MA 46: Magnetic Thin Films I

Time: Thursday 15:00–18:30 Location: H 1012

MA 46.1 Thu 15:00 H 1012

Microscopic analysis of the composition driven spin-reorientation transition in Ni_xPd_{1-x}/Cu(001) — •Daniel M. Gottlob[1], Hatice Doğanay[1], Florian Nickel[1], Stefan Cramm[1], Ingo P. Krug[1,2], Slavomír Nemšák[1], and Claus M. Schneider[1,3] — [1]Peter Grünberg Institut 6, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Institut für Optik und Atomare Physik, Technische Universität Berlin, 10623 Berlin, Germany — [3]Fakultät für Physik and Center for Nanointegration Duisburg-Essen (CeNIDE), Universität Duisburg-Essen, 47048 Duisburg, Germany

The composition driven spin-reorientation transition (SRT) has been investigated in the thin film system Ni_xPd_{1-x}/Cu(001) by photoemission microscopy (PEEM) utilizing the x-ray magnetic circular dichroisim (XMCD) effect at the Ni $L_{2,3}$ edge. The magnetic domain structure and its development has been investigated on microwedges grown in the integrated preparation chamber by molecular beam epitaxy and characterized in-situ. By alloying palladium into nickel the epitaxial strain of a thin film may be varied and the critical film thickness at which an SRT occurs can be controlled. A composition driven SRT could be identified between 37 ML and 60 ML film thickness and 0 to 38 atomic % of Pd. The domain structure in the vicinity of the SRT shows comparable behavior to ultrathin film SRTs, however, additional influences of magnetic in-plane anisotropies could be observed, resulting in a domain alignment along the in-plane easy axis. The SRT is found to take place by a continuous canting of the magnetization axis.

MA 46.2 Thu 15:15 H 1012

Topological defect evolution and transverse instability in magnetic stripe domain patterns — •Michael Zimmermann, Thomas Meier, Matthias Kronseder, and Christian Back — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Deutschland

Magnetic phase transitions in ultra thin films have long been the subject of extensive studies. Particular interest has been dedicated to the spin reorientation transition found in some ultra thin magnetic films with perpendicular anisotropy. Here, the evolution of stripe domain patterns into less ordered phases (i.e. disordered phase) is investigated. Emphasis is placed on the development of topological defects within single stripe domains when heated. The generation of topological defects is closely related to the effect of transverse instability. To quantitatively describe the domain state, numerical order parameters are used. Besides heating, also cooling experiments have been conducted. Thereby the inverse effect of transverse instability could be observed. We use a laboratory based imaging technique with high spatial resolution, which is threshold photoemission magnetic circular dichroism (TP-MCD) in combination with photoemission electron microscopy (PEEM). All measurements were conducted on ultra thin Ni/Fe/Cu(001) and Fe/Ni/Cu(001) samples, since both offer an out-of-plane magnetization direction if the layer thicknesses are chosen properly.

MA 46.3 Thu 15:30 H 1012

Quantification of fluctuations of domain patterns in ultrathin ferromagnetic films — •Thomas Meier, Michael Zimmermann, Matthias Kronseder, and Christian Back — Institut für experimentelle und angewandte Physik, Universität Regensburg, Deutschland

Magnetic phase transitions in ultrathin ferromagnetic films have been subject to intensive studies in the last decades. If the magnetic film exhibits a perpendicular magnetic anisotropy either caused by surface and interface effects or magnetoelastic anisotropy due to a lattice mismatch in epitaxial growth, a spin-reorientation transition (SRT) may take place. Here the SRT of epitaxially grown Fe/Ni/Cu(001) or Ni/Fe/Cu(001) ultrathin films is investigated. We use a laboratory based imaging technique based on the threshold photoemission magnetic circular dichroism (TP-MCD) effect in combination with photoemission electron microscopy (PEEM). This technique provides a high spatial as well as high temporal resolution allowing for the observation of fluctuations of the domain pattern in real time. We quantify fluctuations of the domain pattern in the vicinity of the SRT using the magnetic susceptibility as well as the variance of the total domain wall length calculated on a sequence of images recorded at the PEEM-setup and analyzed via an automatized image processing approach. The fluctuations of the domain pattern are investigated depending on temperature and external out-of-plane magnetic fields.

MA 46.4 Thu 15:45 H 1012

Correlation of magnetic moment and lattice expansion in γ'-Fe_4N thin films — •Dominik Gölden, Imants Dirba, Erwin Hildebrandt, Philipp Komissinskiy, Oliver Gutfleisch, and Lambert Alff — Institute of Materials Science, Technische Universität Darmstadt, Germany

γ'-Fe_4N is the most stable phase among the iron nitrides and can be grown in a wide temperature range. It has been in the focus of research for several decades due to its physical properties such as low electrical resistance, low coercivity, and relatively high saturation magnetization, making it interesting for application in magnetic tunnel junctions. We report on the correlation of the lattice expansion and the magnetic moment of γ'-Fe_4N thin films grown by molecular beam epitaxy on single crystal MgO(100) substrates and give an estimate of the Curie temperature. In addition, the electronic properties were studied by X-ray photoelectron spectroscopy to show the influence of the interstitial nitrogen on the electronic structure in the γ-Fe lattice. By changing the nitridation conditions using a nitrogen radical source, the lattice constant of γ'-Fe_4N could be varied in a wide range. We have correlated nitridation parameters during thin film growth with the structural and magnetic properties using X-ray diffractometry and SQUID magnetometry.

MA 46.5 Thu 16:00 H 1012

Increased magnetic moment induced by lattice expansion from α-Fe to α'-Fe_8N — Imants Dirba[1], Philipp Komissinskiy[1], Dominik Gölden[1], Oliver Gutfleisch[1,2], and •Lambert Alff[1] — [1]Institute of Materials Science, Technische Universität Darmstadt, 64287 Darmstadt — [2]Fraunhofer-Projektgruppe für Wertstoffkreisläufe und Ressourcenstrategie IWKS, 63457 Hanau

We have grown buffer-free and epitaxial α-Fe and α'-Fe_8N_x thin films by RF magnetron sputtering and molecular beam epitaxy onto MgO (100) substrates. The film thicknesses and densities have been determined with high accuracy by evaluating the Kiessig fringes of X-ray reflectometry measurements allowing a precise volume estimation. A gradual increase of the nitrogen content in the plasma led to an expansion of the iron bcc unit cell along the [001] direction resulting finally in a tetragonal distortion of about 10% corresponding to the formation of α'-Fe_8N. The α-Fe lattice expansion was accompanied by an increase in magnetic moment to $2.61 \pm 0.06\,\mu_B$ per Fe atom, and an increase in anisotropy of around 6000 Oe. Our experiments show that - without requiring any additional ordering of the nitrogen atoms - the lattice expansion of α-Fe itself is the origin of the increased magnetic moment in α'-Fe_8N.

MA 46.6 Thu 16:15 H 1012

Strain induced magneto-optical anisotropy in epitaxial hcp Co-films — •Jon Ander Arregi, Juan Bautista González-Díaz, Olatz Idigoras, and Andreas Berger — CIC nanoGUNE Consolider, Donostia San Sebastian, Spain

In nearly all magneto-optical Kerr effect (MOKE) studies, it is assumed for the sake of simplicity that the strength of the magneto-optical coupling factor Q is independent from the magnetization orientation. This is generally understood to be a reasonable assumption for metallic systems, and very few experimental studies have observed only modest deviations from this assumption [1,2].

Here, we investigate the existence and origin of magneto-optical anisotropy in epitaxial hcp Co-films. By employing the generalized magneto-optical ellipsometry (GME) technique [3], we find that the amplitude of magneto-optical anisotropy is strongly correlated with the growth induced crystallographic strain, observing that this anisotropy is very much reduced upon structural relaxation towards the bulk for the thicker films. In addition, we find that the strain state variation produces a redistribution of the first- and second-order magnetic anisotropy fields, while the total saturation field of the films remains basically unaltered. The possibility to tune the magneto-optical anisotropy of the Co-films by engineering their strain state is briefly discussed.

[1] D. Weller *et al.*, *Phys. Rev. Lett.* **72**, 2097 (1994)
[2] D. Schmidt *et al.*, *Appl. Phys. Lett.* **102**, 123109 (2013)
[3] J. A. Arregi *et al.*, *J. Appl. Phys.* **111**, 103912 (2012)

15 min. break

MA 46.7 Thu 16:45 H 1012

Evidenceof Antiferromagnetic Exchange Interaction in Fe Films on Rh(001) — •Yang Meng[1], Khalil Zakeri Lori[1], Arthur Ernst[1,2], Tzu-Hung Chuang[1], Huajun Qin[1], Ying-Jiun Chen[1], and Jürgen Kirschner[1,3] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]Wilhelm Ostwald Institut für Physikalische und Theoretische Chemie, Universität Leipzig, Linnéstr. 2, 04103 Leipzig, Germany — [3]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany

Magnetic properties and high-energy magnon excitations in ultrathin Fe films on Rh(001) are studied by means of magneto-optical Kerr effect and spin polarized high resolution electron energy loss spectroscopy, respectively. The magnon dispersion relation is probed over a large region of the surface Brillouin zone. A strong magnon softening is observed at the high symmetry $\bar{M}$–point, indicating a large antiferromagnetic (AFM) exchange interaction in the films. First-principles calculations showed that this unusual AFM exchange interaction has its origin not only in the strong interfacial electronic hybridizations between the Fe film and the Rh substrate but also in the tetragonal distortion of the film, caused by the film epitaxy. Our results shed light on the long standing question regarding the possibility of having an AFM exchange interaction in Fe films.

MA 46.8 Thu 17:00 H 1012

Thickness-dependent magnetic domain structure of Fe films on Rh(001) — •Stefan Wilfert, Jeannette Kemmer, Pin-Jui Hsu, and Matthias Bode — Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We have investigated the thickness-dependent magnetic domain structure of epitaxial Fe films on Rh(001) by means of spin-polarized scanning tunneling microscopy (SP-STM) at low-temperature ($T = 5$ K). In agreement with earlier density functional theory calculations [1,2] we find a first atomic layer (AL) that exhibits a perpendicular antiferromagnetic spin structure equivalent to a c(2×2) checkerboard pattern. In the Fe thickness range between 1 AL and 3.5 AL the film consists of out-of-plane ferromagnetic domains, as proposed by Takada *et al.* [3]. We find that the domain size quickly decreases with increasing thickness. The data will be discussed in terms of competing contributions to the magnetic anisotropy.

[1] D. Spišák and J. Hafner, Phys. Rev. B **73**, 155428 (2006).
[2] A. Al-Zubi *et al.*, Phys. Rev. B **83**, 024407 (2011).
[3] M. Takada *et al.*, J. Magn. Magn. Mater. **329**, 95 (2013).

MA 46.9 Thu 17:15 H 1012

Layer-resolved in-situ ^{57}Fe conversion electron Mössbauer spectroscopy (CEMS) on 4 ML Fe(001)/Ir(001) at 30 K — •Sergey Makarov[1,2], Werner Keune[1,2], Heiko Wende[1], and Jürgen Kirschner[2] — [1]Faculty of Physics and CeNIDE, University of Duisburg-Essen — [2]Max Planck Institute of Microstructure Physics

Our recent in-situ ^{57}Fe Mössbauer spectroscopy (CEMS) measurements in UHV on the Fe(001)/Ir(001) system have provided experimental prove of magnetic order in Fe(001)/Ir(001) ultrathin films below four atomic Fe monolayers (< 4 ML) at 30 K, and the average spin canting angle $<\Theta>$ (rel. to the surface normal direction) was extracted. The result is consistent with a ground state helical spin configuration in 2 ML and 3 ML Fe(001)/Ir(001) [1]. Moreover, the existence of two inequivalent Fe sites in terms of fct and bct Fe was discussed [2].

In the present work we focus on in-situ ^{57}Fe CEMS measurements of layer-dependent magnetic ordering in homogeneous 4 ML Fe(001)/Ir(001) films resolved by a 2 ML ^{57}Fe probe layer placed at different positions with respect to Ir(001). We conclude that site 1 of fct Fe has a higher abundance near the Fe/Ir interface than in the rest of the film (the opposite is valid for site 2 of bct Fe). We observe a weak tendency for a layer-dependence of the angle $<\Theta>$. The sum spectrum of all tracer layers agrees well with the spectrum of a homogeneous 4 ML ^{57}Fe(001)/Ir(001) film.

[1] A. Deák et al., Phys. Rev. B **84** (2011) 224413
[2] V. Martin et al., Phys. Rev. B **76** (2007) 205418

MA 46.10 Thu 17:30 H 1012

Non bulk-like magnetoelastic coupling in Fe monolayers on Ag (001) — •Kenia Novakoski Fischer, Dirk Sander, and Jürgen Kirschner — Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle

Film strain contributes significantly to the magnetic anisotropy of atomic layers via the magnetoelastic coupling B_i [1]. The magnetoelastic coupling coefficient B_1 is experimentally accessible from measurements of the magnetoelastic stress change upon a magnetization reorientation along the <100> film directions. We present results of magnetoelastic stress measurements of 30 layers of Fe on Ag (001). We find that a reduced growth temperature of 150 K as compared to 300 K influences both epitaxial film stress and magnetoelastic stress. For growth at 300 K we find $B_1 = +25 MJ/m^3$ and for growth at 150 K $B_1 = +3.8 MJ/m^3$. This differs in sign and magnitude from the respective bulk value $B_1^{bulk} = -3.4 MJ/m^3$. This result in conjunction with previous studies [2,3] indicates that intermixing at the Fe-Ag interface needs to be considered for growth at 300 K. Our results shed fresh light on the role of lattice strain and intermixing on the resulting magnetoelastic coupling.

[1] D. Sander, Rep. Prog. Phys. 62 (1999) 809. [2] R.J. Hicken, S.J. Gray, A. Ercole, C. Daboo, D.J. Freeland, E. Gu, E. Ahmad, J.A.C. Bland, Phys. Rev. B 55 (1997) 5898. [3] M. Canepa, P. Cantini, O. Ricciardi, S. Terreni, and L. Mattera, Surface Science 429 (1999) 34.

MA 46.11 Thu 17:45 H 1012

Magnetic properties of iron nanostructures fabricated with electron beam induced deposition — •Fan Tu, Martin Drost, Florian Vollnhals, Esther Carrasco, Andreas Späth, Rainer Fink, Hans-Peter Steinrück, and Hubertus Marbach — Physikalische Chemie II, Universität Erlangen-Nürnberg, Egerlandstr.3, D91058, Germany

In the mask-less, "direct writing" technique, electron beam induced deposition(EBID), a focused electron beam is used to locally decompose precursor molecules on a surface. The non-volatile decomposition products form a deposit, while the volatile fragments are pumped off. With iron pentacarbonyl, we are able to fabricate ferromagnetic iron nanostructures with controlled shape and high purity (>95%) in our ultra high vacuum system. By controlling the electron dose and the autocatalytic growth time, we can fabricate clean nanostructures with arbitrary thickness [1,2]. The nanostructures have been investigated at the PoILux beamline at the Swiss Light Source with Scanning Transmission X-ray Microscopy. X-ray Magnetic Circular Dichroism contrast enables to image magnetic domains of the individual deposits while applying a variable magnetic field. The corresponding magnetic properties can be quantified.

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[1] F. Vollnhals, et al., Beilstein J. Nanotech., 5 (2014) 1175.
[2] H. Marbach, Appl. Phys. A., 117 (2014) 987.

MA 46.12 Thu 18:00 H 1012

Fe_3Si/Ge thin film stacks on GaAs(001) subtrates: An annealing study — •Jochen Kalt, Bernd Jenichen, and Jens Herfort — Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

Multilayer stacks consisting of ferromagnetic metals and semiconductors are promising candidates for the realisation of spintronic device concepts. Implemantable structures feature highly orderd interfaces as well as semiconductor thin films of high crystal quality. Due to considerably different growth temperatures and chemical reactions at the interface, the overgrowth of a metal by a semiconductor requires sophisticated methods in order to achieve both of these features.

This report presents recent results in processing MBE grown Fe_3Si/Ge thin film stacks with a post-growth in-situ annealing step. 9 nm of amorphous Germanium were grown at $T_G = 150\,^\circ$C on top of stochiometric Fe_3Si/Ge on GaAs(001) subtrates. Subsequent annealing with temperatures ranging from 240 °C to 380 °C was done in order to crystallize the film, where the crystallisation process was in-situ monitored by RHEED. AFM measurements show an optimally smooth Germanium surface for an annealing temperature of $T_A = 320\,^\circ$C and an annealing time of 10 min. For $T_A \geq 330\,^\circ$C rough surface structures emerge, while for $T_A \leq 330\,^\circ$C rather smooth surfaces form, with thin bars dominating the surface morphology. XRR measurements reveal

a high interface quality up to $T_A = 330\,^{\circ}\mathrm{C}$. XRD analysis indicates a new phase for $T_A \geq 330\,^{\circ}\mathrm{C}$, namely Fe_3Si. Analysis of the in plane magnetic properties of the Fe_3Si/Ge-layer shows that with increasing T_A saturation magnetization and remanence decrease.

MA 46.13 Thu 18:15 H 1012

Reversible control of magnetism in Fe and FePt/Fe films by voltage induced phase changes — •Kenny Duschek[1,2], Sebastian Fähler[1], Heike Schlörb[1], Margitta Uhlemann[1], and Karin Leistner[1] — [1]Leibniz Institute for Solid State and Materials Research, Dresden, Germany — [2]Hochschule für Technik und Wirtschaft, Dresden, Germany

Voltage control of magnetism in thin films is of key interest for microelectromechanical systems, like sensors or actuators. In FePt and CoPt films, voltage induced faradaic reactions in the native iron oxide layer result in changes in anisotropy and magnetization [1]. As a model system promising even larger magnetization changes we here investigate 2 - 10 nm Fe films charged in 1 M KOH electrolyte. Depending on the applied potential we reversibly reduce the surface layer to Fe or oxidize it to iron oxide. This way we achieve a voltage induced change of saturation magnetization of 23 % for 10 nm, 40 % for 5 nm and 64 % for 2 nm Fe films. Combining this functional Fe layer with an underlying hard magnetic L10-FePt (001) layer, a significant voltage induced change of perpendicular anisotropy is achieved. The results show that electrochemical reactions can be used to tune surface magnetic properties in a large manner, to even switch magnetism on or off or induce a spin reorientation.

[1] K. Leistner, J. Wunderwald, N. Lange, S. Oswald, M. Richter, H. Zhang, L. Schultz, and S. Fähler, Phys. Rev. B 87 (2013) 224411