MA 10: Spinelectronics/Spininjection in Heterostructures

Time: Monday 15:15–19:00 Location: H23

MA 10.1 Mon 15:15 H23

Remanent spin injection and spin density distribution in a spin FET structure — •Philipp Kotissek[1], Matthieu Bailleul[2], Matthias Sperl[1], Alexander Spitzer[1], Dieter Schuh[1], Werner Wegscheider[1], Christian Back[1], and Günther Bayreuther[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]IPCMS/GEMME, 23 rue du Loess, BP 43, 67034 Strasbourg, France

The spin field-effect transistor first proposed by Datta and Das is considered to be the paradigm of spintronic devices. Spin injection and detection are the main requirements for the implementation of such a device. Electric spin injection has recently been achieved by inserting a Schottky barrier or a tunnel barrier between a ferromagnetic metal source contact and the semiconductor. The detection techniques used up to now require large magnetic fields, or they only measure a transient component of the polarization. Here we introduce a novel optical spin detection method from a cleaved edge of the semiconductor wafer which allows us to visualize directly electrical spin injection into GaAs from a magnetically soft FeCo film at remanence. The spin polarization can be reversed by a small magnetic field. Moreover, we could quantitatively determine the dependence of the spin polarization of the current on the injection energy. The local spin density distribution in the semiconducting channel including depth profiles for different geometries can be directly accessed. This method will be particularly useful for the future development of semiconductor-based spintronic devices.

MA 10.2 Mon 15:30 H23

First-principles calculations of conduction electron's spin relaxation time — •Dmitry Fedorov, Peter Zahn, and Ingrid Mertig — Institut für Physik, Martin-Luther-Universität Halle, D-06099 Halle/Saale, Germany

To inject, transfer and detect spin currents in the framework of spintronics, it is decisive to know how long conduction electrons 'keep' their spin state. As it was proposed by Elliott [1] and Yafet [2] and later confirmed by any experimental investigations, the dominant relaxation mechanism at low temperatures is caused by spin-orbit interaction of the conduction electrons with impurities.

We have performed ab initio calculations of the spin relaxation time of conduction electrons in transition metals containing different types of impurities. A screened KKR Green's function method based on density functional theory was applied to these studies. The obtained results are in good agreement with conduction electron spin resonance (CESR) experiments.

[1] R.J. Elliott, Phys. Rev. **96**, 266 (1954)
[2] Y. Yafet, in Solid State Physics, Vol. 14, F. Seitz and D. Turnbull, Eds. (Academic Press, New York, 1963)

MA 10.3 Mon 15:45 H23

Exchange Interactions in Dilute Magnetic Semiconductors: Local Environment Effects — •Peter Dederichs[1], Kazunori Sato[2], and Hiroshi Katayama-Yoshida[2] — [1]IFF, Forschungszentrum Jülich, 52425 Jülich — [2]ISIR, Osaka University, Ibaraki, Osaka 567-0047, Japan

The ferromagnetism in dilute magnetic semiconductors like (Ga, Mn) As is due to the exchange interactions Jij between neighboring Mn impurities. The disorder in these systems is usually described by the powerful coherent potential approximation (CPA). Thus, the exchange interactions Jij are also usually calculated by applying Lichtenstein's formula and using the CPA Green function Gij between the sites i and j. Here we investigate the validity of this approach, by embedding a whole cluster of impurities around the atoms i and j into the CPA medium, and by explicitly calculating the resulting exchange interactions as a function of the disordered environment. We find large fluctuations of the Jij values depending on the positions of neighboring third and fourth impurities. Upon ensemble averaging significant deviations from the standard Lichtenstein-CPA formula are obtained, in particular for small distances i-j and small concentrations. However good agreement with the ensemble average is obtained, if we replace the Green functions by the one for the impurity pair (i, j) properly embedded in the CPA medium. We discuss the reason for the failor of the standard approach in the dilute limit.

MA 10.4 Mon 16:00 H23

First-principles studies on co-doping effects in dilute magnetic semiconductors — •Sanjeev Kumar Nayak[1], Markus Ernst Gruner[1], Hisazumi Akai[2], and Peter Entel[1] — [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

Dilute magnetic semiconductors are a special class of materials that have high spin polarization at the Fermi level, and hence are promising materials for spintronics applications. The occurrence of room temperature ferromagnetism in these materials makes it interesting for practical applications. Recently, giant magnetic moments per dopant atom in experiments for Co doped ZnO [1] and the Gd doped GaN [2] were observed. We present theoretical studies for Co doped ZnO and Gd doped GaN done using the density functional theory together with the PAW method using Vienna ab-initio simulation package. We explore co-doping with other elements like N and Al to study the influence of defects. Furthermore, transport calculations of these systems using the KKR-CPA-LDA aproach are presented.

[1] C. Song et al., Phys. Rev. B, 73, 024405 (2006)
[2] S. Dhar et al., Appl. Phys. Lett. 89, 062503 (2006)

MA 10.5 Mon 16:15 H23

Ultrafast spin and magnetization dynamics in diluted magnetic semiconductors — •Klaus Schmalbuch[1], Johannes Bongers[1], Bernd Beschoten[1], Gernot Güntherodt[1], Nicoleta Kaluza[2], Hilde Hardtdegen[2], Thomas Schäpers[2], Mariana Ungureanu[3], and Heidemarie Schmidt[3] — [1]II. Physikalisches Institut, RWTH Aachen and Virtuelles Institut für Spinelektronik VISel, Templergraben 55, 52056 Aachen — [2]Institut für Bio- und Nanosysteme IBN-1, Forschungszentrum Jülich, 52425 Jülich — [3]Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, 04103 Leipzig

GaN and ZnO are promising material systems for applications in spinelectronics, since they provide extended electron spin coherence times because of their weak spin-orbit coupling. Furthermore these materials might become room temperature ferromagnets upon magnetic doping. To explore the influence of magnetic dopants on the ultrafast spin and magnetization dynamics in these semiconductors, we performed optical fs-pump-probe measurements on Cr-doped GaN and Gd-doped ZnO samples.

The results for the magnetically doped samples are qualitatively different in both systems: electron spin coherence in GaN is not affected by doping Cr at low concentrations. In ZnO:Gd dephasing times of conduction electrons are reduced compared to undoped ZnO. In addition we observe high frequency coherence at ps time scales which arises from the coherent sp-d exchange interaction between the local Gd moments and the conduction electrons. *Work supported by HGF*

MA 10.6 Mon 16:30 H23

Thermal phase transformation and perpendicular exchange coupling of Co nanocrystals embedded in ZnO — •Shengqiang Zhou, Kay Potzger, Wolfgang Skorupa, Manfred Helm, and Jürgen Fassbender — 1Institute of Ion Beam Physics and Materials Research, Forschungszentrum Dresden-Rossendorf, P.O. Box 510119, 01314 Dresden, Germany

Recently, due to the potential application in spintronics, ferromagnet-semiconductor hybrid structures have attracted huge attention [1]. Large magnetoresistance was observed in GaAs consisting MaAs nanocrystals and granular ZnO/Co systems [2, 3]. Wide-band-gap semiconductors (e.g. ZnO) doped with transition metals were reported to be diluted magnetic semiconductors with Curie temperatures above room temperature [4]. However, the origin of the observed ferromagnetism is still controversial. In this work, Co nanocrystals (NCs) were formed inside ZnO by ion implantation. The Co NCs are crystallorgraphically oriented inside ZnO. The magnetic properties, e.g. anisotropy and blocking temperature, can be tuned by annealing. In the as-implanted and annealed (823 K) samples, Co NCs have been found and show superparamagnetism. After annealing at 923 K, the sample exhibits a much higher blocking temperature and shows a perpendicular exchange bias effect. The semiconducting ZnO consisting of Co NCs could be a promising hybrid for spin-injection. 1.Ohno, Semicond. Sci. Technol. 17, 275 (2002). 2.Wellmann, et al., App. Phys. Lett. 73, 3291 (1998). 3.Pakhomov, et al., J. App. Phys. 95, 7393 (2004). 4.MacDonald, et al., Nat. Materials 4, 195 (2005).

MA 10.7 Mon 16:45 H23

First-principles prediction of high Curie temperature for ferromagnetic bcc-Co and its relation to Co/MgO/Co magnetic tunnel junctions — •Phivos Mavropoulos, Marjana Ležaić, and Stefan Blügel — IFF, Forschungszentrum Jülich, Jülich, Germany

We determine from first principles the Curie temperature of bulk Co in the ground state hcp phase and the metastable fcc and bcc phases. For fcc-Co we found a Curie temperature of T_C(fcc-Co) = 1280 K, in reasonable agreement with experimental results. For bcc-Co, a Curie temperature of T_C(bcc-Co) = 1400 K is predicted. This suggests that bcc-Co/MgO/bcc-Co tunnel junctions offer high tunneling magnetoresistance ratios even at elevated temperatures, giving them an advantage over Fe/MgO/Fe junctions. T_C(bcc-Co) appears robust under tetragonalization upon epitaxial growth on MgO, in contrast to Fe for which T_C(bcc-Fe) is found to drop by more than 20% (from 970 K to 750 K) upon such a tetragonalization. We find that FeCo alloys have an even higher T_C, as high as 1660 K for ordered FeCo. We discuss the origin of these effects in terms of the electronic structure and densities of states. The Curie temperatures are calculated by mapping *ab initio* results to a Heisenberg model, which is solved by a Monte Carlo method.

MA 10.8 Mon 17:00 H23

Magnetic and transport properties of embedded magnetic cells for a front-end-of-line MRAM design — •Thomas Uhrmann[1], Theodoros Dimopoulos[1], Christoph Stepper[1], Ludwig Bär[2], Uwe Paschen[3], and Hubert Brückl[1] — [1]Austrian Research Centers GmbH - ARC, Nano System Technologies, Donau-City-Str. 1, 1220 Wien, Austria — [2]Siemens AG, CT MM1, Paul-Gossen-Str. 100, 91052 Erlangen, Germany — [3]Fraunhofer Gesellschaft, Finkenstrasse 61, 45057 Duisburg, Germany

A non-conventional, front-end MRAM design will be presented, based on spin-polarized current injection and detection by adjacent magnetic cells through the semiconductor. Magnetic cells of: tunnel barrier (MgO)/ ferromagnet (CoFe or CoFeB)/ capping, are sputtered on the properly doped Si, inside holes formed in SiO_2 dielectric.

Here we will focus on the characterization of the embedded sub-μm Metal/ Insulator/ Semiconductor(MIS)-tunneling diodes dedicated for spin injection and detection. The magnetic properties of the cells were characterized by magneto-optical Kerr effect, combined with micromagnetic simulations. The thermal stability of the multilayer was verified for annealing conditions up to 550°C. Finally, we used temperature dependent current-voltage and capacitance-voltage measurements to study the electrical transport properties of isolated cells and injector-detector pairs. From these measurements we extract information regarding the quality of the tunnel barrier/silicon interface, which is crucial in order to attain high current spin polarization in silicon.

We acknowledge support from the EU project EMAC-Strep 017412.

MA 10.9 Mon 17:15 H23

The effect of flash lamp annealing on Fe implanted ZnO single crystals — •Kay Potzger, Wolfgang Anwand, Helfried Reuther, Shengqiang Zhou, Georg Talut, Gerhard Brauer, Wolfgang Skorupa, Manfred Helm, and Jürgen Fassbender — Institute of Ion Beam Physics and Materials Research, Forschungszentrum Dresden-Rossendorf, P.O. Box 510119, 01314 Dresden, Germany

Doping of semiconductors with transition metals for the creation of diluted magnetic semiconductors (DMS) recently attracted great attention. For doping of the wide band gap semiconductor ZnO, high temperature processing often leads to diffusion and the formation of unwanted secondary phases. We investigate a combined approach far from thermal equilibrium, i.e. low temperature ion implantation combined with flash lamp annealing. Therefore, ZnO single crystals have been implanted with 3.6 at. % Fe at a temperature of 200 K and flash lamp annealed at a pulse length of 20 ms. For intermediate light power, the implantation induced surface defects could be annealed without creation of secondary phases within the implanted region. At the same annealing temperatures, however, ion beam induced open volume defects start to increase in size. Recrystallization is initiated for the highest light power applied, i.e. the ion beam induced lattice disorder reflected by the minimum channelling yield of Rutherford backscattering spectroscopy decreasing from 76 % to 46 % and the open volume defects are decreased in size. At the same time, the Fe3+ fraction increases at the cost of the Fe2+ states. Weak ferromagnetic properties are induced, that are mainly associated with nanoparticles.

MA 10.10 Mon 17:30 H23

Hot electron transport in fully epitaxial FeCo/Au/FeCo-spin-valves using (Scattering) Ballistic Electron Magnetic Microscopy — •Emanuel Heindl, Christian Back, and Johann Vancea — Department of Physics, Universität Regensburg, D-93040 Regensburg

The transport of nonequilibrium (hot) electrons in FeCo/Au/FeCo spin-valves epitaxially grown on n-GaAsP has been studied at room temperature by the local technique (scattering) ballistic electron magnetic microscopy BEMM (SBEMM).

A STM-tip injects hot electrons into the spin-valve (BEMM-mode), where they undergo spin-dependent scattering processes. Thus the inelastic decay of the nonequilibrium electrons varies for parallel and antiparallel magnetization configuration of the spin-valve. On our fully epitaxial FeCo/Au/FeCo spin-valves we obtained magnetocurrent effects of up to 600% and relative high transmission values compared to similar studies. Unwanted scattering processes within the spin-valve are reduced to a minimum due to its epitaxial structure.

By reversing the tunnel-voltage hot holes are injected into the spin-valve (scattering BEMM-mode). In this mode a signal can only be created via the excitation of electron hole pairs. This excitation spectroscopy (SBEMM) gives insights into the electron-electron-scattering processes within the spin-valve. On our epitaxial spin-valve we also found a dependence on the magnetization configuration of the spin-valve with magnetocurrents of several hundred percent.

MA 10.11 Mon 17:45 H23

Investigation of different Mn states in $Ga_{1-x}Mn_xAs$ by HX-PES — •Benjamin Schmid[1], Andreas Müller[1], Michael Sing[1], Jan Wenisch[2], Karl Brunner[2], Laurens Molenkamp[2], Wolfgang Drube[3], and Ralph Claessen[1] — [1]Lehrstuhl für Experimentelle Physik IV, Universität Würzburg, Germany — [2]Lehrstuhl für Experimentelle Physik III, Universität Würzburg, Germany — [3]HASYLAB, DESY, Hamburg, Germany

The complex interplay of ferromagnetic coupling and compensating effects in the diluted magnetic semiconductor (DMS) $Ga_{1-x}Mn_xAs$ ($x = 2-8\,\%$) is currently under intense discussion. Both the Curie temperature T_C and the carrier concentration induced by manganese hosted in the lattice at regular sites are reduced by interstiatial Mn. In order to minimize those defects for applications and investigate possible changes in the electronic structure under various chemical and physical surface treatments we performed bulk sensitive hard X-ray photoemission spectroscopy (HX-PES) at $h\nu = 4500\,\mathrm{eV}$. The enlarged inelastic mean free path of the photoelectrons provides an information depth of up to 5 nm. A comparison with the related system manganese arsenid, untreated and oxidized under controlled conditions, allows a direct observation of fingerprints associated with different valencies in the core levels.

MA 10.12 Mon 18:00 H23

Proof of coherent electrical spin injection across a Fe/GaAs interface — •Lars Schreiber[1], Sebastian Schulz[1], Bernd Beschoten[1], Gernot Güntherodt[1], Christoph Adelmann[2], Paul Crowell[2], and Chris Palmstrøm[2] — [1]2. Physikalisches Institut, Aachen University, Germany and Virtual Institute for Spinelectronics — [2]University of Minnesota, Minneapolis, USA

Electrical spin injection from a ferromagnet into a semiconductor was shown for different material systems [1,2] and recently even high injection efficiency for electron spins has been achieved [3]. Despite this progress, an essential ingredient for spintronics is still missing: electrical injection of *coherent* spin packets. In all-optical time-resolved measurements, coherent spins can be readily oriented using 100 fs circularly polarised laser pulses and probed by means of time-resolved Faraday rotation (TRFR) [4]. However, no time-resolved measurement of electrical spin injection has been successfully performed yet.

Therefore, we apply ns-current pulses in order to electrically inject short spin packets from a Fe injector through a reverse biased Schottky barrier into 5 μm thick bulk n-GaAs, which exhibits long spin relaxation time. Probing the injected spins in the GaAs layer with TRFR, we observe spin precession and resonant spin amplification [4] in a transverse magnetic field. This proofs the phase-coherence of the electrical injected spin packet. The result will be compared to all-optical TRFR measurements. Supported by BMBF FKZ 13N8244 and HGF.

[1] Y. Ohno, Nature **402** (1999) [2] H. J. Zhu, PRL **87** (2001)
[3] C. Adelmann, PRB **71** (2005) [4] J. M. Kikkawa, PRL **80** (1998)

MA 10.13 Mon 18:15 H23

Curie temperature vs conductivity relation: (Ga,Mn)As alloy
— •Josef Kudrnovsky[1], Georges Bouzerar[2], and Ilja Turek[3] — [1]Institute of Physics AS CR, Prague, Czech Republic — [2]Institut Laue Langevin and Laboratoire Luis Neel, Grenoble, France — [3]Institute of Physics of Materials AS CR, Brno, Czech Republic

We evaluate from first principles the Curie temperature and conductivity of (Ga,Mn)As alloys at various levels of annealing, from as-grown samples to samples with very low compensation.

The Curie temperature was estimated in the framework of the local RPA approach [1] starting from the classical random Heisenberg model constructed from first-principles [2] and assuming that compensating defects are Mn-interstitials [3].

Conductivity is estimated using Kubo-Greenwood formula with the impurity-induced vertex-part [4] and assuming the antiparallel orientation of Mn(Ga) and Mn-interstitial moments. Various stages of annealing are simulated by the effective Mn-concentration and compensation ratio obtained from the experiment [5].

Assuming also a small amount of As-antisites, a good quantitative agreement between theory and experiment [5] was obtained thus giving a strong theoretical support to the carrier-induced model of ferromagnetism in (Ga,Mn)As diluted magnetic semiconductors.

References

[1] Europhysics Letters 69 (2005) 812 [2] Phys. Rev. B69 (2004) 115208 [3] Phys. Rev. B72 (2005) 125207 [4] J.Phys.: Condens. Matter 16 (2004) S5607 [5] Appl. Phys. Letters 81 (2002) 4991

MA 10.14 Mon 18:30 H23

Ferromagnetic interactions in Mn-doped magnetic semiconductors Ga(As,P) and (Al,Ga)As
— •František Máca and Josef Kudrnovský — Institute of Physics ASCR, Praha, Czech Republic

The optimization of the host composition is one way for systematical theoretical search for new spintronic materials. In this contribution we study in detail the hole mediated ferromagnetism in Mn-doped Ga(As,P) and (Al,Ga)As. Mn incorporation in ternary hosts is investigated using ab initio electronic structure calculations based on the density functional theory. For a set of ordered ternary alloys we discuss the influence of lattice parameters as well as valence band off-set on the close neighbor exchange interactions. Our results predict an increase of Curie temperature for systems with larger amount of P, i.e. for materials with smaller lattice constant and with valence band edge closer to Mn d-states. For ternary alloys with a higher content of P also a reduced number of compensating impurities was predicted [1].

[1]J. Mašek at all. Phys. Rev. B (2006) in print.

MA 10.15 Mon 18:45 H23

A THEORETICAL STUDY ON HALFMETALLIC ANTIFERROMAGNETIC DILUTED MAGNETIC SEMICONDUCTORS FROM FIRST-PRINCIPLES AND STATISTICAL METHODS
— •Lars Bergqvist and Peter Dederichs — Institute für Festkörperforschung, Forschungzentrum Jülich, D-525 25 Jülich, Germany

Based on electronic structure calculations and statistical methods we investigate a new class of materials for spintronic applications: halfmetallic antiferromagnetic diluted magnetic semiconductors (HMAF-DMS). As shown recently by Ogura and Akai these DMS systems contain equal amounts of low-valent and high-valent transition metal impurities, such that their local moments exactly compensate each other. We present ab-initio calculations by the KKR-CPA method and by the PAW-supercell methods, using the LDA and LDA+U methods, and show that quite a few halfmetallic antiferromagnets should exist. Our calculations demonstrate, that the exchange coupling parameters in these systems are dominated by a strong antiferromagnetic interaction between the two impurities. The Neel temperatures are calculated by Monte Carlo simulations and in mean field approximation. It is shown that the latter method strongly overestimates the critical temperatures and that the more realistic values obtained by Monte Carlo are rather low.