# MA 55: Thin Films: Magnetic Anisotropy

Time: Thursday 15:00–18:00 Location: HSZ 101

MA 55.1 Thu 15:00 HSZ 101

**New magnetic anisotropy control in thin film multilayers for sensing applications** — •Svenja Willing[1], Kai Schlage[1], Lars Bocklage[1,2], Guido Meier[2,3], and Ralf Röhlsberger[1,2] — [1]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]Max-Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

Magnetic field sensors are frequently used in today's automotive control, industrial process management, and information technology. Sensors based on the giant magnetoresistance are small, low-cost, and easy to produce. They can be as simple as a sandwich of two magnetic layers separated by a non-magnetic spacer layer. Exposing such a trilayer to a magnetic field influences the relative orientation of magnetization in the layers which can be detected as a change in electrical resistance. Recently, the magnetic and magneto-resistive properties of such multilayers stacks were tuned by deposition at oblique incidence angles [1]. The induced shape anisotropy enables full control over each individual layer's coercivity and preferred magnetic orientation without the limitations of interlayer exchange or exchange-biased pinning. This allows for a versatile, individual tailoring of multilayer functionalities to adapt the sensor to the needs of an application. We show how microstructuring influences the magnetic and magneto-resistive properties of the multilayer devices.

[1] K. Schlage, L. Bocklage, D. Erb, J. Comfort, H.-C. Wille, R. Röhlsberger, Adv. Funct. Mater. 2016, 26, 7423-7430.

MA 55.2 Thu 15:15 HSZ 101

**A new interstitial compound: Fe-B** — •Dominik Gölden, Erwin Hildebrandt, and Lambert Alff — Institute of Materials Science, Technische Universität Darmstadt, Germany

One of the most promising potential permanent magnet candidates of the last decades, $\alpha''$-$Fe_{16}N_2$, has a low decomposition temperature of about 180 °C, making it unsuitable for many applications. One alternative is replacing the nitrogen interstitials with boron. This system is predicted to yield similar or even higher saturation magnetization and anisotropy while having a higher decomposition temperature. Previous studies suggest that boron prefers to occupy substitutional positions over interstitial positions. We explored the Fe-B system with boron content below 15% by molecular beam epitaxy (MBE). An increasing tetragonalization was observed, pointing at an interstitial occupation of boron. The measured $c/a$ ratio increased with decreasing growth temperature and scaled linearly with the boron content up to a maximum of 1.07 with a magnetization of about 1580 emu/cm$^3$. However, in contrast to nitrogen interstitials, the interstitial Fe-B system could be grown at up to 300 °C, making it potentially a much more interesting candidate for permanent magnets.

MA 55.3 Thu 15:30 HSZ 101

**Impact of Au interlayer on magnetoelasticity of Fe/Au/Fe sandwich** — •Kenia Novakoski Fischer and Dirk Sander — Max Plack Institute of Microstructure Physics - Halle

Magnetic metallic structures separated by a nonmagnetic spacer are used in magnetic recording media and related devices. The interlayer exchange coupling between ferromagnetic (FM) layers shows an oscillatory response as a function of the spacer thickness. This effect is attributed to the influence of the quantum-well states in the nonmagnetic layer [1]. In this work, we shed light on the understanding of the impact of this nonmagnetic spacer layer on the magnetoelastic coupling of ferromagnetic films. The magnetoelastic coupling coefficients are obtained from measurements of the stress change of FM layers upon a magnetization reorientation [2]. We acquire the values of the magnetoelastic coupling coefficient B1 for Fe (15 ML)/Au (X ML)/Fe (10 ML) layers on Au (001), where X varies from 0 to 12 ML. Up to 2 ML Au, B1 remains constant at -1.3 MJ/m3. With increasing Au thickness B1 exhibits a non-monotonic behavior. We observe a non-monotonic variation of magnitude 3 MJ/m3 in an increment of Au thickness of 1 ML at a spacer thickness near 9 ML. The results of the magnetoelastic coupling in the Fe films sandwiched by Au are discussed in view of the interlayer exchange coupling of the ferromagnetic layers.

[1] J.E. Ortega et al., Phys. Rev. B 47, 1540, (1993); J. Unguris et al., Phys. Rev. B 75, 6437, (1994); W. Geerts et al., Phys. Rev. B 17, 12581, (1994).
[2] D. Sander, Rep. Prog. Phys. 62, 809 (1999).

MA 55.4 Thu 15:45 HSZ 101

**Epitaxial $YCo_5$ thin films with perpendicular anisotropy** — •Shalini Sharma, Erwin Hildebrandt, Iliya Radulov, and Lambert Alff — Institute of Materials Science, Technische Universität Darmstadt, 64287 Darmstadt, Germany

Thin films with perpendicular magnetic anisotropy are particularly important for high-density perpendicular magnetic recording media, magneto-optical recording media, and recently emerging nano-scale spintronic devices. One approach to achieve this is the $c$-axis (easy axis) textured growth of materials which possess strong intrinsic magnetocrystalline anisotropy that is large enough to overcome the shape anisotropy of thin films. This work is focused on growing thin films of $YCo_5$ which possesses a very strong uniaxial magnetocrystalline anisotropy ($K_1$ of 5.78 MJ/m$^3$) as bulk phase. We have explored the growth window of (00$l$) oriented $YCo_5$ thin films grown onto (0006) $Al_2O_3$ substrates by molecular beam epitaxy (MBE). The hexagonal $YCo_5$ phase grows with the $c$-axis perpendicular to the film plane without the use of any additional buffer layer. The highest coercivity was measured to be 4 kOe with a saturation magnetization of 517 emu/cc at 300 K. This is the highest value of magnetization ever reported for $YCo_5$ thin films. Magnetic torque measurements were used to calculate the value of anisotropy constant, $K_1$.

MA 55.5 Thu 16:00 HSZ 101

**Mn-Fe-Ga Films with Perpendicular Magnetic Anisotropy** — •Anastasios Markou[1], Adel Kalache[1], Susanne Selle[2], Gerhard H. Fecher[1], and Claudia Felser[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Fraunhofer Institute for Microstructure of Materials and Systems IMWS, 06120 Halle, Germany

Heusler compounds are a remarkable class of materials with a huge potential for different applications [1]. Tetragonally distorted Mn-based Heusler compounds ($Mn_3Ga$ and $Mn_3Ge$) are promising class of materials, showing high magnetocrystalline anisotropy, large coercivity and high Curie temperature, but suffer from low magnetization [2]. The substitution of Mn with Fe in D022-Mn3Ga can lead to magnetization increment and making Mn-Fe-Ga compound a candidate material for rare-earth-free permanent magnets. Here, we present a systematic X-ray diffraction (XRD), transmission electron microscopy (TEM) and magnetic characterization of Mn-Fe-Ga films with different compositions and perpendicular anisotropy.

[1] C. Felser, L. Wollmann, S. Chadov, Gerhard H. Fecher and S.S.P Parkin, APL Mater. 3, 041518 (2015).
[2] A. Kalache, G. Kreiner, S. Quardi, S. Selle, C. Patzig, T. Hoche and C. Felser, APL Mater. 4, 086113 (2016)

**15 min. break.**

MA 55.6 Thu 16:30 HSZ 101

**Magnetic characterization of the nanolaminated Mn2GaC MAX phase** — •Iuliia Novoselova[1], Ruslan Salikhov[1], Arni S. Ingason[2], Johanna Rosen[2], Ulf Wiedwald[1], and Michael Farle[1,3] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Duisburg, Germany — [2]Department of Physics, Linköping University, Linköping, Sweden — [3]Center for Functionalized Magnetic Materials, Immanuel Kant Baltic Federal University, Kaliningrad, Russia

We report on the magnetic properties of the new magnetic material $Mn_2GaC$ MAX phase [1]. MAX phases are atomically laminated compounds composed of early transition metals M, A - group elements and X is C or N. The crystal structure of MAX phases is hexagonal with M-X-M atomic layers stacking in the c-direction with the A-element as a spacer [2]. $Mn_2GaC$ has been synthesized as a epitaxial film containing Mn as an exclusive M element. First principles calculations suggest that the spins in a Mn-C-Mn trilayer are ferromagnetically ordered, however, the antiferromagnetic (AFM) and ferromagnetic (FM) spin alignments in Mn-Ga-Mn chains are competitive [2]. This competition leads to a rich magnetic phase diagram and structural changes linking to temperature-dependent magnetic order and anisotropy [2].

In-plane alignment of magnetic moments caused by the film shape anisotropy below 240 K has been confirmed using ferromagnetic resonance (FMR). Magnetometry measurements reveal hysteretic behavior with the magnetic moment of 1.7 $\mu$B per Mn atom at saturation. Work supported by DFG, SA 3095/2-1. [1] A. S. Ingason et al., MRL, 2, 89 (2014). [2] A. S. Ingason et al., J. Phys.: Cond. Mat., 28, 433003 (2016).

MA 55.7 Thu 16:45 HSZ 101

**MAX phase magnetic quaternary compounds** — •Ruslan Salikhov[1], Quanzheng Tao[2], Iuliia Novoselova[1], Johanna Rosen[2], Ulf Wiedwald[1], and Michael Farle[1,3] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Department of Physics, Linköping University, Sweden — [3]Center for Functionalized Magnetic Materials, Immanuel Kant Baltic Federal University, Kaliningrad, Russia

Mn+1AXn (n = 1-3) phases, for which M is an early transition metal, A is an A-group element, and X is C (or N), are a family of inherently nanolaminated hexagonal compounds. Due to their unique structure these materials share properties usually associated with ceramics and metals [1]. The ability to stabilize quaternary compounds with isostructural solutions on M and A sites and with different stoichiometry yields a class of new magnetic MAX phase materials. We report on the magnetic properties of the recently discovered compounds: (Cr0.5Mn0.5)2GaC [2], (Mo0.5Mn0.5)2GaC [3], (Cr0.5Mn0.5)2AuC and (V,Mn)3GaC2 [4]. The (Cr0.5Mn0.5)2AuC system shows the smallest magnetic ordering temperature of TC = 120 K, high coercive field of HC = 100 mT and magnetocrystalline anisotropy energy (MAE) at T = 10 K. The MAE of (Cr0.5Mn0.5)2GaC and (Mo0.5Mn0.5)2GaC do not exceed 4 kJ/m3, both systems have similar TC = 210 K and HC = 30 mT at T = 5 K. This work is supported by DFG SA 3095/2-1. [1] M. W. Barsoum, PSSC, 28, 201 (2000). [2] R. Salikhov et al., MRL, 3, 156 (2015). [3] R. Meshkian, et al., APL Mater. 3, 076102 (2015). [4] Q. Tao, et al., APL Mater. 4, 086109 (2016).

MA 55.8 Thu 17:00 HSZ 101

**Compensated magnetic state in tetragonal thin films for antiferromagnetic spintronics** — •Roshnee Sahoo[1], Ajaya K. Nayak[2], Lukas Wollmann[1], Stuart Parkin[2], and Claudia Felser[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany

Heusler compounds are well known for their potential applications in spintronics [1]. In recent years, antiferromagnetic spintronics has received much attention since ideal antiferromagnets do not produce stray fields and are much more stable to external magnetic fields compared to materials with net magnetization. Similar to antiferromagnets, compensated ferrimagnets have zero net magnetization but have the potential for large spin-polarization and strong out of plane magnetic anisotropy. In the present work, we report a completely compensated magnetic state and tunable magnetic anisotropy in Mn-Pt-Ga based tetragonal thin films [2]. It is also demonstrate that bilayers formed from compensated and uncompensated Mn-Pt-Ga layers, exhibit a large interfacial exchange bias field up to room temperature.The present system establishes a distinct approach of designing spintronic devices that are formed from materials with similar elemental compositions and nearly identical crystal and electronic structures, and, hence, are of significant practical value due to their high thermal stabilities.
[1]C. Felser et al, Appl. Phys. Lett. Mater.**3**, 041518 (2015).
[2]R. Sahoo et al, Adv. Mater.**28**, 8499-8504 (2016).

MA 55.9 Thu 17:15 HSZ 101

**Probing the strain induced magnetic anisotropy in $CoCr_2O_4$ with x-ray magnetic circular dichroism (XMCD)** — •Cinthia Piamonteze[1], Yoav William Windsor[1], Sridhar Reddy Avula Venkata[1], Andrea Scaramucci[2,3], Jeroen A. Heuver[4], Beatriz Noheda[4], and Urs Staub[1] — [1]PSI, SLS, Villigen, Switzerland — [2]Mater. Theory, ETHZ, Zürich, Switzerland — [3]Lab. Scient. Devel. and Novel Mater., PSI, Villigen, Switzerland — [4]Zernike Inst. Adv. Mater., Univ. Groningen, Groningen, The Netherlands

$CoCr_2O_4$ (CCO) is a spinel where $Co^{2+}$ and $Cr^{3+}$ occupy tetrahedral and octahedral sites, respectively. CCO is one of the few single-phase multiferroic systems exhibiting a net magnetic moment [1]. It exhibits a collinear ferrimagnetic order below 95K. Below 27K a spiral spin component appears in concomitance with a ferroelectric polarization [2]. Recently it has been shown that strain engineering can successfully control the magnetic easy axis of CCO thin films between in-plane and out-of-plane [3]. In this work we present XMCD and element specific hysteresis curves at the Co and the Cr $L_{3,2}$ edges for both compressive and tensile strained 40-nm-thick films. We explain the behavior of the magnetocrystalline anisotropy using quantitative values of the orbital and spin moments of Co, obtained through sum rule analysis. We specifically show that the ratio of $m_L/m_S$ along the easy axis direction is 0.24 and 0.3 for tensile and compressive strain, respectively, pointing to a large Co orbital contribution. [1] Yamasaki *et al.* PRL **96**, 207204 (2006). [2] Y. Choi *et al.*, PRL **102**, 067601 (2009). [3] J. A. Heuver *et al.*, PRB **92**, 214429 (2015).

MA 55.10 Thu 17:30 HSZ 101

**Metadynamic study on magnetic anisotropy of thin films** — •Balazs Nagyfalusi[1], Laszlo Udvardi[2,3], and Laszlo Szunyogh[2,3] — [1]Wigner Research Center for Physics, Budapest, Hungary — [2]Department of Theoretical Physics, Budapest University of Technology and Economics, Budapest, Hungary — [3]MTA-BME Condensed Matter Research Group, Budapest University of Technology and Economics, Budapest, Hungary

Magnetic anisotropy plays key role in several phenomena having importance in technological applications. In the present contribution the temperature dependence of the magnetic anisotropy energy (MAE) is investigated by means of metadynamic Monte Carlo simulations. Metadynamics[1] is an adaptive biasing potential methods where the free energy of the system is explored along a collective variable (CV).

We studied a model of a ferromagnetic thin film with uniaxial on-site and two-site anisotropy. The CV has been chosen to be the normalized component of the magnetization perpendicular to the substrate. The temperature dependence of MAE provided by the simulations is in good agreement with the Callen-Callen[2] theory in the case of on-site only anisotropy and an exponent close to 2 has been found at higher temperatures for the model containing two-site anisotropy. The competition of the on-site and two-site anisotropy may result in a reorientation of the magnetization which has been also confirmed by our simulations for mono and bi-layers.
[1] A. Laio, M. Parrinello, PNAS **99**, 12562 (2002)
[2] H.B. Callen and E. Callen, J. Phys. Chem. Solids, **27**, 1271 (1966)

MA 55.11 Thu 17:45 HSZ 101

**Domain wall profiles in $Co/Ir_n/Pt(111)$ ultrathin films** — György J. Vida[1], Eszter Simon[1], Levente Rózsa[2], Krisztián Palotás[3], and •László Szunyogh[1] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary — [3]Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia

Motivated by recent experiments [1,2] we present a study of domain walls in $Co/Ir_n/Pt(111)$ ($n = 0, \ldots, 6$) films by a combined approach of first-principles calculations and spin dynamics simulations. We calculate the tensorial exchange interactions and the magnetic anisotropies for the Co overlayer and find strong out-of-plane magnetic anisotropy for the films with FCC geometry. We demonstrate that the rotational sense (chirality) of domain walls is changed upon the insertion of an Ir buffer layer as compared to the pristine Co/Pt(111) system, unambigously associated with the orientation of the in-plane components of the Dzyaloshinskii-Moriya (DM) vectors. Our simulations also indicate a twisting of the spins with respect to the planar domain wall profile on the triangular lattice. We discuss this domain wall twisting using symmetry arguments and by using an appropriate micromagnetic continuum model considering energy terms related to the out-of-plane component of the DM interaction as well as to specific symmetric off-diagonal elements of the exchange tensor. [3]

[1] G. Chen *et al.*, Nat. Comm. 4, 2671 (2013)
[2] A. Hrabec *et al.*, Phys. Rev. B 90, 020402 (2014)
[3] Gy. J. Vida *et al.*, arXiv:1611.09518 (2016)