Markurt[1], Michael Hanke[2], and Martin Schmidbauer[1] — [1]Leibniz Institute for Crystal Growth, Max-Born-Str. 2, 12489 Berlin — [2]Paul-Drude Institute, Hausvogteiplatz 5-7, 10117 Berlin

Many macroscopic characteristics of ferroelectric materials are directly related to the physical properties of domains and domain walls. Therefore it is crucial to investigate structure, size and orientation of domains including their domain walls in order to get a fundamental understanding of formation mechanisms and functionality of domain wall, especially with regard to the incorporated lattice strain. In contrast to films with tetragonal, rhombohedral or orthorhombic symmetry the domain walls of monoclinic phases in $K_xNa_{1-x}NbO_3$ exhibit variable orientation depending on the components of the spontaneous strain tensor allowing the targeted alignment of the domain walls. In this study $K_{0.9}Na_{0.1}NbO_3$ thin films were grown under anisotropic lattice strain on $NdScO_3$ (NSO) substrates by metal-organic chemical vapor deposition. Lateral PFM images reveal bundles of ferroelectric domains along the $[001]_{NSO}$ direction of the substrate. They are superimposed by smaller domains forming regularly ordered herringbone patterns which can be described by alternately arranged monoclinic M_C/a_1a_2 domains. The in-plane angle $\pm\alpha$ between the twin domain walls and the $[1\text{-}10]_{NSO}$ direction is determined by the incorporated lattice strain and can intentionally be adjusted between 15° and 45°.

DF 7.4 Tue 10:50 H25

Probing the interaction of surface adsorbates with ferroelectric domains — •Iaroslav Gaponenko[1], Nicolas Stucki[2], Albert Verdaguer[3], and Patrycja Paruch[1] — [1]DQMP, University of Geneva, 1211 Geneva, Switzerland — [2]University of Applied Sciences Western Switzerland in Geneva (HES-SO/hepia), 1213 Geneva, Switzerland — [3]Institut Català de Nanociència i Nanotecnologia (ICN2), Campus UAB, 08193, Bellaterra (Barcelona), Spain

Surface adsorbates are an ubiquitous presence on all materials exposed to ambient environmental conditions. Water, in particular, by virtue of its polar nature, has been shown to interact strongly with domains and domain walls in ferroelectric materials. We have previously focused on the influence of water on polarisation switching dynamics in Pb(Zr0.2Ti0.8)O3 thin films, and demonstrated its key role (together with redistribution of oxygen vacancies) in the reversible control of electrical transport at 180° domain walls in this material. However, in these systems the reciprocal effect of polarization also needs to be considered, as it will induce changes in the physics of surface adsorbates.

Here, we present our studies of the interaction of adsorbed water with the surface of thin films of Pb(Zr0.2Ti0.8)O3 by combined topographical and electrostatic force microscopy imaging. Comparing domains written with positive and negative tip voltage, and the as-grown state of the film, we map out the changes in the strength of the electrostatic interactions between the microscopy tip and surface as a function of changing humidity, and demonstrate that the surface arrangement of the water depends on the ferroelectric domain orientation.

20 min. break

Topical Talk DF 7.5 Tue 11:30 H25

Conduction and Diode Behaviour in Charged Domain Walls — •Michael Campbell — Queens University Belfast, Belfast, Northern Ireland, UK

It is now clear that ferroelectric domain walls can have functional properties distinct from bulk. Charged domain walls (or CDWs), at which discontinuities in polarisation occur, have been of particular interest, as they are often associated with strong enhancements in localised conductivity[1-2]. Moveable conducting CDWs could have obvious implications for new forms of *domain wall electronics* and are hence worthy of focused study.

Here we present a multi-faceted investigation into CDWs. We have directly measured dc conduction and used Hall voltage measurements to determine carrier types, densities and mobilities in CDWs in both rare-earth manganites and lithium niobate (LNO). We have probed the properties of naturally forming p-n junctions in domain wall intersection points in ErMnO3 and have directly written CDW p-n junctions using AFM in LNO. 2D diode structures have thus been observed and created within CDWs. We have also seen how direct injection of electrons using Scanning Electron Microscopy can affect the conduction properties of CDWs.

[1]M. Y. Gureev et al. Phys. Rev. B 83, 184104 (2011)
[2]D. Meier et al. Nat. Mat. 11, 284-288 (2012)

DF 7.6 Tue 12:00 H25

A closer look inside out - Domain wall functionalities in $LiNbO_3$ single crystals go 3D — •Alexander Haussmann[1], Thomas Kämpfe[1], Christian Godau[1], Philipp Reichenbach[1], André Gemeinhardt[1], Anna-Sophie Pawlik[2], Andreas Koitzsch[2], Lars Kirsten[3], Edmund Koch[3], and Lukas Eng[1] — [1]Institut für Angewandte Physik, TU Dresden, George-Bähr-Str. 1, 01069 Dresden — [2]IFW Dresden, Helmholtzstr. 20, 01069 Dresden — [3]TU Dresden, Medizinische Fakultät, Klinisches Sensoring und Monitoring, Fetscherstr. 74, 01307 Dresden

Both the discoveries of domain-wall (DW) localized photochemistry and DW conductivity have dramatically broadened the huge interests in ferroelectric $LiNbO_3$ for the last decade. Surprisingly, it turned out that the DW geometries in this material differ consistently from the ideal equilibrium "textbook" arrangement of 180° domain walls: Low inclinations with respect to the polar (z) axis ($< 0.5°$) as well as unexpectedly complex topologies have been regularly observed, depending on composition, doping and subsequent heat treatment of the material. Here, we combined multiple 2D and 3D methods in order to achieve a comprehensive characterization of both the geometry and the resulting electronic properties of DWs in $LiNbO_3$. The portfolio of techniques contributing to this study range from high-resolution surface-sensitive techniques (such as PFM, cAFM, KPFM, PEEM) to complementary optical methods allowing for a full 3D inspection (Cherenkov SHG, interferometric quasi-phase-matched SHG, multiphoton photoluminescence, optical coherence tomography).

DF 7.7 Tue 12:20 H25

Methods to create electronically compensated charged domain walls in ferroelectrics without scanning probe techniques — •Tomas Sluka[1], Arnaud Crassous[1], Petr Bednyakov[1], Igor Stolichnov[1], Ludwig Feigl[1,2], Dragan Damjanovic[1], Alexander Tagantsev[1], and Nava Setter[1] — [1]EPFL - Swiss Federal Institute of Technology, Lausanne, Switzerland — [2]Karlsruhe Instute of Technology, Karlsruhe, Germany

Charged Domain Walls (CDWs) in ferroelectrics were predicted to be metallicaly conducting interfaces that can be positioned inside a monolith of nominally insulating materials. Such CDWs are thus promising elements for the envisaged reconfigurable nanoelectronics. Indeed, highly elevated conductivity was observed at CDWs in several ferroelectric materials. The progress towards CDW exploitation is however hindered by the absence of practical CDW engineering techniques. CDWs were found either locked in as grown patterns, were created locally with scanning probe techniques or stochastically with defect assisted compensation. Here we introduce a set of methods which allow to create electronically compensated CDWs without the need of a scanning probe tip or presence of charged defects. The methods range from the use of superbandgap illumination which generates free carries that compensate appearing CDWs to the use of inhomogeneous electric fields and electron injection inside nanoscale structures. It will be shown that CDWs can be reliably produced in forms of large regular patters or few-nanometes long precisely positioned channels. These methods open the doors to the advanced investigation of CDWs.

DF 7.8 Tue 12:40 H25

Tools in study of abnormal photovoltaic effects at domain walls — Mingmin Yang and •Marin Alexe — University of Warwick, Department of Physics, CV4 7AL, Coventry, UK

In the recent past, the field of anomalous photovoltaic effect in non-centrosymmetric perovskite ferroelectric oxides has been revitalized by the reports of photovoltaic effect (PVE) in BiFeO3 (BFO). The microscopic origins of this effect are still under debate. Initial investigations on BFO films assumed that the PVE in BFO is primarily due to the presence of a potential step at the ferroelectric domain walls (DWs). In order to study the PV effect at DWs we need to use characterisation methods that would deliver information at the same characteristic length as DWs. We have developed local photoelectric measurement such as photo-induced transient spectroscopy (PITS) which bring valuable data regarding generation and recombination of the photo-excited carriers. We will present in detail PITS-SPM and data regarding generation and recombination speed at DWs in BFO.