MA 42: Thin films – anisotropy

Time: Thursday 9:30–12:30 Location: EB 301

MA 42.1 Thu 9:30 EB 301

Magnetic properties of Co/Pt multilayers and their dependence on Co thickness — •Lorenzo Fallarino[1], Karine Chesnel[2], Benny Böhm[3], Fabian Samad[3], and Olav Hellwig[1,3] — [1]Institute of Ion Beam Physics and Materials Research, HZDR — [2]Department of Physics and Astronomy, BYU, USA — [3]Institute of Physics, TU Chemnitz

Ferromagnetic (FM) / non-magnetic multilayers with perpendicular magnetic anisotropy (PMA) provide an efficient route for controlling magnetism. They constitute an interesting model system with easily tunable magnetic properties by changing the individual layer thicknesses or number of repetitions[1]. During the past years, an extensive work effort has led to an apparently complete understanding of those structures. The majority of these studies utilized very thin FM layers, since an in-plane reorientation of the magnetization is expected for thicker films. However, for sufficiently thick FM layers, the system undergoes a second transition back to out-of-plane direction[2]. Consequently, we present a thickness dependent study of magnetic properties of $[Co/Pt]_{50}$ multilayers that maintain their PMA through all Co thicknesses. By studying in more detail the influence of the magnetic history on the remanent domain pattern[3], we find an optimal Co thickness for that instead of the typical maze-like inter-connected domains a bubble lattice is stabilized with extraordinary high domain density[4]. [1] M. T. Johnson et al. Rep. Prog. Phys. **59**, 1409 (1996). [2] L. Fallarino et al. PRB **94**, 064408 (2016). [3] Westover et al. JMMM **399**, 164 (2016). [4] K. Chesnel et al. submitted to PRB (25/08/2017).

MA 42.2 Thu 9:45 EB 301

Tunable magnetic properties in perpendicularly magnetized Mn-Fe-Ga tetragonal Heusler for spintronic applications — •Adel Kalache[1], Anastasios Markou[1], Gerhard H. Fecher[1], Susanne Selle[2], Thomas Höche[2], and Claudia Felser[1] — [1]Max Planck Institut CPFS, Dresden, Germany — [2]Fraunhofer Institute for Microstructure of Materials and Systems IMWS, Halle, Germany

Perpendicular magnetic anisotropy was studied in tetragonal $D0_{22}$ Mn-Fe-Ga thin films on different substrates as candidates for spintronic applications. By varying the Mn/Fe ratio, it is possible to tune the magnetic properties such as magnetization and coercivity, while retaining out-of-plane anisotropy over large composition range. The substitution of Fe in $Mn_{2.6-x}Fe_xGa_{1.4}$ maximizes the magnetic anisotropy at a Fe content of $x = 1$. Transmission electron microscope investigations confirmed the single crystalline nature of the film as well as the homogeneity by elemental mapping using EDXS. We emphasize that a careful control over composition, in this case Ga content, is essential to tailor the magnetic properties in Heusler thin films. These findings are expected to benefit the integration of tetragonal Heusler compounds into spintronic devices.

MA 42.3 Thu 10:00 EB 301

Interrelation of local coordination and magnetism in $Fe_{60}Al_{40}$ thin films — •A. Smekhova[1], E. La Torre[2], Th. Szyjka[2], B. Eggert[2], B. Cöster[2], K. Ollefs[2,3], D. Walecki[2], S. Salamon[2], R. Bali[4], J. Lindner[4], F. Wilhelm[3], A. Rogalev[3], E. Weschke[5], D. Többens[5], R. Banerjee[6], B. Sanyal[6], C. Schmitz-Antoniak[1], and H. Wende[2] — [1]FZ Juelich (PGI-6), Berlin — [2]University of Duisburg-Essen and CENIDE, Duisburg — [3]ESRF, Grenoble — [4]HZDR, Dresden — [5]HZB (BESSY II), Berlin — [6]Uppsala University, Uppsala

X-ray absorption spectroscopy (EXAFS, XANES, and XMCD) at K and $L_{2,3}$ edges of Fe as well as K edge of Al together with synchrotron-based diffraction has been applied to probe local rearrangements and related magnetic and electronic properties of Fe and Al atoms in bare $Fe_{60}Al_{40}$ thin films through the order-disorder (B2 → A2) phase transition. Distinct changes of Fe and Al coordination resulting in increased Fe $3d$ spin polarization and characteristic changes in electronic structure of Al due to disordering created by 20 keV Ne^+ ions of (0.75 - 6)×10^{14} ions·cm^{-2} fluences have been demonstrated. The preferential in-plane magnetic anisotropy and variations in coercivity fields depending on temperature and irradiation fluence has been found by element-specific hysteresis loops. An attempt to reduce the top oxide layer by an inductively coupled hydrogen plasma has shown that a use of the capping layer could further increase the macroscopic magnetization of films. A theory support was provided by self-consistent DFT calculations using VASP program package.

MA 42.4 Thu 10:15 EB 301

Effect of N, C and B interstitials on the structural and magnetic properties of alloys with Cu_3Au-structure — •Ingo Opahle, Harish Kumar Singh, and Hongbin Zhang — TU Darmstadt, Germany

High-throughput density functional calculations are used to investigate the effect of interstial B, C and N atoms on the stability, structural and magnetic properties of 21 reported alloys crystallizing in the cubic Cu_3Au structure. For 29 alloy/interstitial combinations the formation of stable interstitial alloys with interstitial concentrations above 5% is expected. The majority of stable interstitials prefers the anti-perovskite structure. It is shown that interstitials can have a huge impact on the magneto-crystalline anisotropy energy (MAE) when the cubic symmetry is broken. For $MnNi_3$ and $FeNi_3$ interstitial N leads to a tetragonal distortion with a moderate uniaxial MAE. Mn_3XN_x (X=Rh, Ir, Pt and Sb) are identified as alloys with strong magneto-crystalline anisotropy. For Mn_3Ir interstitial N leads to a huge enhancement of the MAE. It is expected that N has also a strong influence on the MAE of amorphous Mn_3Ir, which is one of the state-of-the-art materials for exchange bias in hard magnetic films. The impact of the N interstitials on the MAE is discussed at hand of the electronic structure.

MA 42.5 Thu 10:30 EB 301

Electric field controlled domain wall dynamics and magnetic easy axis switching in liquid gated CoFeB/MgO films — Yuting Liu[1], Shimpei Ono[2], Guillaume Agnus[1], Samridh Jaiswal[3], Juergen Langer[3], Berthold Ocker[3], Dafiné Ravelosona[1], and •Liza Herrera Diez[1] — [1]Centre de Nanosciences et de Nanotechnologies, CNRS, Univ. Paris-Sud, Université Paris-Saclay, C2N-Orsay, 91405 Orsay cedex, France. — [2]Central Research Institute of Electric Power Industry, Komae, Tokyo 201-8511, Japan. — [3]Singulus Technology AG, Hanauer Landstrasse 103, 63796 Kahl am Main, Germany.

We present reversible electric (E) field driven switching of the magnetic easy axis in CoFeB/MgO/HfO_2 heterostructures from perpendicular to in-plane using an ionic liquid (IL) gate. The modification of magnetic anisotropy reaches 0.108 mJ/m^2 in a gate voltage range between -3 V and +3.5 V with an efficiency of 82 fJ$(Vm)^{-1}$. The influence of the E-field induced anisotropy changes on domain nucleation and propagation of magnetic domain walls has also been studied in the perpendicular anisotropy state. A significant modulation of the domain wall velocity is observed both in the creep and depinning regimes of domain wall motion consistent with the E-field induced anisotropy variation. In addition, we demonstrate voltage controlled magnetization switching under a constant magnetic field and voltage control of domain wall pinning.

15 minutes break

MA 42.6 Thu 11:00 EB 301

Temperature dependent magnetocrystalline anisotropy model for $La_{0.7}Sr_{0.3}MnO_3$ thin films grown on $SrTiO_3$ (001) and $NdGaO_3$ (110) substrates — •Camillo Ballani, Christoph Hauser, Christian Eisenschmidt, and Georg Schmidt — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, 06120 Halle (Saale), Germany

A well-understood magnetocrystalline anisotropy model for ferromagnetic thin films plays a crucial role in describing spin wave propagation [1], magnetization reversal processes and related effects like tunnelling anisotropic magnetoresistance (TAMR) in organic spin valves [2]. We present a study of $La_{0.7}Sr_{0.3}MnO_3$ (001) thin films epitaxially grown via Pulsed Laser Deposition (PLD) on $SrTiO_3$ (001) and $NdGaO_3$ (110) substrates, which induce tensile and non-homogeneous compressive strain in the film plane, respectively. A detailed temperature dependent model for the magnetocrystalline anisotropy in these films is derived from Ferromagnetic Resonance (FMR) measurements and SQUID magnetometry.

[1] K. Sekiguchi et al., NPG Asia Materials **9**, e392 (2017)
[2] M. Grünewald et al., Phys. Rev. B **90**, 205208 (2014)

MA 42.7 Thu 11:15 EB 301

Origin of defect induced magnetism in TiO_2 anatase probed with X-ray magnetic circular dichroism — •Markus Stiller[1], José Barzola-Quiquia[1], Pablo D. Esquinazi[1], Alpha T. N'Diaye[2], Hendrik Ohldag[3], Thomas Lautenschläger[4], and Daniel Spemann[4] — [1]Abteilung für Supraleitung und Magnetismus, Fakultät für Physik und Geowissenschaften, Universität Leipzig, Linnestr. 5, D-04103, Germany — [2]Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, California 94720, United States — [3]SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, California, 94025 USA — [4]Leibniz-Institut für Oberflächenmodifizierung e.V., Permoserstraße 15, 04318 Leipzig, Germany

The temperature and field dependence of the magnetization of epitaxial, polycrystalline undoped TiO_2 anatase thin films on $LaAlO_3$ and $SrTiO_3$ substrates was investigated. Field hysteresis as well as zero-field cooled and field cooled curves were measured for the as-prepared thin films as well as after irradiation with low energy (200 eV) argon ions. The irradiated anatase thin films show an increased magnetic moment and exhibit ferromagnetism at room temperature, with an easy axis parallel to the c-axis, i.e. an out-of-plane magnetization. The anisotropy depends on film orientation, phase and surface roughness as well as the energy used for defect production. XMCD measurements show that the spin polarized band is at the titanium edge, not at the O 2p band edge, at the thin film surface.

MA 42.8 Thu 11:30 EB 301

Structural and magnetic properties of thin $Tm_3Fe_5O_{12}$ layers — •Oana Ciubotariu, Helmut Karl, and Manfred Albrecht — Institute of Physics, University of Augsburg, 86159 Augsburg

The extremely low Gilbert damping parameter and the insulating nature make $Y_3Fe_5O_{12}$ (YIG) layers the best choice for spin-related experiments. However, nanometric YIG films exhibit in-plane magnetic easy axis due to strong shape anisotropy. Nonetheless, $Tm_3Fe_5O_{12}$ (TmIG) has been reported to poses an out-of-plane magnetic easy axis when grown on $Gd_3Ga_5O_{12}$ (GGG) or substituted GGG (SGGG) substrates [1, 2]. In order to obtain high quality iron garnets, besides optimizing the substrate temperature or the oxygen pressure during growth, the cooling down procedure to room temperature after deposition has to be addressed. Here, we present the effect of the cooling down procedure on the structural and magnetic properties of TmIG layers. 100-nm thick films are grown by pulsed laser deposition on SGGG (111) substrates at optimized substrate temperature and oxygen pressure. After deposition, slow and fast cooling procedures are implemented. The effect on the crystal structure is investigated by X-ray diffraction and on magnetic properties by SQUID-VSM. Although the crystalline structure showed no dependence, the magnetic properties are strongly influenced. [1] A. Quindeau et al., Adv. Electron. Mater. 2017, 3, 1600376; [2] M. Kubota et al., Journal of Magnetism and Magnetic Materials, 339 (2013) 63-70.

MA 42.9 Thu 11:45 EB 301

Non-collinear chiral antiferromagnetic Mn_3Sn films — •Anastasios Markou[1], James Taylor[2], Adel Kalache[1], Peter Werner[2], and Claudia Felser[1] — [1]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [2]Max Planck Institute for Microstructural Physics, Weinberg 2, 06120 Halle, Germany

Antiferromagnetic materials could represent the next step in spintronic applications, since antiferromagnets do not produce stray fields, are robust to external perturbations from magnetic fields, and show ultra-fast spin dynamics and current-induced phenomena. The non-collinear chiral antiferromagnets have attracted much interest, due to their remarkable structural, magnetic and electro-transport properties [1]. Here, we present the structural and magnetic properties of antiferromagnetic Mn_3Sn films with hexagonal $D0_{19}$ structure. For this purpose, we performed systematic X-ray diffraction (XRD), transmission electron microscopy (TEM), and magnetic characterization of films heteroepitaxially grown on appropriate substrates.

[1]A. K. Nayak *et al.*, Sc. Adv. **2**, e1501870 (2016).

MA 42.10 Thu 12:00 EB 301

Nucleation of stripe domains in ferromagnetic thin films — •Sukhvinder Singh, Haibin Gao, and Uwe Hartmann — Institute of Experimental Physics, Saarland University, Saarbrücken, Germany

Since the first observation of stripe domains in ferromagnetic films, i.e., about 50 years ago [1], the formation of these domains was considered as an abrupt transition from the in-plane to a partly out-of-plane magnetization. Domains separated either by Néel or cross-tie domain walls were supposed to be abruptly superimposed by stripes. We found that stripe domains evolve from the domain walls at a thickness well below the critical thickness [2,3]. The latter was so far considered as a threshold for the formation of stripe domains. Local modifications induced by a perpendicular anisotropy inside the domain walls and wall junctions were observed in detail. A periodically oscillating out-of-plane magnetization is formed inside the walls. This expands throughout the in-plane domains to form stripe domains all over the film. On the basis of our work, the widely used domain phase diagram [3] can now be refined.

[1] N. Saito, H. Fujiwara, and Y. Sugita, J. Phys. Soc. Jpn. 19, 1116 (1964).

[2] F. Virot, L. Favre, R. Hayn, and M. D. Kuzmin, J. Phys. D: Appl. Phys. 45, 405003 (2012).

[3] A. Holz and H. Kronmüller, Phys. Stat. Sol. (b) 31, 787 (1969).

MA 42.11 Thu 12:15 EB 301

Element-resolved vibrational density of states of FeRh thin films along the metamagnetic phase transition — •Benedikt Eggert[1], Joachim Landers[1], Soma Salamon[1], Alexandra Terwey[1], Alexander Schmeink[2], Ahmet Alatas[3], Thomas Toellner[3], Michael Y. Hu[3], Jiyong Zhao[3], E. Ercan Alp[3], Markus E. Gruner[1], Kay Potzger[2], Jürgen Lindner[2], Katharina Ollefs[1], Rantej Bali[2], Werner Keune[1], and Heiko Wende[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Argonne National Laboratory, USA

B2-ordered FeRh shows a temperature induced first-order metamagnetic phase transition from the antiferromagnetic (AFM) to the ferromagnetic (FM) state. By applying ^{57}Fe nuclear resonant inelastic X-Ray scattering to epitaxial B2 ordered FeRh(001) thin films, we determined the Fe-projected vibrational density of states (VDOS) and the vibrational entropy change through the transition with and without an applied magnetic field. The Lamb-Mössbauer factor indicates that the AFM lattice is softer than the FM one [1]. In films with different thicknesses we find a small change in the VDOS due to varying film strain, induced by the MgO(001) substrate. Financial support by DFG (WE 2623/17-1) and U.S. DOE is acknowledged.

[1] M. Wolloch et al. Phys. Rev. B **94**, 174435 (2016)