SYMPOSIUM I

Semiconductor Spintronics–Physics, Materials, and Applications

November 28 – 29, 2000

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* Invited paper

SESSION I1: SPINTRONICS MATERIALS I
Chair: Hideo Ohno
Tuesday Morning, November 28, 2000
Room 205 (Hynes)

8:30 AM *I1.1
DOPING-INDUCED FERROMAGNETISM IN II-VI DILUTED MAGNETIC SEMICONDUCTORS. J.Cibert, S. Tatarenko, D. Ferrand, A. Wasiela, Laboratoire de Spectrométrie Physique, Grenoble, FRANCE; T. Dietl, Polish Academy of Sciences, Warsaw, POLAND.

Diluted magnetic semiconductors based on II-VI compounds appear as model materials for the realization and the study of carrier-controlled ferromagnetic interactions. In tellurides, localized spins and excess carriers can be introduced independently, through the incorporation of electrically-inactive Manganese atoms, and of Nitrogen impurities which behave as acceptors, respectively. As a result, various configurations of the carrier gas can be designed, with a broad range of available densities, from the 3D system on both sides of the metal-insulator transition in ZnMnTe layers [1], to the 2D case in modulation-doped CdMnTe quantum wells [2]. In all cases, the RKKY model (or even its uniform limit, i.e. the Zener model) was found to satisfactorily predict the Curie-Weiss temperature, provided one takes into account the superexchange interactions between localized spins, the exact structure of the valence band, and carrier-carrier interactions. Less is known up to now on the ordered phase, especially in the insulating 3D layers and in the 2D system. In addition to these basic studies, the 2D case is particularly suitable for an external control of the interaction, either by adjusting the carrier density (optically or through electrostatic gates), or through the interaction with ferromagnetic metals. [1] D. Ferrand, J. Cibert, A. Wasiela, C. Bourgognon, S. Tatarenko, G. Fishman, S. Kolesnik, J. Jaroszynski, T. Dietl, B. Barbara, D. Dufeu; J. Appl. Phys. 87, 6451(2000) [2] A. Haury, A. Wasiela, A. Arnoult, J. Cibert, T. Dietl, Y. Merle d'Aubigné, S. Tatarenko, Phys. Rev. Lett. 79 (1997) 511

9:00 AM I1.2
GaMnAs AS A DIGITAL FERROMAGNETIC HETERO-STRUCTURE. R.K. Kawakami, E. Johnston-Halperin, L.F. Chen, M. Hanson, N. Guébels, J. Speck, A.C. Gossard, and D.D. Awschalom, Center for Spintronics and Quantum Computation, University of California, Santa Barbara, CA.

The ability to manipulate electron spins in semiconductors introduces the possibility of developing a new class of semiconductor electronics based on the spin degree of freedom. Central to this effort is the development of materials that integrate ferromagnetism with traditional semiconductor structures, such as the recently discovered ferromagnetic alloys GaMnAs and InMnAs. In this work, we grow GaMnAs as a digital ferromagnetic heterostructure (DFH) by alternately depositing GaAs and a submonolayer of MnAs using low temperature molecular beam epitaxy (240°C - 300°C). By controlling the position of the magnetic Mn ions along the growth direction, this digital growth technique enables investigation of the length scales of the ferromagnetic interaction. Furthermore, this technique in principle provides a method of separating the magnetic and electronic doping, which creates new opportunities for engineering desired magneto-electronic properties. Characterization by RHEED, x-ray diffraction, and TEM indicates that the Mn is incorporating digitally and that the crystalline quality is comparable to the random alloy GaMnAs. SQUID magnetization measurements indicate ferromagnetic ordering with in-plane easy axis and Curie temperatures (Tc) up to 50 K. By varying the spacing between neighboring digital Mn layers, we observe that Tc initially decreases with increasing spacer thickness (10 - 40 ML). Subsequently Tc crosses to a regime with weak dependence on the spacer thickness (> 40 ML), persisting to interlayer spacings of at least 200 ML. This suggests that individual digital Mn layers are ferromagnetic. Work supported by ONR and DARPA-ONR.

9:15 AM I1.3
GROWTH AND CHARACTERIZATION OF DIGITAL ALLOYS AND HETEROSTRUCTURES OF GaAs/Mn. X. Chen, K.P. Mooney, T. Yeo, M. Furis, H. Luo, B.D. McCombe and A. Petrou, Department of Physics and Center for Advanced Photonic and Electronic Materials, State University of New York at Buffalo, Buffalo, NY; Y. Sasaki, X. Liu, and J.K. Furdyna, Department of Physics, University of Notre Dame, IN.

Ferromagnetic III-Mn-V alloys have shown many interesting properties that are being intensely studied for spintronic applications. The concentration of Mn, however, has been limited by several basic material problems, making it inherently difficult to incorporate Mn at alloy levels. As a result, the Curie temperature for this group of materials remains well below room temperature. In this study, we have focused on an alternative approach to growing III-Mn-Vs, inserting Mn in digital layer form into GaAs. Because the RKKY interaction, believed to be responsible for ferromagnetism in III-Mn-Vs, depends on the distance between Mn ions, the thickness of GaAs layers separating the Mn layers was varied from 6 to 18 monolayers. All samples were grown on semi-insulating (100) GaAs substrates. The growth sequence starts with GaAs grown at 580°C, followed by lower temperature GaAs growth. The digital layers of Mn were subsequently grown at the lower temperature, which was varied from 275°C to 400°C. The onset for precipitate formation of MnAs is known to be sensitive to growth temperature for conventional random alloys, and was studied in digital alloys in the above temperature range. The layer coverage of Mn was monitored and controlled with reflection high energy electron diffraction (RHEED). The samples were characterized by transmission electron microscopy, magnetic susceptibility and transport measurements. The results indicate that ferromagnetic GaAs/Mn digital alloys can be grown with high structural quality. The connection between magnetic properties and structure dimensions will be discussed.

9:30 AM I1.4
GROWTH AND MAGNETO-TRANSPORT PROPERTIES OF P-TYPE $Be_{(1-x)}Mn_xTe$ LAYERS. L. Hansen, D. Ferrand, G. Mueller, V. Hock, N. Schwarz, G. Schmidt, A. Waag[1], L.W. Molenkamp Experimental Physics III, Wuerzburg University, Wuerzburg, GERMANY; [1]Department of Semiconductor Physics, Ulm University, Ulm, GERMANY.

There is a growing interest in p-type doped dilute magnetic semiconductors where it is possible to induce ferromagnetism through increasing the carrier con- centration. Such ferromagnetic epilayers could be conveniently integrated into semiconductor heterostructures. Carrier-induced ferromagnetism has been observed in III-V DMS layers (GaMnAs, InMnAs)[1] as well as in II-VI heterostructures (CdMnTe QW, ZnMnTe layers)[2]. The possibility in II-VI compounds to control independently the localized spins and the hole concentration make them very attractive for fundamental studies, in particular in modulation doped low dimensional heterostructures. In this respect, the novel DMS material BeMnTe is of considerable potential interest, because it can be strongly p-type doped and has a good lattice match to GaAs for Mn concentrations up to 10%. We report on the first growth of BeMnTe thin film structures, using solid source MBE and nitrogen doping by a RF-plasma source. A (2x1) RHEED pattern and intense RHEED oscillations indicate a 2D growth mode. A low VI/II BEP ratio of 10 is crucial for a high built-in of Nitrogen[3]. The p-type doping level has been optimized by tuning the plasma cell, the II/VI ratio during growth, as well as reducing the growth rate. BeMnTe and BeTe layers have been characterized by magneto-transport measurements from room temperature down to 1.6K. At low temperatures, the BeMnTe samples exhibit a large anomalous Hall effect. A hysteresis on the anomalous Hall effect appears below 2.5K in the best doped sample, which indicates the presence of a transition to the ferromagnetic phase with a critical temperature between 2.5K and 3K. [1]Ohno et al., Phys. Rev. Lett. **68**, 2664 (1992), Science **281**, 951 (1998). [2]Haury et al., Phys. Rev. Lett. **79**, 511 (1997), Ferrand et al., J. Appl. Phys. **87**, 6451 (2000). [3]Cho et al., J. Vac. Sci. Technol. **A 18(2)**, 457 (2000).

9:45 AM I1.5
GROWTH AND CHARACTERIZATION OF MnAs/ZnSe AND (Ga,Mn)As/ZnSe FERROMAGNET/SEMICONDUCTOR HETEROSTRUCTURES. S.H. Chun, J.J. Berry, K.C. Ku, N. Samarth, The Pennsylvania State University, Dept of Physics, University Park, PA; I. Malajovich, D.D. Awschalom, L.F. Chen and J.S. Speck, University of California, Center for Spintronics and Quantum Computation, Santa Barbara, CA.

The compatibility of optimal growth temperatures among MnAs-based ferromagnets and the II-VI semiconductors makes them excellent candidates for the construction of hybrid ferromagnetic/ semiconductor heterostructures. Here, we report the molecular beam epitaxy (MBE) of MnAs and (Ga,Mn)As on (100) ZnSe buffer layers using a dual chamber MBE system. The effects of substrate temperature, flux ratios, surface termination and other growth parameters are studied using structural (RHEED, XRD, TEM, and AFM) and magnetic (MOKE and SQUID) probes. We first demonstrate the coherent, epitaxial growth of hexagonal MnAs on ZnSe buffer layers. Under optimal growth conditions, the Curie temperature, spontaneous magnetization and the coercive field of these MnAs epilayers are comparable to those of MnAs grown directly on GaAs. While the degree and nature of the magnetic anisotropy is highly dependent on detailed growth conditions, we find that highly anisotropic in-plane magnetization can be reproducibly achieved, ensuring well-oriented magnetic domains. We also show that zinc-blende (Ga,Mn)As can be coherently grown on ZnSe. RHEED studies indicate that an initial period of island (3D) growth is followed by layer-by-layer growth as implied by a streaky RHEED pattern with a weak 1x2 reconstruction. So far, (Ga,Mn)As epilayers grown on ZnSe buffer layers appear to be insulating and paramagnetic, whereas those grown on GaAs under identical growth conditions are metallic and ferromagnetic (with Curie temperatures in the range 45 K - 60 K). This suggests that templating and strain conditions may play an important role in optimizing the magnetic properties of these hybrid materials. Supported by ONR and DARPA/ONR.

10:30 AM I1.6
MOLECULAR BEAM EPITAXY OF GaN-BASED DILUTED MAGNETIC SEMICONDUCTORS. S. Kuwabara, K. Ishii, S. Haneda, T. Chikyow[1], T. Kondo and H. Munekata[2]; Tokyo Inst. Tech., Imaging Sci. Eng. Lab., Yokohama, JAPAN; [1]National Research Institute for Metal, Ibaraki, JAPAN; [2]Additional posts at PRESTO and KAST, JAPAN.

We describe experimental results on the preparation and characterization of GaN-based crystalline epilayers doped extremely heavily with two different transition metal elements, Mn and Fe. This work, aiming at the preparation of GaN-based diluted magnetic semiconductors, is motivated by the following two reasons; firstly, the pursuit of carrier-induced ferromagnetic order at room temperature, and secondly, the development of magneto-optical materials suitable for optical information processing in the blue light region.
Samples were prepared by molecular beam epitaxy. Two different series of samples, GaN:Fe and GaN:Mn epilayers, were deposited at substrate temperatures of $T_s = 500 \sim 800°$C on the surface of the hexagonal GaN template layers grown by MOVPE. *In-situ* reflection high-energy electron diffraction (RHEED) has showed a six-fold symmetrical, streaky (2×1) reconstructed pattern during the deposition of the GaN:X (X = Mn and Fe), indicating the retention of the hexagonal structure. The growth rates were in the range of 50-100 nm/hr.
Surface evaluations by scanning electron microscope has revealed that the range of impurity concentrations that yield films without macroscopic precipitation is relatively wide; e.g., $[Mn] \leq 5\times10^{21}$ at $T_s = 600°$C and 5×10^{20} cm^{-3} at 800°C for GaN:Mn. Moreover, high resolution cross-sectional images reveal that no apparent second phase is noticeable in both GaN:Mn and GaN:Fe epilayers. These observations are very encouraging at present.
GaN:Mn epilayers show clear brownish color, and primarily exhibit paramagnetic behavior. The fit with Brillouin function assuming S = 5/2 for Mn^2 indicates that about 30% of incorporated Mn ions contribute to the paramagnetic component. We infer that the rest may condense into very small domains in which Mn ions may be antiferromagnetically coupled. In contrast, GaN:Fe epilayers show somewhat dark color, and both paramagnetic and ferromagnetic components are present in the dc-magnetization data.

10:45 AM I1.7
EPITAXIAL HALF-METALLIC NiMnSb FILMS ON GaAs(001). Willem Van Roy, Jo De Boeck and Gustaaf Borghs, IMEC, Leuven, BELGIUM.

For the injection of spin-polarized electrons from a ferromagnet into a semiconductor through a diffusive contact it is crucial that the injector has 100% spin-polarization, i.e., that it is a half-metallic ferromagnet such as NiMnSb. We present the first growth of epitaxial NiMnSb films on GaAs(001), using molecular beam epitaxy. Ni and Mn were supplied in a 1:1 ratio after EDS calibration, with an overpressure of Sb_2. All growths were started by switching on the three fluxes simultaneously. The growth time was one hour for a film thickness of 250 nm. The orientation of the films was NiMnSb(001)[110] // GaAs(001)[110]. We found a tendency towards the formation of Mn_2As at the interface that could be suppressed by reducing the substrate temperature T_{sub}, increasing the Sb_2 flux, and by the insertion of a 2 nm AlAs diffusion barrier at the interface. The best structural quality was obtained at $T_{sub} = 300°$C and an Sb_2:Ni beam equivalent pressure (BEP) ratio of 8:1. From the onset of NiMnSb the RHEED pattern was streaky with a 2x4 reconstruction that developed within 5 nm. XRD showed a splitting of the NiMnSb peak corresponding to c = 5.91 and 5.93 Å, suggesting partial relaxation of the film towards the bulk value c = 5.903 Å. Magnetic measurements showed a 2-fold in-plane anisotropy with an anisotropy energy of 1600 J/m^3. The easy axis loop was almost square with M_r / M_s = 0.94 and H_c = 16.5 Oe. The saturation magnetization M_s = 550 kA/m was slightly less than the bulk value (720 kA/m), which is possibly related to an Sb-deficiency of this film as suggested by RBS. By raising the Sb_2:Ni BEP ratio to 13:1 we obtained an increase of M_s to 610 kA/m while c = 5.905 Å became identical to the bulk value.

11:00 AM *I1.8
DILUTED MAGNETIC SEMICONDUCTOR HYBRID STRUCTURES AND SELF ASSEMBLED QUANTUM DOTS. J. Kossut, K. Fronc, S. Maćkowski, G. Karczewski, T. Wojtowicz, Institute of Physics, Polish Academy of Sciences, Warsaw, POLAND.

Diluted magnetic semiconductor quantum structures (including spin-engineered structures with a gradient of constituent layers width) based on telluride compounds are fabricated by molecular beam epitaxy (MBE) in several hybrid configurations: (a) with patterned overlayers of magnetic metals (iron, permalloy, etc.); (b) grown on quantum structures made of III-V materials prepared in separate MBE processes. Also research is described on self-assembled quantum dots of CdTe embedded in ZnTe matrix. The latter show a degree of spatial correlation of the dots belonging to different layers separated by ZnTe spacers. All systems are investigated by optical and magnetooptical methods. Transmission electron microscopy, x-ray diffraction and atomic force microscopy are also used as tools for critical assesment of the fabricated structures.

11:30 AM *I1.9
ROOM-TEMPERATURE HUGE MAGNETORESISTANCE CHANGE IN MnSb GRANULAR FILMS GROWN ON GaAs. Hiro Akinaga, JRCAT-NAIR, Tsukuba, JAPAN.

A huge positive magnetoresistance (MR) effect, about 5 orders of magnitude at room temperature, has been discovered in MnSb granular films. Granular film consisting of nanoscale MnSb clusters that are grown on a sulfur-passivated GaAs (001) substrate by molecular-beam epitaxy exhibits magnetic-field-sensitive current-voltage characteristics. When a constant voltage, above the threshold value, is applied to the film, very steep change in the current, which we term *magnetoresistive switch* [1], is driven by the huge MR effect under a relatively low magnetic field (less than about 0.2 T). The origin of the magnetoresistive switch effect is discussed in terms of a novel concept of spin-dependent avalanche breakdown. The MR effect of GaAs is amplified by the avalanche breakdown, and becomes magnetic-field-sensitive by the existence of ferromagnetic clusters. The device-fabrication process and the preliminary evaluation will be shown. By reducing the dark current, the avalanche breakdown of the granular film becomes photo-sensitive. The photo-induced huge MR effect, namely the control of the magnetoresistive switch effect by the photo-generated carriers in GaAs, has been also demonstrated in the granular film. The photon energy dependence of MR curves will be shown. *in collaboration with M. Mizuguchi, T. Manago, T. Sato, H. Kuramochi (JRCAT), S. Yuasa (ETL), K. Ono, H. Ofuchi, M. Oshima (Univ. Tokyo), and supported by the New Energy and Industrial Technology Development Organization (NEDO) and partially by a Grant-in-Aid for Scientific Research on the Priority Area 'Spin Controlled Semiconductor Nanostructures' from the Ministry of Education, Science, Sports, and Culture, Japan. [1] H. Akinaga *et al.*, Appl. Phys. Lett. **73, 357 (2000).**

SESSION I2: SPINTRONICS MATERIALS II
Chair: Nitin Samarth
Tuesday Afternoon, November 28, 2000
Room 205 (Hynes)

1:30 PM I2.1
ELECTRONIC STRUCTURE AND MAGNETIC PROPERTIES OF TRANSITION METAL ATOM DOPED ZnO. Kazunori Sato, Hiroshi Katayama-Yoshida, Institute of Scientific and Industrial Research, Osaka Univ., Osaka, JAPAN.

Recently, diluted magnetic semiconductors (DMS) have been studied intensively as a candidate for a functional magnetic material, and some prototypes of such new material have been realized in the systems of the III-V compound based DMS. To find out another high performance DMS and elucidate the mechanism governing the carrier induced ferromagnetism in DMS, we studied the magnetism of transition metal atom doped ZnO by ab initio electronic structure calculations. We calculated the electronic structure of a doped ZnO with Cr, Mn, Fe or Co within the local density approximation by the Korringa-Kohn-Rostoker method combined with the coherent potential approximation (KKR-CPA). The KKR-CPA method is one of the best ways to simulate substitutionally disordered alloys in arbitrary ratio of components such as the present cases. Total energies of $Zn_{1-x}TM^{\uparrow}_{x}O$ and $Zn_{1-x}TM^{\uparrow}_{x/2}TM^{\downarrow}_{x/2}O$, where TM means Cr, Mn, Fe or Co and up and down arrows mean the directions of respective magnetic moments, were compared and appearance of the ferromagnetism was discussed for various values of x. Effects of carrier doping to these systems were also investigated by introducing one more component of N or Ga at the site of O or Zn, respectively. It was found that their magnetic states were controllable by changing the carrier density. It was also suggested that doped ZnO based DMS had higher Currie temperature than the III-V based DMS and they had potential to realize practical ferromagnetic semiconductors. By analyzing the calculated density of states, it was found that the effect of doping did not occur in the rigid band like. This point will be discussed from the view point of the stabilization mechanism of the ferromagnetism in the present cases.

1:45 PM I2.2
DO As ANTISITES DESTROY THE FERROMAGNETISM OF

(Ga,Mn)As? Stefano Sanvito and Nicola A. Hill, Materials Department, University of California, Santa Barbara, CA.

During the low-temperature MBE-growth of the diluted magnetic semiconductor (Ga,Mn)As the formation of As antisites is hardly avoidable. In this paper we investigate how the presence of such As antisites affect the magnetic properties of (Ga,Mn)As. We use density functional theory in the local spin density approximation with a pseudoatomic orbitals basis which allows us to calculate the ground state properties of very large cells and therefore to investigate different Mn concentrations. We consider several geometric configurations of the Mn ions and the As antisites within large GaAs cells. The main result of our calculation is that the ferromagnetism is strongly weakened by the presence of the As antisites. In particular when the concentration of As antisites is one half of that of Mn the ferromagnetic alignment becomes unstable and a transition to an antiferromagnetic alignment is found. Since each As antisite is a double donor the factor of 1/2 is consistent with the picture of hole-mediated ferromagnetism of (Ga,Mn)As. However the details of such a transition depend strongly on the geometrical arrangement of the Mn ions and the As antisites. This means that non-trivial short-range contributions to the ferromagnetic alignment are also present.

2:00 PM I2.3
APPLICATION OF WAFER BONDING TO MAGNETO-ELECTRONICS. Stephan Senz, Alexander Reznicek and Ulrich Gösele, Max Planck Institute of Microstructure Physics, Halle, GERMANY.

Wafer bonding has been proven as a technology to transfer thin films from a growth substrate to another substrate. Examples are 10 nm thick twist-bonded GaAs films on GaAs. We report on first experiments to use wafer bonding to produce structures which are useful for spinelectronics. The interface in TMR structures has a great influence on performance. Comparing vapour deposition and wafer bonding, a large difference is that during deposition the substrate surface interacts with vapour, while in the case of UHV wafer bonding two solids are brought into contact. The experiments are made in an UHV wafer bonding system with attached vapour deposition chamber. Interfaces of metal and semiconductor produced by vapour deposition and by wafer bonding are compared. Characterisation is done by TEM, I-U and C-V.

2:15 PM I2.4
A CHANGE OF MAGNETIZATION REVERSAL FIELD BY LIGHT ILLUMINATION IN CARRIER-INDUCED FERROMAGNETIC SEMICONDUCTORS. Akira Oiwa[1], Tomasz Slupinski[1], Hiroo Munekata[1,2], [1]Kanagawa Academy of Science and Technology, Kawasaki, JAPAN, [2]Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, Yokohama, JAPAN.

The ferromagnetism in III-V-based diluted magnetic semiconductors has its origin in carrier-induced magnetism (CIM). The control of CIM has been carried out experimentally by photo-generated carriers in (In,Mn)As/GaSb heterostructures. In this work, we demonstrate the light-illumination effect on the process of magnetization reversal within the framework of CIM in ferromagnetic (In,Mn)As/GaSb. A 30nm-thick $In_{0.93}Mn_{0.07}As$ layer was grown on GaSb/GaAs/GaAs(100) substrate at 195°C by molecular beam epitaxy. Curie temperatures is ~45K. Hole concentration at room temperature is $1.7\times10^{19}cm^{-3}$, neglecting the contribution of anomalous Hall effect. The sample magnetization was detected by the Hall resistance. The light illumination was carried out using a 685nm-laser diode in the absence of external magnetic field. The holes photo-generated in GaSb are partially transferred to (In,Mn)As layer and give rise to the persistent photoconductivity. A rectangular hysteresis loop is observed in Hall resistance at 4.2K. After the light illumination, the magnetization reversal occurs at lower magnetic fields. The persistent change in the reversal field becomes larger with increasing temperatures up to around 35K. It disappears only when the persistent photoconductivity vanishes. This phenomenon is clearly different from the conventional Curie point writing in magneto-optical memory, in which the magnetization reversal occurs by heat and external magnetic field. We consider the energy gain of magnetic domain walls by the light illumination since the magnetization reversal is accompanied by the domain wall reversal. The CIM enhances the ferromagnetic exchange constant among magnetic moments. This results in an increase in the exchange energy of domain walls, and alternatively, a decrease in the anisotropy energy to balance the total energy of domain walls. Consequently, the domain reversal occurs at lower magnetic fields. Investigation on angle dependence of magneto-transport behavior suggests that there is no significant change in magnetic anisotropy of sample by the light illumination.

2:30 PM I2.5
ESR INVESTIGATIONS OF MODULATION-DOPED Si/SiGe QUANTUM WELLS. N. Sandersfeld, W. Jantsch, F. Schäffler, Institut für Halbleiter- und Festkörperphysik, Universität Linz, AUSTRIA; Z. Wilamowski, Institute of Physics, Polish Academy of Sciences, Warsaw, POLAND.

Electron spin resonance (ESR) was measured on high-mobility two-dimensional electron gases (2DEG) in modulation-doped SiGe/Si quantum wells. We observe an extremely narrow resonance line of down to 40 mG, which allows the detection of as few as 1E9 spins in a standard microwave absorption configuration. Longitudinal spin relaxation times T1 of up to 30 μs were found, which is 6 to 7 orders of magnitude longer than the momentum relaxation times in these samples. This makes 2DEGs in Si a very attractive material for the storage of spin information. The high sensitivity of ESR measurements in this material system also allows the extraction of new information on the intrinsic properties of the 2DEG. Using either gated samples or samples where the 2D carrier density ns can be adjusted persistently by illumination, the ESR signal was recorded as a function of ns. Since the ESR signal is proportional to the magnetic (Pauli) susceptibility of the 2DEG, the experiments directly yield the density of states (DOS) at the Fermi level. At low ns we find a tail in the DOS, which is indicative of screening breakdown in the 2DEG once ns is lowered below a critical value. These results are corroborated by ns-dependent transport experiments, and have important implications for the controversially discussed metal-to-insulator transition in 2DEGs.

2:45 PM I2.6
PHOTOINDUCED FARADAY ROTATION AND MAGNETIZATION IN SEMI- MAGNETIC SEMICONDUCTOR NANO-STRUCTURES. Robert Frey, Michael Haddad, Laboratoire d'Optique Quantique, Ecole Polytechnique, Palaiseau, FRANCE; Christos Flytzanis, Laboratoire de Physique de la Matiere Condensee de l'ENS, Paris, FRANCE.

We have evidenced giant photoinduced Faraday rotation in semimagnetic semiconductor nanostructures (multiple quantum wells) and micro-cavities close to excitonic transition as well as photoinduced magnetization with circularly polarized light in the absence of an external magnetic field. The underlying mechanisms are delineated and the impact of the spin-exchange interaction is assessed. The photoinduced Faraday rotation angles can be as large as those of the linear Faraday rotation and in fact can cancel the later namely they can reach values of the order of 20 degrees over one micron thick multiquantum well nanostructure (CdTe/CdMnTe) in moderate magnetic fields (~2T) and moderate light fluences (~ $50\mu J/cm^2$). The dynamics of the effect are studied by a pump and probe technique in the picosecond regime which also allows to assess the spin dynamics and reorganization consequent to the photo-excitation. In the absence of the magnetic field circular polarized light of comparable intensity can induce magnetization of up to 0.5T in the same structure. The dynamics were studied by time-resolved photoinduced Faraday rotation, a pump and probe technique. Magnetooptic interaction in microcavities in the strong coupling regime were also studied and the competition of Zeeman and Rabi splittings are analyzed. Buss et al., Phys. Rev. Lett. 78, 4123 (1997)

3:30 PM I2.7
GIANT TUNABILITY OF EXITONIC PHOTOLUMINESCENCE TRANSITIONS IN ANTIFERROMAGNETIC EuTe EPILAYERS. G. Springholz, W. Heiss and G. Prechtl, Johannes Kepler University, Linz, AUSTRIA.

The photo luminescence properties of wide band gap anti-ferromagnetic EuTe heteroepitaxial layers grown by molecular beam epitaxy were investigated. In contrast to all previous work, we observe two narrow excitonic luminescence lines at transition energies around 1.9 eV with a full width at half maximum of about 10 meV. This emission appears only in high qualitiy epitaxial layers whereas in previous investigations only a broad, defect related luminescence at around 1.5 eV was observed. At 2 K, the excitonic emission lines exhibit a huge red-shift of 240 meV in applied magnetic fields of up to 7 T. This correspond to a luminescence tuning rate of -34 meV/T, which is the largest value ever observed in a semiconductor. It corresponds to an effective g factor of 1140. Because of the linear relationship between luminescence energy and magnetic field (H), this g factor is essentially independent of H, whereas in diluted magnetic semiconductors g strongly decreases when H increases. The exceptional luminescence properties are assigned to the formation of magnetic polarons due to d-f exchange interactions. The giant magnetic field tunability provides interesting and new possibilities for applications in magneto-optical devices like magnetic field tunable lasers, detectors, and modulators. Furthermore, epitaxial EuTe could be used, alternatively to diluted magnetic semiconductors, for the development of spintronic devices like spin filters or spin transistors as key elements for future solid state quantum computers.

3:45 PM I2.8
FIRST PRINCIPLES STUDY OF SPIN-ELECTRONICS: ZERO FIELD SPIN-SPLITTINGS IN SUPERLATTICES. Jacek A. Majewski, Peter Vogl, Walter Schottky Institute, Technical University of Munich, GERMANY.

We present first-principles calculations of the fundamental spin-dependent coupling mechanisms in semiconductor-based spin-devices. Since the pioneering proposal of a spin-transistor by Datta and Das [1], a crucial physical mechanism for spin-polarized transport in semiconductors is known to be the so-called Rashba effect, i.e. a k-linear zero-field spin splitting of the lowest conduction bands in non-centrosymmetric semiconductors. However, the magnitude and physical origin of this effect and its dependence on strain, macroscopic electric fields or interfaces has remained highly controversial [2] and no quantitative studies have been published up to now. We have studied the spin splitting of conduction bands by performing fully relativistic pseudopotential local density functional calculations of nearly lattice matched GaAs/AlGaAs as well as InP/AlAsSb and InP/GaAsSb strained layer superlattices with [001] and [111] growth orientations. Only the latter orientation is associated with built-in piezoelectric fields. In addition, the constituent strained bulk systems have been investigated. The linear-k terms have been extracted from the total spin-splittings that contain also higher order k-terms. We find the linear-k spin splitting in superlattices to be completely controlled by the interface-induced microscopic structural asymmetry and to be independent of the polarization induced electric field within the quantum well. In both [001] and [111] InP/AlSb strained layer superlattices, we obtain the Rashba constant α of the order of 0.1 eV Å independently of the superlattice period, whereas in the [001] GaAs/AlAs superlattice we find the Rashba constant to be 0.06 eV Å. In the [001]-superlattices, we show the interference between Rashba (k) and Dresselhaus (k^3) to lead to a spin-splitting. In [111]-strained bulk systems, we predict the Rashba constant to depend sensitively on the internal strain parameter. Altogether, these results demonstrate that the Rashba effect is controlled by *local* rather than by *macroscopic* fields. Specifically, we predict a value of $\alpha = C_3\epsilon_{xy}/2$ with $C_3 = 6.3\ eV$ Å in AlSb. In addition, we find the linear-k spin-splittings of light holes in superlattices to be much larger (by a factor of 2-3) that the corresponding splittings for electrons. [1] S. Datta and B. Das, Appl. Phys. Lett. 56, 665 (1990). [2] P. Pfeffer, Phys. Rev. B 59, 15902 (1999) and references therein.

SESSION I3: POSTER SESSION
Tuesday Evening, November 28, 2000
8:00 PM
Exhibition Hall D (Hynes)

I3.1
MAGNETOPHOTOLUMINESCENCE INVESTIGATIONS OF POSITIVELY CHARGED EXCITONS IN (Al,Ga)As/GaAs QUANTUM WELLS. Kyu-Seok Lee, Electronics and Telecommunications Research Institute, Taejon, KOREA; Sam-Kyu Noh, Chae-Deok Lee, Korea Research Institute of Standard and Science, Taejon, KOREA; Yongmin Kim, Quantum-functional Semiconductor Research Center, Dongguk Univ, Seoul, KOREA.

Photoluminescence investigations of positively charged excitons (X^+) in (Al,Ga)As/GaAs quantum wells in the presence of a magnetic field up to 9 T show that the Zeeman splitting of the singlet X^+ lines is significantly (> 300 %) larger than that of the 1s neutral exciton (X) lines. Our finding is understood in terms of the light hole ($J_z = \pm 1/2$) admixture to the heavy hole ($J_z = \pm 3/2$), the so-called valence-band mixing (VBM). The Zeeman splitting of X^+ is determined by electron spin in the initial state and hole spin in the final state. Because the cyclotron radius of the free hole remaining after X^+ recombination is larger than the spatial extension of the hole within X, the free hole reveals a smaller VBM than the hole within X. Since the effect of VBM is to decrease the effective spin splitting of the heavy hole, the free hole exhibits a larger spin splitting than the hole within X and consequently a considerably larger Zeeman splitting of X^+ than X. The theoretical analysis also allows us to determine the in-plane effective masses of the free heavy hole and the heavy hole within X, demonstrating that the former is lighter than the latter.

I3.2
NEW MAGNETIC-NONMAGNETIC SEMICONDUCTOR HETEROSTRUCTURE $Cd_{1-x}Mn_xGeP_2$-$CdGeP_2$. Gennadiy A. Medvedkin, Ioffe Physico-Technical Inst, St. Petersburg, RUSSIA; Takayuki Ishibashi, Takao Nishi, Katsuaki Sato, Tokyo University of Agriculture and Technology, Dept of Applied Physics, Tokyo, JAPAN.

Recent possibilities of reading and writing steady information through magnetism and spin injection in semiconductor heterostructures attract attention to earlier unknown compound systems. This paper presents a new solid solution $Cd_{1-x}Mn_xGeP_2$ that possesses magnetic properties and a semiconductor heterostructure grown in MBE chamber as the magnetic semiconductor layer $Cd_{1-x}Mn_xGeP_2$ on the nonmagnetic single crystal $CdGeP_2$. The investigation of a crystal structure, microstructure, concentration profiles and magnetization using XRD, SEM, EDX, VSM techniques shows that the grown semiconductor heterostructure is single crystalline and close to "ideal" with the lattice parameter mismatch $\Delta a/a=0.4\%$. The Mn concentration in the upper layer of 0.4μm thickness is about 20% on average and decreases down to 1% at depth of 2μm. A pronounced magnetic hysteresis loop was observed at room temperature, suggesting a high Curie temperature for the magnetic semiconductor. The ferromagnetic behavior in the new phase with addition of diamagnetism by $CdGeP_2$ substrate is forecasted.

I3.3
ELECTRONIC AND MAGNETIC STRUCTURE OF THE V_{15} MOLECULAR MAGNET. Jens Kortus, C. Stephen Hellberg and Mark R. Pederson, Center for Computational Materials Science, Naval Research Laboratory, Washington, DC.

Molecular magnets such as Mn_{12}-ac and Fe_8 are a new class of materials that have raised significant scientific interest due to the observation of quantum tunneling of magnetization and hystereses of a purely molecular origin.[1,2] Such experiments clearly show coherence effects on a macroscopic scale. The V_{15} compound also belongs to this class of materials although it is a low spin compound with $S = 1/2$ in contrast to Mn_{12}-ac and Fe_8 which both have $S = 10$. The weakly anisotropic V_{15} demonstrates quantum behavior, such as tunneling splitting of low lying spin states and is an attractive model system for the study of mesoscopic quantum coherence and processes which destroy it. Understanding such processes is of interest to the field of quantum computing. V_{15} has a crystallographically imposed trigonal symmetry with three sets of inequivalent vanadium atoms.[3] The unit cell contains two V_{15} clusters and is large enough that dipolar interactions between the molecules are negligible. Between 20K and 100K the effective paramagnetic moment is 3 μ_B corresponding to three independent spins and below 0.5K it decreases showing an S=1/2 ground state for the V_{15} molecule. The experimental results were interpreted with antiferromagnetic interactions between all vanadium atoms.[3] We report first principles all-electron density-functional based studies of the electronic structure, magnetic ordering, anisotropy energies and exchange parameters of of the V_{15} molecular magnet. From these calculations we determine a Heisenberg spin Hamiltonian with five couplings, four of which are antiferromagnetic and one which is ferromagnetic. This Hamiltonian reproduces the S=1/2 ground state found experimentally at low temperatures, with a small gap to the S=3/2 excited state.
[1] J. Friedman, M.P. Sarachik, J. Tejeda, J. Maciejewski and R. Ziolo, Phys. Rev. Lett. **76**, 3820 (1996); L. Thomas, F. Lionti, R. Ballou, D. Gatteschi, R. Sessoli and B. Barbara, Nature (London) **383**, 145 (1996)
[2] C. Sangregorio, T. Ohm, C. Paulsen, R. Sessoli and D. Gatteschi, Phys. Rev. Lett. **78**, 4645 (1997)
[3] D. Gatteschi, L. Pardi. A. L. Barra, A. Müller and J. Döring, Nature **354**, 463 (1991)

I3.4
MAGNETIC AND ELECTRIC PROPERTIES OF IMPURITY STATES IN $Pb_{1-x}Ge_xTe$ DOPED WITH YTTERBIUM. Evgenii Skipetrov, Natasha Chernova, Ludmila Skipetrova, Alexander Golubev, M.V. Lomonosov Moscow State University, Low Temperature Physics Department, Moscow, RUSSIA; Evgenii Slyn'ko, Institute of Material Science Problems, Chernovtsi Department, Chernovtsi, UKRAINE; Galina N. Mazo, Moscow State Univ, Moscow, RUSSIA.

Temperature dependences of the magnetic susceptibility, Hall constant (R_H) and resistivity (ρ) of $Pb_{1-x-y}Ge_xYb_yTe$ ($0 \leq x \leq 0.1$, $y \leq 0.036$) single crystals have been investigated over the temperature range $4.2 \leq T \leq 300$ K in the magnetic field up to 0.5 T. The galvanomagnetic properties of the alloys strongly depend upon the composition: if the total Ge and Yb content (xy) does not exceed 0.01-0.02 the $\rho(1/T)$ and $R_H(1/T)$ dependences reveal a metal-like behavior, while at higher xy values the activation behavior is observed. The magnetic susceptibility of the alloys contains two shares: the diamagnetic and the Curie-Weiss paramagnetic. From the values of the Curie constant we have estimated the concentration of magnetically active Yb^3 ions. It has been found that the ratio of the Yb^3 concentration to the total Yb content monotonously grows with the increase of either x or y value in the alloys. However, the Yb^3 concentration is about an order smaller than the total Yb content in the investigated alloys. We explain the obtained results by the formation of Yb-induced states in the vicinity of the valence band edge. When the total Ge and Yb content is low, the impurity states are situated within the valence band, the electrons fill the impurity states, transferring the Yb ions to the non-magnetic and neutral, with respect to the metal sublattice, Yb^2 state. Growth of either Ge or Yb content results in increase of the gap and shift of the impurity states from the valence to the forbidden band. This lead to the flow of electrons from the impurity states to the valence band and transfer of Yb ions to the electrically and magnetically active Yb^3 state. Thus, in $Pb_{1-x-y}Ge_xYb_yTe$ one can control the density of magnetic impurity states and magnetic properties of the alloys via the control over its energy spectrum parameters.

I3.5

GROWTH AND EQUILIBRIUM SURFACE STRUCTURES ON InAs: IMPLICATIONS FOR GROWTH OF SPIN-BASED DEVICES.

William Barvosa-Carter[1,2], Frank Grosse[1,2], Mark Gyure[1], James Owen[1,2], Christian Ratsch[1,2], Richard Ross[1], and Jennifer Zinck[1]; [1]HRL Laboratories, Malibu CA and [2]UCLA Department of Mathematics, Los Angeles, CA.

Heterostructures involving InAs, GaSb, and AlSb are currently being investigated for use in 'spin-tronic' devices, due to conduction band spin-splitting. The chemical bonding and atomic-scale quality of the interfaces in these heterostructures, however, is likely to play a key role in determining the performance of spin-based devices. Hence, robust control over the formation of these interfaces will play a key role in determining device viability, bringing aggressive model-based growth control into a primary role. Any such model, however, ultimately depends on our understanding of the relevant surface reconstructions and epitaxial growth mechanisms. Using atomic-resolution STM, we have studied the reconstructions and "steady-state" surface structures present on MBE-grown InAs homoepitaxial surfaces in the (2x4) growth regime. On InAs we find two relevant reconstructions: the familiar $\beta2(2x4)$ (as on GaAs) and the less familiar $\alpha2(2x4)$, with excellent agreement between detailed atomic-resolution STM and first-principles simulated images of these structures. We also find that "steady-state" InAs surfaces exhibit small islands and adatom-like structures residing on a disordered mixture of the $\beta2$ and $\alpha2$ reconstructions. The proportions of these structures vary as a function of As pressure and temperature, and represent an inherent atomic-scale 'roughness' under typical growth conditions. Hence, the growth surface structure for InAs is remarkably different than for GaAs, where only the b2 reconstruction is present with relatively few defects under device growth conditions. These results are in excellent qualitative agreement with an ab initio-based Monte Carlo model that is being developed in parallel with the experimental effort to describe reconstructions and growth on this surface.

I3.6

MAGNETIC POLARON IN CdMnTe UNDER HIGH-DENSITY EXCITATION.

T. Kuroda, F. Minami, Tokyo Inst of Tech, Dept of Physics, JAPAN; S. Seto, Ishikawa National College of Tech, Ishikawa, JAPAN; S. Kuroda, K. Takita, Univ of Tsukuba, JAPAN.

High-density effects of intrinsic semiconductors with strong pulsed excitation have been extensively studied over the last three decades. General scenario for the high-density phenomena was almost established in non-magnetic semiconductors. However, in diluted magnetic semiconductors, only a few attempts have been reported concerning the high-density effect. Since the many-particle interaction is modified in semimagnetic semiconductor systems due to the magnetic polaron formation, the high-density phenomenon should be also different from that in non-magnetic systems. In the present contribution, we report on time-resolved luminescence measurements under a strong excitation condition. The experiments were performed in a $Cd_{1-x}Mn_xTe$ (x = 0.1) bulk crystal, together with non-magnetic samples of a CdZnTe bulk and a CdMgTe thin film. Resonant fs pulses of 30-nJ pulse were used for excitation. The exciton density at the highest illumination was estimated to be 6×10^{18} cm^3, which is beyond the Mott density of 2×10^{18} cm^3. Major findings are as follows: In low density, the emission signal of CdMnTe indicates well-known time-dependent Stokes shift reflecting the magnetic polaron formation. The formation energy with the lowest density (10^{10} cm^3) is estimated to be $\sim$6 meV at 2 K. With increasing excitation power, it was found that the polaron shift significantly decreases, i.e., $<$ 0.8 meV at $\geq 10^{15}$ cm^3. We carefully checked that this phenomenon is not due to the heating effect by the laser irradiation. We can, therefore, conclude that the magnetic polaron is quite unstable for the scattering process between polarons, excitons, and careers.

I3.7

PHOTOLUMINESCENCE ANOMALY FROM A TWO-DIMENSIONAL ELECTRON GAS IN CdTe/(Cd, Mg, Mn)Te QUANTUM WELLS AT HIGH MAGNETIC FIELDS.

Hiroyuki Yokoi, Yozo Kakudate, Shuzo Fujiwara, Natl Inst of Materials and Chemical Research, Tsukuba, JAPAN; Shojiro Takeyama, Chiba Univ, Dept of Science, Chiba, JAPAN; Yongmin Kim, Los Alamos Natl Laboratory, Natl High Magnetic Field Laboratory, NM; Grzegorz Karczewski, Tomasz Wojtowicz, Jacek Kossut, Polish Academy of Sciences, Inst of Physics, Warsaw, POLAND.

Recent success in carrier doping to diluted magnetic II-VI materials with high mobility would be one of the most remarkable progress in the application of the materials to spin devices. By modulation-doping iodine to a CdMgTe barrier layer, a two-dimensional electron gas (2DEG) with mobility close to 10^5 cm^2/V and a sheet carrier density of about 5×10^{11} cm^{-2} was produced in a CdTe quantum well. Though the mobility is smaller, by one order or more, than those of high quality GaAs/GaAlAs quantum wells or heterojunctions, the modulation doped II-VI quantum structures exhibit photo-luminescence anomaly related to the quantum hall effects. This feature is thought to originate from a large effective g-factor in CdTe, which leads to suggestion that the Zeeman gap will have significant influence on the interacting electrons in II-VI quantum wells. In order to clarify the importance of the spin degree of freedom in the material, we have adopted two procedures. First, in the preparation of the sample, we modulation-doped manganese to the (Cd, Mg)Te barrier layer by 1%, which is expected to modify the effective g-factor of the 2DEG in the quantum well. Moreover, we tilted the sample with respect to a magnetic field in the measurements of photoluminescence in order to adjust effective magnetic fields which the 2DEG feels, and also to change the effective g-factor. The experiments were carried out at 2 K and to 60 T using a 2 sec long pulsed magnet. We discuss angle dependence of the Zeeman gap anomaly in the vicinity of ν=1. Spectral anomaly at the fractional Landau filling will be also reported.

I3.8

PHYSICAL PROPERTIES OF $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) GROWN ON GaN: A POSSIBLE CANDIDATE FOR SPIN-INJECTION INTO SEMICONDUCTORS.

Dong-Wook Kim, Eunsoon Oh, Dae Ho Kim, T.W. Noh, Seoul National University, Department of Physics, Seoul, KOREA.

$La_{0.7}Sr_{0.3}MnO_3$ (LSMO) can be a candidate material for commercial applications, since it has the highest ferromagnetic transition temperature (360 K) among manganese oxides showing colossal magnetoresistance (CMR) effects. Magnetic material/ semiconductor hybrid is of interest for spin-injection into semiconductors and for possible integration of magnetic film with semiconductor circuitry. GaN is a semiconductor with outstanding characteristics such as high thermal and chemical stability. In this investigation, LSMO films were grown on GaN/Al_2O_3 substrates by pulsed laser deposition. X-ray diffraction indicated that the LSMO film grown on GaN was polycrystalline and atomic force microscope measurements showed that the surface was as flat as the underlying GaN. Electrical and magnetic properties of the LSMO layers were found to be very similar to those of LSMO films grown directly on sapphire substrates. These results indicate that the hybrid structure is promising for spin-injection into a semiconductor. Interfacial issues critical to the spin-injection from LSMO into GaN will be also discussed.

I3.9

SPIN-DEPENDENT ANDREEV REFLECTION IN MAGNETIC METAL OR SEMICONDUCTOR/INSULATOR/SUPER-CONDUCTOR JUNCTIONS.

A. Dimoulas, National Center for Scientific Research "DEMOKRITOS", Athens, GREECE.

Renewed interest [1] in ferromagnetic metal/(insulator)/ superconductor junctions is stimulated by the need to accurately measure the spin-polarization parameter and develop new spin-injection devices. In this paper, the boundary conductance is calculated for general values of bias, exchange interaction energy and barrier strength Z, using spin-dependent Andreev reflection. This allows a unified description in the whole range between the transparent (Z0) and the tunneling ($Z\infty$) limits and helps extracting accurate values of the spin polarization parameter by analyzing the data. The approach is also valid for a degenerate semiconductor with an imbalance of spin-up and spin-down carriers in contact with a superconductor. In addition, it is predicted that, in the presence of a finite barrier, Andreev reflection for electrons in the minority-spin band only, is enhanced beyond the value corresponding to perfectly transparent interfaces [2]. This new, counterintuitive effect produces unique features (maxima) in the subgap conductance near the superconducting gap edge and allows selective (minority) spin injection into the superconductor condensate, controlled by the interface barrier. A new device concept will be presented, in wich a magnetic metal/superconductor bilayer can be used as a spin-filtering device to inject more efficiently, spin polarized carriers into a semiconductor. [1] Soulen et al., Science **282**, 85 (1998), [2] A. Dimoulas, Phys. Rev. **B61**, 9729 (2000)

I3.10

FABRICATION APPROACHES FOR AlInAs/InGaAs HIGH ELECTRON MOBILITY SPIN FIELD EFFECT TRANSISTORS.

J.R. LaRoche, F. Ren, Univ of Florida, Dept. Chemical Engineering, Gainesville, FL; Q. Hudspeth, A.F. Hebard, S. Arnason, Univ of Florida, Dept. Physics; J.-M Kuo, Bell Laboratories, Lucent Technologies, Murray Hill, NJ; Y.D. Park, Naval Research Laboratory, Washington, DC; D. Temple, MCNC, Research Triangle Park, NC; S.J. Pearton, Univ of Florida, Dept. Materials Science and Engineering; A.G. Baca and P. Cheng, Sandia National Laboratories, Albuquerque, NM.

The spin FET proposed by Datta and Das (Appl. Phys. Lett. 12, 665, 1990) has proven difficult to realize in practice for a number of reasons, including the low injection efficiency for spin-polarized carriers or ferromagnetic contacts. With the recent demonstration of more efficient spin injection from Mn-doped dilute magnetic semiconductors, we need to develop a reliable fabrication technique for spin-FETs. Application of standard photolithography and processing techniques are critical for large scale commercial realization of the spin injection devices. In this work standard wet etch processing techniques for InGaAs/InAlAs/InGaAs transistors are used to fabricate a N channel HEMT with Fe contacts. It shown that careful mask design will allow testing of several injection geometries with the inclusion of only one extra mask level; the ohmic etch mask level. This extra ohmic etch level allows plasma etching, and therfore plasma damage, to be eliminated from the device processing. It also eliminates the problem of lateral etching under the photoresist; which is shown to inhibit contact formation. A highly selective etch for InGaAs over InAlAs (Selectivity ~250 is also employed for easily repeatable recess gate etching. We expect that this combination of processing techniques can be extended for dilute magnetic semiconductor regrowth (injection efficiency up to 90%) for spin fet realization. A prototype device with Fe-conacts ($R_c \sim 5x10^{-2}\ \Omega cm^2$) has been fabricated and shows excellent I_DS-V_DS characteristics. The effects of external magnetic fields on its performance will be shown.

I3.11
PREPARATION OF FERROMAGNETIC p-(Ga,Mn,Fe)As WITH LOW HOLE CONCENTRATIONS. R. Moriya, T. Kondo and H. Munekata[a]; Tokyo Inst. Tech., Imaging Sci. Eng. Lab., Yokohama, JAPAN; [a]Additional posts at PRESTO and KAST, JAPAN.

Studies on III-V-based diluted magnetic semiconductors (III-V-DMS, or III-V magnetic alloy semiconductors) has brought carrier-induced magnetism in p-(In,Mn)As heterostructures and p-(Ga,Mn)As epilayers. In both systems, hole concentrations of 10^{19} cm^{-3} or higher were necessary to induce the ferromagnetic order. To further understand the nature of this phenomenon and to seek ways towards device applications, it is desired to study the feasibility of carrier-induced magnetism with low hole concentrations.
In this paper, we are concerned with a new magnetic alloy system p-(Ga,Mn,Fe)As. In this system, we found experimentally that ferromagnetic order can be realized with hole concentrations of 10^{18} cm^{-3} or lower, without seriously affecting the relatively high Curie temperatures. Mn is regarded as an acceptor and a prime local magnetic moment with carrier-induced ferromagnetic exchange, whereas Fe is a carrier compensator and the secondary local magnetic moment with antiferromagnetic exchange. Competition between the two different exchanges is another point to be studied in this system. Samples were prepared by molecular beam epitaxy at substrate temperatures of $T_s = 250°C$. The ranges of Mn and Fe contents were 0-0.04 and 0-0.02, respectively. Hole concentration p decreases with increasing the Fe content, resulting in the nominal p value of about 5×10^{18} cm^{-3} at room temperature for p-$Ga_{0.94}Mn_{0.04}Fe_{0.02}As$ epilayers. Anomalous Hall effect becomes significant at low temperatures (< 100 K), and the samples become ferromagnetic at around 30 K or lower. Magneto-transport under the illumination with red light ($P<1mW/cm^2$) has clearly showed a change in magnetization behavior, suggesting a strong photo-magnetic effect. Judging from the sample resistance and the illumination experiments, the original hole concentration is deduced to be in the range of 10^{17} cm^{-3} or lower at low temperatures.

I3.12
GROWTH AND CHARACTERIZATION OF Mn DOPED InAs BY METALORGANIC VAPOR PHASE EPITAXY. A.J. Blattner, B.W. Wessels, Northwestern University, Department of MS&E and Materials Research Center, Evanston, IL.

Intentionally Mn-doped InAs epitaxial layers were grown by metalorganic vapor phase epitaxy (MOVPE) for potential use as a diluted magnetic semiconductor. A Mn cyclopentadienyl compound was used as the precursor. Epitaxial films up to 10 μm thick were grown. The electrical properties of the layers were obtained by van der Pauw measurements. The doped films were p-type with carrier concentrations up to 5.2×10^{17} cm^{-3}. Quantum dot formation on GaAs substrates is currently under study.

SESSION I4: SPIN INJECTION AND COHERENCE
Chair: Tomasz Dietl
Wednesday Morning, November 29, 2000
Room 205 (Hynes)

8:30 AM *I4.1
ELECTRICAL SPIN INJECTION IN A FERRROMAGNETIC HETEROSTRUCTURE. Darron Kuan Hua Young, B. Beschoten, D.D. Awschalom, Center for Spintronics and Quantum Computation, University of California, Santa Barbara, CA; Y. Ohno, F. Matsukura, H. Ohno, Laboratory for Electronic Intelligent Systems, Research Institute of Electrical Communication, Tohoku University, JAPAN.

While conventional electronics is based on the manipulation of electronic charge, an intriguing alternative is the field of spintronics wherein the classical manipulation of electronic spin in semiconductors may enable integration of photonics, electronics and magnetization for new device functionality. Moreover, the ability to conserve coherent electronic states in the solid state may provide an avenue for quantum computation. Electrical spin injection is observed in zero magnetic field from a ferromagnetic semiconductor into a nonmagnetic semiconductor through the fabrication of light-emitting spintronic devices using III-V heterostructures based on GaAs[1]. Under forward bias, spin polarized holes from a p-type ferromagnetic semiconductor (Ga,Mn)As[2] and unpolarized electrons from an n-type GaAs substrate are injected into an embedded (In,Ga)As quantum well (QW) separated from the ferromagnetic region by a spacer layer. The hole spin polarization in the QW is directly measured by analyzing the polarization of the emitted electroluminescence (EL) of the QW. The EL polarization as a function of magnetic field exhibits hysteresis below the ferromagnetic transition temperature of (Ga,Mn)As, with sharp switching fields of H ~40 Oe. Despite possible depolarization due to transport through interfaces, as well as valence band mixing in the bulk and QW regions, the EL polarization reveals that the hole spin polarization in the (Ga,Mn)As can be transported across interfaces over distances greater than 200 nm. This work is supported by the AFOSR, DARPA, NSF, ONR, and JSPS.
[1]Y. Ohno, D.K. Young, B. Beschoten, F. Matsukura, H. Ohno, and D.D. Awschalom, Nature, 402, 790-792 (1999).
[2]B. Beschoten, P.A. Crowell, I. Malajovich, D.D. Awschalom, F. Matsukura, A. Shen, and H. Ohno, Phys. Rev. Lett, 83, 3073-3076 (1999).

9:00 AM *I4.2
SPINTRONICS WITH DILUTE MAGNETIC SEMICONDUCTORS. Laurens W. Molenkamp, Physikalisches Institut (EP3), Universitaet Wuerzburg, GERMANY.

Dilute magnetic semiconductors have proven to be very useful in establishing spin-polarized electronics in an all-semiconductor environment. The reasons for this become apparent from a simple spin-channel model, which predicts that spin-injection into a semiconductor can - within linear response - only readily be achieved from a ferromagnetic injector that has (i) a resistivity that is comparable to the semiconductor and (ii) preferably is 100% spin-polarized. Both of these criteria can be met in magnetic semiconductors, but (so far) are hard to achieve using other materials. Experimentally, we demonstrate how dilute magnetic II-VI semiconductors can be utilized to inject a strongly spin-polarized current into a Light Emitting Diode. Moreover, we discuss the implications of the spin-channel model for the observation of GMR-like effects in the magnetoresistance of an all-semiconductor device.

9:30 AM *I4.3
SPIN COHERENT TRANSPORT IN CARBON NANOTUBES. B.W. Alphenaar, M. Wagner, Hitachi Cambridge Laboratory, Cambridge, UNITED KINGDOM; K. Tsukagoshi, RIKEN, Tokyo, JAPAN.

In spin-electronics, the electron spin is used in conjunction with the electron charge to store and transfer information. Carbon nanotubes have unique properties that make them an intriguing system for spin electronic applications. Nanotube electron scattering lengths are extremely long, allowing for quasi-ballistic transport even at room temperature. In addition, nanotubes are one-dimensional conductors, and are thought to show Luttinger liquid behavior in which spin and charge are carried separately. Signatures of this spin-charge separation are predicted to be observable via a spin-injection technique. We will present the results of magnetoresistance measurements of ferromagnetically contacted carbon nanotubes that provide evidence for spin coherent electron transport. We observe hysteretic switching in the resistance of a number of multi-walled carbon nanotubes as a function of magnetic field, with a maximum change of 9% at 4.2 K. This can be explained by injection and detection of spin-polarized electrons in the nanotube, implying a minimum nanotube spin-scattering length of 260 nm. We will discuss the spin-injection model with respect to our as yet unexplained observations of negative magnetoresistance switches and asymmetric magnetoresistance persisting to high magnetic fields. Preliminary results on single walled nanotubes will also be shown. Finally we describe a new proposal for a ballistic spin transistor based on the ferromagnetic/nanotube device.

10:30 AM *I4.4

COHERENT SPIN TRANSFER ACROSS A GaAs/ZnSe HETEROINTERFACE. I. Malajovich, J.M. Kikkawa, D.D. Awschalom, Center for Spintronics and Quantum Computation, University of California Santa Barbara, Santa Barbara, CA; J.J. Berry, N. Samarth, Physics Department, The Pennsylvania State University, University Park, PA.

Using time-resolved optical techniques, we generate and monitor spin polarized currents across the heterointerface of two materials with different band gaps, carrier concentrations and g-factors[1]. The samples consist of thin epilayers of n-ZnSe (100-300 nm) grown by molecular beam epitaxy on (SI and n-doped) GaAs substrates. A pair of synchronized femtosecond lasers are used as sources of pump and probe pulses in this experiment. Pump pulses set at the GaAs band gap (1.5 eV) excite electron spin polarization solely in the substrate. As the polarized spins cross the interface to the n-ZnSe epilayer, they are selectively measured with probe pulses tuned to the ZnSe absorption threshold (2.8 eV) through the Kerr effect. The presence of a transverse applied magnetic field generates coherent spin precession, which permits the measurement of spin coherence across the interface. Although GaAs and ZnSe have a factor of two difference in band gaps, and very different g-factors (-0.45 and 1.1 respectively), a coherent spin flow across the interface is observed at temperatures ranging from 5K to room temperature. The unusual changes in amplitude and phase-shift of the Kerr rotation can be explained by dephasing resulting from the distribution in spin arrival times in conjunction with the discontinuity of g-factors at the interface. In the absence of an applied bias, 5 to 10% of the spins excited by the pump reach the probe, and the measured spin arrival times are 210 ps and 440 ps for spins originating from SI and n-doped GaAs substrates, respectively. This spin transfer process can be greatly enhanced upon the application of a modest electric field across the structure. The data show that spin information can be preserved by transport to regions of lower spin decoherence, and demonstrate that boundaries with different g-factors can be used to control the resulting spin coherent phase. Supported by ARO, NSF, ONR, and DARPA.

[1]I. Malajovich, *et al.*, Phys. Rev. Lett. **84**, 1015 (2000).

11:00 AM I4.5

BALLISTIC SPIN-DEPENDENT ELECTRON TRANSPORT IN FERROMAGNET/SEMICONDUCTOR SCHOTTKY BARRIER STRUCTURES AT ROOM TEMPERATURE. Atsufumi Hirohata, Yong-Bing Xu, Christian M. Guertler, J.A.C. Bland, Univ of Cambridge, Dept of Physics, Cambridge, UNITED KINGDOM; Stuart N. Holmes, Toshiba Research Europe Ltd, Cambridge Research Lab, Cambridge, UNITED KINGDOM.

Proposed spin analogues to conventional electronic devices, such as a spin-polarised field effect transistor (spin FET), have recently stimulated great interest [1]. In order to realise a spin FET, three major problems still remain to be solved: (i) spin injection at a ferromagnet (FM)/semiconductor (SC) interface, (ii) spin transmission in a SC and (iii) spin filtering at a SC/FM interface. Evidence of spin-dependent electron transport at the NiFe/GaAs interface has been reported previously. Here we present the results of a conclusive study which provides evidence of highly efficient spin filtering associated with ballistic electrons transmitted at the FM/SC interface. We produced samples of 3 nm Au/5 nm FM (NiFe, Co and Fe)/GaAs ((100), $n^+ = 10^{23}$, 10^{24} and $p^- = 10^{25}$ m^{-3}) and attached two Al electrical contacts to the Au layer and one ohmic contact to the bottom of the substrate. NiFe and Co samples show Schottky characteristics, while Fe samples are almost ohmic according to *I-V* measurements. Circularly polarised laser light ($1.6 \leq h\nu \leq 2.4$ eV) was used to excite electrons with a spin polarisation perpendicular to the film plane in the samples. A helicity-dependent photocurrent, dependent upon the magnetisation configuration of the film ($\vec{\sigma} \perp \vec{M}$ or $\vec{\sigma} // \vec{M}$) and the Schottky barrier height ϕ_b, was detected. With NiFe as the FM, an almost constant difference between the helicity-dependent photocurrent for the two configurations is observed at negative bias, which corresponds to the spin-dependent photocurrent passing from the SC to the FM, spin filtering. A change in the helicity-dependent photocurrent with $\vec{\sigma} // \vec{M}$ configuration of up to 20% is observed which is expected to increase further for photon energies approaching the GaAs band gap. These results clearly indicate that ballistic spin-polarised electron transport is not diminished at the FM/SC interface at room temperature. [1] M. Johnson, *IEEE Spectrum* **37**, 33 (2000). [2] A. Hirohata *et al., J. Appl. Phys.* **87**, 4670 (2000).

11:15 AM I4.6

MAGNETO-TRANSPORT IN MnAs-BASED HYBRID FERROMAGNET/SEMICONDUCTOR HETEROSTRUCTURES. J.J. Berry, S.H. Chun, K.C. Ku, N. Samarth, Department of Physics, The Pennsylvania State University, University Park, PA; I. Malajovich, D.D. Awschalom, Center for Spintronics and Quantum Computation, University of California, Santa Barbara, CA.

Novel systems in which ferromagnetic materials are incorporated with optically active semiconductors are of interest for the creation of "spintronic" devices that exploit the spin degree of freedom. An important heterostructure in this context is comprised of ferromagnetic MnAs epitaxially integrated with either GaAs or ZnSe. However, the electronic properties of MnAs epilayers have not yet been extensively studied. Here, we report detailed measurements of magneto-resistance and the Hall effect in ferromagnetic MnAs epilayers grown by molecular beam epitaxy on (100) GaAs and (100) ZnSe. Electrical transport studies are carried out using mesa-etched Hall bars, over a temperature range 300 mK - 100 K in magnetic fields ranging up to 8 T. These transport measurements are complemented by SQUID and optical measurements of the sample magnetization. MnAs epilayers grown on GaAs show a residual resistivity ratio (RRR) comparable to that of single crystals, while those grown on ZnSe buffer layers show reduced metallicity. In a parallel magnetic field, the magneto-resistance shows hysteretic behavior with switching at a characteristic coercive field ($H_c \ll 1$ T), followed by a negative magneto-resistance due to suppression of spin scattering. On the other hand, in a perpendicular magnetic field, the magneto-resistance is more complicated, with a non-monotonic behavior that varies with temperature. Hall effect measurements reveal a significant contribution from the anomalous Hall effect that saturates above magnetic fields of a few Tesla. The sign of the carriers can be determined from the slope of the high field Hall resistivity. We find that the dominant carriers at high temperatures are holes, while at cryogenic temperatures ($T < 20$K), the transport is dominated by electrons. These observations have important implications for designing experiments that attempt to use MnAs as a spin injector into doped semiconductors. Supported Supported by ONR and DARPA/ONR

11:30 AM I4.7

IN-SITU FABRICATION OF EPITAXIAL METAL-SEMICONDUCTOR SCHOTTKY DIODES FOR SPIN INJECTION. A. Isakovic, P.A. Crowell, School of Physics and Astronomy; L.C. Chen, D.M. Carr, C.J. Palmström, Dept. of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN.

We have fabricated ferromagnet-semiconductor Schottky diodes from in-situ grown $Fe_{1-x}Co_x$ (001)/GaAs (001) heterostructures by molecular beam epitaxy (MBE). These all-epitaxial structures provide a large degree of control over both the quality of the semiconductor-metal interface as well as over the magnetic properties of the ferromagnet with minimal impurity incorporation. The magnetic films are grown at low temperature to minimize interfacial reactions. Structural and magnetic measurements indicate high-quality films with magnetic reversal occurring by the nearly coherent rotation of single domains. Control of surface morphology and bonding is used to modify the in-plane magnetic anisotropy as demonstrated in VSM and Kerr rotation measurements. We have recently modified these structures to include an $In_{1-x}Ga_xAs$ quantum well to use as a spin-detector in a manner similar to that used recently by Fledering *et al.* [Nature **402**, 787 (1999)] and Ohno *et al.* [*ibid.*, p. 790]. In this case, an internal photoemission design is employed to inject electrons over the Schottky barrier. The results of photo- and electro-luminescence measurements will be presented.

11:45 AM I4.8

SPIN COHERENCE AND DEPHASING IN GaN. E. Johnston-Halperin, B. Beschoten, J.E. Grimaldi, and D.D. Awschalom, Department of Physics, University of California, Santa Barbara, CA; S. Keller and J. Speck, Electrical and Computer Engineering and Materials Departments, University of California, Santa Barbara, CA.

The emerging interest in the exploitation of both the coherent and incoherent properties of electronic spin to realize such devices as spin diodes or filters, as well as for possible applications in the emerging field of quantum computation, has revealed the need for increased understanding of carrier spin dynamics in semiconductors. An important aspect of those dynamics is the behavior of spins as they scatter from interfaces or impurities, which provides a practical limitation on the viability of such devices and applications. GaN epilayers grown by metallo-organic vapor deposition are known to have a high density of charged threading dislocations while maintaining good optical quality, making this material ideal for the investigation of spin coherence in the presence of defects. Long-lived spin coherence is measured in n-type GaN epilayers using the technique of time-resolved Faraday rotation (TRFR). Three distinct lifetimes are observed in the decay of the TRFR signal ranging from ~200 ps to ~8 - 20 ns at a temperature of 5 K and spin coherence is still visible to temperatures of at least 180 K. This phenomena is observed despite the high density (~5 x 10^8 cm^{-2}) of charged threading dislocations present in the epilayers, indicating that the spin degree of freedom is insensitive to momentum scattering events in this system. Work supported by the AFOSR, DARPA-ONR.

SESSION I5: SPIN STATES, COHERENCE AND QUANTUM INFORMATION

Chair: David D. Awschalom
Wednesday Afternoon, November 29, 0000
Room 205 (Hynes)

1:30 PM *I5.1

ELECTRON SPIN RELAXATION IN GaAs/AlGaAs (110) QUANTUM WELLS. Y. Ohno, Laboratory for Electronic Intelligent Systems, Research Institute of Electrical Communication, Tohoku University, Sendai, JAPAN.

We investigated electron spin relaxation time τ_s in GaAs/AlGaAs (110) quantum wells (QWs), in which a predominant spin scattering mechanism [D'yakonov-Perel' (DP) mechanism] for conventional (100) QWs is substantially suppressed; τ_s in (110) QWs was of nanosecond order at room temperature, more than an order of magnitude longer than that of the (100) counterpart [2]. The mechanism responsible for the spin relaxation in (110) QWs was examined by studying the quantized energy, electron doping and its mobility, and temperature dependences of τ_s DThe results suggest that in the absence of DP interaction, electron-hole exchange interaction limits τ_s in a wide temperature range.
This work was done in collaboration with R. Terauchi, T. Adachi, F. Matsukura, and H. Ohno, and supported by Japan Society for the Promotion of Science (No. JSPS-RFTF97P00202). [2] Y. Ohno et al., Phys. Rev. Lett. 83, 4196 (1999).

2:00 PM *I5.2

SPIN DIFFUSION AND SPIN LIFETIMES IN SEMICONDUCTORS. Michael E. Flatté, Wayne H. Lau, Jonathon T. Olesberg, Univ. of Iowa, Dept of Physics and Astronomy, Iowa City, IA; Jeff M. Byers, Naval Research Laboratory, Materials Physics, Washington, DC.

The motion and persistence of inhomogeneous electronic distributions are central to semiconductor electronic technologies. Recently a broader category of distributions, inhomogeneous spin distributions in doped semiconductors, have been shown to exhibit long lifetimes and anomalously high diffusion rates. This indicates the potential of a new semiconductor electronic technology relying on spin. We have explored the properties of doped and undoped semiconductors which are spin-polarized or unpolarized in equilibrium. Two results will be emphasized: [1] the dramatic influence of approximate local charge balance on the mobility and diffusion of spin packets, and [2] the improved accuracy of spin lifetimes in III-V heterostructures calculated with Hamiltonians non-perturbatively incorporating zincblende symmetry. Also highlighted will be the effect on spin lifetimes of the coupling between orbital coherence and spin coherence in nanostructures. [1] M.E. Flatté and J.M. Byers, Phys. Rev. Lett. 84, 4220 (2000). [2] W.H. Lau, J.T. Olesberg, and M.E. Flatté (cond-mat/0004461).

2:30 PM I5.3

OPTICAL MANIPULATION OF NUCLEAR SPIN BY A TWO-DIMENSIONAL ELECTRON GAS. G. Salis, D.T. Fuchs, J.M. Kikkawa, D.D. Awschalom, University of California, Department of Physics, Santa Barbara, CA; Y. Ohno, H. Ohno, Tohoku University, Laboratory for Electronic Intelligent Systems, Research Institute of Electrical Communication, Sendai, JAPAN.

We demonstrate spatially selective manipulation of nuclear spin in modulation-doped GaAs single and multiple quantum wells (QW). Highly spin-polarized nuclei are prepared in the QW layer by pumping the electron system with circularly polarized laser pulses in a magnetic field transverse to the pump direction. The dependence of the nuclear polarization on magnetic field, temperature and pump-intensity is monitored by time-resolved measurement of the electron spin precession. By tilting the sample, the sign of the polarization with respect to the applied magnetic field can be controlled. These studies yield unambiguous signatures of all-optical NMR, as periodic QW spin excitation induces resonances from all three host nuclear isotopes and results in spatial focusing of the hyperfine tipping field to the thickness of a single QW. This unconventional process shows complex structure, including quadrupolar splittings, nominally forbidden transitions at half the conventional resonance field, and low field resonances indicating the survival of nuclear coherence on millisecond time scales.

2:45 PM I5.4

SPIN LIFETIMES IN SELF-ASSEMBLED InAs QUANTUM DOTS. R.J. Epstein, D.T. Fuchs, D.D. Awschalom, W.V. Schoenfeld, P.M. Petroff, Center for Spintronics and Quantum Computation, Univ California, Santa Barbara, CA; R. Knoble, N. Samarth, Phys Dept. Penn State, PA.

Semiconductor quantum dots are promising structures for the study of spin coherence in zero dimensions and for their potential applications in devices relying on spin polarization or coherence. Photogenerated carrier spin lifetimes in InAs self-assembled quantum dots grown on GaAs are extracted from the depolarization of photoluminescence (PL) due to a transverse magnetic field (the Hanle effect). Hanle theory predicts a Lorentzian field-dependence of the circular polarization with a width inversely proportional to the effective transverse spin lifetime, T_2^*. We observe departures from this predicted form, suggesting that other factors such as spin diffusion as well as a field-dependence of T_2^* play a role in the dynamics. A reduced spin lifetime, T_s/g, is extracted from fits to the data, where T_s is a lower bound on T_2^*. Hanle measurements are taken as a function of detection energy, temperature (6-100K) and excitation intensity on series of samples with different dot sizes. Detection at the first excited state reveals T_s/g to be a factor of two smaller than in the ground state. In the largest dots, T_s/g exhibits the weakest temperature dependence, dropping by 50% from 6K to 100K. In addition, T_s/g sharply increases with decreasing excitation intensity at low intensities. This may be attributed to a transition from many excitons to less than one exciton per quantum dot, as seen through the vanishing of excited-state PL intensity, that eliminates the contribution of exciton-exciton spin scattering to T_2^*. Current time-resolved studies on these and strain-induced III-V/II-VI QD structures will elucidate the processes of spin relaxation and decoherence by directly monitoring their dynamics. Work supported by the ONR and the DARPA-ONR.

3:30 PM *I5.5

TUNABLE SPIN STATES IN TWO COUPLED QUANTUM DOTS. Seigo Tarucha, University of Tokyo, Dept of Physics and ERATO Mesoscopic Correlation Project, Tokyo, JAPAN.

Configuration of quantum states in quantum dots is determined to minimize the energy of the many-particle ground state. This is also the case for the spin configuration, i.e. whether a high-spin state (triplet state) or a low-spin state (singlet state) is favored. We have recently used a circular two-dimensional (2D) harmonic quantum dot to study the spin configuration, and found that whether it is singlet or triplet, is tunable by adjusting the orbital energy as a function of magnetic field. Coupled quantum dot systems have a more freedom for tuning such a spin configuration. In this talk I will discuss a tunable singlet and triplet state in vertically coupled two 2D dot systems, with a special emphasis on the interactions between two electrons. For strongly coupled dots, the vertical tunnel coupling forms a set of a symmetric and an antisymmetric state. The two-electron ground state is usually a singlet state occupying the same lowest symmetric state, independent of the strength of tunnel coupling. The tunnel coupling is, however, weakened by magnetic field parallel to the 2D dot plane. This also favors parallel spins in the lowest symmetric and antisymmetric state, and finally leads to a triplet ground state. On the other hand, in the presence of a magnetic field normal to the dot plane, we observe a conventional singlet-triplet transition only associated with the symmetric states. For weakly coupled dots, electronic states are localized in each dot. We find a self-locked triplet state, having an electron in each of the two dots (lowest state). This can occur when the two dots have such an energy offset that the second lowest (empty) state in the low-lying dot is close to the lowest (occupied) state in the high-lying dot. This triplet state remains stable because transport of the electron in the high-lying dot through the low-lying dot is spin-blockaded.

4:00 PM *I5.6

SPINTRONICS AND QUANTUM DOTS FOR QUANTUM COMPUTING AND QUANTUM COMMUNICATION. Daniel Loss, Dept. of Physics, University of Basel, SWITZERLAND.

If the states of electron spins in solids can be created, manipulated, and measured at the single-quantum level, an entirely new form of information processing, quantum computing, will be possible[1]. I review [2] our proposed spin-quantum dot architecture for a quantum computer, thereby indicating a variety of first generation nanostructures, as well as magnetic and electrical measurements which should be considered. I will discuss a spin filter and spin detection mechanism [3] at the single-spin level which can be used for read-in and read-out in conventional as well as in quantum computer gates. Addressing the feasibilty of quantum communication with entangled electrons [4,5] I discuss electronic Einstein-Podolsky-Rosen pairs and show that the entanglement of two electrons in a quantum double-dot can be detected in mesoscopic transport and noise measurements [4,5]. [1] D. Loss, D.P. DiVincenzo, Phys. Rev. A 57 (1998) 120; cond-mat/9701055. [2] G. Burkard, H.A. Engel, D. Loss, cond-mat/0004182 (Review). [3] P. Recher, E.V. Sukhorukov, D. Loss, cond-mat/0003089. [4] D. Loss, E. Sukhorukov, Phys. Rev. Lett. 84, 1035 (2000). [5] G. Burkard, D. Loss, E. Sukhorukov, Phys. Rev. B 61, R16303; cond-mat/9906071.

4:30 PM I5.7

QUANTUM INFORMATION PROCESSING WITH FERROELECTRICALLY COUPLED QUANTUM DOTS. Joachim Ahner and John T. Yates, Jr., Department of Physics and Astronomy, University of Pittsburgh; David D. Awschalom, Department of Physics, UC Santa Barbara; Bruce E. Kane, Laboratory for Physical Science, University of Maryland; Jeremy Levy, Department of Physics and Astronomy, University of Pittsburgh; Rodney A. McKee, Oak Ridge National Laboratory; Darrell G. Schlom, Department of Materials Science, Penn State University.

We propose to develop and evaluate a new class of semiconductor-based structures that hold promise for spin-based quantum information processing. Regular arrays of uniform Si/Ge quantum dots are grown using newly developed methods of directed self-assembly. Optically spin-polarized electrons are coupled through the electric polarization of an epitaxial ferroelectric thin film. Domain patterns created in the ferroelectric film with an atomic force microscope (AFM) control the static and dynamic interactions between electronic spin qubits. Programmatically controlled spatiotemporal pulse trains are used to process quantum information.