Electronic Materials and Devices
Room: C-107 - Session EL+SC+MI-MoA

Metal-Semiconductor Interfaces
Moderator: C.J. Palmstrom, University of Minnesota

2:00pm **EL+SC+MI-MoA1 Spin Transport in Ferromagnet-Semiconductor Schottky Diodes**, ***P.A. Crowell****, A.F. Isakovic, B.D. Schultz, J. Strand, C.J. Palmstrom*, University of Minnesota **INVITED**

We have completed an investigation of spin injection in semiconductor heterostructures using a Schottky contact between Fe and n-$Al_{1-x}Ga_xAs$ as an injector and an $Al_{1-x}Ga_xAs$/GaAs/$Al_{1-x}Ga_xAs$ quantum well (QW) as the detector. The injector and detector are combined in a single device in which the QW is placed in the depletion region of a p-n junction. The Schottky contact is δ-doped, so that a tunneling current can be obtained under moderate reverse bias.[1] The injected electrons recombine in the QW with holes from the p-contact, and the polarization of the resulting electroluminescence (EL) is used to infer the spin state of the recombining carriers. We demonstrate that the doping profile chosen for the QW has a dramatic effect on the apparent spin-detection efficiency. EL polarizations over 10% are obtained in optimally biased devices in which the QW is intentionally p-doped. The field-dependence of the EL polarization closely matches the magnetization of the Fe electrode. However, the largest polarizations are not observed from ordinary ground-state recombination in the quantum well. The maximum polarization observed from ground-state recombination is approximately 4% and appears to be less sensitive to the doping profile. In contrast, the EL polarization in control samples is less than 2%, does not track the magnetization of the ferromagnetic electrode and depends only weakly on bias voltage. The interpretation of these measurements will rely on a thorough understanding of the QW spin detector and the identification of background contributions. For example, we show using optical pumping measurements that the spin detection efficiency of the QW is a function of the bias voltage, as is the background photoluminescence polarization. This work was supported by DARPA, ONR, and NSF (MRSEC).

[1] H.J. Zhu et al., Phys. Rev. Lett. 87, 016601 (2001); A.T. Hanbicki et al., Appl. Phys. Lett. 80, 1240 (2002).

2:40pm **EL+SC+MI-MoA3 Characterization of an Fe/AlGaAs Tunnel Barrier Interface for Electrical Spin Injection**, *A.T. Hanbicki*, ***R.M. Stroud****, B.T. Jonker*, Naval Research Laboratory

Electrical injection of spin-polarized carriers from a contact into a semiconductor is essential for the success of spintronic devices. Ferromagnetic metals are attractive contact materials because of their ample supply of spin-polarized electrons, but the use of these materials has been limited by small injection efficiencies in the diffusive transport regime.[1] The use of a tunnel barrier between a metal and semiconductor.however. should facilitate usable spin currents.[2] Recent experiments reported spin injection from Fe into a AlGaAs/GaAs-based LED which produced an electron spin polarization of 15% in the GaAs quantum.[3] This was attributed to tunneling through the Schottky barrier. We have characterized the Fe/AlGaAs contact reported in reference 3 to verify the tunneling nature of the contact and to investigate the physical nature of the interface. Samples were grown by molecular beam epitaxy and were specifically engineered to utilize the Schottky barrier between the Fe and the semiconductor as a tunnel contact. Current vs voltage measurements were made through the structure at different temperatures. The conductance shows an asymmetric parabolic dependence on the voltage. Further, there is a weak insulating-like behavior of the zero-bias resistance as a function of temperature, a reliable indication that this is a tunneling process based on the Rowell criteria for tunneling.[4] High-resolution TEM measurements indicate an atomically abrupt interface between the metal and semiconductor. Current-in-plane measurements and the relation of bias voltage to spin polarization will also be discussed. This work was supported by the DARPA SpinS program and ONR.

[1] G. Schmidt, et al, Phys.Rev.B 62, R4790 (2000)
[2] E.I. Rashba, Phys.Rev.B 62, R16267 (2000)
[3] A.T. Hanbicki, et al., Appl.Phys.Lett. 80, 1240 (2002)
[4] B.J. Jönsson-Åkerman, et al., Appl.Phys.Lett. 77, (2000).

3:00pm **EL+SC+MI-MoA4 A Schottky Tunnel Barrier Contact for Electrical Spin Injection into a Semiconductor**, ***B.T. Jonker****, A.T. Hanbicki, G. Kioseoglou*, Naval Research Laboratory, *G. Itskos, R. Mallory, A. Petrou*, SUNY at Buffalo

Electrical injection of spin polarized electrons into a semiconductor heterostructure is a critical issue for semiconductor-based spintronic devices. While very encouraging results have been obtained using magnetic semiconductors as injecting contacts,[1] the desire for room temperature operation at low magnetic fields leads one to consider other materials and avenues. Ferromagnetic (FM) metals offer high Curie temperatures and can be rapidly switched (~ 300 ps) at low applied fields. However, theory has indicated that only very small spin injection (~0.01%) can be expected for typical FM metals as diffusive contacts.[2] We report here electrical spin injection from an Fe Schottky contact into an AlGaAs/GaAs LED structure, with spin injection efficiencies above 34% which extend to room temperature. These robust effects are attributed to spin tunneling[3] through the tailored Schottky barrier contact. The samples are grown by MBE, and the width of the depletion region at the Fe/AlGaAs interface is controlled by the semiconductor doping profile. Under reverse bias, electrons tunnel from the Fe into the semiconductor, and radiatively recombine in the GaAs quantum well. The circular polarization of the surface emitted electroluminescence (Faraday geometry) provides a quantitative, model independent measure of the QW spin polarization, and hence the injection efficiency.[1] The spin tunnel current is dominated by minority spin carriers, in contrast to previous work using Al_2O_3 tunnel barriers and a superconducting film detector. The temperature dependence of the polarization will also be discussed. These results will be compared with previous work[4] and theoretical modeling of Schottky barrier injection. Work supported by the DARPA SpinS program and ONR.

[1] R. Fiederling, et al Nature (1999); B.T. Jonker et al, PRB (2000)
[2] G. Schmidt et al, PRB (2000)
[3] E.I. Rashba, PRB (2000)
[4] H.J. Zhu et al, PRL (2001).

3:20pm **EL+SC+MI-MoA5 Contact Metallurgy for the Antimonide Based Compound Semiconductors**, ***S.E. Mohney****, W.E. Liu, H.S. Wang, J.A. Robinson*, Penn State University **INVITED**

Antimonide based compound semiconductors are promising candidates for both high frequency, low power electronic devices and optoelectronic devices, and the performance of electrical contacts to these semiconductors is critical for some of the devices currently under development, particularly the electronic devices. Control of the interfacial reactions between the contact metals and the semiconductors is necessary during device processing and packaging since interfacial reactions between the metals and semiconductors occur at very low temperatures. Therefore, we have examined the condensed phase equilibria in the metal-III-Sb systems to guide our selection of shallow, thermally stable contact metallizations. We have performed thermodynamic calculations to estimate ternary phase diagrams in the transition metal-Ga-Sb, transition metal-In-Sb and selected metal-Al-Sb systems. We find that W, Re, and Os are the only transition metals predicted to be in thermodynamic equilibrium with both GaSb and InSb under the conditions considered in our calculations, while W is the only transition metal predicted to be in equilibrium with AlSb. Finally, we give an example of our use of the information we have gathered for the design of a very shallow, thermally stable low resistance ohmic contact to p-type GaInSb. Since we have observed using transmission electron microscopy that Pd reacts uniformly with GaSb at low temperatures, we chose a very thin layer of Pd as the first metal in our contact. We then deposited W because of our prediction that it would be in thermodynamic equilibrium with both GaSb and InSb and that it could serve as a diffusion barrier between layers. Finally, we capped the films with Au, which was important for lowering the metal sheet resistance. A contact resistance of 3 x 10^{-7} ohm-cm^2 was measured with good stability at 250 °C for 100 h, as verified using contact resistance measurements and Auger depth profiles.

4:00pm **EL+SC+MI-MoA7 Electrical Contact Behavior of Ni/C60/4H-SiC**, ***W. Lu***, Fisk University, *W.C. Mitchel*, Air Force Research Laboratory, *J.R. Landis*, University of Dayton Research Institute, *T.R. Crenshaw*, Fisk University, *S.R. Smith*, University of Dayton Research Institute, *W.E. Collins*, Fisk University

Ohmic contact formation of Ni/C60 film on n-type 4H-SiC was investigated. A C60 interfacial layer between Ni film and SiC improves ohmic contact properties significantly. The C60 film was deposited by Langmuir-Blodgett method prior to the Ni film deposition on SiC using DC sputtering method. High quality ohmic contact of Ni/C60/4H-SiC is formed after annealing at 800°C in Ar for two hours with a specific resistance of 1.6

x 10^{-6} Ωcm^2 for the SiC with a doping concentration of 1.8 x $10^{19} cm^{-3}$. Raman spectra reveal that the formation of graphitic carbons by Ni catalytic effects result in the formation of ohmic contact on SiC, and the nano-size graphitic flakes identified by Raman spectroscopy play a key role for ohmic contact formation on SiC. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) show a direct relationship between the graphitized morphological features on the film and ohmic contact behavior.

4:20pm **EL+SC+MI-MoA8 Electrical Characterization of AlN MIS/MIM-structures**, ***F. Engelmark***, *J. Westlinder, I.V. Katardjiev, J. Olsson, S. Berg*, University of Uppsala, Sweden

The electrical properties of insulating ceramic films such as AlN, Ta_2O_5, HfO_2, ZrO_2, Al_2O_3, etc. are of substantial interest for a number of microelectronic and electro-acoustic applications owing to their chemical stability in harsh environments along with some very interesting electrical properties. In this work, emphasis has been put on the electrical properties of Aluminum nitride (AlN) films. Thin AlN films have been deposited onto Si(100) and Mo/Si(100) substrates. The sputter deposited Mo is polycrystalline, showing a predominant (110) orientation. AlN film growth is performed using different process conditions in a reactive PVD (Physical Vapour Deposition). Both fully textured (0002) polycrystalline and XRD amorphous films have been grown and studied. MIS- and MIM-structures have been fabricated and electrical properties such as dielectric constant, leakage current as well as their high frequency behaviour are investigated. The measurements indicate that the dielectric constant does not vary with crystallinity of the films, and remains constant at a value of 10. Further, the high frequency behaviour of the dielectric constant have been studied in the range 100 MHz to 20 GHz. The leakage current mechanism is also similar for different films and is believed to be Poole-Frenkel controlled. C-V (Capacitance-Voltage) measurements for MIS structures revealed the presence of charges in the interface between the substrate and the dielectric layer. Trapped charge density was estimated to be $3.5*10^{10}$ cm^{-2}.

Authors Index

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