MA 60: Magnetic Coupling and Anisotropy in Thin Films (joint session MA/DS)

Time: Friday 9:30–13:00 Location: HSZ 04

MA 60.1 Fri 9:30 HSZ 04

Imaging of ultrafast spin dynamics using high-harmonic radiation — •Sergey Zayko[1], Ofer Kfir[1], Michael Heigl[2], Michael Lohmann[1], Jakob Hagen[1], Murat Sivis[1], Manfred Albrecht[2], and Claus Ropers[1] — [1]IV Physical Institute, University of Göttingen — [2]Experimental physics IV, University of Augsburg

The demand for next-generation information processing methodologies increases the interest in spintronic devices, as they may offer energy-efficient operation at THz frequencies [1,2]. Such developments require means for tracking of magnetic dynamics with nanoscale resolution and a temporal precision well below a picosecond, as highlighted in a first experimental effort [3]. Here we utilize MCD (magnetic circular dichroism) imaging with high-harmonic radiation [4] for the mapping of spin-texture dynamics. Our experiment captures magnetic movies with a combined 40 nm spatial- and 40 femtosecond temporal resolutions, and images with resolution better than 20 nm. We use these capabilities to follow the ultrafast responses of magnetic domains in materials with perpendicular magnetic anisotropy, such as local ultrafast demagnetization and non-local dynamics near domain walls. We believe that our approach will yield deeper insights into the corresponding physics of the ultrafast magnetism and become an indispensable tool for applied research.

[1] A. Fert, V. Cros, and J. Sampaio, Nat Nano 8, 152 (2013). [2] Nature Nanotech 10, 185 (2015). [3] C. von Korff Schmising et al., Phys. Rev. Lett. 112, 217203 (2014). [4] O. Kfir, S. Zayko et al., Science Advances 3, eaao4641 (2017).

MA 60.2 Fri 9:45 HSZ 04

Complex spin textures and domain-wall pinning in Sm-Co magnets — Leonardo Pierobon[1], András Kovács[2], Robin E. Schäublin[1], Stephan S. A. Gerstl[1], Urs Wyss[3], •Jan Caron[2], Rafal E. Dunin-Borkowski[2], Jörg F. Löffler[1], and Michalis Charilaou[1] — [1]Laboratory of Metal Physics and Technology, Department of Materials, ETH Zurich, Switzerland — [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, FZ Julich, Germany — [3]Arnold Magnetic Technologies, Switzerland

Sm-Co alloys are the best-performing permanent magnets at high temperatures due to their cellular microstructure, which consists of a Sm2Co17 matrix and SmCo5 cells intersected by Zr-rich platelets. Although extensive research has been done to understand the connection between the magnet's microstructure and its magnetic properties, theory and experiments have still not converged. To tackle this issue, we use Lorentz transmission electron microscopy, off-axis electron holography and micromagnetic simulations. We find that the magnetization reversal starts by domain-wall nucleation at the interfaces between Zr-rich platelets and the Sm2Co17 matrix. Despite strong pinning at the SmCo5 cells, curling instabilities form where all three phases meet, further propagating the reversal. Unexpectedly, we also find topologically non-trivial structures with 2π winding that significantly affect the reversal. Based on this, we propose a modification of microstructure to increase the coercivity and remanence.

MA 60.3 Fri 10:00 HSZ 04

Titanium d-ferromagnetism with perpendicular anisotropy in defective anatase — •Markus Stiller[1], Alpha T. N'Diaye[2], Hendrik Ohldag[2], José Barzola Quiquia[1], Pablo D. Esquinazi[1], Thomas Amelal[3], Carsten Bundesmann[3], Daniel Spemann[3], Martin Trautmann[4], Angelika Chassé[4], Hichem Ben Hamed[4], Waheed A. Adeagbo[4], and Wolfram Hergert[4] — [1]Felix-Bloch-Institute for Solid-state Physics, University of Leipzig, Germany — [2]ALS, Lawrence Berkeley National Laboratory, USA — [3]Leibniz Institute of Surface Engineering, Germany — [4]Institute of Physics, Martin-Luther-Universität Halle-Wittenberg, Germany

Undoped TiO2 anatase thin films were grown on LAO and STO substrates. Ferromagnetism was generated at the surface of anatase films by low-energy ion irradiation. Ar+-ion irradiation resulted in a thin (10nm) ferromagnetic surface layer. Field hysteresis as well as zero-field cooled and field cooled curves reveal that, after irradiation the samples show ferromagnetism at room temperature with an out-of-plane easy axis and low remanence. Magnetic force microscopy reveals that this low remanence is due to oppositely aligned magnetic domains. XMCD measurements at room temperature show that the band at the titanium L-edges is spin polarized, not at the O K-edge. Together with DFT calculations, the results indicate that Ti vacancy-interstitial pairs are responsible for the magnetic order. These results open up interesting possibilities for future applications, e.g. single domain patterns of μm size can be easily prepared. Further, they contradict the theory of paramagnetism due to vacuum fluctuations proposed by Coey.

MA 60.4 Fri 10:15 HSZ 04

Magnetic anisotropy of disordered FeRh thin films probed by X-band ferromagnetic resonance — •Jonas Wiemeler[1], Anna Semisalova[1], Benjamin Zingsem[1], Nicolas Josten[1], Ralf Meckenstock[1], Rantej Bali[3], Kay Potzger[3], Jürgen Lindner[3], Jürgen Fassbender[3], Thomas Thomson[2], and Michael Farle[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]The University of Manchester, UK — [3]Institute of Ion Beam Physics and Materials Research, HZDR, Germany

The ion irradiation induced disorder in FeRh thin films changes certain magnetic properties, such as phase transition temperature from AF to FM states and saturation magnetisation. Furthermore, the free energy density changes correspondingly to the magnetocrystalline anisotropy variation in irradiated films. Here, ferromagnetic resonance (FMR) experiments were carried out to analyse the magnetic anisotropy of 25 keV Ne^+-irradiated 40 nm thick $Fe_{50}Rh_{50}$ films. A total of 6 films, irradiated with an ion fluence of $1 \cdot 10^{13} - 4 \cdot 10^{14} \frac{\text{Ions}}{\text{cm}^2}$, were characterised with FMR at 100 - 400 K and compared with a non-irradiated film.

The anisotropy of Ne-irradiated FeRh thin film changes from cubic for a low ion fluence to a mixture of cubic and in-plane uniaxial anisotropy, the latter contribution turns out to be dominating for higher fluence. The sign of the perpendicular magnetic anisotropy constant $K_U = K_{2\perp}$ was found to reverse while Ne^+ fluence is increasing. Supported by DFG SE2853/1-1, BA5656/1-1.

MA 60.5 Fri 10:30 HSZ 04

Ferromagnetic writing on B2 $Fe_{49}Rh_{51}$ thin films using ultra-short laser pulses — •Alexander Schmeink[1,2], Benedikt Eggert[3], Jonathan Ehrler[1], Mohamad-Assaad Mawass[4], René Hübner[1], Kay Potzger[1], Jürgen Lindner[1], Jürgen Fassbender[1,2], Florian Kronast[4], Heiko Wende[3], and Rantej Bali[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Fakultät für Physik, Technische Universität Dresden, Germany — [3]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany — [4]Helmholtz-Zentrum Berlin, Germany

Laser manipulation of magnetic properties has potential applications in data storage. The equiatomic B2 FeRh alloy is well-known to show a metamagnetic isostructural antiferromagnetic (AFM) to ferromagnetic (FM) transition at ≈370 K. In contrast to the temperature-driven transition an AFM B2 → FM B2 transition can be induced via a decrease of short-range atomic order, which can be realised in alloy thin films using ion beams as well as laser pulses.[1]

Here we irradiate B2 $Fe_{49}Rh_{51}$ thin films of ≲30 nm thicknesses with ∼100 fs laser pulses and observe the induced magnetic and structural changes. Depending on the laser fluence transitions of AFM to FM B2 $Fe_{49}Rh_{51}$ and with further disordering to the paramagnetic A1 structure are observed. The deposited energy influences the resolidifcation of the alloy, thereby determining the structure.

This work is funded by the DFG (BA 5656/1-1 and WE 2623/14-1).

[1] J. Ehrler et al. *ACS Applied Materials & Interfaces* **2018** 10 (17), 15232-15239

MA 60.6 Fri 10:45 HSZ 04

Magnetic structure and coupling phenomena of DyCo alloys — •Dieter Lott[1], Kai Chen[2], André Philippi-Kobs[3], and Valeria Lauter[4] — [1]Institute of Material Research, Helmholz-Zentrum Geesthacht, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin, Germany — [3]Deutsches Elektronen-Synchrotron (DESY), Notkestr. 85, 22607 Hamburg, Germany — [4]Neutron Scattering Division, Neutron Sciences Directorate, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

In the last years, alloys of rare-earth elements and 3d transition metals (RE-TM) became again in the focus of attention due there rich variety of magnetic effects owed to the different anisotropies of both material classes. Despite of their amorphous composition, this material class exhibits complex magnetic ordering resulting into non-collinear spin structures and the occurrence of magnetic chirality effects. Lately, different exchange bias phenomena were discovered in DyCo single films and in heterostructures [1,2]. In a very recent study, the occurrence of skyrmions in a single DyCo film could be observed. The analysis of the magnetic microstructure is one of the important keys for understand the underlying mechanism behind these intriguing phenomena. In this work, we report recent results on DyCo/NiFe thin films investigated via polarized neutron reflectometry. The analysis of the magnetic and chemical depth profiles at different magnetic fields and temperature allows one to gain insights into the coupling mechanism in these heterostructures.

15 min. break.

MA 60.7 Fri 11:15 HSZ 04

Crystallographic and magnetic structure in Co thin films investigated by NMR — •Patrizia Fritsch[1], Juriaan Lucassen[2], Casper F. Schippers[2], Marcel A. Verheijen[2,3], Erik J. Geluk[4], Beatrice Barcones[4], Rembert A. Duine[2,5], Henk J. M. Swagten[2], Bert Koopmans[2], Reinoud Lavrijsen[2], and Sabine Wurmehl[1,6] — [1]IFW Dresden, Germany — [2]Department of Applied Physics, TU Eindhoven, the Netherlands — [3]Eurofins Materials Science, Eindhoven, the Netherlands — [4]NanoLab@TU/e, TU Eindhoven, the Netherlands — [5]Institute for Theoretical Physics, Utrecht University, the Netherlands — [6]Institute of Solid State and Materials Physics, TU Dresden, Germany

Co thin films sandwiched between Pt and Ir (Pt (4 nm) / Co (t) / Ir (3 nm)) with t = 5 - 25 nm were grown. These films showed an increase in the out of plane (oop) magnetic anisotropy constant K above a critical thickness t_{cr}. The increase in the anisotropy K is linked to the formation of hcp Co on top of fcc Co due to lattice relaxation with increasing thickness t. We measured two films with Co thicknesses t = 10 nm $> t_{cr} > t$ = 25 nm by means of ^{59}Co zero-field nuclear magnetic resonance spectroscopy (ZF NMR) exploiting the internal field of the ferromagnetic material. ZF NMR is sensitive to changes in the local crystallographic and magnetic environment. In this contribution we will explain the overall increase of the anisotropy K due to magnetocrystalline (intrinsic) and magnetoelastic (extrinsic) effects on the basis of the ^{59}Co ZF NMR data.

MA 60.8 Fri 11:30 HSZ 04

Magneto-optical signal dependence on Co-layer thickness asymmetry in Co/Pt/Co-films — •Ramon Weber[1], Carmen Martín Valderrama[1,2], Lorenzo Fallarino[1], and Andreas Berger[1] — [1]CIC nanoGUNE, E-20018 Donostia-San Sebastian, Spain — [2]Faculty of Science, University of Valladolid, E-47011 Valladolid, Spain

Ever since the first observation of interlayer exchange coupling, magnetic multilayers have been a research subject of tremendeous importance, leading to many surprising phenomena. In a recent study, Tomita *et al.* [1] observed a most significant enhancement of the magneto-optical response in Fe/Pt multilayers that followed an inverse Fibonacci thickness stacking in comparison to periodically modulated reference samples. This effect could not be explained by classical electromagnetic theory assuming local material dependent dielectric properties, but might be related to quantum mechanical interferences associated with non-periodic stacking of nm-scale magnetic films and their resulting quantum well states. To test this explanation, we fabricated a series of Co/Pt/Co bilayer structures with pre-defined and variable thickness asymmetry of the Co layers, while keeping the total Co thickness constant. The optical and magneto-optical properties of these films were measured using Generalized Magneto-optical Ellipsometry, both as a function of the Co-layer thickness asymmetry and the Pt interlayer thickness.

[1] S. Tomita, T. Suwa, P. Riego, A. Berger, H. Nobuyoshi, and H. Yanagi, Phys. Rev. Appl. 11, 064010 (2019).

MA 60.9 Fri 11:45 HSZ 04

Interlayer exchange coupling in Fe/MgO[001] multilayers — •Tobias Warnatz[1], Fridrik Magnus[2], Sarah Sanz[1], Hasan Ali[3], Klaus Leifer[3], and Björgvin Hjörvarsson[1] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]Science Institute, University of Iceland, Reykjavik, Iceland — [3]Department of Engineering Sciences, Uppsala University, Sweden

Fe/MgO/Fe tunnel junctions are well known for their magnetoresistance, but their interlayer exchange coupling (IEC) [1] is less explored. Recently, we reported a sequential magnetic switching in interlayer exchange coupled Fe/MgO[001] superlattices [2]. The presented results were consistent with a beyond nearest neighbor IEC. Here, we report the first systematic investigation on the range of IEC in epitaxial Fe/MgO[001] multilayers. For that, samples with various Fe/MgO bilayer repetitions (N) were grown on single crystalline MgO(001) substrates. Hystereses curves with discrete magnetization steps were obtained, consistent with our previous results [2]. Taking only nearest-neighbor interactions into account, a reduction of the IEC by a factor of (1-1/N) should be observed [3] (the missing neighbor of the outermost layers becomes less important for many N). Our results deviate drastically from this prediction and verify a strong contribution from beyond nearest neighbor interactions. The results are essential for the understanding of the IEC in tunnel junctions and could even serve as a base for the development of three-dimensional data structures.

[1] Phys. Rev. Lett. 89, 106602 (2002) [2] Phys. Rev. B 97, 74424 (2018) [3] Appl. Phys. Lett. 58, pp. 1473-1475 (1991)

MA 60.10 Fri 12:00 HSZ 04

Probing the origin of ferromagnetic stability in LSMO/SRO — •Anna Zakharova — Swiss Light Source, Paul Scherrer Institut

The technological application of optimally doped mangnite is hindered due to the existence of a magnetic dead layer. However, when in contact with $SrRuO_3$ $La_{0.7}Sr_{0.3}MnO_3$ remains magnetic down to 1-2 u.c. Therefore in this work we investigate the origin of the ferromagnetic stability of LSMO in LSMO/SRO bilayers by using resonant x-ray spectroscopy varying thickness of LSMO and SRO deposited on $SrTiO_3$. Magnetic switching of LSMO in proximity with 20 u.c. SRO was observed even below critical thickness of LSMO. Moreover, 4 u.c. of LSMO shows remanence above SRO T_c. The XLD data evidences a preferential $d3z^2 - r^2$ occupation of Mn in LSMO/SRO interface in agreement with theoretical predictions. In addition, different Mn valence is observed for ultra-thin LSMO/SRO in comparison to LSMO//STO. These results combined can explain why the ferromagnetism is stabilized at LSMO/SRO interface.

MA 60.11 Fri 12:15 HSZ 04

Influence of structure and cation distribution on magnetic anisotropy and damping in Zn/Al doped nickel ferrites — •Julia Lumetzberger, Martin Buchner, Santa Pile, Verena Ney, and Andreas Ney — Johannes Kepler University Linz, Institute for Semiconductor and Solid State Physics, Linz, Austria

In spintronics one aims to obtain pure spin currents as an additional degree of freedom. To ensure a pure spin component ferromagnetic insulators are the material of choice. Promising results are obtained by cubic NiZnAl ferrite thin films grown on spinel $MgAl_2O_4$[1].In this contribution we use reactive magnetron sputtering as a preparation method to optimise the magnetic properties. All samples are analysed with X-ray diffractometry for their crystallographic properties. Furthermore, the angular and frequency dependence of the resonance position is measured by ferromagnetic resonance (FMR) and fitted to quantify the anisotropy fields as well as magnetic damping. Additionally, transmission electron microscopy is performed to investigate the interface on an atomic scale and the chemical composition by means of ion beam analysis. In a last step x-ray magnetic circular dichroism (XMCD) and XMCD (H) at the $L_{3,2}$ edge of Ni and Fe are performed to complement the integral SQUID magnetometry measurements and evidence their magnetic contributions to the hysteresis separately. A comparison between similarly strained materials revealed the importance of site occupancy as a major tuning factor for magnetic anisotropy and damping [2]. [1] S. Emori et. al., Adv. Mater. (2017), 29, 1701130 [2] J. Lumetzberger, arXiv:1908.08257 (2019)

MA 60.12 Fri 12:30 HSZ 04

Artificial bulk metamaterials based on graded epitaxial Co-alloy films — •Lorenzo Fallarino, Mikel Quintana, Ramon Weber, and Andreas Berger — CIC nanoGUNE, 20018 Donostia-San Sebastian, Basque Country, Spain

A very promising alternative to traditional magnetic information storage is based upon encoding information via non-collinear magnetic textures. They occur in certain materials with structure inversion asymmetry, a property that in conjunction with spin-orbit coupling leads to the Dzyaloshinskii-Moriya interaction (DMI). At interfaces between magnetic layers and heavy metals the DMI can be strong enough to promote non-collinear spin textures as ground states [1]. However, any

real multilayer is prone to growth induced imperfections at each interface that can strongly affect the energetic landscape. Likewise, interfaces are the only portions that can be influenced in such multilayers, inherently limiting the total active contributions to a small fraction of an entire structure. Along these lines, we have devised an innovative approach by means of artificial bulk metamaterials $Co_{1-x}A_x$ (with A = Ru, Pt, Cr) exhibiting pre-defined graded composition structures, allowing for an expansion of DMI generating interfaces into the entirety of the material, thus enabling all-interface-bulk metamaterial.
[1] A. Fert, N. Reyren, and V. Cros, Nat. Rev. Mat. 2, 17031 (2017).

MA 60.13 Fri 12:45 HSZ 04

Growth, structure, and magnetic properties of artificially layered NiMn in contact to ferromagnetic Co on $Cu_3Au(001)$ — •Tauqir Shinwari[1], Ismet Gelen[1], Melek Villanueva[2], Yasser A. Shokr[1,3], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Division of Permanent Magnets and Applications, IMDEA Nanoscience, 28049, Madrid, Spain — [3]Faculty of Science, Department of Physics, Helwan University, 17119 Cairo, Egypt

A series of experiments is carried out to identify the fundamental mechanisms leading to the exchange-bias effect in ultrathin epitaxial layered ferromagnetic/antiferromagnetic (FM/AFM) samples on $Cu_3Au(001)$. The studied samples are single-crystalline antiferromagnetic artificially layered [Ni/Mn] films covered by ferromagnetic Co layers, deposited under ultrahigh-vacuum conditions. The approach is to study the structural and magnetic properties of artificially ordered layers of Ni and Mn in contact to Co by using low-energy electron diffraction (LEED) and magneto-optical Kerr effect, respectively, and comparing with disordered Ni_xMn_{1-x} alloy films with the same Ni/Mn ratio and the same film thickness. We found from LEED I(V) curves that the perpendicular interatomic lattice distance is decreased in the artificially layered [Ni/Mn] samples in comparison to the disordered Ni_xMn_{1-x} alloy films. This change in the structure causes higher coercivity, exchange bias, and stronger exchange coupling in artificially layered [Ni/Mn] samples compared to disordered Ni_xMn_{1-x} alloy films.