MA 18: Joint Session "Magnetic Semiconductors" (jointly with HL)

Time: Tuesday 9:30–12:45 Location: H 0112

MA 18.1 Tue 9:30 H 0112

Growth of high-quality EuO films by rf-sputtering — •Thomas Mairoser[1], Alexander Melville[2], Artur Glavic[3], Jürgen Schubert[3], Darrell G. Schlom[2], and Andreas Schmehl[1] — [1]Universität Augsburg — [2]Cornell University, USA — [3]Forschungszentrum Jülich

The ferromagnetic semiconductor europium oxide exhibits a multitude of giant physical properties, such as a metal-to-insulator transition, colossal magneto-resistance, and pronounced magneto-optic effects. Its spin-polarization of >90% in the ferromagnetic state [A. Schmehl *et al.* , Nature Materials **6**, 882 (2007)] and its excellent electronic compatibility with Si have spawned new interest in EuO in the rapidly growing field of spin-electronics.

Because of instability in air the growth of thin films of this highly versatile material is challenging. Up to now high-quality films were only accessible by UHV deposition techniques like molecular beam epitaxy or UHV pulsed laser deposition. Previous film growths using co-sputtering from multiple targets (Eu and Eu_2O_3) resulted in polycrystalline films with second phases.

Here we report the growth of high-quality epitaxial films on (110) oriented $YAlO_3$ substrates using rf-sputtering from a single Eu_2O_3 target. The structural and magnetic properties of the commensurately strained films match those of the best EuO films reported in literature.

MA 18.2 Tue 9:45 H 0112

Ultrafast Enhancement of Ferromagnetism via Photoexcited Carriers in EuO — •Masakazu Matsubara[1], Andreas Schmehl[2], Jochen Mannhart[3], Darrell G. Schlom[4], Mauricio Trujillo Martinez[5], Johann Kroha[5], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zürich, Switzerland — [2]Institut für Physik, Universität Augsburg, Germany — [3]Max Planck Institute for Solid State Research, Germany — [4]Department of Materials Science and Engineering, Cornell University, USA — [5]Physikalisches Institut, Universität Bonn, Germany

EuO is a magnetic semiconductor, which undergoes a ferromagnetic transition at the Curie temperature (T_C) of 69 K. Electron doping to the stoichiometric compound greatly enhances the T_C and is accompanied by a nearly 100% spin polarization of the charge carriers in the ferromagnetic state, which makes electron-doped EuO a very attractive candidate for spintronics applications.

Here we have explored the possibility of the ultrafast control of magnetic properties of EuO via photoexcited carriers by a femtosecond pulse laser irradiation. Ultrafast spin dynamics was investigated in a variety of Gd-doped EuO ($Eu_{1-x}Gd_xO$) films with different carrier densities and T_C, exploiting the time-resolved magnetization-induced second-harmonic generation. The results show the ultrafast increase of magnetization, with a characteristic temperature dependence, in low/medium Gd-doped samples. This is attributed to the increase of the indirect exchange interaction mediated by the photoexcited carriers.

MA 18.3 Tue 10:00 H 0112

EuO on Silicon for spintronics investigated by HAXPES — •C. Caspers[1], M. Müller[1], A. Gloskovskii[2], M. Gorgoi[3], C.S. Fadley[4], and C.M. Schneider[1,5] — [1]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich — [2]Analytische und Anorganische Chemie, Johannes Gutenberg-Universität, Mainz — [3]Helmholtz-Zentrum für Materialien und Energie, BESSY II, Berlin — [4]Department of Physics, University of California Davis, USA — [5]Fakultät für Physik and Center for Nanointegration Duisburg-Essen

Magnetic oxides combine electrical insulation and spin selectivity, qualifying them as highly efficient spin-selective tunnel barriers on silicon. Our approach joins two beneficial aspects: EuO is predicted to be the only magnetic oxide thermodynamically stable on silicon, the mainstay of semiconductors; moreover we are holding full control over structural, chemical, and magnetic properties of the MBE-grown EuO.

EuO thin films were synthesized by Oxide-MBE. RHEED pattern confirm the epitaxial growth of EuO on clean Si(100). A bulk-sensitive HAXPES study revealed an integral Eu(2+) valency (ferromagnetic) of 4 nm thick EuO/Si heterostructures with less than 4% antiferromagnetic Eu(3+). A depth-dependent HAXPES investigation with optimized interface sensitivity provided the optimum chemical parameters for the EuO/Si transport interface: The formation of EuSix can be minimized to less then 10% coverage of the interface, and SiOx is found to be $< 20\%$. Concluding, we succeeded in preparing EuO/Si heterostructures with high-quality magnetic, structural and chemical properties, being promising as spin filter contacts to silicon.

MA 18.4 Tue 10:15 H 0112

Magnetization of Mn implanted Ge annealed by flash lamp — •Zenan Jiang, Danilo Bürger, Slawomir Prucnal, Kun Gao, Wolfgang Skorupa, Heidemarie Schmidt, Manfred Helm, and Shengqiang Zhou — Helmholtz Zentrum Dresden Rossendorf, Inst Ion Beam Phys & Mat Res, Dresden, Germany

Ge-based diluted magnetic semiconductors (DMS) have drawn extensive attentions over the past decades due to the potential to be applied in spintronic devices and to be integrated with the mainstream Si microelectronics. The hole-mediated effect in DMS provides the possibility to realize the control of magnetic properties by the electrical control of free carriers. In this contribution, Mn implanted Ge with the Mn concentrations between 2 and 10% and annealed subsequently with flash lamp was investigated and discussed. All samples show ferromagnetism with the Curie temperature in the range from 250 to 300 K which may be interpreted as the co-contribution of the Ge matrix diluted with Mn ions and of Mn-rich nanoclusters[1]. SQUID measurements show evidence that the Mn-rich nanoclusters may have multiple distinct magnetic phases or a bimodal size distribution. It is also inferred that more Mn atoms are possibly incorporated into the Ge lattice with higher annealing energy using flash lamp annealing at 3 ms time scale. The enhancement of magnetoresistance is consistent with the magnetization as well as the inhomogeneous nature of the implanted layer.

[1] Shengqiang Zhou et al., PHYSICAL REVIEW B 81, 165204 (2010)

MA 18.5 Tue 10:30 H 0112

Magnetic Mn-Doped Indium Tin Oxide Films Prepared by Vacuum Thermal Evaporation — •Scarlat Camelia[1], Xu Qingyu[2], Shalimov Artem[1], Voelskow Matthias[1], Fronk Michael[3], Salvan Georgeta[3], Zahn R.T. Dietrich[3], Helm Manfred[1], and Iacomi Felicia[4] — [1]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany — [2]Southeast University, China — [3]Semiconductor Physics, Chemnitz University of Technology, Germany — [4]Al. I. Cuza University, Iasi, Romania

The optical and electrical properties of indium tin oxide (ITO) thin films are highly dependent on the deposition parameters. Undoped and Mn doped ITO thin films were grown on SiO_2/Si substrates by vacuum thermal evaporation (VTE) using different atomic sources ratio. In order to have practically stress-free ITO films, all the samples were annealed at 450°C for 2 hours in air. The Mn-doped ITO films exhibit room temperature ferromagnetism after annealing. We analyzed the magnetization data from SQUID measurements using simulations based on the Preisach approach and derived the magnetic parameters of superparamagnetic nanoparticles in the Mn-doped ITO films, namely, the magnetization of individual particles and the distribution of coercive fields. The Mn-content in Mn-doped ITO films was investigated by Rutherford backscattering spectrometry and analysed using the RUMP data processing computer code. Results from magneto-optical and magneto-electrical measurements are presented. Magneto-transport measurements reveal negative magnetoresistance, while no anomalous Hall effect is observed.

MA 18.6 Tue 10:45 H 0112

Multiband V-J model for dilute magnetic semiconductors — •Stefan Barthel[1], Gerd Czycholl[1], and Georges Bouzerar[2,3] — [1]Institute for Theoretical Physics, University of Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany — [2]Institut Néel, 25 avenue des Martyrs, B.P. 166, 38042 Grenoble Cedex 09, France — [3]School of Engineering and Science, Jacobs University Bremen, Campus Ring 1, D-28759 Bremen, Germany

A multiband empirical tight-binding model for magnetically doped group-III-V-semiconductors with zincblende structure (e.g. $Ga_{1-x}Mn_xAs$,etc.) is applied to the calculation of effective Mn-Mn exchange couplings J_{ij}. The pd-coupling is treated non-perturbatively

and nonmagnetic scattering is included. A polynomial expansion of the spectral density allows for the study of orbital-resolved exchange couplings for very large system sizes, which can be directly mapped on a disordered Heisenberg model. Finally a comparison of our findings using realistic input parameters (bandstructure, impurity concentration, pd-coupling, impurity potential) to available ab-initio data (LDA, LDA+U) is made. Our approach seems promising to bridge the gap between model and ab-initio methods.

15 min. break

MA 18.7 Tue 11:15 H 0112

Magnetism in Phase Change Materials Doped with Magnetic Impurities — •Wei Zhang[1], Yan Li[1,2], and Riccardo Mazzarello[1,2] — [1]Institute for Theoretical Solid State Physics, RWTH Aachen, Aachen, Germany — [2]JARA Fundamentals of Future Information Technology, Aachen, Germany

Chalcogenide phase-change materials undergo fast and reversible transitions between the amorphous and crystalline phase upon heating. This property is exploited in rewritable optical discs and nonvolatile phase-change memories, which are based on the strong optical and electronic contrast between the two phases respectively. Recently, phase change materials doped with magnetic impurities have drawn interest from both experimental and theoretical sides. In this work, we investigate the structural, electronic and magnetic properties of $Ge_2Sb_2Te_5$, a prototypical phase-change material, doped with several types of magnetic impurities, namely Cr, Mn, Co, Ni, by *ab initio* simulations. Both amorphous and crystalline (hexagonal and cubic rocksalt) phases of $Ge_2Sb_2Te_5$ were considered. We show that, when $Ge_2Sb_2Te_5$ is doped with Cr or Mn, the system displays a strong magnetic contrast between the crystalline phases and the amorphous phase. This behavior is similar to that of Fe-doped $Ge_2Sb_2Te_5$, which was recently investigated experimentally and theoretically. On the contrary, $Ge_2Sb_2Te_5$ doped with Co or Ni turns out to be non-magnetic in the amorphous phase. Our results indicate that Cr and Mn impurities can be used to dope $Ge_2Sb_2Te_5$, with the goal of exploiting the phase-change behavior for magnetic switching applications.

MA 18.8 Tue 11:30 H 0112

Anomalous hysteretic Hall effect in a ferromagnetic, Mn-rich, amorphous Ge:Mn nano-network — •Danilo Bürger, Shengqiang Zhou, Marcel Höwler, Xin Ou, György Kovacs, Helfried Reuther, Arndt Mücklich, Wolfgang Skorupa, Manfred Helm, and Heidemarie Schmidt — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, P.O. Box 510119, 01314 Dresden, Germany

The read out of the magnetization state in magnetic semiconductors by electrical Hall resistance measurements makes it possible to use ferromagnetic semiconductors in nonvolatile memories. In a previous work [1], we fabricated ferromagnetic Ge:Mn by Mn ion implantation and pulsed laser annealing (PLA) and observed hysteretic Hall resistance below 10 K. By applying different PLA conditions we fabricated a percolating, Mn-rich, amorphous Ge:Mn nano-network with hysteretic Hall resistance up to 30 K. This nano-network is embedded in crystalline Ge:Mn between 5 nm and 40 nm under the sample surface. We applied chemical and physical etching to confirm the contribution of the nano-network to the magnetic properties. The nanonet has a significant influence on the correlation between magnetism and anomalous Hall resistance. In the future such nano-networks may be used to spin-polarize free charge carriers in semiconductors at room temperature. [1] S. Zhou *et al.*, Phys. Rev. B **81**, 165204 (2010)

MA 18.9 Tue 11:45 H 0112

Transition metal doped ZnO: Studies from DFT with various types of exchange-correlation treatment — •Sanjeev K. Nayak, Markus E. Gruner, Heike C. Herper, and Peter Entel — Faculty of Physics, University of Duisburg-Essen

Transition metal (TM) doped ZnO has been a long-standing problem. Since the density functional theory (DFT) with local density approximation (LDA) as the exchange-correlation potential underestimates the optical band gap, the impurity state is more likely to overlap with the valence or conduction band and thus the identification of the type of magnetic interaction is hampered. We have used different correction schemes to the exchange-correlation potential to improve the optical band gap of ZnO, namely by adding a orbital specific Hubbard U correlation to the d-orbitals of Zn and TM and by treating the exchange-correlation by the Hartree-Fock exchange through the Heyd-Scuseria-Ernzerhof (HSE) screened hybrid-functional. We focus on the nearest neighbor (n.n.) interactions of TM (TM = Cr, Mn, Fe, Co and Ni) occupying the cationic Zn sites, because in absence of carriers and any lattice defects the n.n. magnetic interaction strength is expected to be the highest. Our preliminary results show that most of the TM in ZnO favor antiferromagnetic interaction. Thus, in the quest for ferromagnetism in ZnO based DMS, focus should be on the role of lattice defects and additional impurities.

MA 18.10 Tue 12:00 H 0112

Ferromagnetische Resonanz an Chromspinellen — •Dieter Ehlers, Hans-Albrecht Krug von Nidda, Vladimir Tsurkan und Alois Loidl — Lst. für Experimentalphysik V, Universität Augsburg, 87435 Augsburg

Am ferromagnetischen Spinell $CdCr_2S_4$, an dem Ferroelektrizität sowie eine goße magnetokapazitive Kopplung nachgewiesen worden ist [Hem], haben wir die magnetokristalline Anisotropie mithilfe der ferromagnetischen Resonanz vermessen und untersucht. Aufgrund der Probenpräparation konnte ausgeschlossen werden, dass die Anisotropie von Verunreinigungen wie Cr^{2+} auf Oktaederplätzen oder Fe^{2+} auf Tetraederplätzen [Hoe, Pin] ausgeht, d. h. sie ist eine intrinsiche Eigenschaft der Verbindung. Weiterhin konnte das Modell der kubischen Anisotropie für das System verfeinert werden, indem eine uniaxiale Anisotropie für Cr^{3+} zusammen mit der Austauschverschmälerung angenommen wurde. Damit lassen sich beobachtete Anomalien der Linienbreite in den ⟨111⟩-Richtungen temperaturabhängig beschreiben.

[Hem] J. Hemberger, P. Lunkenheimer, R. Fichtl, H.-A. Krug von Nidda, V. Tsurkan, A. Loidl, Nature **434**, 364 (2005)

[Pin] H. L. Pinch, S. B. Berger, J. Phys. Chem. Solids **29**, 2091 (1968)

[Hoe] B. Hoekstra, R. P. van Stapele, Phys. Stat. Sol. **55**, 607 (1973)

MA 18.11 Tue 12:15 H 0112

Electronic structure study of the ferrospinel NiFe2O4 — •Martina Müller[1], Christian Caspers[1], Stephan Kramer-Sinzinger[1], Sven Döring[2,4], Michaela Gorgoi[3], Carsten Westphal[2], and Claus M. Schneider[1,4] — [1]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich — [2]Experimentelle Physik 1 und DELTA, Technische Universität Dortmund — [3]Helmholtz-Zentrum für Materialien und Energie, BESSY II, Berlin — [4]Fakultät für Physik and Center for Nanointegration, Universität Duisburg-Essen

The ferrospinel NiFe2O4 is an insulating oxide with high magnetic ordering temperature. This rare combination makes it very attractive for application as magnetic building blocks in spintronics devices, i.e. as spin filter contacts to semiconductors or in artificial multiferroic heterostructures. We succeeded in growing NiFe2O4 (NFO) epitaxial thin films on SrTiO3 substrates. Since the electronic and magnetic properties of NFO thin films can strongly depend on substrate, film thickness and eventually differ from the bulk material, we clarified their electronic properties by means of photoemission spectroscopy in the soft and hard X-ray regime. This (HAX)PES study allows to element-specifically probe the chemical state of the Fe, Ni and O valence bands and core levels both in the bulk and surface-near regions. In particular, analyzing the Fe, Ni 2p and 3p states gives information on the depth-dependent cation stoichiometry and lattice site distribution, which we correlate with NFO/STO structural and magnetic properties.

MA 18.12 Tue 12:30 H 0112

Antiferromagnetism in CuMn-V compounds: from semimetal to semiconductor antiferromagnets — •Frantisek Maca, Jan Masek, and Tomas Jungwirth — Institute of Physics ASCR, Prague, Czech Republic

We report on a theoretical study of CuMn-V antiferromagnets. Previous works showed low-temperature antiferomagnetism and semimetal electronic structure of the semi-Heusler CuMnSb. We present theoretical predictions of high-temperature antiferromagnetism in the stable orthorhombic phases of CuMnAs and CuMnP. The electronic structure of CuMnAs is at the transition from a semimetal to a semiconductor and we predict that CuMnP is a semiconductor.

We show that the transition to a semiconductor-like band structure upon introducing the lighter group-V elements is present in both the metastable semi-Heusler and the stable orthorhombic crystal structures. On the other hand, the orthorhombic phase is crucial for the high Néel temperature. The first experimental results are consistent with the theory predictions.[1]

[1] F. Maca, J. Masek, O. Stelmakhovych, X. Marti, K. Uhlirova, P. Beran, H. Reichlova, P. Wadley, V. Novak, T. Jungwirth, J. Magn. Magn. Mater. (2011) in print.