Monday Morning, November 4, 2002

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+EL-MoM

Spintronic Materials and Hybrid Devices
Moderator: B.T. Jonker, Naval Research Laboratory

8:20am **MI+EL-MoM1 Spin-transport in Ferromagnet/Semiconductor Structures**, ***R. Jansen***, University of Twente, The Netherlands **INVITED**

Taking full advantage of electron spin in spin-electronics will eventually require an intimate integration of ferromagnetic and semiconductor materials. While device concepts are emerging, the understanding of spin transport in such hybrid ferromagnet/semiconductor structures is still at its infancy. We have focused on transport of non-equilibrium, hot-electron spins, for which spin currents can be controlled and manipulated via the electron energy and momentum. A particularly useful device for that purpose is the spin-valve transistor[1], consisting of a metallic spin-valve base, sandwiched between a semiconductor emitter and collector. Using the spin-valve transistor, we address the relative importance of interface, volume and thermal scattering of hot electron spins, and present new insight into the sources of spin-asymmetry in hot-electron transport.[2,3] From an application point of view, enhancing the output current of the transistor is desired. We demonstrate several routes to enhance the transfer ratio, culminating in an overall improvement by two orders of magnitude while preserving the low-field magnetic response above 200% at room temperature.[4] We also present transport in novel structures such as the magnetic tunnel transistor and the hot-electron spin-filter, and demonstrate that the latter allows room temperature injection of almost fully spin-polarized electrons into semiconductors.

[1] R. Jansen et al., J. Appl. Phys. 89, 7431 (2001).
[2] R. Jansen et al., Phys. Rev. Lett. 85, 3277 (2000).
[3] R. Vlutters et al., Phys. Rev. Lett. 88, 027202 (2002).
[4] O.M.J. van 't Erve et al., Appl. Phys. Lett. 80, to appear 20 may 2002.

9:00am **MI+EL-MoM3 Spin Dependent Electron Transport in Hybrid Ferromagnet/GaAs Structures at Room Temperature**, *S.J. Steinmuller, W.S. Cho, A. Hirohata, C.M. Guertler, G. Wastlbauer, T. Taniyama,* ***J.A.C. Bland***, University of Cambridge, UK

We report on the investigation of room temperature (RT) spin dependent electron transport in ferromagnet(FM)/GaAs hybrid Schottky barrier structures by photoexcitation. Spin accumulation in the GaAs was achieved by optical pumping with circularly polarised light. The photon helicity and the applied magnetic field were both introduced perpendicular to the plane of the film. Various FM materials were used (NiFe, Fe and Co) and investigated at different thicknesses (t=2.5nm, 5.0nm and 7.5nm). Furthermore an antiferromagnetic Cr sample was prepared as a reference. We measured the helicity-dependent photocurrent (PC), that is the difference in PC for illumination with right (i^+) and left circularly polarised light (i^-), for applied magnetic fields in the range from -2 T to 2 T as well as the spin polarisation $P=(i^+ - i^-)/(i^+ + i^-)$ of PC. NiFe and Fe showed a rather strong effect (P in the range 0.2-2%) increasing with film thickness, whereas almost no effect was observed in the Co. The magnetic field dependence of the helicity-dependent PC was in good agreement with polar MOKE measurements, proving that magnetic effects in the GaAs are negligible at RT. No field dependent effect was seen for the Cr as expected. Moreover we carried out measurements at different doping densities of the GaAs substrate (n- and p-type), showing the importance of the Schottky barrier in our experiment, and different photon energies. We also discuss the results of similar measurements on NiFe/Cu/Co spin valve structures. We show that our combined data provides strong support for our model of electron spin filtering at RT based on tunnelling of spin polarised electrons across the Schottky barrier followed by ballistic transport in the FM.

9:20am **MI+EL-MoM4 Tunneling Transport Across Reverse Biased Ag/Fe/Ag/GaAs Schottky Barriers**, ***D.A. Hite***, *S.E. Russek, D. P. Pappas*, National Institute of Standards and Technology

Electrical transport characteristics for the epitaxial Ag/Fe/Ag/GaAs(100) system have been studied under various growth conditions. The surfaces and structure of the multilayer were characterized by low energy electron diffraction and angle-resolved Auger electron diffraction at all steps of the fabrication. We have been able to prepare clean, well-ordered, epitaxial multilayers. The ultra-thin Ag buffer layer (~7 atomic layers) was prepared in a manner to create an ultra-thin layer to mediate the growth morphology of the Fe layer, to prevent the undesired intermixing associated with the Fe/GaAs system, and to create a tunneling barrier in reverse bias. In-situ conductance spectroscopy measurements were performed in order to characterize the rate of electron injection into the semiconductor as a function of bias voltage. We find that these multilayer diodes exhibit a reverse bias tunneling effect above 0.6 V. This is significant because it shows that we have been able to overcome the conductivity mismatch problem between the Fe and GaAs using an ultra-smooth, ultra-thin Ag buffer layer. The possibility of using these structures for direct spin injection from the Fe across the Ag/GaAs Schottky barrier will be discussed.

9:40am **MI+EL-MoM5 Modeling of Spin Injection into Disordered Semiconductors**, ***E.Y. Tsymbal***, University of Nebraska-Lincoln, *V.M. Burlakov*, University of Oxford, UK, *I.I. Oleinik*, University of South Florida **INVITED**

Spin injection into semiconductors is a topic of growing interest within the field of spin electronics. Developing a realistic model for spin injection is important both for the understanding of basic mechanisms that govern this phenomenon and for the application of spin injection in semiconductor devices. All the existing models so far either take into account a realistic band structure but neglect disorder within the semiconductor or consider phenomenologically defect scattering within a free-electron-type model. This talk will address the approach which combines an accurate description of the atomic structure, the electronic structure, and the conductance within a unique microscopic model. Within this approach the atomic structure is simulated using Metropolis MonteCarlo technique, the electronic structure is modeled using a multiband tight-binding approximation, and the conductance is calculated using the Landauer-Buttiker formalism including inelastic scattering. We will demonstrate results of the application of this model to amorphous silicon - a representative semiconducting material suitable for spin injection. We will discus decisive factors that control the efficiency of spin injection into disordered semiconductors.

10:20am **MI+EL-MoM7 Surface and Interface Properties of a Half-Metallic Alloy**, ***S.J. Jenkins***, *D.A. King*, University of Cambridge, UK **INVITED**

The ferrimagnetic semi-Heusler alloys have received considerable experimental and theoretical attention since the prediction in 1983 that they may show half-metallic behaviour (i.e. complete spin polarization at the Fermi level). Bulk properties of these alloys are now well understood. Nevertheless, application of these materials in practical situations is likely to be contingent upon the influence of their surface and interface properties, which have thus far been less thoroughly studied. This presentation will focus on recent calculations of the electronic structure of the NiMnSb(001) surface, with and without an Sb overlayer, carried out within the framework of density functional theory. Particular emphasis will be placed on the role of surface- and interface- localised electronic states in modulating the Fermi-level polarization.

11:00am **MI+EL-MoM9 Electrical Spin Injection from NiMnSb into GaAs**, ***W. Van Roy***, *P. Van Dorpe, V.F. Motsnyi, G. Borghs, J. De Boeck*, Imec, Belgium

We demonstrate electrical spin injection from NiMnSb into a GaAs light-emitting diode (LED). We compare single crystalline films grown epitaxially on GaAs(111)B with and without an additional AlAs tunnel barrier, and polycrystalline films grown on top of an AlO_x tunnel barrier on GaAs(001). The LEDs and NiMnSb films were grown by MBE in two chambers connected under vacuum. For the deposition of AlO_x tunnel barriers the samples were transported through air to a sputter system for the deposition of Al and oxidation in a controlled O_2 atmosphere. Spin injection was measured optically at T = 80 K. Electrons were injected with an in-plane spin-component. We used the oblique Hanle effect to transform this spin ensemble into an out-of-plane ensemble and used the circular polarization of the light emitted in the surface-normal direction as a measure of the electrical spin injection. The results were corrected for the out-of-plane tilting of the NiMnSb magnetization in the small oblique magnetic field, and for the MCD effect. We find electrical spin injection of up to 5% for polycrystalline NiMnSb films on top of an AlO_x barrier. The spin injection drops with increasing bias voltage. The low values indicate a strongly reduced spin polarization for the polycrystalline NiMnSb films. Epitaxial NiMnSb films, especially on (111)B interfaces, are expected to show a much larger spin polarization for the conduction carriers. However, we did not yet observe spin injection from these films. This is attributed to the low interface resistance of this configuration in combination with a NiMnSb surface polarization that, although larger than for the polycrystalline films, is still short of 100%.

11:20am **MI+EL-MoM10 Epitaxial Growth and Annealing Studies of Single Crystal, Ferromagnetic Co_2MnGa of GaAs (100)**, ***D.M. Carr****, *S. McKernan, F.M. Abdulle, J.W. Dong, C.J. Palmstrom*, University of Minnesota

Spintronic devices that use electron spin in semiconductor devices are promising candidates for the next generation of electronic devices. Ferromagnetic metals with high spin polarization may be required for successful implementation of these devices. The Heusler alloys are a promising family of metals because the material properties such as lattice parameter, saturation magnetization, Curie temperature, and spin polarization can be altered by changing the elemental composition. In addition, their lattice parameters span most of the lattice parameters of the compound semiconductors. Films of the Heusler alloy Co_2MnGa have been epitaxially grown on GaAs (100) using molecular beam epitaxy. In situ reflection high-energy electron diffraction patterns and ex situ x-ray diffraction patterns of 300 Å thick films indicate single crystal growth with an out-of-plane lattice constant of 5.94 Å, which suggests tetragonally distorted growth since the bulk lattice parameter is 5.77 Å. Variable temperature vibrating sample magnetometry measurements show the Co_2MnGa films to be ferromagnetic with in-plane magnetization and a Curie temperature close to the bulk value of approximately 690 K. Ex situ annealing at different temperatures from 300 to 450 degrees C reveals an increase in the saturation magnetization and reduced coercivity for anneal times as short as 5 minutes at 425 degrees C. Annealed films exhibit a smaller out-of-plane lattice constant suggesting relaxation of the strained films. Cross sectional transmission electron microscopy studies will be used to characterize the level of interfacial reaction before and after annealing.

11:40am **MI+EL-MoM11 Growth Temperature Controlled Magnetism in Molecular Beam Epitaxially Grown Ni_2MnAl Heusler Alloys**, ***X.Y. Dong***, *J.Q. Xie, J.W. Dong*, T.C. Shih, S. McKernan, C. Leighton, C.J. Palmstrom*, University of Minnesota

The Heusler alloy Ni_2MnAl is thought to be either antiferromagnetic or ferromagnetic depending on its crystal structure, B2 (disordered Mn-Al sublattice) or $L2_1$.[1] This suggests that a ferromagnet/antiferromagnet interface should be possible to be formed with Ni_2MnAl by controlling its crystal structure. Single crystal Ni_2MnAl thin films have been grown by MBE on GaAs (001) using $Sc_{0.3}Er_{0.7}As$ interlayers. The effects of growth temperature on its structural and magnetic properties were studied. For all the films grown at different temperatures, streaky RHEED patterns were observed during the growth. The Ni_2MnAl / $Sc_{0.3}Er_{0.7}As$ / GaAs (001) films were single crystals with cube on cube epitaxial relationship. The Rutherford backscattering spectrometry channeling minimum yield, χ_{min}, of ~ 5 %, confirms a relatively good quality crystal. XRD and TEM show that the Ni_2MnAl films have a tetragonally distorted structure with its c axis oriented along the growth direction. Higher growth temperature tends to result in ferromagnetic films suggesting a more $L2_1$-like structure, while lower temperature growth gives rise to non-ferromagnetic behavior, suggesting a more B2-like structure. For the ferromagnetic Ni_2MnAl film, the Curie temperature was determined to be approximately 220K. The exchange bias effect was observed for Co (70Å) / Ni_2MnAl (360Å, B2-like structure) bilayers, suggesting that the low temperature grown Ni_2MnAl is antiferromagnetically ordered. Therefore the self exchange biased Ni_2MnAl bilayers can be expected to be grown by varying the temperature during the growth. In this presentation, the effect of growth temperature on the structural and magnetic properties will be emphasized as well as the approaches of making self exchange biased structures will be reported.

[1] F. Gejima, Y. Sutou, R. Kainuma, and K. Ishida, Metal. Mater. Trans. A 30A, 2721 (1999).

* Falicov Student Award Finalist

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