Magnetic Interfaces and Nanostructures

Room: 619 - Session MI-ThM

Magnetic Semiconductors I

Moderator: A.T. Hanbicki, Naval Research Laboratory

8:00am **MI-ThM1 DMS Ferromagnets: Extrapolating from (III,Mn)V Materials**, ***A.H. MacDonald***, University of Texas at Austin, *T. Jungwirth*, Czech Academy of Sciences, *J. Sinova*, Texas A&M University, *J. Kucera*, *J. Masek*, Czech Academy of Sciences **INVITED**

The body of work on (III,Mn)V diluted magnetic semiconductors (DMSs) started during the 1990's achieved a good understanding of the origins of ferromagnetism in these materials, and of the relationship between magnetic properties and the materials science of growth and defects. From the fundamental point of view, (Ga,Mn)As and several other (III,Mn)V DMSs are now regarded as textbook examples of something which is rare, robust ferromagnets with dilute magnetic moments coupled by delocalized charge carriers. Both local moments and itinerant holes are provided by Mn, which makes the systems particularly favorable for realizing this unusual ordered state. Advances in growth and postgrowth-treatment techniques have played a central role in the field, often pushing the limits of dilute Mn-moment densities and the uniformity and purity of materials far beyond those allowed by equilibrium thermodynamics. In (III,Mn)V compounds, material quality and magnetic properties are intimately connected. I will review[1] some of this progress and use it as a spring board to discuss magnetism in other semiconductors with dilute local moments.[2]

[1] Tomas Jungwirth et al. Rev. Mod. Phys. 78, 809 (2006).

[2] Work suported by the Department of Energy under Grant No. DE-FG03-02ER45958.

8:40am **MI-ThM3 Onset of Nonlinear Transport and Two-Level Fluctuation through a Pinned Domain Wall in Patterned Lateral GaMnAs Constrictions**, ***S.W. Cho****, *H.K. Choi, J.S. Lee, T. Hwang, Y.D. Park*, Seoul National University, Korea

We report on the electrical transport measurements across clean lateral geometrical constrictions in diluted magnetic semiconductor GaMnAs. Constrictions are realized by e-beam lithography to define SiO_x etch masks to pattern nanometer-sized constrictions without plasma etching processes. DC transport behavior across the nanoconstrictions changes from ohmic to non-ohmic below temperatures corresponding to epifilm T_C. The nonlinear IV characteristics fit well with adapted transport equation accounting for spin-flop processes across the domain wall, analogous to pn junctions.[1] Fits to theory also indicate the domain walls to be smooth and wide, inhospitable to tunneling transport, and supported by magnetoresistance behavior dominated by anisotropic magnetoresistance-like response similar to Giddings et al. observations.[2] Extending the 'spin diode' concept of Vignale and Flatté,[3] we conduct a series of dynamic measurements and observe a distinct two-level behavior dependent on bias conditions similar to certain behaviors found in bipolar junctions such as shot noise and random telegraph noise.

[1] G. Vignale and M.E. Flatté, PRL 89, 098302 (2002).
[2] A.D. Giddings et al., PRL 94, 127202 (2005).
[3] M.E. Flatté and G. Vignale, APL 78, 1273 (2001).

9:00am **MI-ThM4 Intrinsic Vacancy Chalcogenides as Dilute Magnetic Semiconductors: Theoretical Investigation of TM-Doped Ga_2Se_3**, ***I.N. Gatuna***, *F.S. Ohuchi, M.A. Olmstead*, University of Washington

The quest to functionalize semiconductors with additional magnetic properties through synthesis of dilute magnetic semiconductors (DMS) has led to a deeperunderstanding of semiconductor physics and the development of new magneticmechanisms. However, most current DMS materials (e.g., Mn-doped GaAs) are magnetic only well below room temperature, and/or have only limited compatibility with existing silicon electronics. We have investigated transition metal (TM) doping of the intrinsic vacancy semiconductor Ga2Se3 to address both scientific and technical goals. The intrinsic vacancies of this III-VI, zinc-blende-based semiconductor open possibilities for self-compensation as well as supply highly anistropic and polarizable band edge states. Ga2Se3 is also closely lattice matched to Si and may be grown heteroepitaxially on Si with high quality interfaces. Our first principles computations of X:Ga2Se3 (X = Mn, V, Cr, concentrations 5% to 16%) reveal that X atoms hybridize with neighboring Se in the p-d hybridization typical of III-V and II-VI DMS materials. This hybridization spin-polarizes states near the Fermi level in these T =0 calculations, and lowers the energy of the Se lone-pair orbitals that neighbor vacancies, reducing their prominent role in determining the properties of intrinsic Ga2Se3. There are distinct differences between substitution on a vacancy or for a Ga. Anisotropic, hole-like conductivity is predicted when X is located in a Ga site, while for X situated in a vacancy, a half-metallic state with an isotropic conductivity appears likely. Our calculations suggest that Mn offers the best choice for the dopant, perhaps because its 3d5 electronic configuration offers a large (~ 0.5 eV) separation of spin up and spin down states near the Fermi level, reducing the metallic densities of states at the Fermi level for all doping concentrations. The large energy splitting suggests that doped Ga2Se3 may be a suitable material for spintronics applications athigher temperatures than these T = 0 initial calculations.

This work was supported by NSF grant DMR 0605601, the Japan Science Promotion International Program, NIMS (Japan) - UW Joint Research Pact and NIMS (Japan) Internal Research Fund.

9:20am **MI-ThM5 Heteroepitaxial Growth and Electronic Structure of Mn:Ga_2Se_3 Thin Films on Si(100):As: Exploration of a Candidate Dilute Magnetic Semiconductor**, ***T.C. Lovejoy***, *E.N. Yitamben*, University of Washington, *T. Ohta*, Lawrence Berkeley National Laboratory, *F.S. Ohuchi, M.A. Olmstead*, University of Washington

Magnetic thin film semiconductors grown on nonmagnetic semiconductors (NMS) may provide a route to injection of spin polarized electrons into the NMS. The lack of magnetic materials with both a high Curie temperature and spin-preserving transport into electronic materials (e.g., silicon) is currently the primary obstacle to the development of useful spintronic devices. A relatively unexplored class of dilute magnetic semiconductor is transition metal doped III-VI semiconductors. Group III-VI semiconductors such as Ga_2Se_3 have intrinsic vacancies which lead to highly anisotropic growth, and which may lead to a high degree of magnetic anisotropy if the films can be made ferromagnetic through suitable doping. Scanning tunneling microscopy (STM), low energy electron diffraction (LEED) and photoemission spectroscopy (PES) have shown the addition of small quantities of manganese, about one percent, has a pronounced effect on the growth morphology and electronic properties of Ga_2Se_3 on arsenic passivated Si(100). Co-deposition of Mn and GaSe on Si(100):As results in tall, highly anisotropic, rectangular, Mn-rich islands with edges parallel to the [011] and [0-11] substrate crystal directions. Deposition of a pure Ga_2Se_3 layer before the doped material results in a different and more laminar structure. While islands still form, these islands are much shorter and wider with seemingly random shapes subject to the constraint that every piece of the perimeter lies along the same two crystal directions. These two structures can be easily distinguished by their LEED patterns where the first case shows 1x1 spots with streak features characteristic of the undoped Ga_2Se_3 structure, whereas the second case transitions to clear 1x1 spots with no other features. The effect of small concentrations of Mn on the band structure of thin film Ga_2Se_3 is equally pronounced. The Mn doping adds a new peak in the valence band about 4.2eV below the Fermi level, an area where pure Ga_2Se_3 has a low density of states.

This work was supported by NSF grant DMR 0605601. TCL acknowledges support from NSF/NCI IGERT DGE-0504573. Some of the research was pursued at the Advanced Light Source, which is supported by the DOE under contract DE-AC02-05CH11231.

9:40am **MI-ThM6 Investigation of Cr:Ga2Se3 as a Candidate Dilute Magnetic Semiconductor for Silicon Based Applications**, ***E.N. Yitamben***, *T.C. Lovejoy, I.N. Gatuna, F.S. Ohuchi, M.A. Olmstead*, University of Washington

The intrinsic vacancy semiconductor Ga2Se3, which may be grown epitaxially on Si, poses several interesting issues for the study of dilute magnetic semiconductors. Substitution of transition metal impurities may occur on either occupied or vacant cation sites in the defected zincblende lattice. For dopants with different valence from the host cation, this may result in self-compensation of donors and acceptors, while an isoelectronic impurity can either add electrons by inserting into a vacancy, or minimally disturb the band structure by replacing a Ga. To probe the interrelationship between magnetism and free carriers in this new class of dilute magnetic semiconductors, we have performed both theoretical and experimental investigations of Cr-doped Ga2Se3 grown epitaxially on Si(001):As. Scanning tunneling microscopy shows nucleation of anisotropic islands, with the area between islands similar to pure Ga2Se3. The size and shape of the islands is dependent both on Cr concentration and on whether or not a pure Ga2Se3 buffer layer is deposited first. Despite the similar intrinsic valence between Cr and Ga, addition of a few percent Cr to Ga2Se3 results in metallic bands with minimal dispersion and leads to significant changes of the Se local environment, as measured with high resolution photoemission spectroscopy. These results may indicate Cr substituting into a vacancy rather than replacing Ga, or possibly creating local areas of CrSe,

* Falicov Student Award Finalist

which computations show to be half-metallic. At higher concentrations, X-ray absorption and photoemission show two distinct Cr environments.

This work was supported byt NSF grant DMR 0605601. TCL acknowledges support from NSF/NCI IGERT DGE-0504573. Some of the research was pursued at the Advanced Light Source, which is supported by the DOE under contract DE-AC02-05CH11231.

10:00am **MI-ThM7 Giant Excitonic Zeeman Splittings in Transition Metal Doped CdSe Quantum Dots**, ***P.I. Archer***, *D.R. Gamelin*, University of Washington

We report the first direct observation of sp-d dopant-carrier exchange interactions in colloidal doped wurtzite CdSe nanocrystals. Doped diluted magnetic semiconductor quantum dots (DMS-QDs) were prepared by thermal decomposition of an inorganic precursor cluster in the presence of $TMCl_2$ (TM^{2+} = Mn^{2+} or Co^{2+}) in hexadecylamine and were characterized by multiple spectroscopic and analytical techniques. Using magnetic circular dichroism spectroscopy, successful doping and the existence of giant excitonic Zeeman splittings in both Mn^{2+}- and Co^{2+}-doped wurtzite CdSe quantum dots are demonstrated unambiguously.

10:20am **MI-ThM8 Size-Dependent Excited State Dynamics in Mn^{2+}-Doped CdSe Quantum Dots**, ***R. Beaulac***, *P.I. Archer, V.A. Vlaskin, D.R. Gamelin*, University of Washington

Colloidal Mn^{2+}-doped II-VI quantum dots are interesting materials for the study of magnetic and luminescent phenomena in quantum confined semiconductor nanostructures. In recent years, several reports have described luminescence, absorption and magnetism of Mn^{2+}-doped ZnS, CdS and ZnSe quantum dots. In general, the emission properties of these nano-scale materials behave much like their bulk counterparts, showing a size insensitive Mn^{2+} ligand-field emission with a long lifetime. In contrast, Mn^{2+}-doped CdSe nanoparticles are expected to behave differently from bulk because of the possibility of size-tuning the band-gap energy from below to above the Mn^{2+} emitting level. For this reason, Mn^{2+}-doped CdSe offers an interesting opportunity for fundamental studies of quantum confinement effects in doped semiconductors. Curiously, although photoluminescence spectra of self-assembled Mn^{2+} quantum dots prepared by vacuum deposition have been reported, the Mn^{2+} is either absent of only tentatively reported, even for high Mn^{2+} concentrations. Moreover, CdSe excitonic emission is observed despite the fact that the energy gap is greater than the Mn^{2+} excitation energy. We recently presented a new method for preparing colloidal doped CdSe quantum dots.[1] Importantly, these particules show a giant Zeeman splitting of their excitonic transitions, as is expected for diluted magnetic semiconductors. Here we will describe the temperature-dependent photoluminescence of these particles, which gives insight into the energy transfer dynamics in Mn^{2+}-CdSe quantum dots. A kinetic model will be described that explains the paradoxical absence of Mn^{2+} emission in Mn^{2+}-doped CdSe quantum dots reported previously.

[1] Archer, P. I.; Santangelo, S. A.; Gamelin, D. R., Nano. Lett., 7, 1037-1043 (2007).

10:40am **MI-ThM9 Structural and Magnetic Properties of Mn-implanted 3C-SiC**, ***K. Bouziane***, Sultan Qaboos University, Oman

Unlike many Dilute Magnetic Semiconductors particularly Si based ones,[1] very little attention has been paid to SiC despite its potential for high-power, high-temperature electronics and its large compatibility with the mature Si technology. With its wide bandgap, excellent transport properties and dopability, it might be a promising candidate for spintronic applications. Due to a limited solubility of Mn in the host SiC materials, we have used Mn+ implantation (energy of 80 keV and dose of 5x1015 cm^{-2}) to achieve higher Mn atomic concentration of 1.8 % in micrometric thick 3C-SiC films; aiming to enhance the Curie temperature. We have used Rutherford backscattering (RBS) and X-ray diffraction (XRD) techniques to asses the defects introduced by Mn–implantation, as well as magnetometry to investigate the magnetic properties. RBS measurements on single SiC indicate high concentration of defects at a depth of about 45 nm from the surface, with Mn randomly distributed in the host SiC material. XRD spectra show no indication of formation of secondary alloying phase. Both single and polycrystalline implanted samples were found to be ferromagnetic at room temperature with a magnetic moment per Mn atom of about 0.37μB and 0.5μB, respectively. The amorphous layer was recrystallized after annealing at 750 °C for 10 min as indicated by RBS results, yielding an enhancement of magnetic moment. First principle calculation using Full-Potential Linearized-Augmented-Plane-Wave method for different environments and vacancy configurations was performed to better understand and establish a correlation between the structure/microstructure and magnetic properties of single and polycrystalline Mn-implanted 3C-SiC.

[1]M. Bolduc et al., Phys. Rev. B 71 (2005) 033302.

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