# MA 22: Thin Films: Coupling Effects and Exchange Bias

Time: Wednesday 9:30–12:15 Location: H 2013

**Invited Talk** MA 22.1 Wed 9:30 H 2013

**Emergence of intrinsic antiferromagnetic topological solitons in thin films** — •Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Antiferromagnetic (AFM) skyrmions are envisioned as ideal localized topological magnetic bits in future information technologies. In contrast to ferromagnetic skyrmions, they are expected to be immune to the skyrmion Hall effect, might offer terahertz dynamics while being insensitive to magnetic fields and dipolar interactions. Although observed in synthetic AFM structures and as complex textures in intrinsic AFM bulk materials, their realization in non-synthetic AFM films, of crucial importance in racetrack concepts, has been elusive. I will discuss progress in finding combination of materials that can host intrinsic (non-synthetic) topological AFM solitons, which can have intriguing properties. They emerge as single and strikingly interpenetrating chains with non-trivial dynamics in a row-wise AFM Cr film deposited on PdFe bilayer/Ir(111) [1], detectable by all-electrical means [2]. Substituting Cr with Mn yields to frustrated AFM multimerons [3], which are also found in 2D van der Waals heterostructures [4]. These findings open up exciting avenues for engineering and detecting intrinsic AFM chiral entities in the same films. – Project funded by DFG (SPP 2137: LO 1659/8-1; SPP 2244: LO 1659/7-1).
–[1] Nat. Comm. 13, 7369 '22; [2] Nat. Comm. 13, 1576 '22; [3] J. Phys. Chem. Lett. 14, 8970 '23; [4] PRB 108, 094409 '23.

MA 22.2 Wed 10:00 H 2013

**Magneto-Optic Kerr Effect in EuO and EuO/Co: Correlating Experiment and Simulations** — •Seema Seema, Moumita Kundu, Henrik Jentgens, Paul Rosenberger, Ulrich Nowak, and Martina Müller — Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany

Ferromagnetic (FM) and insulating europium oxide (EuO) is perfectly suited as a spin-functional material for spintronic applications. EuO is a strong FM of $7\mu_B$ with a Curie temperature ($T_c$) of 69 K. The latter limits the practical applications and thus pathways to enhance the Tc have been explored such as altering stoichiometry, doping etc. Alternatively, it is promising to explore EuO in proximity to a room temperature FM such as Fe or Co to realize an enhancement of $T_c$ in EuO ultrathin films. The present work is the temperature-dependent magnetization in EuO probed using magneto-optic Kerr microscopy. Simultaneous hysteresis recording and domain imaging showed proximity effect-induced variations. To picture the magnetization reversal dynamics in EuO and EuO/Co, micromagnetic simulations were performed using OOMMF and MuMax$^3$ and compared with the experimental findings below and above $T_c$. Examining the changes induced by the proximity effect on a micromagnetic scale, through both experimental studies and modeling, has the potential to advance the enhancement of the $T_c$ of EuO.

MA 22.3 Wed 10:15 H 2013

**Skyrmions stabilization in exchange-biased model systems with compensated, uncompensated, and rough interface** — •Maryna Pankratova[1], Olle Eriksson[1,2], and Anders Bergman[1] — [1]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden — [2]Wallenberg Initiative Materials Science for Sustainability, Uppsala University, 75121 Uppsala, Sweden

The exchange bias appears in systems with contacting ferromagnets (FM) and antiferromagnets (AFM). It manifests itself in the shift of the magnetic hysteresis from the symmetric position with regard to the zero external magnetic field. When only one AFM sublattice is presented at the interface, or uncompensated FM-AFM interface, the magnetization of the AFM interface layer is non-zero, therefore, the effective field acts on the FM from the AFM. When both AFM sublattices are presented in the AFM interface layer, i.e. the case of a compensated interface, such an effective field could appear if two sublattices do not completely compensate each other. Recently, it was experimentally shown that this effective field can be used to stabilize skyrmions in zero external magnetic fields.

We perform atomistic spin-dynamics simulations to study skyrmion stabilizations in an exchange-biased FM-AFM bilayer and the impact of the interface roughness on the skyrmions' stabilization. We show that skyrmions and skyrmion lattices can be stabilized in zero external fields. The presence, stability, and chirality of skyrmions can be tuned by the strength of exchange coupling through the interface.

MA 22.4 Wed 10:30 H 2013

**Proximity Effect in DyCo3 thin films investigated by Polarized Neutron Reflectometry** — •Dieter Lott[1], André Philippi-Kobs[2], Stefan Mattauch[3], and Alexandros Koutsioumpas[3] — [1]Helmholtz Zentrum Hereon, Geesthacht, Germany — [2]DESY, Hamburg, Germany — [3]JCNS, Jülich Forschungszentrum, Jülich, Germany

Alloys of rare-earth elements and 3d transition metals became recently again in the focus of attention due there rich variety of magnetic effects owed to the different anisotropies of both material classes [1-3]. In a thin film system of amorphous DyCo3 alloy, studied by XMCD techniques, a non trivial magnetic ordering was discovered showing a large Atomic Exchange Bias effect owned to the competition between the atomic exchange and the Zeemann interaction [4]. Here in this work, polarized neutron reflectometry was applied providing the sensitivity to study the magnetic structures on a microscopic level that is essential to understand the underlying principles. Here, in particular, the Ta buffer and Ta capping layer has a significant effect on the magnetic properties of DyCo3 leading to a significant proximity effect. The results demonstrate how the choice of the proximity layers may be key to further tailor the magnetic properties of this material system for potential future applications. [1] S. Mangin et.al, Phys. Rev. B 80, 224424 (2009), S. Mangin et.al, Phys. Rev. Lett. 82, 4336 (1999) [2] Chen, K., Lott, D. et al.. Phys. Rev. B 91, 024409 (2015) [3] F. Radu, R. Abrudan, I. Radu, D. Schmitz H. Zabel, Nat. Communications 3, 715 (2012). [4] K. Chen, D. Lott, F. Radu, F. Choueikani, E. Otero, P. Ohresser, Sci. Rep. 5, 18377, (2015)

**15 min. break**

MA 22.5 Wed 11:00 H 2013

**Enhanced magnetism at 3d FM/EuO interfaces: Insights from core level photoelecton spectroscopy** — •Paul Rosenberger[1,2], Moumita Kundu[1], Andrei Gloskovskii[3], Christoph Schlüter[3], Ulrich Nowak[1], and Martina Müller[1] — [1]FB Physik, Universität Konstanz, Germany — [2]Fakultät Physik, TU Dortmund, Germany — [3]DESY, Hamburg, Germany

The semiconducting Heisenberg ferromagnet EuO ($\mu = 7\,\mu_B$/f.u.) is a template for studying novel spin-related phenomena, but suffers from a rather low $T_C$ (69 K) [1]. A magnetic proximity effect (MPE) in EuO interfaced with Fe or Co results in a $T_C$ enhancement, but its microscopic origin and depth-dependence are not yet understood.
Here, the depth-dependent magnetic order at Fe/EuO and Co/EuO interfaces was studied by emission-angle dependent magnetic circular dichroism (MCD) in hard-X-ray photoelectron spectroscopy (HAXPES). Bilayers with EuO film with thicknesses of 4 nm and 11 nm were measured at T= 40 K < $T_C$ and T= 80 K > $T_C$. The results confirm antiferromagnetic coupling between the 3d FM overlayers and EuO. At T > $T_C$, magnetic order in thin EuO is observed. The degree of magnetic order was found to decrease with increasing distance from the interface. Initially magnetized in-plane EuO has a non-zero magnetic out-of-plane component at T > $T_C$. The experiments are complemented by atomistic spin simulations.

[1] P. Rosenberger and M. Müller, PRM 6, 044404 (2022).

MA 22.6 Wed 11:15 H 2013

**Magnetometry of Buried Co-based Nanolayers by Hard X-ray Photoelectron Spectroscopy** — •Andrei Gloskovskii[1], Christoph Schlueter[1], and Gerhard Fecher[2] — [1]Photon Science / DESY, Hamburg — [2]Max Planck Institute for Chemical Physics of Solids, Dresden

The intensity and shape of photoelectron lines of magnetic materials depend on the relative orientation of the sample magnetization, the X-ray beam polarization and the spectrometer axis, i.e. the electron emission direction. In the hard X-ray regime, the beam polarization can be conveniently modified utilizing the phase shift produced by a

diamond phase plate in the vicinity of a Laue or Bragg reflection. A single-stage in-vacuum phase retarder is installed and commissioned in 2020 at the HAXPES beamline P22 at PETRA III (Hamburg) [1].

The electronic and magnetic properties of CoFe, CoFeB and Co-based Heusler nanolayers were studied using the magnetic circular dichroism (MCD). Both the polarization-dependent spectra and the dichroism indicate that the lines of the multiplet extend over the entire spectral range. It is demonstrated that MCD in HAXPES is an effective and powerful technique to perform element and depth specific magnetometry of deeply buried ferromagnetic and antiferromagnetic magnetic materials. [1] C. Schlueter, A. Gloskovskii, K. Ederer et al., AIP conference proceedings 2054(1), 040010 (2019).

MA 22.7 Wed 11:30 H 2013

**Spin currents in ferrimagnetic heterostructures** — •Felix Fuhrmann[1], Akashdeep Akashdeep[1], Sven Becker[1], Zengyao Ren[1,2], Mathias Weiler[3], Gerhard Jakob[1,2], and Mathias Kläui[1,2,4] — [1]Institute of Physics, University of Mainz, Germany — [2]Graduate School of Excellence "Materials Science in Mainz" (MAINZ), Germany — [3]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische UniversitätKaiserslautern-Landau, 67663 Kaiserslautern, Germany — [4]Center for Quantum Spintronics, Norwegian University of Science and Technology, Trondheim, Norway

In response to the growing demand for energy-efficient information technology, magnons emerge as promising information carriers [1]. To advance magnon-based devices, essential materials requirements must be met. The insulating ferrimagnet Yttrium Iron Garnet (YIG, $Y_3Fe_5O_{12}$) and related garnets, such as Gadolinium Iron Garnet (GIG, $Gd_3Fe_5O_{12}$), stand out with their low damping and resulting large magnon propagation lengths [1]. Employing pulsed laser deposition, we fabricated heterostructures of YIG and GIG, revealing a ferromagnetic coupling between the Fe sublattices of the two layers, leading to complex magnetic response to external magnetic fields and a nontrivial temperature dependence [2]. Exploring spin current generation via the spin Seebeck effect and spin pumping at ferromagnetic resonance, our findings align with our macrospin model [3]. [1] A. Chumak et al., Nat. Phys. 11, 453 (2015). [2] S. Becker et al., Phys. Rev. Appl., 16, 014047 (2021). [3] F. Fuhrmann et al., ArXiv:2303.15085 (2023).

MA 22.8 Wed 11:45 H 2013

**Double Exchange Bias and Ultraslow Magnetization Relaxation in TbFe-based Bilayers** — •Johannes Seyd and Manfred Albrecht — Institut für Physik, Universität Augsburg, Universitätsstraße 1, 86159 Augsburg

Exchange bias (EB) is a phenomenon that manifests itself in the horizontal shift of a hysteresis loop. This usually occurs in systems with coupled FM-AFM or FM-FiM interfaces. We report on the magnetic reversal characteristics of exchange-biased heterostructures consisting of two ferrimagnetic $Tb_xFe_{100-x}$ layers whose respective magnetizations are Fe-dominated and Tb-dominated. Both layers are amorphous and display perpendicular magnetic anisotropy.

Based on previously published results, we expanded the range of investigated layer compositions of $Tb_xFe_{100-x}$-based bilayers and layer structures. Since not a sharp interface, but a gradual change of composition over a region of about 2.5 nm thickness between the two layers was found in the bilayer structure, we investigated the influence of different additional interlayers on the magnetic reversal behaviour at low temperatures after field cooling (FC).

While investigating these samples, another phenomenon was observed: ultraslow magnetization relaxation. This manifests itself in an overcrossing of the hysteresis branches in the first and third quarter of the M-H-diagram. Usually, the slowest process in magnetization dynamics is domain wall motion with a timescale between a few ns to hundreds of $\mu$s. The process observed here, however, takes in the order of a few tens to thousands of seconds to complete.

MA 22.9 Wed 12:00 H 2013

**Investigation of proximity effects in $YBa_2Cu_3O_{7-x}$/$SrRuO_3$ and $SrRuO_3$/$YBa_2Cu_3O_{7-x}$ heterostructures** — •Vitor de Oliveira Lima[1,2], Michael Faley[1], Omar Concepcion[1], Connie Bednarski-Meinke[1], Mai H. Hamed[1], Emmanuel Kentzinger[1], Shibrabata Nandi[1,2], and Thomas Brückel[1,2] — [1]Forschungszentrum Jülich GmbH, Jülich, Germany — [2]RWTH Aachen, Lehrstuhl für Experimentalphysik IVc, Jülich-Aachen Research Alliance (JARA-FIT), Aachen, Germany

Heterostructures (HS) based on superconductors and ferromagnets exhibit strong potential for innovating devices in spintronics and quantum computing applications. $SrRuO_3$ (SRO) has attracted much attention among transition metal oxides for being the only $4d$ oxide to show itinerant ferromagnetism and metallic conductivity. On the other side, $YBa_2Cu_3O_{7-x}$ (YBCO) is one of the most studied high $T_c$ superconductors with a large variety of applications. We report structural, morphological, magnetic and magnetotransport characterization of YBCO/SRO (S1) and SRO/YBCO (S2) HS prepared on low miscut $SrTiO_3$ (001) single crystals by high oxygen pressure sputtering. The HS exhibit epitaxial growth with good crystal quality and sharp interfaces, with critical temperatures of 87.5 K and 57 K for S1 and S2, respectively, both reduced in relation to YBCO (91 K). We observe an inversion of the magnetoresistance peak around the onset of superconductivity, a robust indicator of proximity effects at both interfaces. The nature of the proximity effect will be discussed.