MA 9: Magnetic Particles, Clusters

Time: Monday 15:15–19:30 Location: H23

MA 9.1 Mon 15:15 H23

Magnetic properties of NiO nanoparticles investigated by SQUID and magnetic Raman scattering — •Farrakh Shahzad[1], Peter Knoll[1], Karl Ettinger[2], Kashif Nadeem[1], Heinz Krenn[1], Gabor Kozma[4], Akos Kukovecz[4], Zoltan Konya[4], Ilse Letofsky-papst[3], Karin Pressl[1], and Petra Granitzer[1] — [1]Institute of Physics , Karl-Franzens University, graz, austria — [2]institute of earth sciences, karl-franzens university, Graz, Austria — [3]Technical University, Graz, Austria — [4]Department of applied and environmental chemistry, University of Szeged, Hungary

We have measured the magnetization of NiO Nanoparticles with sizes ranging from 4nm-85nm by SQUID magnetometer. The Nanoparticles were prepared by Sol-gel and ball milling techniques. However, these measurements are very sensitive to induced small magnetic moments but do not directly measure the anti-ferromagnetic ordered spin pairs. This can be done by magnetic Raman scattering. Temperature-dependent magnetic Raman spectra for NiO single crystal are well known and understood, in which two-magnon peak (2M) is due to the anti-ferromagnetic nature of this material. In our measurements for Nanoparticles of diameter 40nm, 2M peak is not present at room temperature but appears at certain lower temperature range and then again disappears at very low temperature. For Nanoparticles of diameter 85nm, this peak is present at room temperature but still not present at very low temperature. 2M peak is not observed at any temperature for particles having diameter less than 40nm. These new experimental results will be presented within the so for established models.

MA 9.2 Mon 15:30 H23

Alloying of Co nanoparticles on differently oriented films and its influence on magnetic properties — •Luyang Han[1], Ulf Wiedwald[1], Johannes Biskupek[2], Ute Kaiser[2], and Paul Ziemann[1] — [1]Institut für Festkörperphysik, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]Materialwissenschaftliche Elektronenmikroskopie, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm, Germany

It has been reported previously [1,2] that ultra-thin Co film deposited on top of a Pt single crystal at elevated temperature will form a $Co_{1-x}Pt_x$ alloy near the surface. Here, we investigate the local formation of $Co_{1-x}Pt_x$ alloys starting from a self assembled array of Co nanoparticles (diameter 3 nm and 8 nm) deposited on Pt(001) and Pt(111) films by micellar method [3]. AFM and SEM investigations show a gradual decrease of particle sizes when the particles are annealed above 500 K, while TEM reveals that a few monolayer thick alloy is formed around the particles, whose crystalline orientation is defined by underlying Pt film. The magnetic properties are characterized by means of SQUID magnetometry and XMCD. We observe an increase of both the coercive field and induced Pt magnetic moment after annealing at 570 K. XPS and XMCD reveals a reduced amount of Co after annealing at 770 K, indicating the start of long range diffusion.

[1]S. Ferrer et al., *Phys. Rev. B*, **56**, 9848, (1997)
[2]M. Pan et al., *J. Vac. Sci. Technol. A*, **23**, 790, (2005)
[3]A. Ethirajan et al., *Adv. Mater.*, **19**, 406, (2007)

MA 9.3 Mon 15:45 H23

Spin and orbital moments of small size-selected FePt clusters — •Torben Beeck, Ivan Baev, Kai Chen, Steffen Fiedler, Michael Martins, and Wilfried Wurth — Institute for Experimental Physics, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

Size-selected Fe_xPt_y alloy clusters $(x, y = 1, 2)$ were deposited in situ under UHV conditions and soft landing. The substrate was a well defined and remanent magnetized Ni thin film evaporated upon a small Cu(100) crystal. The system was investigated in an element specific way at the Fe $L_{2,3}$ absorption edges by means of x-ray magnetic circular dichroism (XMCD) at the UE52 SGM beamline, BESSY II. Our aim was to determine separately the size and composition dependent spin and orbital moments by applying sum rules.

The results show an increase of the magnetic moments by adding Pt ligands to the Fe cluster. Especially the orbital moment is enhanced.

Because of the limited cluster sizes the experimental results are, in contrast to bigger systems, good candidates for complex theoretical calculations.

This work is supported by the DFG in the framework of the SFB 668 subproject A7.

MA 9.4 Mon 16:00 H23

Cross-over between spin-glass freezing and blocking in $NiFe_2O_4$ nanoparticles — •Kashif Nadeem and Heinz Krenn — Institute of Physics, Karl-Franzens University Graz, Universitätsplatz 5, A-8010 Graz, Austria

Single-phase $NiFe_2O_4$ nanoparticles (8-27nm) dispersed in SiO_2 matrix have been prepared by sol-gel method. Disorder and core-shell interaction induces surface spin-glass like freezing which is manifested by a low temperature peak in the AC susceptibility well separated from magnetic blocking peak. The spin-glass freezing peak vanishes as the particle size grows (>18nm). Exchange bias is present down to 8nm particle sample which indicates the existence of core-shell interactions. For 8nm sample, Arrhenius model is fitted to the frequency dependent AC susceptibility data and it gives spin-flip time τ_o~2.10^{-12} sec and activation energy E_A/k_B = 370 K. The dynamic scaling law is also fitted to the same data and it yields: T_o = 11 K, τ_o~10^{-05} sec and zv = 7.5 (which lies in spin-glass regime zv = 4-12). In the presence of DC field (10-500 Oe) in AC susceptibility, the freezing peak (T_f = 13 K) does not shift but the blocking peak (T_b = 233 K) moves towards lower temperature and finally collapses into the freezing peak as the DC field is increased. Time dependent TRM shows a non-monotonic behaviour in the vicinity of freezing peak which is consistent with the sharp increase of coercivity in the same temperature regime. Our system also exhibits memory effects. All these measurements demonstrate the presence of blocking/unblocking at high temperatures and core-shell mediated spin-glass like freezing at low temperatures.

MA 9.5 Mon 16:15 H23

Structural and Magnetic Deconvolution of $FePt/FeO_x$-Nanoparticles using X-Ray Magnetic Circular Dichroism — •Daniela Nolle[1], Eberhard Goering[1], Giesela Schütz[1], Albert Figuerola[2], and Liberato Manna[2] — [1]MPI for Metals Research, Heisenbergstrasse 3, 70569 Stuttgart, Germany — [2]IIT, Via Morego, 30 16163 Genova, Italy

In order to analyse the related magnetic and structural properties of bi-component nanoparticular systems we present XAS and XMCD studies at the Fe $L_{2,3}$-edges simultaneously performed in surface sensitive total electron yield (TEY) and bulk sensitive transmission mode, at room and low temperatures. This provides the separation of volume and surface related properties especially. The investigated systems were made up of $FePt/FeO_x$ hybrid nanoparticles of different diameters. A detailed deconvolution in terms of a linear superposition of suitable reference spectra (FePt, γ-Fe_2O_3, and Fe_3O_4) is presented. Absolute magnetic moments, determined by XMCD sum rule analysis, provide reliable and consistent magnetization values, in contrary to SQUID related results, due to the unknown size of the organic ligand shell around each nanoparticle. For the necessary magnetic characterization of these nanoparticles, SQUID results must be renormalized by the complementary XAS/XMCD investigations. Finally this method demonstrates the strength of simultaneously performed XMCD experiments using different scanning depth measurement modes for the investigation and characterization of nanoparticular systems, which are consistent and supplemental to corresponding SQUID measurements.

MA 9.6 Mon 16:30 H23

Templated self-assembly of Iron oxide nanoparticles in lithographically prepatterned tracks — •Oleg Petracic[1], Maria Jose Benitez[1,2], Durga Mishra[1], Philipp Szary[1], Frank Brüssing[1], Giovanni Badini Confalonieri[1], Matthias Feyen[2], Anhui Lu[2], Leonardo Agudo[3], Günther Eggeler[3], and Hartmut Zabel[1] — [1]Experimentalphysik IV, Ruhr-Universität Bochum, D-44780 Bochum — [2]Max-Planck Institut für Kohlenforschung, D-45470 Mülheim an der Ruhr — [3]Institute for Materials, Department of Materials Science, Ruhr-Universität Bochum, 44780 Bochum

Magnetic nanostructures hold the potential for numerous applications, e.g., in magnetic data storage, logic devices, sensors or bio-medical applications. In particular, magnetic nanoparticles are in the focus of huge interest, because they could serve as building blocks for future

high-density data storage media and spintronics. We report on self-assembled Iron oxide nanoparticle films on silicon substrates. Furthermore, using electron beam lithography we fabricate patterned trenches of 40-1000nm width for assisted self-assembly. The nanoparticles with a diameter of 20 nm +/- 1.6 nm were synthesized by thermal decomposition of iron oleate complexes in trioctylamine in presence of oleic acid. Samples with different track widths and nanoparticle concentration have been characterized by magnetometry, X-ray diffraction and high resolution transmission electron microscopy.

MA 9.7 Mon 16:45 H23

NdFeB nanoparticles prepared by wet-milling — •Juliane Thielsch, Julia Lyubina, Thomas Woodcock, Ludwig Schultz, and Oliver Gutfleisch — IFW Dresden, P.O. Box 27 01 16, D-01171 Dresden

Since the prediction of a giant energy product of textured nanocomposite magnets [1] those materials where believed to be the next generation of permanent magnets. For effective exchange-coupling in such two-phase magnets grain sizes need to be in the range of the domain wall width of the hard magnetic phase. That makes a homogenous phase distribution and a microstructure with nanograins necessary. One option of preparing such materials is the synthesis of magnetic nanoparticles which further could be aligned and compacted to a bulk magnet. For this we performed wet-milling experiments of a NdFeGaNbB alloy. XRD studies revealed that by using a surfactant and a solvent during the high energy ball milling process amorphization sets in later than compared to dry milling experiments under the same conditions. Dynamic Light Scattering investigations showed a Gauss distribution of the particle size with a mean diameter of about 12nm which was also proven by TEM. Magnetic properties were measured with SQUID and showed so far rather poor coercivity values.

[1] R. Skomski and J.M.D. Coey, Phys. Rev. B, 1993, 48:15812

MA 9.8 Mon 17:00 H23

Magnetic nanoparticle arrays in 2-D and 3-D investigated with specular and diffuse X-ray scattering — •Durga Mishra[1], Maria Jose Benitez[1,2], Oleg Petracic[1], Frank Brüssing[1], Philipp Szary[1], Giovanni Badini Confalonieri[1], Matthias Feyen[2], Anhui Lu[2], Leonardo Agudo[3], Günther Eggeler[3], and Hartmut Zabel[1] — [1]Experimental Physik IV, Ruhr Universität Bochum, D-44780 Bochum — [2]Max-Planck-Institut für Kohlenforschung, D-45470 Mülheim an der Ruhr — [3]Institute for Materials, Department of Materials Science, D-44780 Bochum

Magnetic (single domain) nanoparticles show promising potential for future nanotechnology applications. The novel applications manifest itself depending on the size and shape distribution of the nanoparticles which in turn affects the arrangement in 2-D or 3-D lattice structure. We report here the X-ray investigation of continuous array of 20nm diameter Iron Oxide nanoparticles spin coated on Si substrate (monolayer and multilayer). The in-plane hexagonal ordering and the out of plane superlattice structure were investigated with GISAXS and X-ray reflectivity measurements. A Grazing Incidence Diffraction (GID) study shows a mixed phase of iron oxide with different crystal structures (fcc and inverse spinel) due to annealing. The Zero Field Cooling (ZFC) and Field Cooling (FC) magnetization curves support the X-ray observation and show an exchange bias effect due to a core/shell structure, which was confirmed by TEM dark field imaging. This paves a way for tuning the magnetic and electronic properties without changing the ordering of the self organization.

MA 9.9 Mon 17:15 H23

Manipulation of the magnetic properties of Co nanoparticles by Pt or Pd capping — •Astrid Ebbing[1], Oleg Petracic[1], Olav Hellwig[2], Leonardo Agudo[3], Gunther Eggeler[3], and Hartmut Zabel[1] — [1]Experimentalphysik IV, Ruhr-Universität Bochum, 44780 Bochum — [2]San Jose Research Center, Hitachi Global Storage Technologies, San Jose, California 95135, USA — [3]Institute for Materials, Department of Materials Science, Ruhr-Universität Bochum, 44780 Bochum

We have prepared self-assembled Co nanoparticles with a diameter of approximately 3 nm by sputter-deposition on alumina buffer layers and investigated the effect of capping with different amounts of Pt or Pd. The magnetic properties have been studied using a superconducting quantum interference device (SQUID) magnetometer and magneto-optic Kerr effect as function of the nominal thickness of the capping material. Structural characterization has been performed by employing transmission electron microscopy (TEM) and atomic force microscopy (AFM). Co particles covered only by the Al2O3 protection layer show regular superparamagnetic behavior with a blocking temperature of T_B = 22 K. However, the Pt or Pd cap layer strongly modifies the magnetic properties and shifts the blocking temperature to higher values. E.g. for a nominal Pt capping thickness of 0.7 nm the system becomes even ferromagnetic with a Curie temperature of approx. 487 K.

15 min. break

MA 9.10 Mon 17:45 H23

Magnetic Properties of Fe and Co Clusters on Aluminum Oxide on $Ni_3Al(111)$ — •Andreas Buchsbaum[1], Pardeep Kumar Thakur[2], Alexei Preobrajenski[3], Edvin Lundgren[4], Michael Schmid[1], and Peter Varga[1] — [1]Institut für Angewandte Physik, Technische Universität Wien, Austria — [2]ID08, ESRF, Grenoble, France — [3]MAX-lab, Lund — [4]Division of Synchrotron Radiation Research, Lund University, Sweden

The structure of the aluminum oxide on $Ni_3Al(111)$ with a $(\sqrt{67} \times \sqrt{67})R12.2°$ unit cell can be used to grow well ordered arrays of Fe and Co clusters [1]. The size of these clusters can range from 1 up to ≈1000 atoms before reaching the limit of coalescence. We have investigated the magnetic properties of Fe clusters (≈900 atoms/cluster) and Co clusters (≈500 atoms/cluster) using x-ray magnetic circular dichroism (XMCD), assisted by scanning tunnelling microscopy (STM). This technique allowed us to measure the orbital and spin contribution to the magnetic moment per Fe or Co atom, as well as hysteresis curves down to temperatures of 7 K and up to fields of 5 T. From fitting the hysteresis curves we found clusters with a tilted easy axis in both cases and contributions of different cluster species in accordance to STM. Co clusters are superparamagnetic down to 7 K and Fe clusters are ferromagnetic below ≈50 K. The anisotropy energy is slightly higher than for bulk Fe or Co.

[1] M. Schmid, et.al., Phys. Rev. Lett. 99, 196104 (2007).

MA 9.11 Mon 18:00 H23

Magnetism of small Cr clusters: Structure, magnetic order and electron correlation effects — •Pedro Ruiz Díaz, Jose Luis Ricardo Chávez, Jesús Dorantes Dávila, and Gustavo Pastor — Institut für Theoretische Physik, Universität Kassel, Heinrich Plett Str. 40, 34132 Kassel, Germany

The magnetic properties of small Cr_N clusters ($N \leq 6$) are investigated in the framework of density-functional theory (DFT). The interplay between electron correlations, cluster structure and magnetic order is quantified by performing fully non-collinear spin-unrestricted calculations. Results obtained using the spin-polarized local density approximation (LDA) and the generalized-gradient approximation (GGA) are contrasted. A dimer-based growth pattern is found in all considered low-lying isomers, with very short equilibrium bond lengths (typically $d_{eq}^{\rm GGA}$ =1.55-1.65 Å) alternating with relative long ones (typically $d_{eq}^{\rm GGA}$ =2.75-2.85 Å). Strong local magnetic moments $\vec{\mu}_i$ are obtained for the relaxed geometries which show a *collinear* magnetic order with antiparallel (parallel) alignment of the $\vec{\mu}_i$ along the short (long) bonds. Despite quantitative differences, both LDA and GGA functionals yield collinear ground-state solutions for the fully relaxed structures, non-collinear spin arrangements are found only for particular highly symmetric (non dimerized) geometries. The present work demostrates that the magnetic frustration in compact Cr clusters, is solved by *dimerization* rather than by non-collinearity of the local moments. Finally, implications of the present trends for the ground-state structure and magnetism of larger Cr_N clusters are discussed.

MA 9.12 Mon 18:15 H23

Magnetism, structure and chemical order in small FeRh clusters — •Junais Mokkath and Gustavo Pastor — Institut für Theoretische Physik, Universität Kassel, Heinrich Plett Straße 40, 34132 Kassel, Germany.

The structural, electronic and magnetic properties of small Fe_mRh_n clusters having $N = m+n \leq 8$ atoms are investigated in the framework of a generalized gradient approximation to density-functional theory. The optimized cluster structures are compact with a clear tendency to maximize the number of nearest-neighbor FeRh pairs. For very small sizes the low-lying isomers present a different topology than the optimal structure, while for larger clusters the lowest-energy isomerizations imply mainly changes in the chemical order. The correlation between structure, chemical order, and magnetic behavior is analyzed as a func-

tion of size and composition. For all clusters having the optimized most stable structure the magnetic order is found to be Ferromagnetic-like, Antiferromagnetic-like spin arrangements were found in some low-lying isomers. The average magnetic moment per atom $\overline{\mu}_N$ increases approximately linearly with Fe content. A remarkable enhancement of the local Fe moments is observed as result of Rh doping. This is a consequence of the increase in the number of Fe d holes, due to FeRh charge transfer, combined with the extremely reduced local coordination. The Rh local moments, which are important already in the pure clusters ($N \leq 8$) are not significantly enhanced by Fe doping. However, the overall stability of magnetism– as measured by the total energy gain upon spin polarization at $T = 0$– increases when Rh is replaced by Fe.

MA 9.13 Mon 18:30 H23

Magnetic properties and anisotropy energies of deposited transition metal clusters on Pt(001) and Pt(111) surfaces — •Sanjubala Sahoo, Markus E. Gruner, Alfred Hucht, and Peter Entel — Faculty of Physics, University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

Magnetic properties of transition metal (TM) clusters of Fe, Co, Ni and in particular, Fe-Pt deposited onto (001) and (111) surfaces of Pt are studied because of their importance in technology as possible data storage devices. We perform ab-initio structure optimization and finite temperature molecular dynamics using the Vienna Ab-initio Simulation Package (VASP) [1]. In addition, We have studied the magneto-crystalline anisotropy energy of free and deposited Fe, Co and Ni clusters. Calculations on free clusters show that for small elemental clusters of 13 atoms, (distorted) icosahedral structures are energetically favorable. We have studied supported icosahedral and cuboctahedral clusters on Pt(001) and Pt(111) surface for different starting orientations of clusters. Binary Fe-Pt clusters have large magneto-crystalline anisotropy in $L1_0$ structure. It is hence interesting to see whether this structure is stable when deposited on Pt surface, keeping in mind that Pt(001) and Pt(111) have different surface energies [2], which can influence the structure and magnetic properties of the deposited clusters. [1] G. Kresse, and J. Joubert, Phys. Rev. B. 59, 1758 (1999). [2] A. Dannenberg, M. E. Gruner, A. Hucht, and P. Entel, Phys. Rev. B (2010), in print

MA 9.14 Mon 18:45 H23

Synthesis and magnetic properties of carbon-coated FeRu, CoRu, and NiRu nanoalloys — •A.A. El-Gendy, V.O. Khavrus, S. Hampel, A. Leonhardt, R. Klingeler, and B. Büchner — Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Germany

Carbon coated FeRu, CoRu and NiRu nanoalloys have been synthesised by high pressure chemical vapour deposition (HPCVD). The formation of the core-shell nanoalloys with a mean diameter around 8 nm has been confirmed by means of high resolution transmission electron microscopy imaging (HRTEM), energy dispersive X-ray (EDX) analysis, and X-ray diffraction (XRD. We show the effect of the synthesis parameters on the actual composition of the nanoalloys and on their magnetic properties and we discuss their feasibility for applications in medical hyperthermia.

MA 9.15 Mon 19:00 H23

Magnetic and structural properties of TiO2 - FeCo nanocomposite — •Amit Kulkarni[1], Vladimir Zaporojtchenko[1], Thomas Stunkus[1], Franz Faupel[1], Eckhard Quandt[2], Venkata sai kiran Chakravadhanula[3], and Lorenz Kienle[3] — [1]Institute for Materials Science - Multicomponent Materials, Faculty of Engineering, Christian-Albrechts University at Kiel — [2]Institute for Materials Science - Synthesis and Real Structures, Faculty of Engineering, Christian-Albrechts University at Kiel — [3]Institute for Materials Science - Inorganic Functional Materials, Faculty of Engineering, Christian-Albrechts University at Kiel

Composite films of TiO2 as an insulator and FeCo as a ferromagnetic component with different metal volume fractions (MVF) were prepared by co-sputtering. High resolution transmission electron microscopy (HRTEM) analysis reveals that the microstructure of the TiO2/FeCo nanocomposites depends on the MVF. Amorphous nanocomposites are formed at lower MVF whereas FeCo crystallites are present at higher MVF. Likewise, the magnetic characteristics of these films depend on the MVF. At low MVF, composite films contain single domain particles exhibiting superparamagnetism whereas at high MVF FeCo forms percolating network of crystallites resulting in enlargement of the hysteresis loop. These composite films show a considerable tunnel magneto resistance of 5 % at RT and could be interesting as low cost magnetic field sensors.

MA 9.16 Mon 19:15 H23

The role of the tip material for switching fields measured by spin polarized STM — •yasmine nahas[1], safia ouazi[1], marco corbetta[1], fabio donati[1,2], hirofumi oka[1], sebastian wedekind[1], guillemin rodary[1], dirk sander[1], and jürgen kirschner[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany — [2]CNISM, NEMAS and Dipartimento di Energia - Politecnico di Milano, Milano, Italy

Spin polarized scanning tunneling microscopy (SP STM) enables us to probe the magnetism of single objects down to the single atom level. Switching fields of individual Co islands on Cu(111) were already measured using Cr coated W tips [1]. We study the same system using bulk Cr tips fabricated by standard electrochemical etching [2]. The switching fields of Co islands measured with a bulk Cr tip are consistently larger as compared to those obtained with Cr coated W tips. Whereas we measured with the Cr coated W tip a typical switching field of 0.6 T for a Co island with 1800 atoms at 8 K, we measure 1.2 T for an island of the same size using the bulk Cr tip. This surprising result is discussed in view of the role of the island size, temperatures, the island environment and tip material for the magnetic switching field.

[1] G. Rodary et al., Jpn. J. Appl. Phys. 47, 9013 (2008).
[2] A. Li Bassi et al., Appl. Phys. Lett. 91, 173120 (2007).