MA 33: Magnetic Coupling Phenomena/ Exchange Bias

Time: Wednesday 15:00–18:00 Location: EB 202

Invited Talk MA 33.1 Wed 15:00 EB 202

Exchange bias and domain evolution at 10 nm scales — •Hans J. Hug[1,2], Miguel A. Marioni[1], Sara Romer[1], Sevil Oezer[2], and Niraj Joshi[1,2] — [1]Empa - Swiss Federal Laboratories for Materials Testing and Research, Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland — [2]Department of Physics, University of Basel, CH-4056 Basel, Switzerland

An obstacle to understanding the EB effect is that only a subset of the UCS (those pinned and coupled to the F) are responsible for the EB effect. Experimental methods that measure the pinUCS density distribution with spatial resolution comparable to the materials grain size are needed. Here we use quantitative, high-resolution magnetic force microscopy (MFM) to measure the local areal density of pinned uncompensated spins (pinUCS) and to correlate the F-domain structure in a perpendicular anisotropy CoPt multilayer with the pinUCS density [1]. Larger applied fields drive the receding domains to areas of proportionally higher pinUCS aligned antiparallel to F-moments. This confirms our prior results [2] that these antiparallel pinUCS are responsible for the EB effect, while parallel pinUCS coexist. The data confirm that the evolution of the F-domains is determined by the pinUCS in the AF-layer, and also present examples of frustration in the system. Grain-boundary engineering can be used to decouple the AF grains leading to a stronger EB-effect but a smaller coercivity. New types of thin film system showing and exchange bias field of 1T will be discussed. [1] I. Schmid et al. EPL, 81 (2008) 17001 [2] I. Schmid et al. PRL, 105 (2010) 197201

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XMCD-XRMR studies of Exchange Bias Systems — •Patrick Audehm[1], Mathias Schmidt[1], Sebastian Macke[2], Gisela Schütz[1], and Eberhard Goering[1] — [1]Max Planck Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany — [2]The University of British Columbia, 2329 West Mall, Vancouver, Canada

Since the discovery of the exchange bias (EB) in 1956 by Meiklejohn and Bean, the effect in all its varieties is not completely understood. We investigated a widely studied EB-system of polycrystalline Co on FeMn. The sputtered samples are investigated with a broad range of different techniques, like as X-ray magnetic circular dichroism (XMCD) and x-ray resonant magnetic reflectivity (XRMR) at the L2,3 edges of the transition metals, simultaneously performed in surface sensitive total electron yield (TEY) and bulk sensitive total fluorescence yield (TFY), all at room and low temperatures. With our state of the art soft-X-ray reflectometer we are able to identify element specifically even smallest amounts of magnetic moment contributions via magnetic reflectivity asymmetry and sum rules. Additionally we are measuring the energy dependent reflection with constant momentum transfer which is the direct combination of XMCD and XRMR. With all these techniques we found uncompensated, non-rotatable magnetic moments in iron. All these moments are located at the interface to the Co-layer. Our results lead to a better understanding of the micro magnetic understanding of the EB.

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Antiferromagnetic coupling across silicon with Fe3Si magnetic layers — •Rashid Gareev[1], Sergey Makarov[2], Alexey Drovosekov[3], Markus Härtinger[1], Georg Woltersdorf[1], Werner Keune[2], Heiko Wende[2], and Christian Back[1] — [1]University of Regensburg, Universitätstrasse 31, 93040 Regensburg, Germany — [2]University of Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany — [3]Kapitza Institute for Physical Problems, Kosygina st. 2, 117334 Moscow, Russia

Combined ferromagnet/semiconductor Fe/Si/Fe tunneling structures demonstrate strong antiferromagnetic coupling (AFC) [1]. Formation of magnetic silicides at interfaces affects AFC as demonstrated by Co interface *dusting* [2]. Substitution of Fe by magnetic Fe3Si can increase interface spin-polarization, influence AFC and reduce interface diffusion. Epitaxial growth of structures with Si spacers and Fe3Si magnetic layers was controlled by RHEED. We realized AFC in Fe3Si-based structures grown on both GaAs(001) and Si(001) substrates. Formation of interfacial iron-silicides was confirmed by Conversion-electron Mössbauer spectroscopy (CEMS) utilizing 0.5 nm-thick interfacial 57Fe tracing layers. The room temperature AFC for samples grown on GaAs(001) is substantially weaker compared to Fe/Si/Fe and reaches /J/~10 mkJ/m2 for 1.2 nm-thick Si. For structures grown on Si(001) AFC is well above /J/~ 0.1 mJ/m2. The possible reasons for observed AFC behavior are discussed. Support by the Project DFG 9209379 is appreciated. [1]. R.R. Gareev et al, J. Magn. Magn. Mater. 240, 235 (2002). [2]. R.R. Gareev et al, AIP Advances 1, 042155 (2011).

MA 33.4 Wed 16:00 EB 202

Ripple formation in ion bombarded exchange bias systems — •Alexander Gaul[1], Dieter Engel[1], Hans Peter Oepen[2], Sebastian Hankemeier[2], and Arno Ehresmann[1] — [1]Department of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel — [2]Institute of Applied Physics and Microstructure Advanced Research Center, University of Hamburg, Jungiusstr. 11, D-20355 Hamburg

Artificial magnetic domain patterns with three different magnetization directions in the same layer system have been fabricated by keV-He ion bombardment induced magnetic patterning in IrMn/NiFe exchange biased layers.

High resolution magnetic imaging via scanning electron microscope with polarization analysis (SEMPA) revealed magnetic ripple domains as a fine structure in the artificially fabricated domains. It is shown that the long axes of the ripple domains are always perpendicular to the exchange bias field direction of the respective domain. The magnetic ripple period length has been obtained by fast Fourier transform (FFT) of the SEMPA data. The ripple period length increases with decreasing magnetic anisotropy, which has been varied by applying different fluencies of the ions during bombardment.

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Structural and magnetic properties of the Fe layers in CoO/Fe/Ag(001) heterostructure — •Rantej Bali[1], Marcio Soares[2], Aline Ramos[2], Helio Tolentino[2], Fikret Yildiz[1], Clemence Boudot[2], Olivier Proux[3], Maurizio De Santis[2], Marek Przybylski[1], and Jürgen Kirschner[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, 06120 Halle, Germany — [2]Institut Néel, CNRS and Université Joseph Fourier, BP 166, F-38042 Grenoble Cedex 9, France — [3]Observatoire des Sciences de l'Univers - OSUG-Grenoble, F-38051 Grenoble, France

We elucidate the influence of interfacial oxidation on the magnetic behaviour of CoO/Fe grown on Ag(001) at 340 K. The Fe layer was in the form of a wedge from 0 to 10 monolayers (ML) thickness. Magneto-optic Kerr Effect (MOKE) and X-ray Absorption Near Edge Spectroscopy (XANES) were employed to obtain the Fe-thickness dependence of the magnetic and structural characteristics respectively. The interfacial region consists of a disordered $Fe_{1-x}O_x$ layer with x varying from 0.6 at the interface to 0 in deeper Fe layers. The depth of $Fe_{1-x}O_x$ formation depends on the Fe thickness prior to CoO coverage; from 0 to 4 ML Fe the whole depth forms the oxide. The depth of $Fe_{1-x}O_x$ decreases linearly from 4 to 2 ML as Fe thickness increases from 4 to 8 ML above which the depth of $Fe_{1-x}O_x$ remains constant. Correspondingly 4 ML of CoO covered Fe show zero magneto-optic signal and at 8 ML the largest exchange bias can be induced by zero field cooling. The results can be explained by considering the growth mode of Fe on Ag(001) and defects from the interfacial $Fe_{1-x}O_x$ layer.

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Exchange Bias in $IrMn_3$/Co bilayers — •Rocio Yanes[1], Laszlo Szunyogh[2], and Ulrich Nowak[1] — [1]Universität Konstanz, Konstanz, Germany — [2]Budapest University of Technology and Economics, Budapest, Hungary

The exchange bias (EB) effect is a unidirectional anisotropy of a magnetic system, which is characterized by a shift in the hysteresis loop, called exchange bias field H_E. The EB is related to the coupling between a ferromagnet (FM) and an antiferromagnet (AFM) or ferrimagnet (FI), and its stiffness depends on the exchange coupling through the interface.

We studied the magnetic properties of a bilayer of $IrMn_3$/Co using a multiscale modeling, from ab-initio to spin model simulations. The

$IrMn_3$ is an AFM which exhibits a T1 magnetic ground state within a [111] magnetic easy plane [1]. When the $IrMn_3$ is capped by a Co layer, a measurable Dzyaloshinskii-Moriya (DM) interaction arises owing to the breaking of symmetry at the interface [2].

Numerical calculations of the hysteresis loops of $IrMn_3$/Co were carried out for different values of the thickness of the Co capping and the different contributions to the exchange interaction. The results show that $IrMn_3$/Co displays a strong EB effect and its origin is the DM interaction.

[1] L. Szunyogh, et.al., Phys. Rev. B, 79,020403(R) (2009)
[2] L. Szunyogh, et.al., Phys. Rev. B, 83,024401 (2011)

15 min. break

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Magnetic exchange interactions in perovskites ATcO$_3$ (A = Ca, Sr, Ba) with high Neel temperature studied from first principles — •Vladislav Borisov[1], Igor Maznichenko[2], Sergey Ostanin[1], Arthur Ernst[1], and Ingrid Mertig[1,2] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle, Germany

An extraordinary high Neel temperature (T_N) has been found for the 4d transition metal oxides ATcO$_3$ (A = Ca, Sr, Ba) with the perovskite structure. The magnetic properties and the exchange interactions in the system were studied from first principles using the KKR-CPA method based on the multiple-scattering theory. For each perovskite, the most preferable magnetic configuration was found to be G-type antiferromagnetic with antiparallel alignment of the neighboring magnetic moments. The observed magnetic ordering is accounted for by the strong superexchange interaction between the Tc cations which is mediated by a pronounced overlap of the technetium 4d orbitals and oxygen p orbitals. We obtained the values of the Neel temperature T_N of 840 K for $CaTcO_3$ and 930 K for $SrTcO_3$ which are in a good agreement with the recent experiments. For $BaTcO_3$ which is not available so far, we predict the fundamental band gap of 0.3 eV and $T_N \approx 1000$ K. In general, an increase in the volume leads to a noticeable enhancement of T_N whereas the presence of vacancies on both the oxygen and Tc sites significantly lowers the critical temperature as well as the magnetic moments of Tc cations.

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Exchange coupled Sm-Co/Fe thin films — •Martin Kopte, Simon Sawatzki, Christine Mickel, Darius Pohl, Alexander Surrey, Bernd Rellinghaus, Ludwig Schultz, and Volker Neu — Institut für Festkörper- und Werkstoffforschung Dresden

We present hard/soft magnetic tri- and fivelayered thin film stacks grown epitaxially by pulsed laser depostion (PLD), where the Fe layers are sandwiched in between highly uniaxial anisotropic Sm-Co layers [1]. With the total thickness of the Sm-Co layers remaining constant the exchange coupling effect in the fivelayered system is enhanced due to the larger number of Sm-Co/Fe interfaces, i.e. the maximum of the energy density product is shifted to larger Fe contents. Microstructural analysis by TEM/EELS confirms the intended film architecture, but also shows rough and diffused Sm-Co/Fe interfaces. The overall behaviour in the reversible part of the demagnetization can be simulated very well by a simple one-dimensional micromagnetic model [2]. The characteristic behaviour of the polarization, nucleation field and energy density product with varying Fe content is reproduced for both tri- and fivelayers. However, the irreversible switching field remains overestimated. An attempt to account for lateral domain processes in the model, which reduce this field, is made by introducing a defect with a pinning potential assigned to that occuring in single $SmCo_5$ layers.

[1] Sawatzki et al., *Journal of Applied Physics* **109**, 123922 (2011)
[2] Kopte et al., *IEEE Trans. Mag.* **47**, 3736 (2011)

MA 33.9 Wed 17:30 EB 202

Probing antiferromagnetism in NiMn/Ni/(Co)Cu$_3$Au(001) single-crystalline epitaxial thin films — •Muhammad Yaqoob Khan, Chii-Bin Wu, and Wolfgang Kuch — Institut für Experimentalphysik, Freie Universität Berlin, 14195 Berlin, Germany

Antiferromagnetism of equi-atomic single-crystalline NiMn thin film alloys grown on Ni/Cu_3Au(001) is probed by means of magneto-optical Kerr effect (MOKE). Thickness-dependent coercivity (H_c) enhancement of NiMn/Ni/Cu_3Au(001) showed that NiMn thicker than 7 atomic monolayers (ML) order antiferromagnetically at room temperature. It is found that NiMn can couple to out-of-plane (OoP) as well as in-plane (IP) magnetized Ni, the latter stabilized by Co underlayer deposition. The antiferromagnetic (AFM) ordering temperature (T_{AFM}) of NiMn coupled to OoP Ni is found to be much higher (up to 110 K difference) than in the IP case, for otherwise identical interfacial conditions. This is attributed to the *magnetic proximity effect* in which the ferromagnetic (FM) layer substantially influences the T_{AFM} of the adjacent AFM layer and can be explained by either (i) a higher interfacial coupling strength or/and (ii) a thermally more stable NiMn spin structure when coupled to Ni magnetized in OoP direction than in IP. An exchange-bias effect could only be observed for the thickest NiMn film studied (35.7 ML); the exchange-bias field (H_{eb}) is higher in the OoP exchange-coupled system than in the IP one due to the same reason/s.

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Spin-structure and spin-reorientation transitions in the CoPd/ IrMn exchange bias system. — •Muhammad Bilal Janjua and Gernot Güntherodt — II. Physikalisches Institut A, RWTH Aachen University, 52074 Aachen, Germany.

In MBE grown polycrystalline Co22Pd78/ Ir25Mn75 thin films with [111] texture, a transition in the exchange bias (EB) is observed at low temperatures, where the in-plane EB field becomes greater than the out-of-plane EB field. Despite the out-of-plane magnetization of CoPd at low temperatures, this behavior of EB is an evidence of the change in the spin structure of the antiferromagnet (AFM) IrMn. It is found that with decreasing temperature there is a spin structure transition in IrMn thin films related to the 3Q to 2Q transition in the bulk [1], which implies a change of the AFM spin structure from an out-of-plane component (3Q) to in-plane component (2Q). This transition is responsible for the increase in the in-plane EB at low temperatures. Besides the 3Q-2Q transition of IrMn, a spin reorientation transition from out-of-plane to in-plane (at higher temperatures) is also observed in the thermoremanent magnetization of Co22Pd78(t nm)/Ir25Mn75(15nm) for different thicknesses t. This effect is due to CoPd, but is too weak to perturb the spin structure transition of IrMn, which dominates the temperature dependence of EB.

[1]. A. Sakuma, K. Fukamichi, K. Sasao and R. Y. Umetsu, Phys. Rev. B 67, 024420 (2003).