MA 26: Exchange Bias

Time: Thursday 15:15–18:30 Location: H10

MA 26.1 Thu 15:15 H10

Anisotropy and interlayer exchange coupling in thin magnetic films: beyond the Landau-Lifshitz evaluation of spin wave spectra — •Stephan Schwieger[1], Jochen Kienert[2], Fritz Körmann[2], and Wolfgang Nolting[2] — [1]Technische Universität Ilmenau, Theoretische Physik I, Postfach 10 05 65, 98684 Ilmenau, Germany — [2]Festkörpertheorie, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

We present a general theory to determine the temperature-dependent magnetic anisotropies and interlayer exchange coupling in thin films from experiments probing collective spin excitations. Unlike the classical evalutation based on the Landau-Lifshitz equations our approach, by using the quantum Heisenberg model, considers self-consistently the effects of thermally activated spin waves. The close correspondence to the Landau-Lifshitz formulas for T→0 is demonstrated and the benefits of the theory for T>0 are worked out.

We show results on the magnetic reorientation transition due to a Cu cap layer in thin Ni films. For thin Ni and Co films we derived the T-dependence of the lattice and shape anisotropies. We finally discuss the evaluation of FMR experiments on exchange coupled Ni/Cu/Co trilayer systems. Here, for the first time, it was possible to separate *quantitatively* the two main sources of the temperature dependence of IEC, namely magnetic excitations and spacer layer effects.

We propose our method as a general tool to properly include finite temperature in the evaluation of anisotropy effects and IEC in experiments yielding spin wave spectra.

MA 26.2 Thu 15:30 H10

Interlayer exchange interaction in local-moment systems: doping-induced switching of the coupling — •Jochen Kienert and Wolfgang Nolting — Festkörpertheorie, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

We present an RKKY study of the interlayer exchange coupling (IEC) between localized magnetic moments for layered structures of finite thickness. Whereas the main focus in the work on IEC has been put on the oscillatory spatial dependence using bulk-like spacers and considering large spacer thickness [1-3], we investigate the influence of reduced dimensionality, small separations of the magnetic layers, and charge carrier density. The interplay between the localized perturbing potential and confinement effects leads to a strong dependence of the interlayer interaction on the charge carrier density/doping. Most drastically, we observe a switching of the IEC tunable by interlayer hopping and band filling, and there is a complete magnetic interlayer decoupling for certain band occupations. The inclusion of correlations beyond perturbation theory in the Kondo lattice (or sd-, sf-, double exchange) model and their consequences for IEC are discussed.The dependence of the interlayer coupling on the charge carrier density is of current interest in diluted magnetic semiconductor heterostructures and in manganite bilayer systems.

[1] P. Bruno, J. Phys.: Condens. Matter **11**, 9403 (1999)
[2] M.D. Stiles, in: *Ultrathin Magnetic Structures III*, Springer 2005
[3] Y. Yafet, Phys. Rev. B. **36**, 3948 (1987)

MA 26.3 Thu 15:45 H10

Multiferroically composed exchange bias systems — •Pavel Borisov, Andreas Hochstrat, and Wolfgang Kleemann — Angewandte Physik, Universität Duisburg-Essen, 47048 Duisburg, Germany

Magnetoelectric (ME) antiferromagnetic Cr_2O_3, being exchange coupled to a ferromagnetic multilayer $(Pt/Co/Pt)_n$, $n \geq 1$, is treated as a multiphase multiferroic material with sophisticated multifunctional properties. It is shown that the exchange bias (EB) of the ferromagnetic hysteresis loop cannot only be controlled by the magnetic freezing field, H_{fr}, but additionally also by an external electric freezing field, E_{fr}, via the ME effect of Cr_2O_3. Apart from the well-known gradual shift on the magnetic field axis also complete switching from $-H_{EB}$ to $+H_{EB}$ is possible [1]. Based on the latter effect novel electrically controlled spintronic applications like ME MRAM (MERAM) and XOR logic cell (MEXOR) devices have been proposed [2]. These require a proper downscaling of the Cr_2O_3 component into the nanometer region. We report on recent progress in the preparation of thin films of chromium oxide and corresponding exchange bias systems. Thickness dependences of structural, magnetic and magnetoelectric properties of Cr_2O_3 thin films are discussed.

[1] P. Borisov *et al.*, Phys. Rev. Lett. **94**, 117203 (2005).
[2] X. Chen *et al.*, Appl. Phys. Lett. **89**, 202508 (2006).

MA 26.4 Thu 16:00 H10

Néel Temperature Shifts Due to Magnetic Proximity Effects in Ni/Fe$_x$Mn$_{1-x}$ Bilayers — •K. Lenz, S. Zander, and W. Kuch — Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

We present a study of the ordering temperature of an ultrathin antiferromagnetic film in the proximity of a ferromagnetic layer. Magneto-optical Kerr effect measurements have been used to monitor the Néel temperature of a single-crystalline antiferromagnetic Fe_xMn_{1-x} film on Cu(001) in contact to a ferromagnetic Ni layer. The Néel temperature was determined from the discontinuity in the coercivity as a function of temperature. This ordering temperature decreases by up to 60 K if the magnetization axis of the ferromagnet is switched from out-of-plane to in-plane by deposition of a Co overlayer. As the application of the Co overlayer does not alter the antiferromagnet/ferromagnet interface, these results give clear evidence for a magnetic proximity effect in which the coupling to the ferromagnetic layer substantially influences the ordering temperature of the antiferromagnetic layer.

MA 26.5 Thu 16:15 H10

Orthogonal exchange bias directions in FeMn/NiFe microstructures — •Patrizio Candeloro[1], Georg Wolf[1], Stefan Trellenkamp[2], Christian Dautermann[2], Sandra Wolff[2], Helmut Schultheiss[1], Hans Nembach[1,3], and Burkard Hillebrands[1] — [1]FB Physik and Forschungsschwerpunkt MINAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Nano+Bio Center, TU Kaiserslautern, 67663 Kaiserslautern, Germany — [3]NIST, Boulder, Colorado 80305

The exchange bias effect, arising in ferromagnetic(F)/ antiferromagnetic(AF) bilayers, can be described as an additional unidirectional anisotropy in the F layer. Recently several works have investigated the interplay between unidirectional and uniaxial anisotropies [1,2].

In this work we explore the interplay between exchange bias and twofold shape anisotropy. For this purpose, L-shaped and cross shaped FeMn/NiFe microstructures are fabricated by means of lithographic techniques. Exploiting the shape anisotropy, two orthogonal exchange bias directions are initialized inside the same microstructure via a zero-field cooling technique. MOKE measurements confirm the presence of two biasing directions, parallel to the arms of the structures. Furthermore an unusual angular dependence of the bias field and coercivity is observed, due to the interplay between the twofold unidirectional and shape anisotropies.

Financial support by the EU-RTN NEXBIAS is acknowledged.

[1] S. H. Chung et al., Phys. Rev. B 71 (2005) 214430
[2] S. Brück et al., Adv. Mater. 17 (2005) 2978

MA 26.6 Thu 16:30 H10

Analysis of effective magnetic anisotropies in exchange-coupled bilayer systems — •Daniel Markó[1,2], Jeffrey McCord[2], Rudolf Schäfer[2], Rainer Kaltofen[2], and Ludwig Schultz[2] — [1]Forschungszentrum Dresden-Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, Bautzner Landstr. 128, D-01328 Dresden — [2]Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden, Helmholtzstraße 20, D-01069 Dresden

We have investigated the effective magnetic anisotropies in FM/AFM exchange-coupled $Ni_{81}Fe_{19}/Ir_{19}Mn_{81}$ bilayers with constant FM and varying AFM layer thickness. The samples have been prepared by either RF or DC magnetron sputtering to study the effect of different AFM grain sizes. In addition, the influence of thermally activated processes in the AFM layer has been investigated by annealing the samples with varying temperature, durations, and cooling rates. By using two magnetometric methods with different experimental time scales, a separation of different anisotropy contributions was possible. Quasistatic measurements yield the coercivity H_C and the exchange-bias field $H_{eb,ea}$. From the dynamic experiment the exchange-bias field $H_{eb,dyn}$, the rotatable anisotropy H_{rot}, the ferromagnetic resonance frequency f_{res}, and the effective magnetic damping parameter α were determined. Moreover, magnetization processes have been observed by means of Kerr microscopy. Our experimental results were compared with models for exchange-bias and are in agreement with the models of Malozemoff, Fulcomer and Charap, and McMichael and Stiles.

MA 26.7 Thu 16:45 H10

X-ray magnetic circular dichroism and X-ray resonant magnetic scattering investigations of IrMn/NiFe exchange bias bilayer — •Florin Radu, Shrawan Mishra, Detlef Schmitz, Enrico Schierle, Hermann Dürr, and Wolfgang Eberhardt — BESSY GmbH, Albert-Einstein Strasse 15, D-12489,

We have employed Soft X-ray Magnetic Circular Dichroism(XMCD) and Soft X-ray Resonant Magnetic Scattering (XRMS) to study the magnetic interface of an antiferromagnet/ferromagnet (AF/F) exchange bias Si(100)/SiO_2/Cu(5 nm)/$Ni_{81}Fe_{19}$(7.5 nm)/$Ir_{20}Mn_{80}$(2.5 nm)/Cu(2.5 nm) bilayer. The XMCD curves for the AF layer measured at the Mn L3 and L2 edges show a non-vanishing weak signal. In the positive magnetic saturation the Mn XMCD signal is different in magnitude and shape with respect to the one measured in the negative magnetic saturation. By comparison, the XMCD signals measured at the Ni L2 and L3 edges are equal for both magnetization orientations. This suggests that two types of uncompensated AF spins behave differently upon magnetization reversal. The frozen-in AF spins do not change sign upon magnetization reversal whereas the rotatable AF spins do follow the rotation of the F spins. Element specific reflectivity curves measured at the Mn L3 edge with circular polarized light for both helicities exhibits a deviation at the minima of the reflectivity curves. This might indicate that the uncompensated AF spins are localized at the F/AF interface. The depth profile can be retrieved after numerical analysis which is under consideration.

MA 26.8 Thu 17:00 H10

Ultrathin planar domain-wall in NiO/Fe_3O_4(110) — •Ingo Peter Krug[1], Franz Ulrich Hillebrecht[1], Helen Gomonaj[2], and Claus M. Schneider[1] — [1]Institut für Festkörperforschung IFF-9 "Elektronische Eigenschaften", Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Bogolyubov Institute for Theoretical Physics NAS of Ukraine, st.Metrologichna, 14-b, 03143, Kiev, Ukraine

Despite numerous experimental and theoretical studies, the details of exchange-mediated interface coupling and their consequences for technologically relevant effects like exchange bias are still not sufficiently understood. The work presented here is aimed at clarifying the magnetic proximity effect in both a ferrimagnetic (Fe_3O_4) and antiferromagnetic material (NiO), when brought into contact. The magnetic structure at the interface is altered by the interfacial exchange interaction, leading to an ultrathin planar domain-wall (3-4 ML) in the antiferromagnet as well as a small spin-reorientation in the ferrimagnet, as was observed by PEEM measurements using soft x-rays. The antiferromagnet couples spin-flop to the ferrimagnet, as is expected for the compensated (110) interface. These results are well described by a theoretical model based on continuum theory, also yielding an estimation of the interfacial superexchange coupling, which is in the order of 10 meV, close to the value in bulk NiO.

MA 26.9 Thu 17:15 H10

Magnetic depth profiling of an exchange bias system: x-ray resonant magnetic reflectivity of FeMn/Co. — •Sebastian Brück, Valeriano Ferreras-Paz, Eberhard Goering, and Gisela Schütz — Max-Planck-Institut für Metallforschung, Heisenbergstraße 3, D-70569 Stuttgart

X-ray Resonant Magnetic Reflectivity (XRMR) extends reflectivity by the x-ray magnetic circular dichroism as additional contrast thus providing element selective magnetic depth information. This makes it a perfect tool to investigate magnetic coupling effects in multi-layered systems. Such systems are for example ferromagnet-antiferromagnet bilayers which can show an exchange coupling between the two layers, the so called exchange bias effect. We present results on Co/FeMn bilayers which have been investigated by XRMR at the BESSY II synchrotron, Berlin. The bilayers were prepared by molecular beam epitaxy on a Cu (100) single crystal which ensures epitaxial growth of both FeMn (in the antiferromagnetic phase) and Co. The magnetic depth profile for room temperature and for 120 K is investigated with respect to changes of the exchange coupling.

MA 26.10 Thu 17:30 H10

Tuning exchange bias in thin Fe/CoO bilayers by introducing a Cr dusting layer — •Yuriy Yanson[1], Florin Radu[2], Kurt Westerholt[1], and Hartmut Zabel[1] — [1]Department of Physics, Ruhr-University Bochum, D-44780 Bochum, Germany — [2]BESSY GmbH, Albert-Einstein-Str. 15, 12489 Berlin, Germany

We investigated the change of the hysteresis loop shift and the coercive field of exchange biased Fe/CoO bilayers as a function of the Cr dusting layer thickness at the interface. Cr layers were grown at room temperature to ensure layer-by-layer growth. Magnetic properties of the system were measured using MOKE and SQUID. Above the Cr-thickness of one monolayer the coercive field and the exchange bias field decay exponentially as expected from the distance dependence of the exchange interaction. For submonolayer Cr-thickness, however, significant deviations of the behavior of the coercive field and the exchange bias field were observed. For that thickness range coercivity decays much more rapidly than the exchange bias field. This suggests that Cr atoms prefer to cover defect locations on the CoO surface and neutralize them. These defects are responsible for domain wall pinning and determine the coercivity. We show that by choosing certain growth temperatures and Cr dusting layer thicknesses one can tune the magnetic properties of the exchange biased system by setting the coercive field and the exchange bias field independently.

MA 26.11 Thu 17:45 H10

Effects of nonmagnetic dilutions in metallic antiferromagnets on exchange bias — •Marian Fecioru-Morariu[1], Syed Rizwan Ali[1], Cristian Papusoi[2], Martin Sperlich[1], and Gernot Güntherodt[1] — [1]Physikalisches Institut (IIA), RWTH Aachen, 52056 Aachen, Germany — [2]SPINTEC, CEA/CNRS, 38054 Grenoble Cedex 9, France

The effects of dilution of metallic antiferromagnets by nonmagnetic elements on the exchange bias are investigated in bilayers of $Co_{70}Fe_{30}/(Ir_{22}Mn_{78})_{1-x}Cu_x$ from a structural, magnetic and Monte Carlo simulation point of view. The nonmagnetic dilution by Cu throughout the volume of the antiferromagnet (AFM) $Ir_{22}Mn_{78}$ gives rise to an enhanced exchange bias field (H_{EB}). At the same time, lattice matched Cu dilutions give rise to a reduction of the AFM grain size and hence of the blocking temperature (T_B). The enhancement and maximum of H_{EB} as a function of Cu dilution is found to result from the competition of the increased number of uncompensated AFM moments and the reduction of T_B. The thermoremanent magnetization (M_{TRM}) of the diluted AFM-only, is also enhanced and decreases with increasing temperature in qualitative agreement with H_{EB}. This indicates the underlying close connection between H_{EB} of the FM/AFM bilayer and M_{TRM} of the AFM only. Our experimental results are in very good agreement with Monte Carlo simulations based on a Heisenberg model. The financial support through the EU Research Training Network NEXBIAS (Contract No. HPRN-CT-2002-00296) is gratefully acknowledged.

MA 26.12 Thu 18:00 H10

Magnetic order in exchange bias patterns in a continuous film — •Katharina Theis-Bröhl[1], Boris Toperverg[1], Ulrich Rücker[2], Jeffrey McCord[3], Andreas Westphalen[1], Volker Höink[4], Jan Schmalhorst[4], Tanja Weis[5], Dieter Engel[5], Arno Ehresmann[5], Maximilian Wolff[1], and Hartmut Zabel[1] — [1]Ruhr-University, 44780 Bochum — [2]Forschungszentrum, 52425 Jülich — [3]Leibniz Institute for Solid State and Materials Research, 01169 Dresden — [4]University of Bielefeld, 33615 Bielefeld — [5]University of Kassel, 34132 Kassel

Understanding and controlling competing exchange bias (EB) and exchange coupling effects is an important issue in the design of advanced AF-coupled hard disks with increasing storage density. For this purpose we used magnetic patterning by ion bombardment and designed a model system of alternating EB stripes. This creates an alternating frozen-in interfacial EB field competing with the external field in the course of re-magnetization. It was found that at magnetic fields applied along and at an angle with respect to the EB axis parallel to stripes the re-magnetization processes goes through a variety of different stages. Each of those magnetic states is quantitatively characterized via the comprehensive analysis of data on specular and off-specular polarized neutron reflectivity. The results are interpreted within the phenomenological model containing a few parameters which can readily be controlled designing systems with desired configuration of magnetic moments of micro- and nano-elements.

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MA 26.13 Thu 18:15 H10

Size dependent scaling of perpendicular exchange bias in nanostructures — •Ildico Guhr[1], Olav Hellwig[2], Gregory Malinowski[3], Sebastiaan van Dijken[3], and Manfred Albrecht[1] — [1]University of Konstanz, Dept. of Physics, Konstanz, Germany — [2]Hitachi San Jose Research Center, HGST, USA — [3]SFI Trinity Nanoscience Laboratory, Trinity College, Dublin, Ireland

A magnetic nanopattern created by depositing Co/Pd or Co/Pt multilayers onto 2D arrays of self-assembled nanoparticles [1] will be introduced. The magnetic nanostructures formed on top of the particles are in a magnetically exchange-isolated quasi-single-domain state. This nanoscale system is quite distinct from the classical geometries. Here the deposited film is extended over a wide region of the sphere and thus shows substantial curvature. The film thickness varies and so do the intrinsic magnetic properties most notable the magneto-crystalline anisotropy [2]. This magnetic nanopattern is used to study the size-dependent scaling of exchange bias in nanostructures. [Pd/Co]-CoO and [Pt/Co]-IrMn layers with perpendicular magnetic anisotropy were deposited onto different arrays of monodisperse PS nanospheres with a diameter ranging from 58 to 320 nm. Below the blocking temperature we find for both systems a strong increase of the exchange bias field compared to continuous films. Interestingly, the exchange bias field increases drastically with decreasing particle size and shows a strong dependence on the applied cooling fields and training.

[1] M. Albrecht et al., Nature Material 4, (2005) 203.
[2] T. Ulbrich et al., Phys. Rev. Lett. 96, (2006) 077202.