



9th JEMS Conference 2018

Joint European Magnetic Symposia

3rd – 7th September 2018 • Mainz • Germany

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 1

SP5 - Parallel Session 1

SP5.1.02

Tuning spin spirals via surface reconstruction in 2Fe/Ir(111)

M. Dupé, N. Hauptmann, A. A. Khajetoorians, S. Heinze, J. Sinova, B. Dupé

Text The next generation of high-density and low-energy data storage devices will require novel materials and phenomena, such as skyrmions in thin films.

Skyrmions are chiral non-collinear magnetic textures that occur at surfaces and interfaces and are stabilized by the Dzyaloshinskii-Moryia interaction (DMI). The Fe/Ir interface is an ideal playground to study skyrmions since Fe/Ir(111) exhibits a nanoskyrmion lattice [1] and isolated skyrmions can be manipulated via spin transfer torque in Pd/Fe/Ir(111) [2,3] and electric field in 3Fe/Ir(111) [4].

Here, we investigate the interplay between the surface structure and the magnetic properties of 2Fe/Ir(111) using first-principles calculations based on DFT and atomistic model calculations. We show that if a second Fe monolayer is deposited on Fe/Ir(111), the stacking changes from fcc to bcc(110)-like. This reconstruction results in a complex superstructure, which is characterised by reconstruction lines and hosts a spin spiral [5]. Based on our findings, we envision that surface reconstructions can be used to engineer the symmetry of the DMI in multilayers. The resulting DMI symmetry may stabilize higher-order skyrmions or antiskyrmions [6].

[1] S. Heinze et al., Nature Phys. (2011).

[2] N. Romming et al., Science (2013).

[3] B. Dupé et al., Nature Comm. 5, 4030 (2014).

[4] P.-J. Hsu et al. Nature Nanotechnology 12, 123 (2016).

[5] N. Hauptmann et al., Phys. Rev. B 97, 100410(R) (2018).

[6] M. Hoffmann et al., Nature Comm. 8, 308 (2017).



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 1

SP5.1.03

Tuning Exchange and Dzyaloshinskii-Moriya interactions of ultrathin Co films on Ir(111)

S. Meyer, S. von Malottki, S. Haldar, S. Heinze

Text Non-collinear spin structures such as chiral domain walls and skyrmions are being intensively studied since they are promising for spintronic applications [1]. Skyrmions have been experimentally observed in ultrathin transition-metal films on surfaces, such as in Pd/Fe/Ir(111) [2] and more recently in Co/Ru(0001) [3]. Skyrmion formation in these systems has been explained based on first-principles calculations [3,4] using density functional theory (DFT).

Here we demonstrate how to tune the magnetic interactions in Co monolayers on the Ir(111) surface by 4d transition-metal overlayers. We perform DFT calculations using the full-potential linearized augmented plane wave method as implemented in the FLEUR code (www.flapw.de). For overlayers of Tc, Ru, Rh, and Pd on Co/Ir(111) we calculate the energy dispersion of spin spirals with and without spin-orbit coupling as well as the magnetocrystalline anisotropy energy. Based on these DFT calculations we parametrize an atomistic spin model which we numerically solve using spin dynamics simulations. While the Dzyaloshinskii-Moriya interaction is reduced in 4d/Co/Ir(111) with respect to Co/Ir(111), we find that the exchange frustration can be tuned by the overlayers. This leads to systems promising for skyrmion formation.

- [1] Fert A., Cros V., Sampaio J., Nature Nano. **8**, 152 (2013)
- [2] Romming, N., *et al.*, Science **341**, 636 (2013)
- [3] Hervé, M., *et al.*, Nature Comm. **9**, 1015 (2018)
- [4] Dupé, B. *et al.*, Nature Comm. **5**, 4030 (2014)



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 1

SP5.1.04

Asymmetric and symmetric exchange in a generalized 2D Rashba ferromagnet

M. Titov

Text We derive general finite temperature expressions for Dzyaloshinskii-Moriya interaction (DMI) and symmetric exchange in a 2D s-d ferromagnet model with momentum-dependent spin-orbit coupling (SOC) of Rashba type and arbitrary (generally non-parabolic) kinetic energy of itinerant electrons. We show that in commonly used parabolic model with Rashba SOC both DMI and exchange stiffness vanish identically in the metal regime, i.e. when two spin-split sub-bands are occupied. Both quantities are, however, finite and opposite in sign if non-parabolic corrections to kinetic energy are taken into account. We demonstrate that the commonly assumed symmetry of DMI and exchange stiffness in the form of Lipshitz invariants is valid only to the leading order with respect to SOC strength. In the opposite limit of strong SOC the DMI is also characterized by a simple symmetry invariant which is, however, notably different from that in the weak SOC. Our results suggest that the size and chirality of magnetic textures can be efficiently controlled by gate voltage in 2D FM systems with strongly non-parabolic kinetic energy of itinerant electrons.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 1

SP5.1.05

Artificial all-amorphous magnetic superstructures

G. Muscas, R. Brucas, P. Jönsson

Text Composites and superstructures represent an effective way to create new materials with improved properties. The success of such approach depends on the integration among the components and the quality of the interfaces. Interfaces strongly influence magnetic properties but are difficult to control. We deal with this problem realizing a fully amorphous system to avoid the defects of crystalline interfaces. We have selected $\text{Fe}_{89}\text{Zr}_{11}$ as a model amorphous material and we have modulated its magnetic properties by locally tuning the chemical composition by means of boron ion implantation through a mask, without inducing crystallization or any other major structural modification, obtaining amorphous $\text{Fe}_{80}\text{Zr}_{10}\text{B}_{10}$ elements in regular patterns fully embedded in the original amorphous matrix. The investigation of 20 μm ferromagnetic discs embedded in a paramagnetic matrix by MOKE microscopy reveals a vortex as the ground state configuration, suggesting an extremely low concentration of defects acting as pinning center for the magnetization reversal. When also the matrix is in a ferromagnetic state, the magnetic coupling between the two phases can extend over the micrometer-scale thanks to the structurally smooth transition between FeZrB and FeZr. This has been investigated by means of first-order reversal curves, which showed a single reversal of the two-phase sample. Our results open new perspectives for magnetic all-amorphous nano- and microstructures with tunable properties.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 1

SP5.1.06

Magnetic ground states of perfect Py nanotubes and rings

E. Josten, A. Kovács, F. Oertel, A. Glavic, T. Jansen, A. Kákay, T. Wessels, M. Langer, J. Raabe, D. E. Bürgler, K. Höflich, R. E. Dunin-Borkowski

Text Magnetic nanotubes (MNTs) and their ensembles exhibit unique physical properties, in particular magnetic, due to their size, aspect ratio and hollow structure. It is important to optimize the magnetic ground states of such MNTs and to control the magnetic domain walls for their successful implementation in novel devices. Recently, the synthesis of MNTs with perfectly circular cross-sections was achieved. Such MNTs are expected to support different magnetic states from those in hexagonal nanotubes, which were investigated previously. The circular MNTs were fabricated by coating a carbon core template with a magnetron-sputtered permalloy (Py) shell. We focus on the characterization of magnetic states in individual Py nanotubes and their cross-sections, which take the form of magnetic rings (MRs). The MRs were prepared by slicing individual MNTs using focused ion beam milling. Off-axis electron holography (EH) performed in a transmission electron microscope reveals the presence of magnetic vortex states and was used to study switching processes in MRs, while the magnetic states of full-sized MNTs were investigated using both EH and scanning transmission X-ray microscopy. Experimental results will be compared by finite element micromagnetic simulations. This work was supported by European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ ERC grant agreement number 320832. A.Ká. acknowledge J.Lindern and J.Faßbender for their support.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 1

SP5.1.07

Anatomy of magnetic proximity effects in platinum inferred by magnetotransport measurements

C. O. Avci, E. Rosenberg, J. Mendil, L. Beran, P. Gambardella, C. A. Ross, G. S. D. Beach

Text A nonmagnetic heavy metal can substantially influence magnetic anisotropy, exchange interactions, and spin-transport in an adjacent magnetic thin film. In such systems, magnetic order in the ferromagnet can also induce a proximate magnetic moment in the heavy metal. Although the magnetic proximity effect (MPE) has been speculated to play an important role in these phenomena, a clear understanding of its origin, extent, and impact on magnetotransport is still lacking in such systems. Here we show that ferrimagnetic insulating iron garnet films can induce ferromagnetism in Pt over a length scale extending nearly 1 nm from the interface at low temperature. We show that the MPE in Pt/magnetic-insulator (MI) bilayers derives mainly from interactions with the magnetic transition metal ions and results in strong ferromagnetic coupling to the transition metal sublattice. We disentangle the contributions of spin-transport across the MI/Pt interface, and spin scattering within the heavy metal, to the complex magnetotransport behaviors such as spin Hall magnetoresistance, resolving an issue of much recent debate. Moreover, our results highlight new opportunities to exploit magnetic interactions at interfaces to detect and control magnetism in low-dissipation insulating spintronic devices.



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SP5 - Parallel Session 2

SP5 - Parallel Session 2

SP5.2.01

Magnetism of 4f-atoms adsorbed on metal and Graphene substrates

A. Shick

Text Surface supported single magnetic atoms, the so-called "single-atom magnets", open new opportunities in a quest for the ultimate size limit of magnetic information storage.

Initially, the research mainly focused on 3d-atoms on surfaces. Recently, the attention was turned to the 4f-atoms, culminating in the experimental discovery of magnetically stable Ho atom on MgO(001) substrate, and Dy atom on graphene/Ir(111).

We address the electronic and magnetic character of 4f-atoms on metal and Graphene substrate making use of a combination of the DFT with the exact diagonalization of Anderson impurity model DFT+U+ED. The spin and orbital magnetic moments of Dy@Ir(111) and Dy/Graphene/Ir(111) are evaluated and compared with experimental XMCD data. The magnetic anisotropy energy is estimated, and the magnetic stability is discussed. The role of 5d-4f interorbital exchange polarization in modification of the 4f-shell energy spectrum is emphasized.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 2

SP5.2.02

FePt-Tb alloy thin films designed for all-optical switching

N. Safonova, F. Radu, E. Goering, M. Albrecht

Text Ultra-fast magnetization reversal processes induced by fs laser pulses was observed in ferrimagnetic TbFe alloy thin films [1] and partially in hard magnetic FePt granular films [2]. Therefore, magnetic materials designed for ultrafast all-optical switching of magnetization are of high interest. Two series of (FePt)(1-x)Tb(x), where $x = 5-28$ at.%, ternary alloy films with a thickness of 10 nm were sputter deposited on MgO(100) substrates at 530°C (series I) and 700-770°C (series II). Series I reveal limited L10 chemical ordering with an in-plane easy axis at room temperature. It is suggested that Tb is initially located as an interstitial atom in the FePt lattice, but with higher Tb content of 11 at % it its local environment gets amorphous. At low temperatures a spin reorientation transition, indicated by the appearance of strong perpendicular magnetic anisotropy (PMA), was observed. Higher deposition temperatures of 700-770°C (series II) promote L10 chemical ordering with (001) orientation and strong PMA (12 Merg/cc at RT). However, with addition of Tb up to 6 at.%, PMA, saturation magnetization as well as coercivity get strongly reduced and further Tb addition leads to the formation of other crystalline phases. The spin and orbital moments of Fe and Tb were extracted from XMCD studies revealing rather small values in these alloys.

[1] A. Hassdenteufel et al., Phys. Rev. B 91, 104431 (2015).

[2] C.-H. Lambert et al., Science 345, 1337 (2014).



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 2

SP5.2.03

Perpendicular anisotropy, unconventional spin texture and extraordinary gradual spin reorientation transition of cobalt films in contact with graphene

J. Coraux, A. D. Vu, G. Chen, A. N'Diaye, A. Schmid, N. Rougemaille

Text Owing to its peculiar electronic band structure, high carrier mobility and long spin diffusion length, graphene is a promising two-dimensional material for microelectronics and spintronics. While recent results illustrate the potential advantages of integrating graphene within a magnetic stack, the influence of graphene on the magnetic properties of a ferromagnetic metal is still largely unexplored.

Using spin-polarized low-energy electron microscopy [1], we study how a graphene overlayer affects the magnetic properties of atomically flat, nm-thick Co films grown on Ir(111). In this contribution, we report several astonishing magnetic properties of graphene-covered Co films [2, 3]:

- 1) Perpendicular magnetic anisotropy is favored over an unusually large thickness range,
- 2) Vectorial magnetic imaging reveals an extraordinarily gradual thickness-dependent spin reorientation transition (SRT),
- 3) During the SRT, cobalt films are characterized by an unconventional spin texture,
- 4) Spectroscopy measurements indicate that incident spin-polarized electrons do not suffer substantial spin-dependent collisions a few electron-Volts above the vacuum level.

These properties strikingly differ from those of pristine cobalt films and could open new prospects in surface magnetism and spintronics.

[1] N. Rougemaille and A. K. Schmid, *Eur. Phys. J.: Appl. Phys.* 50, 20101 (2010)

[2] A. D. Vu et al., *Sci. Rep.* 6, 24783 (2016)

[3] H. Yang, A. D. Vu et al., *Nano Lett.* 16, 145 (2016)



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SP5 - Parallel Session 2

SP5.2.04

Interface coupling between 3d-La_{0.67}Sr_{0.33}MnO₃ and 5d-SrIrO₃

L. Bergmann, D. Rata, P. Düring, K. Dörr

Text Iridate compounds are of high scientific interest, since they show emergent phenomena due to competition between the relevant energy scales of electron correlation, bandwidth and, most importantly, strong spin-orbit coupling. We investigate how the interface coupling between 3d-La_{0.67}Sr_{0.33}MnO₃ (LSMO) and 5d-SrIrO₃ (SIO) alters the magnetic properties such as magnetic order and anisotropy of LSMO which is a bulk collinear ferromagnet with high spin polarization.

High-quality superlattices and bilayers of LSMO and SIO were coherently grown with systematically varied layer thicknesses by pulsed laser deposition on TiO₂ terminated (100) SrTiO₃ substrate. The structure characterization was done by XRD. The magnetic and electrical properties were investigated by SQUID and transport measurements. Bilayers of reversed growth sequence show strongly different magnetic properties. The atomic interfacial structure with regard of the chemical termination and the collective rotations of oxygen octahedrons is considered as responsible for the appearance of such different types of interfacial magnetism. Depending on layer thickness and sample type, the saturated magnetic moment and the Curie temperature of LSMO is strongly suppressed. The loss of collinear ferromagnetic order is associated with insulating behavior. Our results suggest the occurrence of non-collinear Mn spin textures at the LSMO/SIO interfaces.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 2

SP5.2.05

Tuning the magnetic anisotropy in exchange coupled bimagnetic core/shell nanoparticles

F. Fabris, G. Lavorato, E. Lima Jr., C. Quinteros, L. Neñer, M. Granada, M. Sirena, R. Zysler, H. Troiani, V. Leborán, F. Rivadulla, E. Winkler

Text The advance in the fabrication methods allows the design and production of new nanostructures with tailored properties. In particular, the combination of proper materials in a single nanoparticle with a core/shell structure, and the possibility to form large areas of self-assembled membrane, opens a wide range of possibilities to control the magnetoelectric response of these nanostructures. One of the characteristic that determines the range of application of each system is the magnetic anisotropy, which can be tuned by the interface exchange coupling in bimagnetic nanoparticles (NPs). In this work we present the evolution of the magnetic anisotropy of exchange coupled core/shell systems as a function of the shell composition. We studied two systems, one formed by an AFM CoO core and the other one is formed by FiM half-metallic Fe₃O₄ core, both encapsulated with a Co_{1-x}Zn_xFe₂O₄ ($x = 0-1$) shell. The results show that the effective magnetic anisotropy of core/shell NPs can be precisely tuned by replacing the Co²⁺ with Zn²⁺ ions in the shell. Large area of Fe₃O₄/Co_{1-x}Zn_xFe₂O₄ self-assembled NPs was then produced to develop tunnel magnetoresistance devices. We found that the magnetoresistance curves are related to the field dependence of the magnetization, where the magnetoresistance switching field is correlated to the coercivity field of the systems. These results are very promising for designing novel devices with tuned magnetoelectric properties based in core/shell NPs.



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SP5 - Parallel Session 2

SP5.2.06

Pt/Co/W as a Candidate for Low Power Nanomagnetic Logic

S. Mendisch, G. Žiemys, V. Ahrens, M. Becherer

Text Perpendicular Nanomagnetic logic (pNML) is listed as a promising beyond CMOS candidate in the ITRS 2015. PNML thereby utilizes the anti-parallel stray field coupling of adjacent nano-magnets to achieve complex logic operations [1]. Pt/Co/Heavy-Metal multilayer have attracted much attention in the last years due to strong net Dzyaloshinskii-Moriya interactions. Recently we reported performance gains in Pt/Co/Ir multilayer with domain wall velocities up to 3 times higher compared to conventional Co/Pt [2]. In this work, we investigated the Pt/Co/W trilayers system for the use as base for pNML building blocks. We optimized the layer composition for maximum magnetic moment while preserving PMA, ferromagnetic exchange coupling, as well as single domain behavior for micrometer structures. Experimental results show that tungsten enables significantly higher cobalt thicknesses for stacks with higher number of repetitions, even surpassing the best results for Co/Pt/Ir by a significant margin (up to 7x [Pt1.4/Co1.62/W0.9] compared to 5x [Pt1.0/Co0.8]). This is combined with significantly reduced nucleation fields of less than 20 mT for coupling sub-micrometer pNML structures, thus more than halving earlier results with Pt/Co or Pt/Co/Ir. This opens the prospect for low-power on-chip clocking of pNML circuits as assessed in [3].

[1] Breitzkreutz et al. IEEE Transactions on Magnetics 49.7 2013

[2] Ziemys et al. AIP Advances 8.5 2018

[3] Becherer et al. Solid-State Electronics 102 2014



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 2

SP5.2.07

Engineering nanoscale defects in $\text{Sr}_2\text{FeMoO}_6$ thin films

M. Saloaro, I. Angervo, H. Huhtinen, P. Paturi

Text Earlier investigations have revealed that nanoscale defects can be used to modify and improve the magnetic properties of magnetoresistive $\text{Sr}_2\text{FeMoO}_6$ (SFMO), which possesses high spintronic application potential. In order to actualize this high potential by reaching the best possible magnetic and electrical properties, a route to engineer the nanoscale defects in a controlled way is needed. Therefore, we have investigated the effect of post-annealing in pulsed laser deposited SFMO films. The X-ray diffraction, positron annihilation spectroscopy and hard X-ray photoelectron spectroscopy studies confirmed that we have been able to affect the amount of nanoscale defects in SFMO films and that way modify the magnetic properties by *in situ* and *ex situ* annealing treatments. For example, we observed that the amount of oxygen vacancies is increased by *in situ* and *ex situ* vacuum annealing and that the amount of anti-site disorder is reduced by increasing the *in situ* annealing temperature and pressure. In addition, our previous experimental and theoretical studies have shown that the increasing amount of oxygen vacancies increases the Curie temperature of SFMO without diminishing the half metallicity and the increasing amount of anti-site disorder decreases Curie temperature and reduces the spin polarization. Hence, we have found a preliminary route to engineer nanoscale defects in SFMO thin films, which will allow us to improve the films towards spintronic applications.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 2

SP5.2.08

Field Dependence of the Ferromagnetic/Superconducting Proximity Effect in a YBCO/STO/LCMO Multilayer

F. Klose, O. Paull, A. Pan, G. Causer

Text The interaction between superconductivity and magnetism in spatially confined heterostructures of thin film multilayers is investigated in the ferromagnetic manganite $\text{La}_{2/3}\text{Ca}_{1/3}\text{MnO}_3$ (LCMO) and the high-temperature superconductor $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ (YBCO) mediated by an intermediate insulating SrTiO_3 (STO) layer.

The STO layer is used to mediate and tune the range of interactions between the ferromagnet and the superconductor. A magnetically depleted layer with zero magnetisation within the LCMO layer is shown by polarised neutron reflectometry measurements. This zero-magnetisation layer is caused by the onset of superconductivity in YBCO despite being separated by an insulating layer with a thickness much larger than the superconducting coherence length. The magnetic field dependence of this interaction is also explored. We show that the magnetism of the depleted layer can be restored by applying a magnetic field that partially destroys the superconductivity in YBCO, restricting the electronic interaction between the materials.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5 - Parallel Session 3

SP5.3.01

Modification of Spin-Orbit Torques by Interfacial Oxygen

J. Nath, A. V. Trifu, S. Auffret, I. Joumard, G. Gaudin, I. M. Miron

Text In Spin-Orbit Torque-Magnetic Random Access Memories (SOT-MRAM), a current injected into a heavy metal (HM) layer with high Spin Orbit Coupling (SOC) gives rise to torques that act on the magnetization of an adjacent Ferro-Magnetic (FM) layer. These torques, namely the Damping-Like (DL), switches the magnetization during the write operation of the memory cell [1-2]. Here, we present the enhancement of these DL torques by oxygen implantation of the FM/HM interface in Ta/Cu/Co/Pt heterostructures. Interfacial oxygen at cobalt - metal oxide interfaces is known to give rise to Perpendicular Magnetic Anisotropy (PMA) due to the increased asymmetric band splitting of the Co 3d bands [3]. However its effect on SOTs is only starting to be explored experimentally [4-6]. By controlling the amount of oxygen at the interface by means of varying the top Pt thickness, we show that, when the amount of interfacial oxygen crosses a certain threshold, there is a sharp increase in torques. Such an enhancement of torques, with the corresponding increase in the PMA, could lead to SOT-MRAMs with higher energy efficiency and longer retention times.

[1] Miron, I. M. et al., Nature 476, 189, 2011

[2] Liu, L. et al., Science 336, 555, 2012

[3] Monso, S. et al., Applied Physics Letters 80, 4157, 2002

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[5] An, H. et al., Nature Communications 7, 13069, 2016

[6] Qui, X. et al., Nature Nanotechnology 10, 333, 2015



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.02

Tailoring the in-plane magnetic anisotropy at the Fe(110) surface

M. Ślęzak, T. Ślęzak, P. Drózdź, K. Matlak, A. Kozioł-Rachwał, J. Korecki

Text We have recently reported on huge in-plane magnetic anisotropy (MA) in epitaxial bcc Co/Fe(110) bilayers [PRB 94 (2016) 014402] and indicated the possibility for precise MA tuning by minor changes of Co overlayer thickness.

In the present contribution we will discuss our MOKE studies of MA at the Fe(110) surface covered with various magnetic and nonmagnetic overlayers, including Au, Co/Au bilayers, Co/Fe superlattices and CoO(111) films. Here we briefly summarize two of the above mentioned examples.

In a commonly accepted picture of the AFM/FM system, the AFM, considered as rigid due to its high anisotropy and magnetic hardness, controls the magnetic properties of the FM. We show that this AFM-FM master-slave hierarchy is not generally valid, and that the influence of the FM to the MA of neighboring AFM must be considered. Our computer simulations and MOKE studies of EB in epitaxial CoO(111)/Fe(110) bilayer show that the FM layer with strong uniaxial magnetic anisotropy decides on the interfacial spin orientations of the neighboring AFM layer and rotates their easy axis.

Bcc Co/Fe superlattices (SLs) grown at the Fe(110) provide another efficient method to tailor the in-plane MA. We show that the in-plane MA of Co/Fe SL can be drastically modified by the adsorption of residual gases or CO. We find that only in Co terminated SLs MA is sensitive to adsorption effects while in the Fe terminated SLs it remains almost unchanged.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.03

Graphene-based synthetic antiferromagnets and ferrimagnets with perpendicular magnetic anisotropy

P. Gargiani, L. Melo, H. B. Vasili, R. Cuadrado, M. Pruneda, P. Perna, J. Camarero, F. Sanchez, M. Valvidares

Text Graphene-spaced magnetic systems provide the opportunity to combine the unique electronic and mechanical properties of graphene with ferromagnetic layers for the development of graphene-based spintronic applications. The epitaxial growth of graphene together with the intercalation of magnetic-material layers, *Coraux, J. et al. J. Phys. Chem. Lett. 3, 2059–2063 (2012)*. allow the realization of layered graphene-spaced magnetic heterostructures with well-defined interfaces and with tunable magnetic properties. Here we report on the realization of graphene-based synthetic antiferromagnets (SAF) and ferrimagnets (SFIM) Fe/graphene/Co layered systems with strong PMA, robust antiferromagnetic coupling above room temperature and tunable magnetic properties depending on layer thicknesses. *Gargiani, P., Cuadrado, R., Vasili, H. B., Pruneda, M. & Valvidares, M. Nat. Commun. 8, 699 (2017)*. Element-resolved soft X-ray absorption (XAS) and magnetic circular dichroism (XMCD) measurements indicate that sample growth can be engineered to realize fully compensated SAF or SFIM. Atomistic first-principle DFT calculations indicate that graphene mediated super-exchange type coupling is responsible for the observed strong perpendicular antiferromagnetic coupling. Furthermore we show that exchange biased structures can be realized by exploiting the co-intercalation of other magnetic materials that provide uncompensated moment at the interface.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.04

TbCoFe/[Co/Ni/Pt] Exchange-Coupled Heterostructures

M. Heigl, R. Wendler, X. Zhao, A.-O. Mandru, C. Vogler, D. Suess, H. J. Hug, M. Albrecht

Text Heat-assisted magnetic recording (HAMR) is envisioned to increase the achievable storage density in future magnetic hard disk drives [1].

We present a candidate composite structure consisting of two exchange-coupled materials with different Curie temperatures T_c . The heterostructure consists of an amorphous ferrimagnetic TbCoFe thin film as a storage layer coupled to a magnetic softer [Co/Ni/Pt] multilayer, acting as a write and read-out layer. TbCoFe is highly tunable by its composition, exhibits a well suited T_c , large damping, and perpendicular magnetic anisotropy. Due to its low magnetization, a switching and read-out layer is required.

We report on the magnetic and structural properties of the individual layers as well as the coupled system for various compositions, thicknesses, and temperatures. We observe changing coupling types for different temperatures, supporting the heat-assisted writing process. However structural relaxation of the amorphous TbCoFe sets already in at 120 °C which leads to a decrease in uniaxial anisotropy. By the use of magnetic field dependent high-resolution magnetic force microscope measurements [2] creation and annihilation of lateral and interface domain walls can be observed. These studies are accompanied by micromagnetic simulations, providing a deeper understanding of the underlying reversal process.

References:

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.05

High-resolution Kerr microscopy investigations on polygonal nanowires for reliable domain wall position prediction

E. Lage, R. Mattheis, J. McCord

Text Domain wall (DW) based logic and sensing devices rely on well predictable positioning of DWs. Various devices require curved structures exhibiting complex DW motion, compared to well-studied straight nanowires (NWs) [1]. We investigate curved NWs realized as polygon sections comprising straight wires with connecting kinks [2]. Using high-resolution MOKE microscopy [3] and special differential imaging sequences we extract the exact location of DW in 300 nm wide NWs with in-plane magnetization [4]. The technique allows for easy acquisition of statistics of DW positions depending on the magnetic field history.

We present our results on DW positions in giant magneto resistive nanowire stacks with varying polygon angles, which influences the DW pinning at the connections. DW positions and distributions vary systematically with orientation and strengths of magnetic fields, and polygon arrangement. We observe reliable DW positioning with standard deviations down to 60 nm.

In consequence, the capability to optically determine DW positions with nanometer accuracy is shown, which allows for repetitions and statistics with short acquisition time. No electrical contacts to the devices are required. Thus, we facilitate the acquisition of statistical data for DW positioning and can provide feedback for the design of nanowire-based DW devices.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.06

Artificial tubular exchange bias domain patterns for paternoster-like transport of magnetic particles

H. Huckfeldt, T. Ueltzhöffer, R. Streubel, I. Koch, D. Holzinger, D. Makarov, O. G. Schmidt, A. Ehresmann

Text In the past, superparamagnetic beads were introduced as a mobile substrate to capture, separate and transport biological specimen in microfluidic applications. To control their motion, a dynamical change of the beads' magnetic potential energy landscape has been used. For a further improvement, we suggest an approach in which planar magnetic patterns are transferred into tubular magnetic structures via a strain-induced coiling process. For this purpose, exchange bias films are deposited on pre-stressed substrates, magnetically patterned by ion bombardment and coiled by dissolving a sacrificial layer.

The result is a tubular structure with a diameter of around 10 μm . The magnetic pattern resembles hollow cylindrical domains with alternating axial orientation of the remanent magnetization. These create magnetic stray fields in the surrounding volume. Thereby, a strong 3D potential energy environment trapping superparamagnetic particles in a aqueous suspension is defined. A distortion of the particles' potentials with small external fields can lead to a controlled stepwise transport on the in- and outside of the magnetic tubes. Interestingly, the particles automatically follow a paternoster-like movement, i.e. entering and exiting the tubes at the ends.

A transport concept will be presented, highlighting the interaction of the inherent stray fields with external magnetic field pulses. In addition, I will elaborate on future applications for microfluidic systems and biosensing.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.07

Influence of segment length on domain wall pinning in multisegmented Co/Ni nanowires for next generation data storage

H. Mohammed, J. A. Moreno, A. Salimath, A. Manchon, J. Kosel

Text Cylindrical nanowires grown in nanoporous templates shows considerable prospects for 3D data storage applications. These nanowires (NWs) display a single domain structure, therefore a higher storage capacity can be achieved by introducing multiple bits or domains. For this, several approaches such as diameter and material modulations have been demonstrated. Multisegmented Co/Ni NWs with segment lengths of 700 nm display pinning of domain walls (DW) near the Co/Ni interfaces, due to the larger stray field emanating from Co. For the design of such a Co/Ni NW-based device, a higher number of bits as well as optimal values of pinning and depinning field are crucial. Here, we investigate the switching field as well as depinning strength of Co/Ni NW (80 nm diameter) with various segment lengths. Utilizing the Magpar package, simulations of three different segment lengths namely 200 nm, 300 nm and 700 nm, were performed with a finite element discretization of 4.5 nm. We find that DW pinning is observed in all three segment lengths. In addition to the two segmented NWs, a three segmented NW of 700 nm long segments also displays DW pinning. Experimental studies have revealed the displacement of the DW by ≈ 150 nm away from the interface, which is in agreement with our findings. In addition to this, we find that the smaller segments result in the DW pinning at the interface itself. This would shrink the segment length needed to pin DWs, thereby resulting in a higher bit density.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 3

SP5.3.08

Layer-resolved magnetic imaging of domains in multilayered mesoscale tubes and their response to magnetic field

M. Stano, S. Schaefer, S. Y. Martin, L. Cagnon, C. Thirion, F. Genuzio, T. O. Mendes, A. Locatelli, M. Rioult, R. Belkhou, M. Antoni, W. Ensinger, O. Fruchart

Text Curved geometries and 3D magnetic nanostructures (nanohelices, cylindrical nanowires, nanotubes, ...) bring new challenges as well as promise for new magnetic configurations, physics (curvature-induced anisotropy, breaking of inversion symmetry), and higher areal density of elements in devices such as vertical racetrack memory. Here, we investigate trilayered magnetic tubes combining magnetic and non-magnetic layers. The tubes consist of NiFeB outer layer, non-magnetic SnOx spacer, and CoNiB inner layer. The outer diameter is around 400nm and thickness of layers in tens of nm. Further miniaturization of the stack is feasible, with single-shell tubes of 80nm in diameter already demonstrated.

For magnetic domain imaging we used X-ray magnetic circular dichroism coupled with photoemission electron microscopy in shadow geometry [1]. By tuning the X-ray energy we could selectively image magnetic domains in each magnetic layer. With continuous spacer the magnetization in both layers is exchange-decoupled: axial domains in NiFeB and azimuthal ones in CoNiB, similar to simple tubes from these materials [2].

After application of magnetic field lying predominantly in axial direction we could observe magnetic reversal in NiFeB tube (axial domains) via nucleation and displacement of a domain wall as well as influence of the wall stray field on the inner CoNiB layer with azimuthal domains.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5 - Parallel Session 4

SP5.4.01

Domain structures in $\text{Fe}_{100-x}\text{Ga}_x/\text{MgO}(001)$ films

M. Ciria, A. Begué, M. G. Proietti, J. I. Arnaudás

Text In this work we present the magnetic domain structures of $\text{Fe}_{100-x}\text{Ga}_x/\text{MgO}(001)$ ($x < 30$) epitaxial films with in-plane tensile stress [1] obtained by Magnetic Force Microscopy. The domain images for films with $x < 16$ display uniform areas separated by Bloch domain walls while if $x > 16$ a fine stripe-like structure is observed. The stripe phase is explained considering a perpendicular anisotropy K_u with a value comparable and lower than the shape anisotropy coefficient K_{sh} . Hysteresis loops performed along the film normal indicate that K_u/K_{sh} is around 0.4 ($x > 16$), a value for which the observation of the stripe phase is expected. The magnetoelastic (ME) anisotropy energy term favors in-plane magnetization due to the signs of residual strain and ME stress coefficient [1]. The presence of next-nearest-neighbor Ga pairs in $\text{Fe}_{100-x}\text{Ga}_x$ alloys has been addressed as source for the cubic anisotropy constant K_1 [2] while in epitaxial films a preferential asymmetry in the formation of these Ga-Ga pairs, along the out-of-plane direction, can result in large K_u [3] and explain the stripe structure observed for $x > 16$. It appears that small variations of the Ga-Ga pair distribution in a body, although undetected by local probes techniques, such as EXAFS [1], could introduce strong magnetic anisotropy in that specimen.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

Magnetic anisotropy in sputtered Ga-rich Fe-Ga thin films

A. Muñoz-Noval, S. Fin, D. Bisero, R. Ranchal

Text Fe-Ga alloys have appeared as promising materials because they are rare-earth free systems with a large magnetostriction and a low coercivity. The magnetostriction shows two maxima in two Ga ranges, around 20 at.% and 28 at.%, being higher in the Ga-rich range. The strong influence of processing on the magnetostrictive properties of bulk alloys has been reported [Acta Materialia 56, 4536 (2008)] highlighting the relevance of a precise control of the growth method. Reducing the dimensions, e.g. thin films, can further modify the magnetic properties but it is required to develop miniaturized devices.

In this work, we present our recent investigations about sputtered Ga-rich Fe-Ga alloys. We have explored how the flow regime of the sputtering technique can be used to tune the in-plane magnetic anisotropy [PRB 93, 214408 (2016)]. Furthermore, we have also studied how the anisotropy is also dependent on the layer thickness [JALCOM 745, 413 (2018)]. Our structural (XRD and XAS) and magnetic (VSM and MOKE) characterizations indicate that both growth parameters and thickness have an influence on the structural phases present in the Fe-Ga alloys. The increase of ordered phases together with a preferential order of the Ga-pairs seem to play a role on the enhancement of the anisotropy. Therefore, this experimental work sheds light on the correlation between structural and magnetic properties and how to exploit them to tune the magnetic properties in Fe-Ga thin films.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5.4.03

Magnetoelastic and Damping Properties of $\text{Co}_2\text{Fe}_x\text{Mn}_{1-x}\text{Si}$ Heusler Alloys Thin Films

O. Chumak, A. Pacewicz, A. Nabiałek, B. Salski, T. Yamamoto, T. Seki, K. Takanashi, L. T. Baczewski, H. Szymczak

Text The series of half-metallic $\text{Co}_2\text{Fe}_x\text{Mn}_{1-x}\text{Si}$ (CFMS) Heusler alloys epitaxial thin films with the thickness of about 30 nm were investigated to determine the composition influence on magnetoelastic and damping properties. Magnetoelastic properties were examined by means of the Strain Modulated Ferromagnetic Resonance (SMFMR). Magnetic damping properties were studied by means of Vector Network Analyzer FMR (VNA FMR) which is a fast and powerful tool for the analysis of ferromagnetic thin film parameters, including damping and effective field contributions like anisotropies. Magnetoelastic constant as well as Gilbert damping factor dependencies versus magnetic layer composition were obtained. Magnetoelastic constant was found to be in the range $5\text{-}25 \cdot 10^6 \text{ erg/cm}^3$, with corresponding magnetostriction coefficient λ of about $6\text{-}30 \cdot 10^{-6}$, and Gilbert damping factor in the range $2\text{-}6 \cdot 10^{-3}$. Correlations between the last two parameters were considered. Both parameters have small values, which is expected for CFMS magnetic layers as for representative of materials for both spintronic and magnonic applications. Magnetoelastic constants have similar values range as for $\text{Co}_2\text{Fe}_{0.4}\text{Mn}_{0.6}\text{Si}$ thin films with thickness in the range 15-50 nm [1]. Gilbert damping factor has a minimum for composition $x=0.4$. This composition corresponds to the highest tunnel magnetoresistance ratio [2].

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5.4.04

Relationship between spacer material and thickness on the damping and anisotropy of CoFeB in perpendicular double MgO free layer for MRAM

S. Couet, T. Devolder, J. Swerts, S. Mertens, E. Liu, S. Van Elshocht, G. S. Kar

Text Free layers with double MgO/CoFeB interfaces are a solution for improving the thermal stability at small device dimensions in perpendicular STT-MRAM devices. A thin spacer layer, composed usually of Ta, W, Hf, ..., is used to improve the perpendicular magnetic anisotropy (PMA), leading to a typical stacking of MgO(tunnel)/CoFeB(~1.xnm)/spacer/CoFeB(~1nm)/MgO(cap). Ta is the historical material of choice, but a push towards 400°C robust systems have highlighted W as a material generating a greater PMA. However, the free layer damping is as crucial in reducing/controlling the STT current. Here, we use ferromagnetic resonance (FMR) to evaluate the impact of Ta or W containing spacer layers on the intrinsic anisotropy H_k and damping α in p-MTJ stacks encompassing a synthetic antiferromagnet system as reference layer. We show that Ta and W can each achieve high PMA under certain circumstances, but the lowest achievable damping remains material dependent. We also study how the amount of heavy metal material present in the double MgO structure impacts anisotropy and damping. A clear link between damping versus spacer thickness is identified, which supports the interpretation that the heavy metal content increases the damping. While a finite quantity of spacer material remains necessary to ensure good crystallization and sufficient PMA, damping values as low as 0.005 can be achieved after a 400C 30' annealing of a full p-MTJ MRAM stack.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5.4.05

Mechanisms of electric field effect on magnetism in Pt/Co with solid-state gating under different fabrication condition

T. Hirai, T. Koyama, D. Chiba

Text Electric field (EF) effect on magnetism in 3d ferromagnetic metals and alloys has great importance from an application viewpoint due to low energy consumption for the writing operation of magnetic memories. The mechanism behind this effect is generally considered to be the change in the electronic structure by electrostatic charge doping, but recently it was reported electrochemical reaction also caused change in magnetic properties. In this talk, EF effect on magnetic anisotropy (MA) and magnetic moment (mS) in Pt/Co using solid-state gate insulator HfO_x deposited under different conditions is discussed. We prepared two samples in which HfO_x layer is deposited under different growth temperature in atomic layer deposition chamber; one is deposited at 150 °C (sample A) and another is deposited at 200 °C (sample B). Both samples show clear perpendicular MA. In sample A, the change in 2-wire resistance (R), coercivity, and MA following to applied gate voltage (VG) is seen. The ac frequency response of capacitance (C-f) also endures a conventional capacitor with charge accumulation. On the other hand, in sample B, drastic modulation of magnetic properties and R can be observed, but the value gradually changes even though VG is fixed, and anomalous appearance of C-f is shown. Furthermore, direct magnetization measurements show clear change in mS by VG applications. These results mean the modulation of effective Co thickness caused by redox reaction is dominant in sample B.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5.4.06

Large Room Temperature Voltage Control of Magnetic Anisotropy in SrTiO₃/Co/Pt

B. Vermeulen, J. Swerts, S. Couet, M. Popovici, I. Radu, K. Temst, G. Groeseneken, K. Martens

Text The standard material stacks with Perpendicular Magnetic Anisotropy (PMA) using MgO as a dielectric have an inherently limited Voltage Control of Magnetic Anisotropy (VCMA) effect^{1,2}. A higher permittivity of the gate dielectric increases the injected charge, likely enhancing the VCMA effect.

We demonstrate an enhanced VCMA effect on SrTiO₃(STO)/Co/Pt trilayers. The VCMA effect has a strength up to 181 ± 23 fJ/Vm in 0.65 nm Co layers, as compared to ~ 40 fJ/Vm for MgO/Co interfaces³. This increase of the VCMA effect is correlated with an increase of the dielectric strength with a factor of 4. In addition, the VCMA effect and the magnetic anisotropy are shown to be crucially dependent on the STO/Co interface condition. In samples with strong PMA (i.e. high interfacial anisotropy energy and square hysteresis loops), X-Ray Photoelectron Spectroscopy indicates that a thin layer of CoO_x is present at the interface.

These results shed light on the physical effects behind VCMA, and provide evidence that the VCMA effect is due to either accumulation¹ or reordering⁴ of surface charges in the metallic 3d orbitals of the surface atoms.

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⁴Miwa, N Comm 8, 15848 (2017)



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5.4.07

Voltage-induced magneto ionic switching of anisotropy and magnetic domains in FeOx/Fe nanostructures

J. Zehner, K. Duschek, N. Pérez, I. Soldatov, R. Schäfer, S. Fähler, K. Nielsch, K. Leistner

Text Within the last ten years, voltage control of magnetism (VCM) became increasingly attractive because it paves a powerful way to manipulate magnetic nanostructured systems without Joule heating or external magnetic field¹. Electrochemical mechanisms in oxide/metal thin films were recently added to the family of VCM effects and have been denominated magneto-ionic effect^{1,2,3}.

We present large magneto-ionic changes of coercivity and anisotropy in sputtered and natively oxidized FeOx/Fe thin films with uniaxial in-plane anisotropy at room temperature. To apply the voltage, we utilize a liquid alkaline electrolyte, which, in comparison to solid oxide gate barrier layers, yields an enhanced electric field and a higher ion mobility at the interface⁴. A transformation of the native iron oxide into ferromagnetic iron and vice versa is obtained via the application of only 1 V. A novel in situ Kerr microscopy set up has been developed to probe local changes in hysteresis and the magnetic microstructure during voltage operation. Significant voltage-induced changes in the in-plane anisotropy as well as in the magnetic domain size are visible which have not been reported so far. The underlying mechanism is discussed with regard to the role of the oxide layer and the thickness change during the magneto-ionic transformation.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 4

SP5.4.08

Magnetic reorientation in anisotropic Heisenberg ferromagnets

J. Vanherck, B. Sorée, W. Magnus

Text The downscaling of traditional charge-based transistors is becoming problematic and the Spin Wave MAjority Gate (SWMAG) could be an alternative. Miniaturizing the SWMAG typically requires its ferromagnetic spin wave buses to become very thin. While quantum effects become important in materials of only a few atomic layers thick, they are not taken into account in today's device models. Moreover, such thin magnetic films cannot generally be expected to retain their bulk magnetization profile at room temperature.

Here, we study a Heisenberg ferromagnet (both two- and three-dimensional) using double-time temperature-dependent Green's functions, while considering anisotropic exchange interactions. The system is studied in the presence of an external magnetic field, which can be in any arbitrary direction, thereby mimicking possible experimental uncertainties.

The magnitude and direction angle of magnetization are calculated as a function of both the applied magnetic field (direction) and temperature, and for both easy-plane and easy-axis ferromagnets. Relevant characteristics of the magnetization, such as the Curie temperature and the reorientation transition, are obtained. The impact of differences in anisotropy and dimensionality on the magnetization behavior can be interpreted and understood in terms of the spin wave dispersion relation.

Apart from the SWMAG, also novel MRAM devices and even quantum computing processes might gain valuable insights from this research.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5 - Parallel Session 5

SP5.5.01

Direct Measurement of the Intrinsic Sharpness of Magnetic Interfaces Formed by Ion Beams

G. Causer, D. Cortie, H. Zhu, M. Ionescu, G. Mankey, X. Wang, F. Klose

Text Using ion-beams to locally modify material properties is rapidly gaining momentum as a technique of choice for the fabrication of magnetic nano-elements because the method provides the capability to nano-engineer in 3D, which is important for many future spintronic technologies. The precise definition of the resulting element shape is crucial for device functionality. In this work, the intrinsic sharpness of a magnetic interface formed by nano-machining FePt₃ films using He⁺ irradiation is investigated. Through careful selection of the irradiating ion's energy and fluence, ferromagnetism is locally induced into a fractional volume of a paramagnetic (PM) FePt₃ film by modifying the chemical order parameter. Using a combination of magnetometry, transmission electron microscopy and polarised neutron reflectometry it is demonstrated that the interface over which the PM to ferromagnetic modulation occurs is confined to a few atomic monolayers only. Using density functional theory, the mechanism for the ion-beam induced magnetic transition is elucidated and shown to be caused by an intermixing of Fe and Pt atoms in anti-site defects above a threshold density.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.02

Disorder-induced ferromagnetism in Fe₆₀Al₄₀ films on a local scale

A. Smekhova, E. La Torre, T. Szyjka, B. Eggert, B. Cöster, K. Ollefs, D. Walecki, S. Salamon, R. Bali, J. Lindner, F. Wilhelm, A. Rogalev, E. Weschke, D. Többers, R. Banerjee, B. Sanyal, C. Schmitz-Antoniak, H. Wende

Text X-ray absorption spectroscopy at Fe and Al K edges together with synchrotron-based diffraction has been applied to probe Fe and Al local environment and Al electronic structure in bare Fe₆₀Al₄₀ films of 40 nm thickness through the order-disorder (B2 → A2) phase transition initiated by 20keV Ne⁺ irradiation with low fluences ($\sim 10^{14}$ ions·cm⁻²). In the course of the transition, distinct changes of Fe and Al coordination have been found and related to formation of Fe-rich regions due to inhomogeneous disordering created by ions. As a result, visibly increased 4p and 3d Fe polarizations with a characteristic fluence dependence have been found by XMCD technique at the Fe K and L_{2,3} edges, respectively. Furthermore, strong variations in coercive fields depending on temperature and irradiation fluence have been revealed by element-specific hysteresis loops recorded at the Fe L₃ edge.

To reduce the unfavorable top oxide layer and to uncover a specific shoulder related to hybridization effects between Fe and Al an inductively coupled hydrogen plasma treatment has been performed in situ. Depending on the time of treatment an increase or decrease of Fe 3d spin magnetic moments in the surface region has been found. The former suggests that a use of a capping layer could further enhance the macroscopic magnetization of films which is more attractive for technological applications. A theory support was provided by self-consistent DFT calculations using VASP program package.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.03

Modification of the magnetization ordering in Pt/Co/Pt trilayers depending on the scanning direction of the focused ion beam

P. Mazalski, P. Kuswik, I. Sveklo, I. Soldatov, J. McCord, R. Schafer, A. Wawro, A. Maziewski

Text In ultrathin cobalt films, which were uniformly irradiated by ions, new effects like an irradiation-induced increase of magnetic anisotropy or the appearance of an out-of-plane component of magnetization have been reported [1,2]. The aim of the presented work is to study the changes of the magnetic domain structure (DS) in the squares that are irradiated by a Focused Ion Beam (FIB). A Pt/Co/Pt film was grown by MBE technique with a cobalt thickness favoring in-plane orientation of magnetization. Numerous squares ($50 \times 50 \mu\text{m}^2$) have been irradiated by FIB with a wide range of ion fluences. The FIB was scanning in square spiral from the center of the square to its border. Detailed in-plane and out-of-plane magnetization measurements were performed using a recently developed magneto-optical technique [3] based on both, the polar (PMOKE) and longitudinal (LMOKE) Kerr effects. Two fluence ranges of increased remanent magnetization were observed by PMOKE. Four triangles with inclined out-of-plane magnetization (depending on FIB direction) and unexpected reversing of DS while applying in-plane field were distinguished inside the FIBed squares. The DS with vectorial magnetization analysis are discussed as a function of in-plane and out-of-plane field.

Supported by NCN FUGA project (DEC-2015/16/S/ST3/00450).

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.04

Magnetic anisotropy of nanostructured ferrite oxides

K. Pitala, A. Zywczyk, K. Kollbek, A. Szkudlarek, J. Kuciakowski, G. Szwachta, J. M. Ablett, A. Juhin, M. Sikora

Text The size and shape of magnetic material can greatly influence stray fields and electronic structure - both having significant impact on magnetic anisotropy. Lowering the dimension of magnetic materials and introducing structural damage to outer layers during nanostructuring not only enhances the impact of surface states but it may also change the volume properties. In this work we explore how e-beam lithography (EBL) and focused ion beam (FIB) affect the properties of magnetic oxide films, especially in terms of structural defects introduced by those processes.

We studied a set of samples formed from magnetite, maghemite and hematite, namely epitaxial layers obtained by pulsed laser deposition, nanostructured by either EBL combined with ion etching or direct lithography using FIB, and nanocomposites obtained using reactive magnetron sputtering. Their magnetic properties, local structure and electronic configuration of iron in different types of nanoscale oxide were probed using VSM, 1s2p RIXS and MCD. The latter two are sensitive probes of the local atomic environment and site-selective magnetization. We discovered the well-resolved pre-edge structures, which are strongly affected in nanostructured samples due to the change in crystal field symmetry of the metal ions. Despite modifications introduced to the local structure the magnetic contrast was sufficient to probe angular dependent magnetization curves and thus anisotropy of selected nanostructures using RIXS-MCD.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.05

Ultrafast single laser pulse demagnetization via domain formation

J. Kisielewski, I. Sveklo, T. Ostler, O. Chubykalo-Fesenko, A. Wawro, A. Maziewski

Text Homogeneously out-of-plane magnetized ultrathin Pt/Co/Pt sandwiches were illuminated with single femtosecond laser pulses. Within the irradiated spots the sample become demagnetized. A closer view reveals a sub-micrometer magnetic domain structure. Deposited energy density was far below any damage or modification thresholds and the irradiation process is fully reversible, e.g. by applied magnetic field. We characterize in detail the conditions which allow this process to take place. It is found to occur above a certain pulse energy density threshold, which further depends on the effective magnetic anisotropy of the film, varied by the Co layer thickness. We discuss the possible microscopic mechanisms and their thermal nature. The results of micromagnetic simulations exploiting the Landau-Lifshitz-Bloch equation correlate well with the experimental observations.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.06

Time resolved MOKE measurements with calibrated lattice Temperature

L. Willig, A. von Reppert, J.-E. Pudell, M. Kronseder, C. Back, M. Bargheer

Text We measure the response of the spin system in thin Ni films after excitation with a 800nm pump pulse via the time-resolved magneto-optical Kerr effect (MOKE) for various pump fluences. We analyse the recovery of the magnetization. We calibrate the absorbed energy by ultrafast x-ray diffraction (UXRD), which is sensitive to the transient temperature of the Nickel lattice. We are particularly interested in high fluence measurements, where the lattice temperature rises above the Curie temperature. The tr-MOKE signal shows that the spin system is recovering with a small linear slope even with the Temperature above the Curie-Temperature on timescales up to 80 ps. When the lattice Temperature falls below TC the magnetization recovery changes from linear to exponential.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.07

Magnetic Proximity Effect and Exchange Coupling in Pt/Cr Bilayers

M. Asa, C. Autieri, R. Pazzocco, S. Picozzi, M. Cantoni

Text We report a combined *ab-initio* and experimental investigation of the Pt/Cr system. Density functional theory indicates that a net magnetic moment up to $0.3 \mu_B$ can be induced in Pt by antiferromagnetic (AFM) Cr films via magnetic proximity at interfaces. At the same time, the exchange coupling between Pt and Cr layers enables the control of Pt magnetization by field cooling the AFM across its Neél temperature T_N . The existence of a net out-of-plane magnetization in Pt, dependent only on the field cooling direction and insensitive to external magnetic fields below $T_N \sim 290$ K, is confirmed in single-crystal Pt/Cr//MgO heterostructures by means of anomalous Hall resistance measurements. Because of the peculiar transport properties originating from the spin density wave antiferromagnetism in Cr, it is possible to relate unambiguously the insurgence of magnetization in Pt to the AFM state of the underlying layer. Finally, the possibility to measure electrically this proximity-induced magnetic moment enables the access to the magnetic state written in Cr and allows to determine independently properties such as T_N and its dependence on Cr thickness and strain.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 5

SP5.5.08

Direct printing of metallic 3D magnetic nanostructures by focused electron beam induced deposition

L. Keller, M. K. I. Al Mamoori, J. Müller, M. Huth

Text Building nanotechnological analogues of naturally occurring magnetic structures has proven to be a powerful approach to studying topics like geometry-induced magnetic frustration and to provide model systems for statistical physics. Moreover, it practically allows to engineer novel physical properties by realizing artificial lattice geometries that are not accessible via natural crystallization or chemical synthesis. Although first proposals have been made to advance into three dimensions (3D), established nanofabrication pathways based on electron beam lithography have not been adapted to obtain free-form 3D nanostructures. In parallel, fabrication of 3D nano-architectures by focused electron beam induced deposition (FEBID) has matured to a level that highly complex and functional deposits are becoming available for nanomagnetism. Moreover, the magnetic 3D elements can be combined with other 3D elements of different chemical composition and intrinsic material properties. In our contribution we demonstrate the direct-write fabrication of freestanding ferromagnetic Fe-Co 3D nano-architectures. Micro-Hall sensing was used to determine the magnetic stray field generated by the free-form structures in an externally applied magnetic field and we have performed micromagnetic simulations to deduce the spatial magnetization profiles in the structures and analyze their switching behavior.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 6

SP5 - Parallel Session 6

SP5.6.01

Geometrically defined spin structures in ultrathin Fe₃O₄ with bulk like magnetic properties

M. Foerster, S. Ruiz-Gomez, L. Perez, A. Mascaraque, A. Quesada, P. Prieto, I. Palacio, L. Martin-Garcia, L. Aballe, J. de la Figuera

Text Being the oldest magnetic material known to mankind, magnetite (Fe₃O₄) still remains fascinating for fundamental research and possible applications in oxide spintronics, fueled by one of the highest Curie Temperatures among oxides and conducting properties with high spin polarization (half metallicity). However, it has been realized that when growing magnetite as ultrathin film and/or nanostructures, typically its properties are deteriorated and dominated by defects like Anti-phase boundaries.

We report on the growth of high quality magnetite microcrystals free from antiphase boundaries on Ru(0001) by reactive molecular beam epitaxy, conserving bulk magnetic properties below 20 nm thickness [1]. 3D Magnetization vector maps are obtained by Photoemission Electron Microscopy with X-ray magnetic circular dichroism contrast (XMCD-PEEM) and compared with micromagnetic simulations using bulk parameters. The observed domain configurations are dictated purely by shape anisotropy, overcoming the possible influences of (magneto)crystalline anisotropy and defects, thus demonstrating the possibility of designing spin structures in ultrathin, magnetically soft magnetite at will.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 6

SP5.6.02

Double magnetic proximity in Fe/Fe_{0.32}V_{0.68} superlattices

H. Palonen, F. Magnus, B. Hjörvarsson

Text A set of fully coherent high quality Fe/Fe_{0.32}V_{0.68} superlattices were grown to study conventional magnetic proximity effects, double proximity effects and the long range exchange interactions between the Fe layers over different distances. The thickness of the Fe layer was chosen to be one monolayer and the thickness of the bcc FeV random alloy was varied from 10 to 30 monolayers. The samples were grown by magnetron sputtering. The double proximity effect causes a single monolayer of Fe, which on its own would be non-magnetic, to become ferromagnetic. Furthermore, the long range exchange interactions enhance the double proximity effect, i.e. the ordering temperature of the source, by 48% (12%) across 1.5 nm (3 nm). The ordinary magnetic proximity effect enhances the ordering temperature of the Fe_{0.32}V_{0.68} alloy by 40% - 100%. By applying a simple model to the saturation magnetization it was shown that the magnetic proximity effect has a gigantic magnitude in the alloy - the magnetization is enhanced by 20% - 450%. The model also confirms that the huge double proximity effects can be explained by the large susceptibility of the alloy above its intrinsic ordering temperature. The results give insight into possible new ways of using alloying and large magnetic susceptibility combined with magnetic proximity effects to enhance the functionality of materials that are of interest for spintronic devices.



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SP5.6.04

Magnetization reversal in electrodeposited FePd sub-micron structures

M. Cialone, E. Dislaki, F. Celegato, M. Coisson, G. Barrera, E. Pellicer, J. Sort, P. Rizzi, P. Tiberto

Text FePd alloys attract much attention because of their unique mechanical and magnetic properties, tunable with Pd content. Given the current trend toward miniaturization, Fe₇₀Pd₃₀ sub-micron structures were produced by electrodeposition for potential application in micro and nano electromechanical systems [T. Kakeshita *et al.*, *Mater. Sci. Forum* 394-395 (2002)]. Three different geometries, namely crosses, stripes and disks, and three different feature sizes were targeted, ranging from 200 nm to 1 micron with an average height of 300 nm. Hence, we obtained an aspect ratio currently unexplored in literature with existing studies focusing only on nanodots or nanowires [R.P. Cowburn *et al.*, *Phys. Rev. Lett.* 83, 1042 (1999)]. Elemental and morphological properties of the structures were analysed via scanning electron microscopy. Slight variation of stoichiometry and height are observed according to the different shapes and feature sizes. The magnetization reversal process has been studied via magnetic force microscopy, acquiring images at room temperature with a static magnetic field applied along the in-plane direction. Increase in geometry complexity, corresponds to an increase in the complexity of the magnetization reversal process. Indeed, disks show a low contrast, implying for flux closure within the structure, while for the crosses, due to the different length of the two branches, the contrast indicates a complex variation of the magnetization direction across the structure.



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SP5 - Parallel Session 6

SP5.6.05

Imaging the magnetization reversal in strongly exchange-coupled bilayers of TbFe and Co/Pt

A.-O. Mandru, X. Zhao, M. Marioni, H. Hug, C. Vogler, D. Suess

Text Perpendicular exchange-coupled systems, consisting of a rare earth-based ferrimagnet (amorphous TbFe) and a transition metal-based ferromagnet (crystalline Co/Pt), exhibit strong and surprisingly complex coupling interactions at the interface, different from those in conventional systems. Macroscopic magnetization measurements alone cannot account for all the details behind such interactions, thus studying the reversal locally is crucial. In this work, the reversal mechanism is understood by high-resolution and quantitative MFM combined with micromagnetic simulations. The Tb₂₅Fe₇₅/[Co/Pt]_x5 films are prepared at 300K by DC magnetron sputtering. The imaging is performed in a home-built UHV MFM at 10K and in fields of up to 7T. The TbFe layer alone reveals no change in its domain structure between 0 and 6T. Due to this high coercivity value, the behavior of the adjacent Co/Pt can be studied over a large field span. The net moments of TbFe and Co/Pt are antiparallel aligned and as the field increases, the reversal of Co/Pt is known to be accompanied by the formation of an interfacial domain wall (iDW). In addition to a highly inhomogeneous iDW, we find that the reversal of Co/Pt can be described by a three-stage magnetization process, where isolated grains switch over a wide field range. Unexpectedly, nanoscale inhomogeneities in both TbFe and Co/Pt are responsible for the observed behaviors and have to be taken into account in order to understand such exchange-coupled systems.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 6

SP5.6.06

Bonding character and magnetism at the interface between Fe and MoS₂ nanosheets

R. Mantovan, Y. Matvayev, G. Vinai, C. Martella, P. Torelli, A. Molle, S. Zarubin, Y. Lebedinskii, A. Zenkevich

Text To integrate ferromagnetic layers with the prototypical 2D-layered MoS₂ is of interest in the context of emerging spintronic devices. Four monolayers MoS₂ thin films have been grown by chemical vapor transport on large scale Si/SiO₂ substrates. Then, a ⁵⁷Fe tracer layer (~1 nm) has been grown by pulsed laser deposition in direct contact with 2D-MoS₂ and capped with ⁵⁴Fe layer (~10 nm), thus allowing interface-sensitive conversion electron Mössbauer spectroscopy (CEMS). By combining CEMS with hard X-ray photoelectron spectroscopy (HAXPES) and transmission electron microscopy, we investigate the chemical, structural, and magnetic properties of the Fe/2D-MoS₂ interface. CEMS shows that out of the first 1 nm of Fe in direct contact with 2D-MoS₂, about half of the Fe atoms keeps an unperturbed Fe local environment. The remaining Fe atoms exclusively bond with Mo, with the majority of them being characterized by a ferromagnetic environment and the rest coordinating in a paramagnetic Fe-Mo configuration. The preferential Fe bonding with Mo is corroborated by HAXPES analysis. Our results provide detailed insight into the link between the bonding configuration and the interfacial magnetism at the Fe/2D-MoS₂ heterojunction. We will also present preliminary results obtained by X-ray absorption spectroscopy (XAS) as performed *in situ* following sequential Fe deposition by molecular beam epitaxy on 2D-MoS₂, which revealed a peculiar thickness-dependent chemical reaction at the interface.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 6

SP5.6.07

Tuning the magnetic properties of Mn₅Ge₃ by C doping

L. Michez, M. Petit, E. Prestat, Q. Ramasse, V. Le Thanh

Text Much attention has been recently devoted to Mn₅Ge₃ as this compound meets all the requirements for spin-polarized transport and injection into Ge. This material may therefore represent a new route to develop the beyond complementary metal-oxide-semiconductor technology. Its limited Curie temperature (TC~296K) greatly hinders its use for potential applications but can be enhanced up to 450K by incorporating a small amount of carbon. Theoretical calculations attribute this behavior to an enhancement of the Mn-Mn interactions mediated by C atoms placed in interstitial sites.

In this work, we have extensively studied the structural and magnetic properties of Mn₅Ge₃C_x films grown on Ge(111) by molecular beam epitaxy as a function of C concentration. Besides the compressive strain induced by the incorporation of C, the latter modifies significantly the Mn₅Ge₃ magnetic properties. While the Curie temperature increases from 296K to 450K as x is increased from 0 to 0.7, the magnetocrystalline anisotropy in C-doped samples is reduced by nearly one order of magnitude. This effect is assigned to hybridization between MnII and C atoms whose position has been investigated via STEM experiments. The magnetic properties of carbon-doped Mn₅Ge₃C_x thin films can therefore be tuned by adjusting the amount of C. This is very promising for the realization of spintronics devices and in addition, the presence of C is essential for the thermal stability and the high performances of Mn₅Ge₃ thin films.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5 - Parallel Session 7

SP5.7.01

Magnetic anisotropy and depth-resolved magnetization in Pt/Co₈₀Cr₂₀/Pt trilayers

F. Fettar, J. M. Tonnerre, K. Sengupta, P. David, D. Barral, V. Pedruzzi Nascimento

Text Perpendicular magnetic tunnel junctions (p-MTJs) are promising for spin transfer torque random access memory application, since they offer non-volatility, high speed, low power consumption, infinite endurance and data retention simultaneously. Important for high performance memory devices are the tunneling magneto resistance, and the thermal stability factor D , that depends on the saturation magnetization, the interface anisotropy (K_{eff}), and the thickness of the magnetic layer (t). Intensive researches are devoted to perpendicular magnetic anisotropy (PMA) in CoFeB. Unfortunately, PMA is observed only for thicknesses less than 2nm limiting D . In this work, the thickness dependence of the magnetic anisotropy of sputtered Pt(6nm)/Co₈₀Cr₂₀(t)/Pt(3nm) is investigated at RT by SQUID. For $t=5\text{nm}$ the sample exhibits an in-plane magnetic anisotropy. Interestingly, an allowing effect is evidenced as PMA is obtained for thickness up to 3nm. CoCr samples with $t=3$ and 5 nm were investigated by x-ray resonant magnetic reflectivity in order to probe an eventual difference in the in-plane and out-of-plane depth resolved magnetization profile. They turn out to be very similar. The magnetization of Co is homogeneously distributed across 80% in the center of the layer and is reduced, compared to pure Co, due to alloying with Cr in agreement with SQUID data. The profile also shows an enhancement at the interfaces which is stronger at the rougher top interface.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5.7.02

Temperature dependent sign inversion of large uniaxial magnetostriction in the nanolaminated MAX phase Mn_2GaC

I. Novoselova, A. Petruhins, U. Wiedwald, Á. S. Ingason, T. Hase, F. Magnus, V. Kapaklis, J. Palisaitis, M. Spasova, M. Farle, J. Rosen, R. Salikhov

Text Inherently nanolaminated $M_{n+1}AX_n$ ($n = 1, 2, 3$) compounds – MAX phases – have unique anisotropic structural and physical properties showing ceramic as well as metallic response [1]. Following theoretical predictions, the magnetic ternary MAX phase, Mn_2GaC , has been synthesized as a hetero-epitaxial film by magnetron sputtering [2]. Here, we present a comprehensive study of the temperature and field dependent magnetization, magnetoresistive (MR) and magnetostrictive (MS) properties. The system exhibits two non-collinear antiferromagnetic states with a spin-reorientation transition occurring at $T_t = 214$ K and a high Neel temperature of $T_N = 507$ K, where the system transitions into a disordered state [3]. A large uniaxial MS of 450 ppm at T_t in 2 Tesla was observed. The MS undergoes a sign change, being compressive (negative) above T_t and tensile (positive) below T_t . It is accompanied by a highly asymmetric MR up to 3% in $H = 9$ T at $T = 300$ K. A simultaneous sign change of MS and MR is observed, indicating a direct coupling between the spin and lattice degrees of freedom.

This work is supported by DFG, Grant SA 3095/2-1 and DAAD Doctoral Programmes in Germany, 2017/18 (57214224).

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5.7.03

Iron-based magnetic nanostructures in large area fabricated by glancing angle deposition with magnetron sputtering

E. Navarro, M. U. González, F. Tejo, J. Escrig, J. M. Garcia-Martin

Text Glancing angle deposition with magnetron sputtering (MS-GLAD) allows for obtaining nanostructures in large area at RT onto any kind of flat substrates [1-3]. Depending on deposition parameters (such as gas pressure, tilt angle, etc.), several morphologies can be obtained. Recently, we have prepared Ti nanocolumns with antibacterial properties [4] and Au nanopillars exhibiting black metal behavior [5]. In this new work, MS-GLAD has been used to fabricate Fe-based nanostructures. The morphology has been analyzed by SEM and the structural characterization has been performed by X-ray diffraction. It is shown that vertical or tilted nanopillars can be fabricated whether or not substrate rotation is used, respectively. Moreover, nanopillars prepared with higher ratio between ballistic and thermalized atoms have been fabricated with a collimating mask. The magnetic properties of all these nanostructured systems have been studied with SQUID magnetometry and understood with the help of micromagnetic simulations. In summary, this is a sustainable technique to obtain magnetic nanostructures in large area, which can be of interest for several applications (e.g. water remediation).

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5.7.04

Magnetic properties of $(Y_{1-x}Ce_x)Co_5$ thin films and bulk single crystals

S. Sharma, I. Radulov, L. Diop, P. Komissinskiy, M. Major, K. Skokov, O. Gutfleisch, L. Alff

Text Cobalt based rare earth (*RE*) intermetallic compounds, $RECo_5$ are known for their extremely large magneto-crystalline anisotropy which is the most important property of bulk permanent magnets and thin films *K. Strnat et al., J. Appl. Phys. 38 (1967) 1001-1002*. In this work, we investigate the evolution of magnetic properties of two lesser critical rare-earth material systems, YCo_5 and $CeCo_5$ and their mixed compounds $(Y_{1-x}Ce_x)Co_5$ when Y is gradually substituted by Ce. A combined study of thin films and bulk single crystals is performed. The thin films were grown by co-evaporation of elemental *RE* and Co by electron beam at 10^{-8} mbar onto (0001) Al_2O_3 substrates using Molecular beam Epitaxy (MBE). MBE allows to tune the composition of the *RE*-Co system by *in situ* controlling the evaporation rates of *RE* and Co *S. Sharma et al., J. Magn. Magn. Mater. 432 (2017) 382-386, S. Sharma et al., J. Magn. Magn. Mater. 452 (2018) 80-85*. In the series $(Y_{1-x}Ce_x)Co_5$, a varying *4d/5d-4f* hybridization of *RE* coupled to *3d* Co within the anisotropic crystalline environment gives rise to interesting magnetic behavior. In fact, both for thin films and bulk single crystals, the highest anisotropy is observed for $(Y_{0.5}Ce_{0.5})Co_5$ which is greater than that of parent compounds, YCo_5 and $CeCo_5$. These results provide guidelines to tailor future materials with high magnetic anisotropy in the current search for sustainable permanent magnets.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5.7.05

Spin-orbit gaps in ferromagnetic thin films

L. Plucinski, E. Mlynczak, S. Borek, J. Minar, J. Braun, P. Gospodaric, M. Gehlmann, I. Aguilera, G. Bihlmayer, S. Bluegel, H. Ebert, C. M. Schneider

Text Magnetization direction can control topological phases in ferromagnets by influencing the existence of nodal points and spin-orbit gaps, which control intrinsic magnetotransport properties. Using high resolution angle-resolved photoemission (ARPES) we demonstrate signatures of magnetization direction-dependent spin-orbit gaps near the Fermi level in Fe(001) thin films [PRX 6, 041048 (2016)]. The gaps and thus the Fermi surface could be manipulated by changing the remanent magnetization direction, and we find qualitative agreement of the experimental data to the one-step model photoemission calculations. For thinner films the quantum confinement leads to quantum wells which also exhibit anisotropy. The analysis of spin-polarized photoemission from these quantum wells allows the unambiguous identification of the initial bands, which has been often challenging due to correlation effects in the band structure, which are beyond the description of popular exchange-correlation potentials.

Good agreement is found by comparison ARPES data to the bulk band structure calculated using the GW method under the assumption of perpendicular momentum broadening due to the finite probing depth of photoemission.

This study contributes to better understanding of the role of Berry phase physics in anomalous Hall conductivity and related phenomena in 2D ferromagnetic layers.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5.7.06

Ultrathin antiferromagnetic oxides with tunable properties

A. Mandziak, G. Delgado, M. Sánchez-Arenillas, P. Prieto, J. E. Prieto, A. Quesada, M. Foerster, J. de la Figuera, L. Aballe

Text Antiferromagnetic (AFM) oxides are strong candidates for spintronic applications due to a combination of interesting features: robust against perturbation due to magnetic fields, no stray fields, ultrafast dynamics and large magneto-transport effects.

We demonstrate the growth of ultrathin micrometric islands of AFM transition metal monoxides with different compositions and lateral sizes. Combining oxygen-assisted molecular beam epitaxy on a metallic substrate with in situ Low Energy Electron Microscopy it is possible to optimize the growth parameters for each composition and thickness between a few nanometers and tens of nanometers.

In the same instrument, we determine the surface atomic structure of each island by microspot Low Energy Electron Diffraction, as well as their chemistry and magnetization by synchrotron based X-ray Absorption Spectroscopy and X-Ray Magnetic Linear Dichroism spectromicroscopy.

At elevated temperature and low growth rates each island grows from a single nucleus, resulting in an extremely low density of pinning centers and large magnetic domains, providing an ideal playground to understand fundamental properties of ultrathin microstructures and their coupling to e.g. ferromagnetic layers. In addition, by varying the composition ratio the magnetic properties can be tuned to a certain degree. For example, the Neel temperature can be shifted between 291 K and 525 K in mixed nickel-cobalt monoxides, which is extremely useful for applications.



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SP5.7.07

Imaging the confinement effects on the metamagnetic behavior of FeRh structures

M. Horký, J. A. Arregi, M. Staño, J. Jaskowiec, V. Schánilec, E. Fullerton, V. Uhlíř

Text Magnetic materials featuring first-order phase transitions that exhibit an interplay between multiple degrees of freedom are outstanding candidates for finding and exploiting new functionalities and emergent phenomena on the mesoscale. Here we focus on the metamagnetic transitions between the antiferromagnetic (AF) and ferromagnetic (FM) phases in sub-micron-wide FeRh wires, where the transition becomes greatly asymmetric when comparing the heating and cooling cycles [1]. The abrupt variation of the FM content upon cooling, recorded by measurements of resistivity and magneto-optical Kerr effect [1, 2], has been attributed to the different role of FM and AF interactions in the presence of disorder. Here, we investigate the effects of mesoscale confinement on the metamagnetic behavior of patterned FeRh structures via Kerr microscopy [2] and a combination of magnetic force microscopy and electrical transport measurements. Our study reveals larger supercooling with decreasing the structure size and reduction of the transition temperature by about 20 K in sub-micron-wide wires, which is a result of strain relaxation caused by patterning. We further map the dependence of the FM correlation length upon the transition on the structure size and discuss the crossover from the uncorrelated behavior upon cooling to the correlated one.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 7

SP5.7.08

Magnetization processes in FeNi cylindrical nanowires with chemical notches

L. Perez, S. Ruiz-Gomez, C. Fernandez-Gonzalez, M. Foerster, L. Aballe, R. Guerrero, J. Camarero, J. de la Figuera, A. Quesada, A. Mascaraque

Text Race-track memories might be the base of future magnetic storage technology based on the movement of magnetic domain walls using spin polarized currents [1]. In these devices, when not in motion the magnetic domain walls should be pinned in artificially created notches along magnetic wires [2]. The depinning of a domain wall from geometrical notches has an intrinsic stochastic component which complicates the application of the proposed scheme in real devices [3], so new types of notches are needed to overcome this problem. In this work we have introduced local changes in composition along permalloy nanowires, that may act as local pinning sites (chemical notches).

To study the behavior of magnetic domain walls in these nanowires, we have followed two different approaches. On one hand, we have used LEEM-PEEM microscopy to study the magnetization processes of individual nanowires. We have proven that chemical notches act as pinning sites for the domain walls. On the other hand, we have used magneto-optical Kerr effect to study ordered arrays of individual nanowires, to have a deeper knowledge of the magnetic behavior of these nanowires when changing the distance between notches as well as the pinning force of each notch. All measurements have been correlated with micromagnetic simulations.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5 - Parallel Session 8

SP5.8.01

Comparison between magnetization reversal processes of bi-and tri-segmented diameter modulated nanowire arrays

V. Prida, M. Mendez, S. Gonzalez, V. Vega, R. Caballero-Flores, E. Palmero, M. Jaafar, C. Bran, A. Asenjo, M. Vazquez

Text The magnetization processes of bi-and trisegmented FeNi and FeCo NW arrays with one or two modulations in diameter, fabricated by an innovative combined method of electrochemical anodization, followed by pore widening by chemical etching and further atomic layer deposition (ALD) of a protective cover of silica layer, are studied. NWs were grown inside the geometrical modulated pores of the patterned alumina templates by potentiostatic electrodeposition, with different segment lengths ranging from 1.6 up to 7 μm , and diameter of each segment varying between 30 and 90 nm. The diameter modulation in the NWs was checked by HRTEM, which also indicated their polycrystalline structure. Magnetization processes were determined by angular hysteresis loops measured under different applied field angle respect to the nanowires axis, showing a predominant axial easy magnetization axis, while the magnetostatic interactions among nanowires in the array were analyzed by First-Order Reversal Curves, FORC, technique. The NWs segmentation determines a stepped magnetization reversal process (i.e., several susceptibility ranges) by propagation of a transverse domain wall. This fact is also confirmed by the FORC diagrams for the bi-and trisegmented nanowires, where an elongation parallel to the interaction axis around coercive field values is obtained, which is correlated to the difference in segmented diameter of the nanowires.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.02

Co₂MnX (X=Si, Ge, Ga, Al, Sn) Half-Metal Magnetic grown by Molecular Beam Epitaxy

C. Guillemard, S. Petit-Watlot, S. Andrieu, P. Le Fevre, F. Bertran, C. Rojas-Sanchez

Text Half Metal Magnets (HMM) are of great interest in spintronics because of their lack of density of states at the Fermi energy for minority spin. In other words, an HMM material is a metal for majority spins and an insulator for minority spins. Such properties lead to full spin-polarization at the Fermi energy and low magnetization damping. In theory, magnetic ternary alloys belonging to the Heusler compounds family can get this HMM behavior [1]. The HMM property was thus claimed for many Heusler alloys thin layers, despite any direct proof of the existence of the spin gap. Recently, we observed 100% spin polarization on the Co₂MnSi Heusler compound using SR-PES experiments performed on CASSIOPEE beamline at SOLEIL synchrotron source. More interestingly, we measured very low magnetic damping below 10⁻³ [2]. This peculiar behavior, predicted by theory, is of particular interest to switch the magnetization by using spin transfer torque for instance.

We will show that many Heusler compounds may be grown by Molecular Beam Epitaxy. We will present a new MBE set-up (called quaternary MBE) equipped with 24 sources. This MBE is coupled to a 40m long UHV tube, equipped with many characterization tools: Auger and X-ray spectroscopies, ARPES, Spin-resolved photoemission, in situ KERR magnetometry, AFM and STM. Spin-resolved phototemission and ferroamgnetic resonance results obtained on several Co₂MnX Heusler compounds with X=Si, Ge, Ga, Al, Sn, Sb, Al_xSi_{1-x} will be presented.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.03

X-ray magnetic circular dichroism discloses surface spins disorder in maghemite hollow nanoparticles

V. Bonanni, M. Basini, D. Peddis, A. Lascialfari, G. Rossi, P. Torelli

Text Iron oxide magnetic nanoparticles (MNPs) have received increasing attention due to their expanding application fields, from catalysis to biomedicine. The spins located at the MNPs surface play a crucial role in the magnetic response of these systems. Often the processes involving the surface spins depend not only on the uncompensated atomic structure, typical of the surface geometry, but also on a variation of the electronic state of the surface atoms related to processes like oxidation or contamination. The turn to element sensitive techniques like the x-ray absorption spectroscopy (XAS) and the x-ray magnetic circular dichroism (XMCD) offers to the scientist the capability of combining and exploring these two aspects. We have conceived a XMCD measurements procedure at low magnetic field (160 Oe) and at remanence in hollow (H) and full (F) maghemite NPs in order to disclose the presence of a reduced magnetic correlation among the spins of the H NPs system compared to the F one. The results show that the state of oxidation in the maghemite NPs is preserved in the F as well as in the H structures. Clear differences in the magnitude and in the lineshape of the XMCD spectra between F and H NPs emerge. By comparing XMCD measurements performed with a variable degree of surface sensitivity, we were able to address the specific role played by the surface spins in the magnetism of the NPs¹.

[1] V. Bonanni et al., Appl. Phys. Lett. 112, 022404 (2018)



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.04

FexMn1-x/PMN-PT magnetic configuration around ferromagnetic/antiferromagnetic transition

G. M. Vinai, F. Motti, V. Bonanni, G. Rossi, G. Panaccione, P. Torelli

Text Converse magnetoelectric coupling between a ferromagnetic (FM) and a ferroelectric (FE) layer allows modifying the magnetic response of the former by changing the polarization state of the latter [1]. In the last years, antiferromagnetic (AFM) layers have gained attention in such heterostructures replacing the FM one, because of their high data robustness [2]. It is in between these two cases that our study is focused. Here we investigate the magnetic response at the intermediate condition, i.e. close to the FM to AFM transition, when deposited onto a FE substrate.

To do so, we deposited thin films of FexMn1-x ($50 < x < 100$) on PMN-PT (001) substrates, with the x ratio spanning from the AFM to the FM response. MOKE measurements showed that the transition takes place around $x \approx 85$, with increasing coercivity and magnetic saturation at higher Fe concentrations. By means of x-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD) at Fe and Mn L_{2,3} edges, we observed an antiparallel alignment between the two elements, in contrast with what usually reported in similar FexMn1-x alloys on different substrates [3].

Ongoing studies by means of photoemission electron microscopy (PEEM) and Kerr microscopy are aiming at locally investigating the relative order of the two elements around the FM/AFM transition.

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.05

Cobalt magnetic moment in Co/Pd multilayers

N. Soriano, B. Mora, V. Rollano, C. Quirós, P. Gargiani, F. Gálvez, C. Redondo, E. M. González, I. Montoya, M. Vélez, M. Valvidares, J. L. Vicent, R. Morales

Text The Co magnetic moment was experimentally measured in Co/Pd multilayers with a different number of Co/Pd bilayer repetitions. For this systematic study, all the samples were fabricated by sputtering at room temperature, keeping constant the growing conditions and varying the number of Co (0.4 nm)/ Pd (0.6 nm) bilayers from $n = 2$ to 40. Both orbital and spin components of the Co magnetic moment were estimated from X-ray magnetic circular dichroism (XMCD) spectra. The analysis demonstrates that the total Co magnetic moment, given mainly by the spin contribution, is notably low for very thin multilayers ($n = 2$) and progressively increases with the number of repetitions, reaching a saturation value at $n = 10$. Similar trend is also observed for the orbital magnetic moment, which increases with n and scales with the perpendicular magnetic anisotropy of Co/Pd multilayers, providing a straightforward relationship between microscopic and macroscopic magnetic parameters. [1]

[1] Work supported by MINECO-AEI FIS2016-76058, UE FEDER "Una manera de hacer Europa"



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.06

Direct probe of electronic and magnetic properties at the g-Al₂O₃/SrTiO₃ interface

J. Mardegan, D. Christensen, Y. Chen, S. Parchenko, M. Decker, C. Piamonteze, N. Pryds, U. Staub

Text The two-dimensional electron gas (2DEG) confined at the interface between the two nonmagnetic band insulator materials g-Al₂O₃ (GAO) and SrTiO₃ (STO) has been investigated by means of x-ray absorption spectroscopy at the Ti L_{2,3} absorption edges.

X-ray magnetic circular dichroism (XMCD) measurements exhibit a surprisingly confined magnetism at the interface with the Ti 3d orbitals developing a localized 3d¹ moment. Magnetization curves measured at low temperature display a saturation of the magnetic moments above 3 T with a null coercive field which might indicate a paramagnetic or metamagnetic state for the Ti ions.

The Ti 3d orbital configurations are also probed via x-ray linear dichroism (XLD). Multiplet calculations and experimental data reveal a large crystal field splitting of ~2 eV between the t_{2g} and e_g states for the Ti 3d₀ orbitals. Remarkably, we found that the out-of-plane subbands (dx_z/dy_z) for the t_{2g} states are comparable or even lower in energy relative to the in-plane (dxy) which is in contrast to the LaAlO₃/STO material.

These findings allow for a better understanding of the confined magnetism at the interfaces of nonmagnetic materials and shed some light on the high electron mobility observed for the GAO/STO systems.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.07

Insights into magnetic proximity effects at topological insulators/magnetic insulator interfaces using x-ray magnetic circular dichroism

A. I. Figueroa, F. Bonell, M. G. Cuxart, M. Valvidares, A. Mugarza, S. O. Valenzuela

Text Magnetic proximity effects (MPE) at topological insulators (TIs) interfaced with magnetic insulators (MI) are fundamental for observation of exotic magneto-electric phenomena, as well as incorporation of TIs into future electronic and spintronic devices. Recent works have reported topologically enhanced interface magnetism on TI/MI structures, such as the Bi₂Se₃/EuS system [F. Katmis et al., Nature 533, 513 (2016)]. Unravelling the microscopic origin of these MPE requires the use of characterization techniques that provide information at the local level. Thus, we have performed x-ray magnetic circular dichroism (XMCD) measurements on (Bi,Sb)₂(Se,Te)₃/EuS heterostructures. A negligible magnetic signal (below the detection limit of the XMCD technique) was found on Bi, Sb, Te or Se atoms of the TIs in contact with EuS, at temperatures and conditions where the latter is magnetic and could polarize these non-magnetic atoms. Our work provides essential information concerning MPE of TI/MI heterostructures that has been challenging to obtain with other characterization methods. It suggests that signatures observed in magneto-electric transport measurements do not originate from induced ferromagnetic order on the TI atoms at the TI/MI interface as several works conclude.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 8

SP5.8.08

Altering magnetic and electronic properties of 3d metal ions in cuboid palladate nanoshells by hydrogenation

C. Schmitz-Antoniak, N. V. Izarova, N. Svechkina, A. Smekhova, D. Schmitz

Text Cuboid-shaped polyoxopalladates hosting either Fe³⁺ (3d⁵) or Co²⁺ (3d⁷) ions in their centres have been investigated by means of x-ray absorption spectroscopy at the L_{3,2} absorption edges of the 3d elements. While the x-ray absorption near-edge structure (XANES) contains already important information on the valence states, the x-ray magnetic linear dichroism (XMLD) and x-ray magnetic circular dichroism (XMCD) were used to refine the quantification of the crystal fields related to the eight oxygen ions surrounding the central ions in the as-prepared state by comparison with simulations using the CTM4XAS program. Element-specific effective spin and orbital magnetic moments were derived by a sum-rule based analysis of the XMCD.

After a soft hydrogen plasma treatment, the Fe ions were reduced from the 3d⁵ to a 3d⁶ state while the Co ions stay in their 3d⁷ configuration. However in both cases, drastic changes of the crystal fields and a reduction of the magnetic moments by 30-40% were obtained. The results are in line with the observed change in the visual appearance and analysed differences in the nephelauxetic effect.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5 - Parallel Session 9

SP5.9.01

Band structure modification and the origin of magnetism in (Ga,Mn)As: from paramagnetic through superparamagnetic to ferromagnetic phase

O. Yastrubchak, N. Tataryn, L. Gluba, J. Z. Domagała, T. Wosinski, J. Zuk, J. Sadowski, M. Sawicki

Text Our research are aimed at the optimization of the low-temperature molecular-beam epitaxy (LT-MBE) growth conditions to fabricate epitaxial (Ga,Mn)As layers with the lowest level of undesirable defects, such as arsenic antisites and Mn interstitials. The 100 nm thick (Ga,Mn)As layers have been prepared at approximately 230°C on semi-insulating (001) GaAs substrates with the LT-MBE growth technique, with the Mn contents ranging from 0 to 1.6%. The high-spectral-resolution optical studies of the energy gap evolution, supplemented with electronic, magnetic, and structural characterization, show that the modification of the GaAs valence band caused by Mn incorporation occurs already for a very low Mn content, much lower than that required to support ferromagnetic spin–spin coupling in (Ga,Mn)As. Only for n-type (Ga,Mn)As with the Mn content below about 0.3% the Mn-related extended states are visible as a feature detached from the valence-band edge and partly occupied with electrons. The combined magnetic and low-temperature photoreflectance studies presented here indicate that the paramagnetic↔ferromagnetic transformation in p-type (Ga,Mn)As takes place without imposing changes of the unitary character of the valence band with the Fermi level located therein. The whole process is rooted in the nanoscale fluctuations of the local (hole) density of states and the formation of a superparamagnetic-like state.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5.9.02

Anisotropic spin-orbit torques in single crystal IrMn/Co/Pt and Pt/Co/Pt thin film multilayers

K. Lee, G. V. Karnad, A. Wells, R. Khan, T. Moore, M. Kläui

Text For magnetic memory devices, the efficient manipulation of magnetization is a key requirement. The main mechanisms for this have changed from utilizing magnetic fields that entail poor scaling to using currents and resulting spin transfer torque (STT). However, the efficiency of adiabatic STT is limited leading to problems in operating magnetic memory devices quickly. Recently, a new and more efficient method of current induced effects has been found which utilizes the spin-orbit coupling and transfer orbital angular momentum, called spin-orbit torque (SOT)¹⁻⁴.

There have been many theoretical and experimental studies on SOTs recently¹⁻⁴, however using polycrystalline multilayer stacks. To allow a comparison to theory and for a possibility to tune the torques we study the effective fields generated by SOTs in single crystal IrMn/Co/Pt and Pt/Co/Pt films using the second harmonic⁵. We have made Hall bars in different directions relative to the crystalline directions. By measuring the SOTs for different angle orientation, we observed the effect of the crystalline structure of Pt and IrMn on the SOTs. A angular dependence could be observed in the fieldlike and dampinglike effective fields with a variation of a factor 5.

1 I. M. Miron et al., Nat. Mater. 9, 230 (2010) 2 K. Garello et al., Nat. Nanotechnol. 8, 587 (2013) 3 R. Lo Conte et al., Phys. Rev. B 91, 014433 (2015) 4 T. Schulz et al., Appl. Phys. Lett. 107, 122405 (2015) 5 T. Schulz et al., Phys. Rev. B 95, 224409 (2017)



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5.9.03

Temperature dependent spin polarization in EuO thin film investigated by high resolution ARPES

T. Heider, T. Gerber, P. Lömker, C. M. Schneider, L. Plucinski, M. Müller

Text The ferromagnetic insulator EuO is predicted to show 100% spin polarization at the valence band maximum, which makes this material a prototype candidate for research in the field of spintronics. Our goal is to interface it with a topological insulator to introduce time-reversal symmetry breaking without an external magnetic field.

As a first approach we studied MBE growth of EuO on Cu(001), because Cu is a very good electrical conductor, thus, ideally suited as an aid for charging problems in band mapping from an insulating thin film. After we could narrow down the EuO synthesis to a very small parameter window, in which single-crystalline growth is mastered, we performed temperature dependent high resolution spin-ARPES measurements. A non-vanishing spin polarization of the O 2p band as well as up to 52% in the Eu 4f band could be obtained. Furthermore the temperature dependence of the Eu 4f polarization can be described by the Brillouin function and confirm the literature value of TC = 69 K



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5.9.04

Development of superparamagnetism in solution of iron oxide nanoparticles examined with RIXS-MCD

J. Kuciakowski, A. Kmita, J. Zukrowski, M. Gajewska, S. Lafuerza, K. Pitala, D. Koziej, M. Sikora

Text Magnetic properties of iron oxide nanoparticles were probed in solution using hard X-ray spectroscopy, providing a measure of the first critical radius, namely the size limit between paramagnetism and superparamagnetism. Particles of diameter less than 10 nm were obtained in thermal decomposition of iron (III) acetylacetonate in a non-aqueous solution. Samples obtained at different stages of the reaction were examined ex-situ using vibrating sample magnetometry to measure magnetic moment of particles and correlate it with size distribution measured in transmission electron microscopy.

Magnetic photon-in photon-out spectroscopy, namely magnetic circular dichroism of 1s2p resonant inelastic x-ray spectroscopy (RIXS-MCD) was employed to probe the development of iron magnetization on reacting solution in-situ. High energy resolution of RIXS spectra results in well-defined spectral features, which can be ascribed to specific local properties. Edge and pre-edge shape analysis gives information on the evolution of formal oxidation state and the local symmetry of iron ions, while magnetic circular dichroism is proportional to magnetic ordering of iron moments. These results can be directly related to structure development and, based on diameter vs. reaction time calibration obtained from ex-situ characterization, to size of the nanoparticles at the characteristic stages of reaction.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5.9.05

X-ray magneto-optical effects quadratic in magnetization - Voigt and XMLD

D. Legut, H.-C. Mertins, A. Gaupp, P. M. Oppeneer

Text We report investigations of x-ray magneto-optical effects quadratic in magnetization using first-principle calculations and experimental data on bcc Fe and fcc Ni. By means of polarization analysis the Voigt rotation and ellipticity of linearly polarized synchrotron radiation is measured for Ni, Fe films at the L2 and L3 edges upon transmission. The same spectra are calculated using first-principle calculations and solving Fresnel equations using multi-layered Yeh's formalism [1]. On the basis of ab initio calculations it is shown that the x-ray Voigt effect follows sensitively the amount of spin polarization of the 2p core states. Therefore it provides a unique measure of the spin splitting of the core states. The x-ray magnetic linear dichroism is obtained from calculated intensity spectra in reflection and transmission. A highly anisotropic XMLD signal at the L2 and L3 edges is observed, which origin is analyzed in detail. The XMLD anisotropy is shown to be a consequence of the cubic crystal-field split density of 3d states, which are selectively probed by transitions from the spin-orbit and exchange-split 2p core levels. The relation between the asymmetry of XMLD is related to the 2*Voigt rotation [2,3].

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SP5 - Parallel Session 9

Spin Diffusion-Enhanced Non-Adiabatic Spin Torque in Rare-Earth-Doped Permalloy determined by Direct SEMPA Imaging

P. Krautscheid, R. M. Reeve, D. Schönke, I. Boventer, A. Conca, A. V. Chumak, B. Hillebrands, J. Ehrler, J. Osten, J. Fassbender, M. Kläui

Text State-of-the art data storage devices such as MRAM rely on spin-transfer torque switching of the magnetization. The dynamics are described by an extended Landau-Lifschitz-Gilbert equation including current-induced torques and containing both damping and non-adiabaticity parameters, α and β . While α is relatively well understood, the contributions to β and its relation to α remains under debate. Here we investigate the relation between β and α in Py based micro-disks. High resolution imaging of current-induced vortex core displacement via SEMPA for different initial states yields β , with a large value of 0.067 ± 0.014 found for undoped Py, as previously seen for vortex cores (PRL 117, 277203 (2016)). Next we engineer the damping via rare-earth doping. We find that with increasing damping α , a clear trend to higher β is seen: $\beta = 0.29 \pm 0.15$ is determined for 1.7% Dy doping. Yet β/α remains roughly constant, supportive of a similar scaling of α and β here, which would indicate that there is a related origin between the spin relaxation which is the basis of nonadiabatic transport and the dissipation of angular momentum that provides damping. Furthermore the results indicate that in addition to the previously determined contribution of the magnetization gradient to the non-adiabaticity, there is a significant contribution of spin relaxation processes for the non-adiabatic spin torque in the case of rare-earth dopants, highlighting avenues for property tailoring in future devices.



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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5.9.07

Nanostructures akin to graphene as attractive candidates for spintronic applications

S. Krompiewski

Text Graphene is well known for its extraordinary electronic and mechanical properties. Additionally it has been shown that graphene's magnetic properties are also interesting due to its long spin diffusion length [1], and theoretically expected and experimentally demonstrated, spontaneous spin-polarization of graphene nanoribbon's zigzag edges (see [2] and references therein). Yet, it has recently been shown that there is a wide class of other quasi 2-dimensional graphenelike nanomaterials which in many respects can outperform graphene. Here the attention is directed to silicene, germanene, stanene and phosphorene, i.e. nanosystems of buckled (puckered) honeycomb structures, having finite bandgaps. It is shown that these materials constitute a great promise for spintronics [3].

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SP 5 Magnetic thin films, surface, interfaces, and nano-structured low dimensional systems

SP5 - Parallel Session 9

SP5.9.08

CMR effect in La_{1-x}Sr_xMnO₃ nanowire networks

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Text We fabricated nanowire networks of La_{1-x}Sr_xMnO₃ with different doping levels x via electrospinning [1] and a subsequent thermal treatment. Scanning electron microscopy revealed an average diameter of the resulting nanowires of around 220 nm and a length of more than 50 μ m, forming the network structure with numerous interconnects. The individual nanowires are polycrystalline with a grain size of about 15-20 nm, as observed by transmission electron microscopy.

Analyses of the electronic transportation properties and of the magnetoresistive effects of the nanowire networks were carried out by four-probe measurements in external magnetic fields up to 10 T, in order to investigate the high-field magnetoresistance behavior which sheds light on the influence of the sample microstructure via the interface response [2]. SQUID measurements of $M(T)$ and $M(H)$ were carried out as well, revealing the soft magnetic character of the nanowires.

We employed the transmission electron-backscattering diffraction (t-EBSD) technique [2] to obtain details on the grain and grain boundary arrangement within an individual nanowire. The t-EBSD technique allows a proper analysis of samples with nanometer-sized grains. The grains are oriented randomly as indicated by the large amount of grain boundaries with high misorientation angles.

References

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