MA 3: Magnetic Semiconductors

Time: Monday 10:15–13:00 Location: H 1012

MA 3.1 Mon 10:15 H 1012

Influence of correlation effects on the magnetic properties of half-metallic ferromagnets — •Stanislav Chadov[1], Jan Minár[1], Hubert Ebert[1], Mikhail Katsnelson[2], and Alexander Lichtenstein[3] — [1]Dept. Chemie und Biochemie, Physikalische Chemie, Universität München, Butenandtstr. 5-13, D-81377 München, Germany — [2]Institute for Molecules and Materials, Radboud University Nijmegen, NL-6525 ED Nijmegen, The Netherlands — [3]Institute of Theoretical Physics, University of Hamburg, Germany

In contrast to the Heisenberg magnets and itinerant ferromagnets an interesting feature of the half-metallic Heusler alloys is that the Rodes-Wolfarth ratio can be essentially smaller than unity. This property can be used for their preliminary experimental identification. We present results for magnetic moments of the half-metallic ferromagnets calculated within the relativistic full potential Korringa-Kohn-Rostoker (KKR) method. Particular attention is paid to the influence of local correlation effects which make a noticeable influence on the reduction of the local magnetic moment with increase of the temperature. Local correlations are taken into account within the framework of the Dynamical Mean Field Theory (DMFT) combined with the KKR in a fully self-consistent scheme. The relativistic version of the DMFT solver used in the present work allows to take the temperature dependence of the local correlations explicitly into account. A comparison of theoretical results with corresponding experimental data is presented.

MA 3.2 Mon 10:30 H 1012

First-principles studies on dilute magnetic semiconductor based on ZnO — •Sanjeev Nayak[1], Alfred Hucht[1], Peter Entel[1], Masako Ogura[2], and Hisazumi Akai[2] — [1]Physics Department, University of Duisburg-Essen, Duisburg Campus, 47048 Duisburg, Germany — [2]Department of Physics, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan

First-principles density functional theory is used to study the electronic properties of transition metal doped ZnO. Based on the experimental observation for low doping concentrations, only the substitutional doping of transition metal atoms in ZnO is considered. Our results shows spin-glass type of state for magnetic arrangement of Co spins as the lower energy state. Addition of on-site correlation energy in terms of Hubbard U, and the exchange coupling constants of cobalt spins suggest no long-range magnetic order in the diluted limit case. Our results can be compared to recent experiments, where no ferromagnetism has been observed in the system. Thus, this poses the questions whether ferromagnetism in the system can be from secondary phases?

MA 3.3 Mon 10:45 H 1012

Magnetic and structural properties of nanocrystals embedded in semiconductors — •Shengqiang Zhou, Kay Potzger, Johannes v. Borany, Wolfgang Skorupa, Manfred Helm, Jörg Grenzer, and Jürgen Fassbender — Forschungszentrum Dresden-Rossendorf, Bautzner Landstrasse 128, 01328 Dresden

Traditional electronics can be greatly stimulated by an additional degree of freedom, i.e. the electron spin. In diluted magnetic semiconductors (DMS), transition metal (TM) ions are substituted onto cation sites of the host semiconductor. In case of magnetic coupling via the free charge carriers, spin polarized currents can be generated. However, most experimental investigations have only concentrated on reporting a high Curie temperature (T_C) and interpreted the observed ferromagnetism in terms of DMS without detail structural characterization. In this work, TM implant-doped ZnO, TiO_2 and Si samples are described by correlating magnetic and structural properties [1-2]. By means of synchrotron radiation x-ray diffraction, phase separations (Fe, Ni, Co and Mn-silicide nanocrystals) are observed. Those are the origin of the observed ferromagnetism. Depending on their crystalline structure, those nanocrystals are crystallographically oriented with respect to the host matrix. If they are randomly oriented, these nanocrystals are very difficult to detect by a simple Bragg-Brentano scan. This nature results in the pitfall of using XRD to exclude secondary phases in DMS materials.

[1] Shengqiang Zhou, et al., J. Appl. Phys. 100, 114304 (2006).
[2] Shengqiang Zhou, et al., J. Phys. D: Appl. Phys. 40, 964 (2007).

MA 3.4 Mon 11:00 H 1012

X-band magnetic resonance investigation of wide band gap dilute magnetic semiconductors — •Tom Kammermeier[1], Verena Ney[1], Shuangli Ye[1], Subhabrata Dhar[2], Klaus Ploog[2], Fang-Yuh Lo[3], Andreas Wieck[3], Tiffany Kaspar[4], and Scott Chambers[4] — [1]Experimentalphysik, Universität Duisburg-Essen, Duisburg — [2]Paul-Drude-Institut, Berlin — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum — [4]Pacific Northwest National Laboratory, Richland, Washington USA

ZnO and GaN are the most prominent wide band gab semiconductors expected to show ferromagnetic behaviour when doped with transition metals or rare earths. Although intensely studied by several groups the experimental results are inconsistent up to now [1,2]. We present electron paramagnetic resonance (EPR) studies on Co:ZnO, Gd:ZnO and Gd:GaN, respectively. Different growth techniques enable investigations of magnetic resonance properties in relation to structural quality and dopant content. Here we discuss magnetic anisotropies caused by crystal fields and/or phase separation as well as temperature dependencies. As EPR is a very sensitive technique for investigation of any kind of paramagnetic impurities, we can compare our findings with models favouring an interplay of the dopant with defects as the origin of ferromagnetic like behaviour in these materials [3].

[1] S. Dhar et al, Appl. Phys. Lett. 89, 062503 (2006) [2] A. Ney et al., Appl. Phys. Lett. 90, 252515 (2007) [3] S. Dhar et al., PRL 94, 037205 (2005)

MA 3.5 Mon 11:15 H 1012

Element specific investigations of the strutural and magnetic properties of Co-doped ZnO — •Katharina Ollefs[1], Shuangli Ye[1], Verena Ney[1], Tom Kammermeier[1], Andreas Ney[1], Fabrice Wilhelm[2], Andrei Rogalev[2], Tiffany Kaspar[3], and Scott Chambers[3] — [1]Fachbereich Physik, Universität Duisburg-Essen, Duisburg, Germany — [2]Pacific Northwest National Laboratory, Richland, Washington, USA — [3]ESRF, Grenoble, France

Element specific structural and magnetic properties of the dilute magnetic semiconductor (DMS) Co:ZnO were studied using synchrotron radiation in the hard x-ray regime. It was shown by means of x-ray linear dichroism (XLD) measurements at the Co and Zn K-edge that the local crystallographic environment of both Cobalt and Zinc is the wurtzite structure of the ZnO bulk material, and virtually all Co dopant atoms are incorporated on cation lattice sites. The respective XLD spectra were simulated employing the FDMNES code [1] using the multiple scattering formalism within the muffin tin approximation. Various samples fabricated with different preparation methods display significant differences in the local structural quality. X-ray magnetic circular dichroism (XMCD) and the corresponding element specific hysteresis at the Co K-edge reveal pure paramagnetic behaviour for samples of high structural quality. This is corroborated by SQUID measurements. Similar results are known for the DMS Cr:TiO_2 [2].

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[1] Y. Joly, Phys. Rev. B **63**, 125120 (2001)
[2] T.C. Kapar *et al.*, Phys. Rev. Lett. **95**, 217203 (2005)

MA 3.6 Mon 11:30 H 1012

Ferromagnetism and magnetic clusters in cobalt-doped ZnO — Matthias Opel[1], Karl-Wilhelm Nielsen[1], Sebastian Bauer[1], •Sebastian T. B. Goennenwein[1], Rudolf Gross[1], Júlio C. Cezar[2], Dieter Schmeisser[3], Jürgen Simon[4], and Werner Mader[4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]European Synchrotron Radiation Facility, Grenoble, France — [3]Angewandte Physik II, Brandenburgische Technische Universität Cottbus, Germany — [4]Institut für Anorganische Chemie, Rheinische Friedrich-Wilhelms-Universität Bonn, Germany

Ferromagnetic semiconductors (FMS) - i.e. semiconductors exhibiting long-range magnetic ordering - are intriguing materials. However, in spite of intensive research in the last decade, the existence of homogeneous FMS with a Curie temperature around or above room temperature still is controversial. A particularly tedious issue are local sample inhomogeneities or magnetic clusters, which can yield strong magnetic signals resembling the behaviour expected for a homogeneous FMS. Using pulsed laser deposition, we have grown cobalt-doped ZnO films on single crystalline ZnO substrates. Combining x-ray magnetic circu-

lar dichroism, DC magnetometry, and AC susceptibility measurements with a detailed structural analysis by high resolution x-ray diffraction, transmission electron microscopy, and electron-spectroscopic imaging, we can unambigously trace the characteristic, ferromagnetic-like behaviour of our ZnO:Co samples at room-temperature to nanometer-sized superparamagnetic metallic cobalt precipitates.

MA 3.7 Mon 11:45 H 1012

Induced Ferromagnetic Order at Room Temperature in (Ga,Mn)As — F. Maccherozzi[1], •M. Sperl[2], G. Panaccione[2], M. Hochstrasser[3], G. Rossi[1,4], J. Minár[5], S. Polesya[5], H. Ebert[5], U. Wurstbauer[2], G. Woltersdorf[2], W. Wegscheider[2], and C. H. Back[2] — [1]Laboratorio Nazionale TASC, INFM-CNR, in Area Science Park, S.S. 14, Km 163.5, I-34012, Trieste, Italy — [2]Institut für Experimentelle Physik, Univ. Regensburg, D-93040 Regensburg, Germany — [3]Laboratorium für Festkörperphysik, Wolfgang-Pauli-Strasse 16, ETH Hönggerberg, CH-8093 Zürich, Switzerland — [4]Dipartimento di Fisica, Univ. di Modena e Reggio Emilia, Via A. Campi 231/A, I-41100, Modena, Italy — [5]Department of Chemistry, Ludwig-Maximilians University Munich, Germany

The low Curie temperature of Diluted Ferromagnetic Semiconductors (DMS) has been an obstacle for the integration of DMS into electronic prototypes. Here we demonstrate that this disadvantage can be overcome by using ferromagnetic proximity polarization. We show that a thin layer of (Ga,Mn)As can be spin polarized at room temperature by the proximity to an iron layer. X-ray magnetic circular dichroism and superconducting quantum interference device magnetometry are used to study magnetic order in the iron film and in (Ga,Mn)As film. We conclude that the induced magnetic order in the (Ga,Mn)As layer extends over more than 2 nm, even at room temperature. Furthermore, we show by experiment as well as by theory that the magnetic moment of the Mn ions couples antiferromagnetically to the moment of the Fe layer.

MA 3.8 Mon 12:00 H 1012

Control of Magnetic Anisotropy by Strain Engineering in (Ga,Mn)As Nanostructures — •Jan Wenisch, Charles Gould, Lars Ebel, Jan Storz, Katrin Pappert, Manuel J. Schmidt, Christian Kumpf, Georg Schmidt, Karl Brunner, and Laurens W. Molenkamp — Physikalisches Institut, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Understanding and utilizing the magnetic properties of semiconducting materials is one of the key issues in the field of modern electronic device technology. In this presentation, we report control of magnetic anisotropy in ferromagnetic epitaxial (Ga,Mn)As by anisotropic strain relaxation. A thin MBE-grown, pseudomorphic (Ga,Mn)As layer is patterned lithographically into an array of 200nm x 100μm stripes, which induces a large degree of elastic strain relaxation perpendicular to the stripe axis, while retaining pseudomorphic conditions along this axis. We find that the magnetic anisotropy, which shows biaxial easy axes along [100] and [010] before patterning, is replaced by a hard axis in the direction of large elastic strain relaxation and a uniaxial easy axis along the stripes. We model the strain distribution in such nanostructures by finite element simulations and find the results to be in good agreement with real structures characterized by x-ray techniques. We anticipate that this technique of local, lithographic engineering of magnetism in (Ga,Mn)As nanostructures, especially when used in conjunction with simulations to optimize sample parameters, proves very useful for realizing novel spintronic memory and logic devices.

MA 3.9 Mon 12:15 H 1012

A non-volatile memory device based on locally engineered anisotropies in (Ga,Mn)As — •Kia Tavakoli, Katrin Pappert, Charles Gould, Jan Wenisch, Karl Brunner, Georg Schmidt, and Laurens W. Molenkamp — Physikalisches Institut (EP3), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Ferromagnetic semiconductors (FS) promise the integration of magnetic memory functionality and semiconductor information processing within the same material system. Recently we have shown that improvements in lithographic patterning enable the fabrication of a novel class of devices in which the anisotropy of many individual elements can be independently engineered [1]. Here, we present a first device application of anisotropy engineering; we consider two (Ga,Mn)As nanobars coupled via a small constriction and contacted with sub-micron sized Ti/Au-contacts [2]. The device behaves as a non-volatile memory element, where information can be written by setting the relative orientation of the magnetization of the nanobars, and read by measuring the constriction resistance.

[1] J. Wenisch et al., Phys. Rev. Lett. 99, (2007) 077201
[2] K. Pappert et al., Nature Physics 3, (2007) 573

MA 3.10 Mon 12:30 H 1012

Hydrogen in GaN:Mn — •Christoph Bihler, Tobias Graf, Mario Gjukic, Moritz Hauf, Martin Stutzmann, and Martin S. Brandt — Walter Schottky Institut, Technische Universität München, Garching, Germany

Post-growth hydrogenation is known to switch the ferromagnetic semiconductors GaAs:Mn and GaP:Mn from their ferromagnetic to a paramagnetic state via passivation of Mn acceptors. In the wide-bandgap material GaN, the $Mn^{2+/3+}$ charge transfer level is too deep for Mn to lead to effective p-type doping. Rather, a combination of optical absorption spectroscopy, elastic recoil detection and electron spin resonance (ESR) has led to the conclusion that Mn is predominantly in the 3+ oxidation state in this material. Nevertheless, a similar change of the oxidation state to 2+ by hydrogenation is expected, as found for GaAs:Mn and GaP:Mn. GaN:Mn with [Mn] $\approx 10^{20}$ cm^{-3} was subjected to hydrogenation in a remote DC hydrogen plasma for 2 hours at temperatures above 500°C. We find that the ESR signal intensity of substitutional Mn^{2+} is increased by a factor of about 3 after this treatment. Moreover, hydrogenated samples exhibit further anisotropic hyperfine-split ESR lines which can be explained via additional uniaxial crystal field contributions along the different Ga-N bond axes in the spin Hamiltonian. The latter are attributed to local lattice distortions caused by the formation of Mn-H complexes with the hydrogen atom incorporated in a bond-centred or back bonded position. The changes in the ESR spectra upon hydrogenation can be reversed via annealing for 1 hour at temperatures above 600°C.

MA 3.11 Mon 12:45 H 1012

Domain Wall Dynamics in GaMnAs — •Liza Herrera Diez[1], Matthias Rössle[1], Erhan Arac[1], Violetta Sessi[1], Fabrizio Arciprete[2], Ernesto Placidi[2], Axel Enders[1], Jan Honolka[1], and Klaus Kern[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [2]Dipartimento di Fisica, Università di Roma 'Tor Vergata' , Rome, Italy

GaMnAs is among the most prominent representatives of ferromagnetic semiconductor materials for spintronics. The linkage between carrier density and magnetic properties like Tc [1] and magnetic anisotropy enables the tuning of magneto-transport properties [2], which makes this material a potential candidate for the development of magneto-logic devices. However, the latter requires full control over magnetic reversal dynamics, which in most cases happens via the nucleation and propagation of domain walls.

Based on the energy landscape given by the interplay of biaxial and uniaxial anisotropy contributions in this material, we are able to directly observe and identify magnetization reversal processes mediated by 90° and 180° domain walls using Kerr microscopy as well as magneto-transport measurements.

Results obtained from the analysis of the nucleation and propagation processes give valuable information for controlling domain wall dynamics and for the development of single domain devices.

[1]T. Dietl, et al., Science 287, 1019 (2000).
[2]D. Chiba, M. Yamanouchi, F. Matsukura, H. Ohno, Science 301, 943 (2003).