Magnetic Interfaces and Nanostructures
Room 206 - Session MI+EL-WeA

Magnetic Semiconductors and Hybrid Structures II
Moderator: P.N. First, Georgia Institute of Technology

2:00pm **MI+EL-WeA1 Spin-dependent Behavior in Magnetic / Semiconductor Heterostructures**, ***B.T. Jonker,*** Naval Research Laboratory **INVITED**

Magnetic / semiconductor heterostructures offer many exciting opportunities for spintronic applications, ranging from hybrid device structures to direct spin injection. We describe here recent results of each. We have fabricated hybrid logic cells which provide fully reprogrammable, nonvolatile logic operation by combining GMR elements with InAs/AlSb/GaSb resonant interband tunneling diodes (RITDs). Such programmable cells allow the use of a low component count common building block for multiple logic functions, and combine the low power, high speed operation of the RITD with the nonvolatile character of GMR elements. Electrical spin injection and transport in semiconductors is another promising avenue to add spin-dependent functionality to the many attractive device properties of semiconductor compounds -- it provides a very simple means of spin injection, and significantly broadens the potential for practical applications.@footnote 1-3@ We have recently demonstrated highly efficient electrical injection of spin-polarized electrons into a AlGaAs/GaAs-based quantum well LED heterostructure using a non-lattice matched epilayer of the semimagnetic semiconductor ZnMnSe as the spin injecting contact. The electroluminescence (EL) from the quantum well is strongly polarized, and provides a quantitative measure of spin injection across the ZnMnSe/AlGaAs interface. Other components of the EL spectrum exhibit little polarization, and provide insight into spin relaxation mechanisms. Ferromagnetic semiconductors provide an ideal contact for electrical spin injection and/or transport -- they are closely matched in conductivity and band structure, and require no large magnetic bias field to produce spin polarized carriers. Several candidate materials will be discussed. ** Supported by ONR and the DARPA SPINS program.@FootnoteText@ @footnote 1@ B.T. Jonker et al, submitted. @footnote 2@ R. Fiederling et al, Nature 402, 787 (1999) @footnote 3@ Y. Ohno et al, ibid p. 790.

2:40pm **MI+EL-WeA3 MBE Growth of Ni@sub 2@MnIn/InAs (001) Heterostructure**, ***J.Q. Xie***[1], *J.W. Dong, L.C. Chen, J. Lu, C.J. Palmstrom,* University of Minnesota

InAs is the semiconductor of choice for spintronic applications due to the ease of forming ohmic contacts and its high electron mobility. The former arises from the fact that the Fermi level tends to be pinned in the conduction band at the metal/InAs interface. Although no elemental ferromagnetic metals are lattice matched to InAs, Ni@sub 2@MnIn is nearly lattice matched. In the bulk, stoichiometric Ni@sub 2@MnIn is ferromagnetic at room temperature and has the cubic L2@sub 1@ Heusler structure with a lattice parameter 0.2% larger than that of InAs. In this talk, we report on the growth of ferromagnetic Ni@sub 2@MnIn films on (001) InAs by molecular beam epitaxy (MBE). Both in situ reflection high energy electron diffraction and ex situ X-ray diffraction measurements indicate that Ni@sub 2@MnIn films grow epitaxially on MBE-grown (001) InAs substrates. Vibrating sample magnetometer and superconducting quantum interference device magnetometer measurements show that the deposited films are ferromagnetic with a Curie temperature ~300 K. Our initial results indicate that Ni@sub 2@MnIn grows in a hexagonal Ni@sub 2@In@sub 3@-type structure, which probably results from either interfacial chemistry or composition. In this talk, the effects of interfacial layers on the growth, structure and magnetic properties of Ni@sub 2@MnIn thin films will be discussed.

3:00pm **MI+EL-WeA4 Investigation of the Microstructural Dependence of Magnetic Properties for MnSb/Bi Multilayers Grown on Sapphire**, ***M.L. Reed***, *H.H. Stadelmaier, N.A. El-Masry,* North Carolina State University

The microstructural dependence of the magnetic properties for MnSb/Bi multilayer films grown on sapphire substrates by pulsed laser deposition were investigated by X-ray diffraction(XRD), vibrating sample magnetometer (VSM), and magnetoresistance measurements. Typical hysteresis loops for the MnSb/Bi multilayers are characteristic of ferromagnetic materials. However, altering the growth parameters produces a second coercive field indicating the formation of a second magnetic phase. XRD analysis identified the presence of a peak centered between (0002)MnSb and (0002) MnSb, which in previous samples had not been observed. A change in the relative planar Hall resistance from 1% to 16% with applied magnetic field was also observed in the films that exhibit this second phase. We discuss the nature of this phase and its effect on the magnetic properties of MnSb/Bi.

3:20pm **MI+EL-WeA5 Ferromagnetic Fe/Ag-GaAs Waveguide Structures for Wideband Microwave Notch Filter Devices**, ***W. Wu,*** University of California, Irvine; *C.S. Tsai,* University of California, Irvine and Academia Sinica, Taiwan; *C.C. Lee, H.J. Yoo, J. Su,* University of California, Irvine

Ferromagnetic Fe/Ag thin films were epitaxially grown on GaAs substrate by molecule beam epitaxy (MBE) system. Magneto-optic kerr effect (MOKE) experiment was used to measure the magnetization and sample magnetic anisotropy. Ferromagnetic resonance (FMR) peak-to-peak linewidths @delta@H@sub pp@ are identified with the narrowest linewidth of 23 Oe. Wideband electronically tunable microwave band-stop filters were successfully fabricated utilizing both the flip-chip and the integrated configurations, using Fe/Ag-GaAs waveguide structures. The coupling between the microwave signal and the spin excitations happened in ferromagnetic Fe films. Maximum coupling and thus strong attenuation of the microwave power occur at the FMR frequency of Fe, as determined by the applied magnetic fields. A frequency tuning range of 10.6 to 27.0 GHz has been measured with the flip-chip type filter. For the integrated type filter, a tuning range as large as 10.7 to 36 GHz for the peak absorption carrier frequency of a propagating microwave has been accomplished by varying a magnetic field from 0 to 4,600 Oe. Our studies show that Fe/Ag-GaAs waveguide structure is a very promising system for use in future microwave magnetoelectronics as they have well-defined magnetic properties, as well as favorable electrical properties.

3:40pm **MI+EL-WeA6 Non-Volatile Reprogrammable Logic Elements using a Hybrid RTD-GMR Circuit@footnote 1@**, ***A.T. Hanbicki,*** *R. Magno, S.-F. Cheng,* Naval Research Laboratory; *J.E. Mattson,* Naval Research Laboratory, US; *Y.D. Park, A.S. Bracker, B.R. Bennett, B.T. Jonker,* Naval Research Laboratory

Programmable logic devices and gate arrays are increasingly important in new computation and digital logic systems. The resonant tunneling diode (RTD) is an especially attractive device component for such applications because it offers high frequency and low power operation due to its unique IV characteristics. It has been shown that memory, multi-value logic and monostable-bistable logic elements (MOBILE)@footnote 2@ can be constructed using RTDs and FETs. We describe here the fabrication and operation of programmable gates and logic cells based on the combination of RTDs with magnetic elements, yielding fully reprogrammable, nonvolatile functions. The circuits discussed are constructed with resonant interband tunneling diodes (RITD) combined with giant magneto-resistance (GMR) elements. The RITDs are fabricated from MBE-grown InAs/AlSb/GaSb/AlSb resonant tunneling structures using standard processing techniques, and provide a peak current of 1.4 x 10@super 4@ A/cm@super 2@. The GMR elements consist of Co/Cu multilayers, and exhibit a value of @DELTA@R/R = 28% at 300 K (CIP). Simple series and parallel circuit combinations demonstrate continuous or 2-state tunability of the RITD I-V characteristic. Threshold detection is demonstrated, for the RITD and GMR in series, by ramping the magnetic field. With the elements we have chosen, the output can be switched by 0.5 V. MOBILE-like inverter operation is observed in a GMR/2-RITD circuit. Specifics of several other circuits will also be discussed. Work is in progress to fabricate an on-chip GMR/RITD integrated circuit. @FootnoteText@ @footnote 1@This work was supported by the Office of Naval Research. @footnote 2@K. Maezawa and T. Mizutani, Jpn. J. Appl. Phys., 32 (1993) L42.

4:00pm **MI+EL-WeA7 Magnetization-Controlled Resonant Tunneling in Magnetic Heterostructures**, *D.O. Demchenko, A.N. Chantis,* ***A.G. Petukhov,*** South Dakota School of Mines and Technology

Recent advances in molecular beam epitaxial growth made it possible to fabricate exotic heterostructures comprised of magnetic films or buried layers (ErAs, Ga@sub x@Mn@sub 1-x@As) integrated with conventional semiconductors (GaAs) and to explore quantum transport in these heterostructures.@footnote 1,2@ It is particularly interesting to study spin-dependent resonant tunneling in double-barrier resonant tunneling diodes (RTD) with magnetic elements such as GaAs/AlAs/ErAs/AlAs/GaAs, Ga@sub x@Mn@sub 1-x@As/AlAs/GaAs/AlAs/GaAs, and GaAs/AlAs/Ga@sub x@Mn@sub 1-x@As/AlAs/GaAs. We present the results of our theoretical studies and computer simulations of transmission

[1] **Falicov Student Award Finalist**

coefficients and current-voltage characteristics of resonant tunneling diodes based on these double-barrier structures. Interband resonant tunneling of electrons (ErAs-based RTDs) and resonant tunneling of holes (Ga@sub x@Mn@sub 1-x@As-based RTDs) is considered. Our approach is based on 8x8 k.p perturbation theory with exchange splitting and strain effects taken into account. We analyze Zeeman splittings of different resonant channels as a function of magnetization. We found that resonant tunneling I-V characteristics of the double-barrier magnetic heterostructures strongly depend on the doping level in the emitter as well as on the orientation of the magnetization. The peculiarities spin-dependent tunneling in GaAs/ErAs- and GaAs/GaMnAs-based heterostructures are explained in terms of strong interaction of confined hole states with magnetization, spin-orbit interaction and angular momentum selection rules. @FootnoteText@ @footnote 1@ D. E. Brehmer, K. Zhang, C. J. Schwartz, S. P. Chau, and S. J. Allen, Appl. Phys. Lett. 67, 1268 (1995). @footnote 2@ H. Ohno, N. Akiba, F. Matsukura, K. Ohtani, A. Shen, and Y. Ohno, Appl. Phys. Lett. 73, 363 (1998).

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