Functional Magnetics: From Nanomagnetism to Multiferroic Materials

Tuesday, 01.07.2014, Room D 230

Time	ID	Oxides and Multiferroics *Chair: Carlos A. F. Vaz, PSI Villigen*
14:00	601	**Multiferroics: From Unusual Ferroelectricity Towards Universal Scaling** *Manfred Fiebig, Dept. Materials, ETH Zürich, Vladimir-Prelog-Weg 4, 8043 Zürich* Materials with a coexistence of magnetic and electric order, called multiferroics, are rare because (anti)ferromagnetism and ferroelectricity tend to be mutually exclusive. In this sense, any occurrence of magnetoelectric multiferroicity involves unusual manifestations of ferroelectric order. In my talk I will highlight examples for these "exotic ferroelectrics". Some of their abnormal properties affect device-related like ferroelectric domain walls with tunable conductance or insulating domain walls due to oxygen vacancy ordering. Other properties are of a very fundamental nature such as a distribution of domains that follows universal scaling laws up to the realm of cosmology.
14:30	602	**Epitaxial strain-induced point-defect formation and ordering in oxides** *Ulrich Aschauer, Nicola A Spaldin* *Materials Theory, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich* Using density functional theory calculations we recently established the existence of a strong coupling between epitaxial strain and the formation energy of oxygen vacancies in $CaMnO_3$ (PRB 88, 054111, 2013). Here we investigate the generality of this concept for other oxides and the effect of strain on the formation of cation vacancies. The response of the defect profile generally follows the behaviour expected from chemical expansion arguments but material specific deviations exist under both tensile and compressive strain. We will discuss the implications of our findings in the context of using epitaxial-strain to engineer multiferroic materials.
14:45	603	**Magnetoelectric control of multiferroic domain walls** *Naëmi Leo [1], Manfred Fiebig [1], Dennis Meier [1], Bernd Lorenz [2], Jack Kao-Chen Liang [2], Anders Bergman [3]* *[1] Department of Materials. ETH Zürich, Vladimir-Prelog-Weg 4, 8093 Zürich* *[2] Texas Center for Superconductivity, University of Houston, Science Center, 3201 Cullen Blvd., Houston, TX 77204-5002, USA* *[3] Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala* We investigate the spin-spiral ferroelectric compound $Mn_{0.95}Co_{0.05}WO_4$ using optical second harmonic generation (SHG) and demonstrate the electric-field control of its multiferroic domain state. We reveal a remarkable robustness of the domain distribution against the magnetic-field-driven rotation of the ferroelectric polarization. This exceptional stability in magnetic fields implies so far unexplored physical properties of the multiferroic domain walls, as their microscopic structure must accommodate the change from energetically preferable side-by-side polarization configuration at zero fields to head-tohead or tail-to-tail walls. We discuss possible magnetic structures for such boundaries and implications for their functional behaviour.
15:00	604	**Multiferroic Aurivillius Phases: the Case of $Bi_5FeTi_3O_{15}$ by Ab Initio** *Yael Birenbaum, Claude Ederer* *Materials Theory, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich* The Aurivillius phases form a family of naturally-layered perovskites-related materials with good ferroelectric properties [1]. $Bi_5FeTi_3O_{15}$ is perhaps the simplest known member of this family to also incorporate magnetic degrees of freedom. However, due to the low concentration of magnetic cations, it is unclear whether long-range multiferroic order can be achieved. To address this question, we establish the ferroelectric and magnetic properties of $Bi_5FeTi_3O_{15}$ as a function of Fe^{+3} site preference. We use ab initio electronic structure calculations, comparing two exchange-correlation functionals. In addition, a brief comparison with $Bi_5FeTi_3O_{15}$ will be made. [1] C. A-Paz de Araujo, J. D. Cuchiaro, L. D. McMillan, M. C. Scott, and J. F. Scott, Nature, 374 (1995) 627-629

15:15	**605**	**Towards charge-mediated ferroelectric control of ferromagnetism at room temperature** *Igor Stolichnov, Ceramics Laboratory, EPFL, 1015, Lausanne* Control of magnetic domain propagation is intensively explored for future information processing and storage devices. Recently demonstrated non-volatile ferroelectric field effect on domain walls in ferromagnets offers an alternative to well-established domain manipulation techniques based on spin-torque transfer. The integrated ferromagnet/ferroelectric structures yield two superimposed ferroic patterns coupled by electric field. Using this coupling we demonstrate a stable, non-destructive, and electrically re-writable switch on magnetic domain wall propagation. In proof-of-concept experiments the regimes where the ferroelectric domains enhance/inhibit the magnetic domain nucleation, increase/reduce domain wall velocity or block domain growth have been demonstrated on different materials including metals (cobalt) at room temperature.
15:45	**606**	**Controlling magnetism in $La_{0.7}Sr_{0.3}MnO_3$ via piezostrain** *Jakoba Heidler [1], Cinthia Piamonteze [1], Rajesh Chopdekar [2], Michele Buzzi [1], Stefano Rusponi [3], Harald Brune [3], Frithjof Nolting [1]* *[1] Paul Scherrer Institut, Swiss Light Source, 5232 Villigen PSI* *[2] Dep. of Chemical Engineering and Materials Science, University of California, Davis, 95616, USA* *[3] Institute of Condensed Matter Physics, EPFL, 1015 Lausanne* Multiferroic composites consisting of cross-coupled ferromagnetic and ferroelectric layers are promising candidates amongst the strategies to achieve electric field control of magnetism. The talk explores magnetoelectric coupling in an oxide heterostructure consisting of a thin film of ferromagnetic $La_{2/3}Sr_{1/3}MnO_3$ (LSMO) grown on the relaxor ferroelectric crystal $[Pb(Mg_{1/3}Nb_{2/3})O_3]_{1-x}$-$[PbTiO_3]_x$ (011) (x=0.32). This growth direction [1] allows studying strain dependent changes regarding the magnetization and orbital occupation of LSMO on a single substrate by means of electrical switching. X-ray magnetic circular dichroism measurements show a strain and charge induced change in the Curie temperature of 10 K and X-ray linear dichroism measurements display an accompanying change in crystal field. [1] Wu et al., APL. 98, 012504 (2011)
16:00	**607**	**Structure and Magnetic Coupling in $YBaFeCuO_5$** *Andrea Scaramucci [1], Mickael Morin [2], Marek Bartkowiak [2], Ekaterina Pomjakushina [2], Denis Sheptyakov [3], Lukas Keller [3], Juan Rodriguez-Carvajal [4], Michel Kenzelmann [2], Kazimierz Conder [2], Marisa Medarde [2], Nicola Spaldin [1]* *[1] Departement of Materials, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich* *[2] Laboratory for Developments and Methods, Paul Scherrer Institut, 5232 Villigen* *[3] Laboratory for Neutron Scattering, Paul Scherrer Institut, 5232 Villigen* *[4] Institut Laue Langevin, rue Jules Horowitz 6, FR-38042 Grenoble* We theoretically study the structure and exchange couplings in multiferroic $YBaFeCuO_5$. Using density functional theory we calculate energies of configurations with various Fe^{3+}/Cu^{2+} ordering. We find that configurations with different distribution of Fe^{3+} and Cu^{2+} ions fall into two groups with distinctly different energies. The energies of those in the lowest energy group are close to that of the ground state suggesting Fe^{3+} and Cu^{2+} to be disordered. We calculate exchange coupling for low energy configurations and show their compatibility with the experimentally-observed high-temperature commensurate magnetic ordering. Finally, we discuss possible microscopic origins of the magnetic spiral phase.

16:15	**608**	**Asymmetric properties of $LaNiO_3$-$LaMnO_3$ bilayers** *Marta Gibert [1], Michel Viret [2], Pavlo Zubko [1], Sara Catalano [1], Cinthia Piamonteze [3], Nicolas Jaouen [4], Jean-Marc Tonnerre [5], Almudena Torres-Pardo [6], Alex Gloter [6], Stephan Odile [6], Jean-Marc Triscone [1]* *[1] Département de Physique de la Matière Condensée, University of Geneva, 24 Quai Ernest-Ansermet, 1211 Geneva* *[2] Service de Physique de l'Etat Condensé, CEA Saclay, DSM/IRAMIS/SPEC, URA CNRS, Saclay, FR-91191 Gif-Sur-Yvette* *[3] Swiss Light Source, Paul Scherrer Institute, 5232 Villigen PSI* *[4] Synchrotron SOLEIL, FR-91192 Gif-Sur-Yvette* *[5] Institut Neel, CNRS, 25 avenue des Martyrs, FR-38042 Grenoble* *[6] Laboratoire de Physique des Solides, Université Paris-Sud, Orsay Campus, FR-91405 Orsay* We investigate the properties of $LaNiO_3$-$LaMnO_3$ bilayers, i.e. $SrTiO_3$//8 u.c. $LaNiO_3$/8 u.c. $LaMnO_3$. TEM images have revealed that the interface $LaNiO_3$/$LaMnO_3$ is much sharper than the $LaMnO_3$/$LaNiO_3$ one, which displays two monolayers intermixing. Surprisingly, this structural asymmetry results into very distinct transport and electronic properties. Particularly, enhanced conductivity and extremely reduced magnetization is observed for the "sharp interface" samples in comparison to the rough ones. State-of-the-art synchrotron techniques enable us to reproduce the magnetic profile of the systems as well as to elucidate differences in interfacial charge transfer and induced magnetic moment in the Ni atoms.
16:30		***Coffee Break***
		Nanomagnetism *Chair: Cinthia Piamonteze, PSI Villigen*
17:00	**611**	**Quantum properties of single atoms and molecules at graphene and boron-nitride surfaces** *Harald Brune, EPFL, Station 3, 1015 Lausanne* Can a single atom be a stable magnet in a sense that it exhibits remanence ? We investigate this question by measuring the magnetic anisotropy energy and relaxation times for surface adsorbed Co atoms. On MgO we realize the maximum possible anisotropy energy and on graphene we see a strong dependence of the magnetic properties on the underlying metal substrate. We also report the spectroscopy of molecular rotations for physisorbed H_2 and its isotopes where we are able to discern the nuclear spin isomers ortho and para.
17:30	**612**	**Spin-orbit torques in ferromagnetic heterostructures: fundamentals and applications** *Kevin Garello [1], Pietro Gambardella [1], Abhijit Gosh [1], Can Onur Avci [1], Mihai Miron [2], Gilles Gaudin [2], Olivier Boulle [2], Frank Freimuth [3], Stephan Blügel [3]* *[1] Departement of Materials, ETHZ, Hönggerbergring 64, 8093 Zürich* *[2] Spintec, CEA, Rue des martyrs, FR-38054 Grenoble Cedex 9* *[3] Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, DE-52425 Jülich* Current-induced spin torques are of great interest to manipulate the orientation of nanomagnets without applying external magnetic fields. They find direct application in non-volatile data storage and logic devices. Recent demonstrations of perpendicular magnetization switching induced by in-plane current injection in ferromagnetic heterostructures have drawn attention to a class of spin torques based on orbital-to-spin momentum transfer (SOTs), which is alternative to pure spin transfer torque (STT) between non collinear magnetic layers and amenable to more diversified device functions. We will present advance made to build first perpendicular SOT-MRAM devices and to describe the symmetry and amplitudes of SOTs, revealing unexpected physics

17:45	**613**	**Direct Observation of Thermal Relaxation in Artificial Spin Ice** *Alan Farhan [1], Peter M. Derlet [1], Armin Kleibert [1], Ana Balan [1], Rajesh V. Chopdekar [1], Marcus Wyss [1], Andreas Scholl [2], Frithjof Nolting 1, Laura J. Heyderman [1]* *[1] Paul Scherrer Institute, 5232 Villigen PSI* *[2] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley 94720, USA* Artificial spin ice systems, comprised of elongated monodomain nanomagnets arranged in frustrated geometries are considered to be two-dimensional analogues to the bulk pyrochlore spin ice. Here, we present here a real-space and real-time observation of thermal relaxation in quasi-infinite arrays of artificial square ice, going from a well defined energetically excited state to one of the two degenerate ground states. Microscopically we show how the migration of thermal excitations governs the relaxation process. The experimental results and their temporal evolution are in good agreement with kinetic monte carlo simulations, if disorder is taken into account.
18:00	**614**	**Freestanding Magnetic and Topographic Structures Induced by Ion Treatment** *Peggy Schönherr [1], Benedikt Boehm [1], Philipp Eib [1], Andreas Bischof [1], Santos Francisco Alvarado [2], Rolf Allenspach [1]* *[1] IBM Research-Zürich, Säumerstrasse 4, 8803 Rüschlikon* *[2] Magnetism and Interface Physics, ETH Zürich, Hönggerbergring 64, 8093 Zürich* We describe a novel scheme to fabricate freestanding magnetic structures by a combination of epitaxial growth and ion-beam treatment. Starting from a 2.5 nm Au / 7 nm Fe / GaAs(001) heterostructure, sputtering by Ne ions of sufficiently high energy (3.5 keV) leads to protrusions in the Fe film, so-called blisters. These blisters are composed of a void forming below a part of the film and show characteristic magnetic domain patterns as well as distinctive topographical features. We will show that blisters form at the interface of Fe/GaAs and can be avoided by lowering the penetration depth of the noble gas ions by either reducing the energy or using heavier ions.
18:15	**615**	**Dynamics of topological defects in an artificial spin-ice lattice** *Sebastian Gliga, Department of Materials, ETH Zürich, Hönggerbergring 64, 8093 Zürich* *Attila Kákay, Peter Grünberg Institute, Forschungszentrum Jülich, Wilhelm-Johnen-Straße, DE-52428 Jülich* *Riccardo Hertel, Institut de Physique et de Chimie de Strasbourg, Batiment 69, 23 Rue du Loess, FR-67200 Strasbourg* *Olle Heinonen, Materials Science Division, Argonne National Laboratory, 9700 South Cass Avenue, 60439 Lemont, USA* Arrays of suitably patterned and arranged magnetic elements may display artificial spin-ice structures [1] with topological defects in the magnetization, such as Dirac monopoles and Dirac strings [2]. These defects, arising from frustration, strongly influence the quasi-static and equilibrium behavior of the overall structure. Using micromagnetic simulations we study the dynamics of such defects in a square spin ice lattice. We find that the topological defects give rise to distinct signatures in the mode spectrum that can be measured experimentally [3]. [1] R. F. Wang, et al., Nature 439, 303 (2006) [2] E. Mengotti, et al., Nature Physics 7, 68 (2011) [3] S. Gliga, et al., Phys. Rev. Lett. 110, 117205 (2013)

18:30	**616**	**Direct Observation of Magnetic Metastability in Individual Iron Nanoparticles using X-ray Photoemission Electron Microscopy** *Armin Kleibert [1], Ana Balan [1], Peter Derlet [2], Arantxa Fraile Rodriguez [3], Joachim Bansmann [4], Rocio Yanes [5], Ulrich Nowak [5], Frithjof Nolting [1]* *[1] Paul Scherrer Institute, Swiss Light Source, 5232 Villigen PSI* *[2] Paul Scherrer Institute, Condensed Matter Theory Group, 5232 Villigen PSI* *[3] Universitat de Barcelona, Departament de Física Fonamental and Institut de Nanoci, ES-08028 Barcelona* *[4] University of Ulm, Institute of Surface Chemistry and Catalysis, DE-89069 Ulm* *[5] University of Konstanz, Department of Physics, DE-78457 Konstanz* By combining X-ray photoemission electron microscopy with x-ray magnetic circular dichroism we study the magnetic properties of individual iron anoparticles with sizes ranging from 20 down to 8 nm. While the magnetocrystalline anisotropy of bulk iron suggests superparamagnetic behavior in this size range, ferromagnetically blocked particles are also found at all sizes. Spontaneous transitions from the blocked state to the superparamagnetic state are observed in single particles and suggest that the enhanced magnetic energy barriers in the ferromagnetic particles are due to metastable, structurally excited states with remarkable life times.
18:45	**617**	**Magnetic Exchange Coupling of Strongly Anisotropic Erbium Single-Ion Magnets to a Metallic Surface** *Jan Dreiser [1], Christian Wäckerlin [1], Md. Ehesan Ali [2], Cinthia Piamonteze [3], Fabio Donati [1], Aparajita Singha [1], Kasper S. Pedersen [4], Stefano Rusponi [1], Jesper Bendix [4], Peter Oppeneer [2], Thomas Jung [5], Harald Brune [1]* *[1] ICMP, EPF Lausanne, Station 3, Boite B, 1015 Lausanne* *[2] Uppsala University, Department of Physics and Astronomy, SE-75120 Uppsala* *[3] Paul Scherrer Institute, Swiss Light Source, 5232 Villigen PSI* *[4] Copenhagen University, Dep. of Chemistry, DK-2100 Copenhagen* *[5] Paul Scherrer Institute, Lab. for Micro- and Nanotechnology, 5232 Villigen PSI* Single-Ion Magnets (SIMs) are molecular complexes exhibiting long magnetization relaxation times. The Er(trensal) SIM provides an ideal model system to study molecule-surface interactions in view of potential molecular spintronics applications because its bulk ligand-field parameters are known from detailed spectroscopic studies. Moreover, this SIM is unique in that it provides access to the ultrasharp Er(III) 4f-4f optical transitions, and it can be prepared by vacuum sublimation. By combining surface spectroscopies, scanning tunneling microscopy and theory we find that monolayers of Er(trensal) are physisorbed on Au(111) and chemisorbed on thin-film Ni/Cu(100). On the latter substrate a significant but weak Er-Ni exchange coupling is found.
19:00	**618**	**Anisotropy and hysteresis in sub-monolayers of endohedral single-molecule magnets: The link between structural and magnetic ordering** *Rasmus Westerström [1], Jan Dreiser [2], Roland Stania [1], Cinthia Piamonteze [3], Matthias Muntwiler [3], Fumihiko Matsui [4], Stefano Rusponi [2], Harlald Brune [2], Alexey Popov [5], Shangfeng Yang [6], Thomas Greber [1]* *[1] Physik-Institut, Universität Zürich, Winterthurerstr. 190, 8057 Zürich* *[2] Institute of Condensed Matter Physics, EPFL, Station 3, 1015 Lausanne* *[3] Swiss Light Source, Paul Scherrer Institut, 5232 Villigen* *[4] Nara Institute of Science and Technology (NAIST), 8916-5 Takayama, JP-6300192 Nara* *[5] Department of Electrochemistry and Conducting Polymers, Leibnitz Institute of Sol, IFW, DE-01069 Dresden* *[6] Department of Materials Science and Engineering, University of Science and Techn., 96 Jinzhai Road, CN-230026 Hefei* Here we present an x-ray absorption spectroscopy (XAS) study of the endohedral single-molecule magnet $Dy_2ScN@C_{80}$ [1] on a Rh(111) surface. At sub-monolayer coverage is a significant angle dependence in the Dy M5 multiplet spectra observed which indicates that the endohedral-unit adopts a preferable orientation with respect to the surface. Angle dependent x-ray magnetic circular dichroism (XMCD) also reveals a large magnetic anisotropy. Magnetization curves from a sub-monolayer and a multilayer both exhibits hysteresis at a temperature of 3.5 K. However, the magnetic bi-stability appears reduced in the proximity of the substrate. [1] R. Westerström et al, Phys. Rev. B 89 060406(R) (2014).

19:15	**619**	**The effetc of substrates on molecular spin dynamics in thin films of single molecule magnets** *Zaher Salman [1], Evan Kiefl [1], Andrea Hofmann [1], Matteo Mannini [2], Roberta Sessoli [2], Kevin Bernot [3], Thomas Prokscha [1], Elvezio Morenzoni [1], Andreas Suter [1]* *[1] Paul Scherrer Institut, Laboratory for muon spin spectroscopy, 5232 Villigen* *[2] University of Florence, Department of Chemistry, IT-50019 Florence* *[3] Laboratoire ISCR/CSM-INSA, UMR CNRS-INSA 6226 INSA-Rennes, FR-35708 Rennes* We present measurements of the magnetic properties of thin film single molecule magnets (SMMs) and compare them to those in bulk. Zero field muon spin relaxation measurements were used to determine the molecular spin fluctuation rate of different types of SMMs as a function of temperature. We find that depending on the type of SMM, the substrate of the film can have a significant effect on the moleculars spin dynamics. We discuss the origin of these substrate effects, their implications on the depth dependence of spin dynamics in film and provide clues for synthesizing new robust SMMs.
19:30		***END***
19:45		***Conference Dinner***

ID	Functional Magnetics Poster
621	**Magnetic and conducting properties of strained epitaxial $SrFeO_3$-d films** *Edith Perret, Saikat Das, Premysl Marsik, Benjamin Mallett, Meghdad Yazdi, Ivan Marozau, Christian Bernhard, Solid State Physics, University of Fribourg, Chemin du Musée 3, 1700 Fribourg* Spin-singlet Cooper pairs from a superconductor can penetrate into a ferromagnetic material with an oscillating and fast decaying density. However, if the SC/FM interface affects the spin orientation of the Copper pairs due to a non-collinear magnetic structure, then spin-triplet Cooper pairs are generated that penetrate much further into the ferromagnetic material. $SrFeO_3$ is a promising interface material due to its helical spin properties below 110 K. We studied the magnetic and conducting properties of pulsed-laser deposited epitaxial $SrFeO_{3-d}$ films of different thicknesses on various substrates. The effect of strain, thickness and growth conditions on the physical properties has been investigated.
622	**Crystallography-Driven Positive Exchange Bias in Co/CoO Bilayers** *Anna Suszka [1], Olatz Idigoras [2], Elizavieta Nikulina [2], Andrey Chuvilin [2], Andreas Berger [2]* *[1] ETH Zürich & Paul Scherrer Institute, 5232 Villigen PSI* *[2] CIC nanoGUNE, Tolosa Hiribidea 76, ES-20018 Donostia-San Sebastian* We have studied the temperature dependence of the exchange bias effect in epitaxial Co/CoO bilayer structures with in-plane uniaxial magnetocrystalline anisotropy. We have measured the anisotropic positive exchange bias, which is independent from the initial cooling field value. Synchronous with the occurrence of positive exchange bias, distinct changes in the magnetization reversal process indicate a temperature-dependent rotation of the effective anisotropy and exchange bias axis. Model calculations based upon the electron microscopy-determined epitaxial Co/CoO-interface structure corroborate this interpretation.
623	**Potential multiferroic $Re_nTi_nO_{3n+2}$: Candidate materials to search for the electric dipole moment of the electron** *Maribel Núñez Valdez, Nicola Spaldin* *Department of Materials Theory, ETH Zürich, Wolfgang-Pauli Strasse 27, 8093 Zürich* We use density functional theory (DFT) to explore the suitability of $Re_nTi_nO_{3n+2}$ perovskite oxides as materials for searching for the electron electric dipole moment (eEDM). Observation of the eEDM would confirm the violation of charge-parity (CP) symmetry in the Universe. Experiments involving electric-field-correlated measurements in solids are promising. The multiferroic $Eu_{0.5}Ba_{0.5}TiO_3$, designed specifically to search for the eEDM, set an improved limit compared with previous solid-state searches, but suffered from hysteretic heating. Here we show that the $Re_nTi_nO_{3n+2}$ layered perovskites [n=4, Re=Pr, Nd, Tb, (Pr,Gd)] have an alternative mechanism for ferroelectricity plus could exhibit appropriate magnetic interactions, suggesting that they are promising candidates for an eEDM search.

624 Strain induced coupling between ferromagnetism and ferroelectricity in o-$LuMnO_3$ thin films

Saumya Mukherjee [1], Christof Niedermayer [1], Jonathan White [1], Joachen Stahn [1], Michel Kenzelmann [1], Hubertus Luetkens [1], Christof Schneider [1], Kenta Shimamoto [1], Manfred Fiebig [2], Morgane Trissan [2]
[1] Paul Scherrer Institut, 5232 Villigen PSI
[2] ETH Zürich, Wolfgang-Pauli-Strasse, 8093 Zürich

Recent progress in multiferroics has made this class of materials a central research interest for condensed matter physicists. In the o-$ReMnO_3$ systems such multiferrocity arises from the novel coupling of magnetisation and ferroelectric polarisation [1, 2]. Highly crystalline o-$LuMnO_3$ thin films were grown by pulsed laser deposition. We identified strain induced ferromagnetism and antiferromagnetism in o-$LuMnO_3$ films by polarised neutron reflectometry and neutron diffraction [3]. The ferroelectric properties were shown by second harmonic generation measurements . A sharp increase of the remanence field below the ferroelectric transition temperature indicates the existence of strong magnetoelectric coupling in o-$LuMnO_3$ films.

[1] M. Kenzelmann et al. Phys. Rev. Lett. 95, 087206 (2005).
[2] V. Y. Pomjakushin et al. New.Journ.Phys. 11, 043019 (2009).
[3] J. S. White et al. Phys. Rev. Lett. 111, 037201 (2013).

625 Magnetic exchange coupling of MnTPPCl molecules to a ferromagnetic substrate investigated by X-ray Photo-Emission Electron Microscopy

Milos Baljozovic [1], Jan Girovsky [1], Michele Buzzi [2], Christian Wäckerlin [1], Dorota Siewert [3], Jan Nowakowski [1], Peter M. Oppeneer [4], Frithjof Nolting [2], Thomas A. Jung [1], Nirmalya Ballav [5], Armin Kleibert [2]
[1] Laboratory for Micro and Nanotechnology, Paul Scherrer Institute, 5232 Villigen PSI
[2] Swiss Light Source, Paul Scherrer Institute, 5232 Villigen PSI
[3] Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel
[4] Department of Physics and Astronomy, Uppsala University, BOX-516, SE-75120 Uppsala
[5] Department of Chemistry, Indian Institute of Science Education and Research, Dr. Homi Bhabha Road, Pashan, IN-411008 Pune

Magnetism of the square-planar metallo-porphyrins and –phthalocyanines has recently attracted significant attention. When adsorbed on ferromagnetic substrates, they possess an induced magnetic moment that can be further modified by the introduction of a spacer layer made of a non-magnetic material [1]. We use the X-PEEM combined with XMCD to investigate the magnetic exchange coupling between Mn-porphyrin molecules and a native, oxygen-treated and ferromagnetic cobalt (001) substrate covered by a Cr spacer layer with increasing thickness. The spectro-microscopy correlation enables us to investigate spatial variations in the magnetic coupling of the molecules and their chemical state as well as spatial distribution of the respective elements on the sample [2].

[1] N. Ballav et al., J. Phys. Chem. Lett. 4, 2303, (2013)
[2] J. Girovsky et al., Chem. Commun. (2014), DOI: 10.1039/c3cc47726f

626 Magnetic properties of multiferroic $TbMnO_3$

Natalya Fedorova, Andrea Scaramucci, Claude Ederer, Nicola Spaldin
Materials Theory, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich

We use ab initio calculations to investigate the magnetic properties of multiferroic $TbMnO_3$. $TbMnO_3$ demonstrates an incommensurate spiral ordering of Mn spins accompanied by appearance of spontaneous electric polarization. The establishment of such spin ordering is usually described by a Heisenberg model with competing exchange interactions. However, our theoretical estimations of these interactions demonstrate a clear deviation from Heisenberg model. We consider first the coupling between magnetic and orbital orderings as a main source of non-Heisenberg behavior in $TbMnO_3$, but conclude that it does not explain the observed deviation. We find that higher order exchange couplings should be taken into account for proper treatment of the magnetism in $TbMnO_3$.

627 Multiferroic properties of o-$LuMnO_3$ controlled by b-axis strain

William Y. Windsor, S. W. Huang, Y. Hu, Laurenz Rettig, Aurora Alberca, Kenta Shimamoto, Valerio Scagnoli, Thomas Lippert, Christof W. Schneider, Urs Staub, Paul Scherrer Institute, 5232 Villigen PSI

The magnetoelectric coupling between magnetic order and structural distortion in epitaxial films of the orthorhombic (o-) perovskite $LuMnO_3$ is investigated by synchrotron x-ray diffraction. Using resonant soft x-ray diffraction at the Mn L3 edge, a spin canting in the antiferromagnetic E-type structure is shown to be related to the ferroelectrically induced structural distortion and to a change in the (0q0) magnetic propagation vector. This structural distortion is directly probed through hard x-ray diffraction at symmetry-forbidden (0K0) reflections with K-odd. These quantities are found to be controlled by b-axis strain, and we show that compressive strain destabilizes the commensurate

628 X-ray resonant magnetic reflectometry study of the magnetic proximity effect in $YBa_2Cu_3O_7/La_{2/3}Ca_{1/3}MnO_3$ superlattices

Aurora Alberca [1], Miguel Angel Uribe Laverde [2], Kaushik Sen [2], Saikat Das [2], Christian Bernhard [2], Jochen Stahn [3], William Y. Windsor [1], Mahesh Ramakrishnan [1], Laurenz Rettig [1], Urs Staub [1]
[1] Synchrotron Radiation and Nanotechnology (SYN), Paul Scherrer Institut, 5232 Villigen PSI
[2] Inst. de Physique, Univ. Fribourg, 1700 Fribourg
[3] Lab. for Neutron Scattering (LNS), Paul Scherrer Institute, 5232 Villigen PSI

Artificially-grown multilayers from cuprate high-T_c superconductors (SC) and ferromagnetic (FM) manganites are unique systems to study the interplay between superconducting and ferromagnetic order parameters. $YBa_2Cu_3O_7/La_{2/3}Ca_{1/3}MnO_3$ (YBCO/LCMO) heterostructures exhibit an anomalous magnetic proximity effect (MPE) which gives rise to a strong suppression of the FM moment of the Mn ions on the LCMO side of the interface and yet a small induced FM moment of the Cu ions (antiparallel to the one of Mn) on the YBCO side. We use x-ray resonant magnetic reflectivity (XRMR) to determine with high spatial resolution the magnetic depth profiles of YBCO/LCMO superlattices.

629 Magnetoelectric monopolar ordering in solids

Florian Thöle, Michael Fechner, Nicola Spaldin
Materials Theory, ETH Zürich, Wolfgang-Pauli-Str. 27, 8093 Zürich

The formalism of the macroscopic magnetoelectric monopolization is developed and its relation to the magnetoelectric response is given [1]. Using first-principles calculations, we use two different strategies to calculate the monopolization: (i) By using a multipole expansion of the magnetization density in atomic spheres around magnetic sites, and (ii) by using a formalism inspired by the modern theory of electric polarization. As an example, results for a series of lithium transition metal compounds $LiMPO_4$ (M = Co, Fe, Mn, Ni) are shown, which can show ferromonopolar and antiferromonopolar ordering.

[1] N. A. Spaldin et al., PRB 88, 094429 (2013)

630 Domain Wall Roughness in Stripe Phase $BiFeO_3$ Thin Films

Benedikt Ziegler [1], Patrycja Paruch [1], Thierry Giamarchi [1], Kirsten Martens [2]
[1] DPMC-MaNEP, University Geneva, Quai Ernest-Ansermet 24, 1211 Geneva
[2] IPhy, Université Joseph Fourier Grenoble 1, 140 Av. de la physique, FR-38402 Saint Martin d'Hères

Using the model system of ferroelectric domain walls, we explore the effects of long-range dipolar interactions and periodic ordering on the behavior of pinned elastic interfaces. In piezoresponse force microscopy studies of the characteristic roughening of intrinsic 71° stripe domains in $BiFeO_3$ thin films, we find unexpectedly high values of the roughness exponent ζ=0.74±0.10 [1], significantly different from those obtained previously. This large exponent value suggests that random field-dominated pinning, combined with strong disorder and strain effects due to the sample step-bunching morphology, could be the dominant source of pinning in the system.

[1] Ziegler, B. *et al.* Phys. Rev. Lett. **111**, 247604 (2013)

631 Influence of La and Mn vacancies on the electronic and magnetic properties of $LaMnO_3$ thin films grown by pulsed laser deposition

Ivan Marozau [1], Proloy T. Das [2], Max Döbeli [3], James G. Storey [4], Miguel A. Uribe-Laverde [1], Saikat Das [1], Chennan Wang [1], Matthias Rössle [1], Christian Bernhard [1]
[1] Department of Physics, University of Fribourg, Chemin du Musee 3, 1700 Fribourg
[2] Department of Physics and Meteorology, Indian Institute of Technology, IN-721302 Kharagpur
[3] Laboratory for Ion Beam Physics, ETH Zürich, Schafmattstrasse 20, 8093 Zürich
[4] Callaghan Innovation, P.O. Box 31310, Lower Hutt, New Zealand

We have grown epitaxial thin films of $LaMnO_3$ (LMO) by PLD. Depending on the oxygen background pressure during growth, the LMO films contain sizeable amounts of La and/or Mn vacancies that strongly influence their electronic and magnetic properties. All as-grown and thus slightly oxygen deficient LMO films are ferromagnetic insulators, their transport and optical properties can be understood in terms of trapped ferromagnetic polarons. Upon oxygen annealing, the most La-deficient films develop a metallic response with a larger ferromagnetic moment. In contrast, in the oxygenated Mn-deficient films the ferromagnetic order is strongly suppressed and the transport remains insulator-like.

632 Resonant Soft X-Ray Scattering On Artificial Spin Ice

Luca Anghinolfi [1], Jonathan Perron [2], Bharati Tudu [2], Nicolas Jaouen [3], Jean Marc Tonnerre [4], Maurizio Sacchi [3], Fritjof Nolting [1], Jan Lüning [2], Laura Heyderman [5]
[1] Paul Scherrer Institut, 5232 Villigen PSI
[2] Sorbonne Universités, UPMC Univ Paris 06, UMR 7614, LCPMR, FR-75005 Paris
[3] Synchrotron SOLEIL, SEXTANTS, FR-91192 Gif-sur-Yvette
[4] Université Grenoble Alpes, Institut Néel, FR-38042 Grenoble
[5] Departments of Materials, ETH Zürich, Laboratory for Mesoscopic Systems, 8093 Zürich

In this work we employ soft x-ray resonant magnetic scattering to study artificial square ice. The scattering patterns are recorded with a CCD camera, providing an extended picture of the reciprocal space in two dimensions. Pure magnetic Bragg peaks observed in as-grown samples indicate the presence of a long-range antiferromagnetic ordered phase. The evolution of the magnetic configuration with applied magnetic field was tracked via the variations of the dichroic contrast intensity at the Bragg peak positions. Our numerical simulations correctly reproduce the experimental scattering patterns, allowing us to estimate the number of nanomagnets with reversed moments in each of the two sublattices.

633 Growth of CuO crystals and optical investigation of magnetoelectric coupling

Adrien Stucky, Alexey Kuzmenko, Alberto Ubaldini, Dirk Van der Marel, Enrico Giannini
University of Geneva - DPMC, 24 quai Ernest-Ansermet, 1211 Geneva

CuO is a promising high-temperature magnetoelectric multiferroic. Crystal growth of CuO is very challenging, high oxygen pressure is required for stabilizing nucleation process and crystals exhibit often mosaicity, twinning and structural defects. We have grown high quality single crystals of CuO both by the floating zone method and a newly developed BaO-assisted chemical vapor transport. Infrared reflectivity was measured under magnetic field (7 T) over the temperature range of the spin spiral state and along various light polarizations, searching for magnetoelectric effect in optical spectra. The magnetic field is found to have a very weak effect on optical spectra.

634 Electric field induced anisotropy manipulation in LSMO/PMN-PT patterned heterostructures

Michele Buzzi [1], Carlos Vaz [1], Rajesh Chopdekar [2], Simone Finizio [3], Matthias Kläui [3], Yayoi Takamura [2], Frithjof Nolting [1]
[1] Paul Scherrer Institut, Villigen PSI, 5232 Villigen
[2] Dept. of Chemical Engineering and Materials Science, University of California, Davis, 95616 CA, USA
[3] Johannes Gutenberg University Mainz, Staudinger Weg 7, DE-55128 Mainz

We demonstrate electric field induced, non-volatile, control of magnetic domains in fully epitaxial $La_{0.33}Sr_{0.67}MnO_3$ (LSMO) / PMN-PT artificial multiferroic patterned heterostructures. We investigated the magnetic domain configuration of patterned elements by photoemission electron microscopy with X-ray magnetic circular dichroism at the Mn L_3 edge. Our experimental findings directly show that the magnetic anisotropy of the LSMO layer changes from a two-fold in-plane easy axis to a four-fold in-plane easy axis when an electric field causing a reversal of the ferroelectric polarization is applied. Voltage pulses can then be employed to set and reset the magnetic anisotropy of patterned LSMO elements, paving the way towards electric-field manipulation of magnetization.

635 Effects of strain into multiferroic properties of orthorhombic $LuMnO_3$ thin films

Kenta Shimamoto [1], Liliana Viciu [2], Thomas Lippert [1], Alexander Wokaun [1], Christof Schneider [1]
[1] General Energy Research Department, Paul Scherrer Institut, 5232 Villigen PSI
[2] Department of Chemistry and Applied Bioscience, ETH Zürich, Wolfgang-Pauli-Strasse 10, 8093 Zürich

The control and manipulation of coupling between crystal lattice and magnetism by epitaxial strain in thin films is an attractive tool for multiferroic materials design. Recently we found that strained orthorhombic $LuMnO_3$ (o-LuMO), an E-type antiferromagnet in bulk, exhibits a spin gradient including a ferromagnetic layer at the film-substrate interface when grown on $YAlO_3$ (110). Here, we investigate the effect of strain by inserting a buffer layer between o-LuMO and the $YAlO_3$ substrate. Investigation of crystallographic, magnetic, and ferroelectric properties of these films will give us detailed insight on the effect of strain on multiferroic o-LuMO thin films.

636 Resonant X-Ray Diffraction studies on the Commensurate-Incommensurate Magnetic Transition of $LiNiPO_4$

Mahesh Ramakrishnan, William Yoav Windsor, Laurenz Rettig, Aurora Alberca, Valerio Scagnoli, Urs Staub, Paul Scherrer Institut, 5232 Villigen PSI

The relation between a possible Dzyaloshinskii-Moriya (DM)interaction driven soliton lattice order and the orbital magnetic moment on the Ni^{2+} ionic sites in $LiNiPO_4$ is being studied using resonant soft x-ray diffraction at Ni-$L_{2,3}$ edges. Strong linear magnetoelectric effect and a weak ferromagnetic canting indicate dominant DM interaction in the antiferromagnetic ground state of the material. Recent theoretical predictions of existence of localized magnetoelectric monopoles several lattice sites is also being explored.

[1] D. Vaknin et al., Phys. Rev. Lett. 92, 207201 (2004)
[2] N. A. Spaldin at al., Phys. Rev. B 88, 094429 (2013)