SYMPOSIUM I
Semiconductor Spintronics—Physics, Materials, and Applications
November 28 – 29, 2000

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*Invited paper
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 micrometers. 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 600°C to 480°C. The case for precipitation, 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 GaMnAs/Mn digital alloys can grow with high structural quality. The connection between magnetic properties and structural dimensions will be discussed.

9:30 AM II-L
GROWTH AND MAGNETO-TRANSPORT PROPERTIES OF P-TYPE Be (1-x) Mn, Te LAYERS L. Hassen, D. Ferrand, G. Mueller, V. Hock, N. Schwarz, G. Schmid, A. Wray, L. W. Molenkamp, Experimental Physics III, Ruhr University, Bochum, GERMANY. 1Department 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 concentration. Such ferromagnetic epilayers could be conveniently integrated into semiconductor heterostructures. Carrier-induced ferromagnetism has been observed in III-V DMS layers (GaMnAs, InMnAs) as well as in GaTe/MnTe (CdMnTe QW, ZnMnTe layers) 2. The possibility in III-V 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 (RHEED). In this respect, the novel DMS material BeMnTe is of considerable potential interest, because it can be strongly p-type doped and has a higher lattice match to GaAs for Mn concentrations up to 10%. We report on the first growth of BeMnTe thin film structures, using MBE and source MBE and nitrogen doping by a RF-plasma source. A 251 RHEED pattern and intense RHEED oscillations indicate a 2D growth mode. A low V/I DEP ratio of 10 is crucial for a high quality growth of BeMnTe. The growth rate has been optimized by tuning the plasma cell, the V/I ratio during growth, as well as reducing the BeMnTe sample temperature. BeMnTe and BeTe layers have been characterized by magnetic-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. 2Ohto et al., Phys. Rev. Lett. 68, 2664 (1992), Science 281, 951 (1998). 3Haury et al., Phys. Rev. Lett. 79, 511 (1997), Ferrand et al., J. Appl. Phys. 87, 6451 (2000). 4Cho et al. J. Vac. Sci. Technol. A 18(2), 457 (2000).

9:45 AM II-L
GROWTH AND CHARACTERIZATION of MnAs/ZnSe and (Ga,Mn)As/ZnSe FERROMAGNETIC SEMICONDUCTOR HETEROSTRUCTURES. S.H. Choo, J.J. Berry, K.C. Ku, N. Smorch, The Pennsylvania State University, Dept. of Physics, University Park, PA; I. Mihajlovich, 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 III-V semiconductor 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 growth temperature, surface stress, and termination and other growth parameters are studied using structural (RHEED, XRD, TEM), and AFM) and magnetic (M(E) and SQUID) probes. We first demonstrate the coherent, epitaxial growth of hexagonal MnAs on ZnSe buffer layers. Under optimal growth conditions, the Cuire temperature, spontaneous magnetization and the coercive field of these MnAs epilayers are comparable to those of MnAs grown directly on GaAs. While the degree of correlation in 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 3% Fe-doped (Ga,Mn)As can be grown using MBE. 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 1*2 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 determining the magnetic properties of these hybrid MBE materials. Additional post-deposition experiments are currently in progress at ONR and DARPA/ONR.

10:30 AM II.6

We describe experimental results on the preparation and characterization of metallic spinel crystals as epitaxial films deposited extremely heavily with two different transition metal elements, Mn and Fe. This work, aiming at the preparation of Mn-based diluted magnetic semiconductors, is motivated by the following two reasons: firstly, the presence of natural magnetic properties at room temperatures and, secondly, the development of magnetic-optical materials suitable for optical information processing in the blue light region. Samples were prepared by molecular beam epitaxy. Two different types of sources, GaNFe and GaNMn epitaxial layers, were deposited at substrate temperatures of \( T_s = 500 \sim 800^\circ \text{C} \) on the surface of the hexagonal GaN template layers grown by MOVPE. In situ reflection high-energy electron diffraction (RHEED) has shown a stoichiometric,Analytical study of the deposition of the GaN layers (\( X = \text{Mn} \)) 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 microscopy has revealed that the range of impurity concentrations that yield films without macroscopic precipitation is relatively wide: e.g., [Mn] \( \leq 5 \times 10^{10} \text{cm}^{-2} \) at \( T_s = 600^\circ \text{C} \) and 5x10^{10} cm^{-2} 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 GaNFe epitaxial layers. These observations are very encouraging at present. GaN-Mn epitaxial layers show clear brownish color, and primarily exhibit paramagnetic behavior. The fit with Brillouin function assuming S = 5/2 for Mn 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 not ferromagnetically coupled. In contrast, GaNFe epitaxial layers show somewhat dark, and both paramagnetic and ferromagnetic components are present in the dc-magnetization data.

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

For the injection of spin-polarized electrons from a ferromagnetic 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 ferromagnetic semiconductor. We present 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 about 500hPa. All growths were started by switching on the three fluxes simultaneously. The growth time was always 1 hour for a film thickness of 250 nm. The orientation of the films was \( \text{NiMnSb}(001)[110] / \text{GaAs}(001)[110] \). We found a tendency towards the formation of \( \text{NiMnSb} \) at the interface that could be suppressed by reducing the substrate temperature \( T_s < 600^\circ \text{C} \) increasing the \( \text{As}_{2} \text{H}_{2} \) flux, and by the insertion of a 2 nm AlAs diffusion barrier at the interface. The best structural quality was obtained at \( T_s < 400^\circ \text{C} \), with a NiMnSb equivalent pressure \( \text{PEP} \) 8.1. From the onset of the \( \text{NiMnSb} \) growth the RHEED pattern was already 2x2 reconstructed that developed within 5 nm. XRD showed a splitting of the NiMnSb peak corresponding to \( c \sim 5.91 \) and \( 5.93 \) Å, suggesting partial relaxation of the film towards the bulk value \( c = 5.903 \) Å. Magnetic measurements showed a 2x2 in-plane anisotropy with an anisotropy energy of 1600 J/m². The easy axis was almost square with \( M//M_\perp = 0.94 \) and \( H//H_\perp = 2.5 \text{ Oe} \). The saturation magnetization \( M_s = 5500 \text{ kA/m} \) was slightly lower than the value \( 7200 \text{ kA/m} \) which is possibly related to an inability of the film as suggested by RBS. By raising the \( \text{As}_{2} \text{H}_{2} \) PEP ratio to 12:1 we obtained an increase of M from 610 kA/m while \( c = 5.905 \) Å became identical to the bulk value.

11:00 AM II.8
DILUTED MAGNETIC SEMICONDUCTOR HYBRID STRUCTURES AND SELF-ASSEMBLED QUANTUM DOTS. J. Kossut, K. Prezer, S. Msiokowski, G. Kurczewski, T. Wojtkowiak, Institute of Physics, Polish Academy of Sciences, Warsaw, POLAND.

Diluted magnetic semiconductor quantum structures [including spin-engineered heterostructures with a genetic component of constituent layers (width) based on telluride compounds are fabricated by molecular beam epitaxy (MBE) in several hybrid configurations: (a) with patterned overlayers of metallic films (iron, permalloy, etc.), (b) grown on quantum structures made of HIL materials prepared in the MBE processes. Also research is described on self-assembled quantum dots of CuFe 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 magnetic and magnetotransport methods. Transmission electron microscopy, x-ray diffraction and atomic force microscopy are also used as tools for critical assessment of the fabricated structures.

11:30 AM III.9
ROOM-TEMPERATURE HUGE MAGNETORESISTANCE CHANGE IN MnSe GRANULAR FILMS GROWN ON GaAs. Hiro Akina, JRCAT/NAIR, Totsuka, JAPAN.

A huge positive magnetoresistance (MR) effect, about 5 orders of magnitude at room temperature, has been discovered in MnSe granular films. Granular films of the type MnSe clusters that are grown on a sulfur-passivated GaAs(001) substrate by molecular-beam epitaxy exhibit magnet-field-sensitive current-voltage characteristics. When a constant voltage, above the threshold value, is applied to the film, the voltage change in the current, which we term the 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 magnet-field-sensitive by the existence of ferromagnetic clusters in the device-fabrication process and the preparation method 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 photocarriers generated 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. Masago, T. Sato, H. Kosumata (JRCAT), S. Yamasaki (EFL), K. Omi, H. Ofuchi, M. Otsu (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. Akina et al., Appl. Phys. Lett. 73, 357 (2000).

SESSION 12: SPINTRONICS MATERIALS II
Chair: Nitin Samarth
Tuesday Afternoon, November 26, 2000
Room 205 (Hynes)

1:30 PM II.1
ELECTRONIC STRUCTURE AND MAGNETIC PROPERTIES OF TRANSITION METAL ATOM DOPED ZnO. K. Kummer, Sato, Hiroshi Kirihara, Yokohama, 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 magnetism in DMS, we studied the magnetism of transition metal doped ZnO by ab initio electronic structure calculation. 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 \( Zn_{1-x} \text{TM}_xO \) and \( Zn_{1-x} \text{TM}_xO \) with 0.01% donor concentration in the site of O or Zn, respectively, was calculated. 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 Curie temperature than the III-V based DMS and they could have potential to realize practical ferromagnetic semiconductors. By analyzing the calculated density of states, it was found that the effect of dopant 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 II.2
DO AS ANTI-BEXTES DESTROY THE FERROMAGNETISM OF
QUANTUM WELLS. N. Sandersfeld, W. Jantsch, F. Schäffer, Institute für Halbleiter- und Festkörperphysik, Universität Innsbruck, Austria, Z. Wilczkowski, 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 Si/Ge quantum wells. We observe an extremely narrow resonance line of down to 40 mG, which allows the detection of a few as few as 10^9 spins in a standard microwave absorption configuration. Logarithmic spin relaxation times T1 of the order of 5 ms were found, which are 2 orders of magnitude longer than the conventional 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 can be adjusted persistently by illumination, the ESR signal was recorded in a function of n. 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 as we find a tail in the DOS, which is indicative of screening breakdown in the 2DEG once as is lowered below a critical value. These results are corroborated by independent transport experiments, and have important implications for the controversy discussed metal-insulator transition in 2DEGs.

2:45 PM 12.6 PHOTOINJECTED FARADAY ROTATION AND MAGNETIZATION IN SEMI-MAGNETIC SEMICONDUCTOR NANO-STRUCTURES. Robert Frey, Hubert Lafontaine Quonquint, Ecole Polytechnique, Palaiseau; France; Christos Fylykos, Laboratoire de Physique de la Matière Condensée de l’ENS, Paris, France.

We have evidenced giant photoinduced Faraday rotation in semi-magnetic semiconductor nanostructures (multiple quantum wells) and micro-resonators close to excitonic transition as well as photoinduced magnetization in 2D bulk material 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 inter-namely they can reach values of the order of 20 degrees over one micron thick multilayer well nanostructure (Cu/Ge/Cu/Ge) in moderate magnetic fields (B=1T) and moderate light flux [I=50mW/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 recognition consequent to the photo-excitation. In the absence of the magnetic field circularly polarized light of comparable intensity can induce magnetization of up to 0.2T in the same structure. The dynamics were studied by time-resolved photoinduced Faraday rotation, a pump and probe technique. Magneto-optic interaction in micro-cavities in the strong coupling regime were also studied and the coexistence of Zeeman and Hache splittings are analyzed. Blass et al. Phys. Rev. Lett. 78, 4128 (1997)

3:30 PM 12.7 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 heterostructural 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 quality epitaxial layers whereas in previous investigations only a broad, defect related luminescence at around 1.5 eV was observed. The excitonic lines exhibit a huge red-shift of ~0.4 eV 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 1.140. 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 it 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, magnetooptic modulators, and magnetic laser. Furthermore, epitaxially grown 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.

2:30 PM 12.5 ESR INVESTIGATIONS OF MODULATION-DOPED Si/Ge.

(2, Min As? Ethanol in a mixture of Volatile and Non-volatile)
FIRST PRINCIPLES STUDY OF SPIN-ELECTRONICS. ZERO FIELD SPIN-SPLITTINGS IN SUPERLATTICES. Jack 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 Dutta and Das [1], a crucial physical mechanism for spin-polarized transistors and other related devices is known to be the 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, microscopic 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 on nearby lattice matched GaAs/AlGaAs as well as InP/AlAsSb and InP/GaAsSb strained layer superlattices with [011] 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 lineark terms have been extracted from the total spin-splittings that contain also higher order k-terms. We find the lineak spin splitting in superlattices to be controlled by the interface-induced microscopic structural symmetry and to be independent of the polarization induced electric field within the quantum well. In both [011] and [111] InP/AlAsSb strained layer superlattices, we obtain the Rashba constant of a of 0.1 eV independently of the superlattice period, whereas in the [011] GaAs/AlAs superlattice we find the Rashba constant to be 0.06 eV A. In the [011]-superlattices, we show the interference between Rashba (k) and Dresselhaus (k^3) to lead to a spin-splitting. In [111]-strained bulk semiconductors 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 microscopic fields. Specifically, we predict a value of a = 0.1 eV A for the Rashba constant in AlGaAs/GaAs superlattices. In addition, we find the lineark spin-splittings of light holes in superlattices to be much larger (by a factor of 2-3) than the corresponding splittings for electrons. [1] S. Dutta and B. Das, Appl. Phys. Lett. 56, 665 (1990); [2] P. Pfeiffer, Phys. Rev. B 59, 15082 (1999) and references therein.

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

D.1
PHOTOINJECTION EXERGONOMIC INVESTIGATIONS OF POSITIVELY CHARGED EXCITONS IN GaAs/AlGaAs QUANTUM DOTS
Seok Lee, Frederick J. Himpsel, Lawrence C. Kimerling
Telecommunications Research Institute, Taejon, KOREA; Sungkyu Noh, Chuen-Dee Lee, Korea Research Institute of Standard and Science, Taejon, KOREA; Yongmin Kim, Quantum functional Semiconductor Research Center, Dongguk Univ, Seoul, KOREA.

Photonics investigations of positively charged excitons (X+) in [AlGaAs]/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 isolated neutral exciton (X) lines. Our findings are understood in terms of the light hole (j = 3/2) admixture to the heavy hole (j = 1/2), the so-called valence-band mixing (VBM). The Zeeman splitting of X+ is determined by electron spin in the isolated heavy hole spin in the ground 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 whole 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 whole 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.

D.2
NEW MAGNETIC AND NONMAGNETIC SEMICONDUCTOR HETEROSTRUCTURE Cd1-xMnxGe0.75P0.25
Gennadiy A. Medvedkin, Ioffe Physico-Technical Inst, St. Petersburg, RUSSIA; Takayuki Ishibashi, Kazuo Nishi, Kosasuke Sato, Tokyo University of Agriculture and Technology, Dept of Applied Physics, Tokyo, JAPAN.

Recent possibilities of reading and writing steady information through magnetic and spin injection in semiconductor heterostructures...
states, transferring the Yb ions to the non-magnetic and neutral, with respect to the metal sublattice, Yb\(^{3+}\) state. Growth of either Ge or Yb containing substrates in the center of the growth chamber deviates 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\(^{3+}\) ions to the electrically and magnetically active Yb\(^{3+}\) state. Thus, in Pb\(_{1-x}\)Ge\(_x\)Te, Ge control the density of magnetic impurity states and magnetic properties of the alloys via the control over its energy spectrum parameters.

B.5 GROWTH AND EQUILIBRIUM SURFACE STRUCTURES ON InAs: IMPLICATIONS FOR GROWTH OF SPIN-BASED DEVICES.
William Bowers\(^{1,2}\), Frank C. Tseng\(^{3}\), James A. Jensen\(^{4,5}\), Christopher Russell\(^{1,2}\), Richard Ross\(^{1}\), and Jennifer Zink\(^{1}\)

\(^{1}\)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 spintronic devices, due to conduction band spin-splitting. The chemical bonding and atomic-scale quality of the interfaces in these heterostructures is key, allowing a role in determining the performance of spin-based devices. Hence, robust control over the fabrication 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 atomistic-resolution STM, we have studied the reconstructions and steady-state surface structures present on \(\beta\)-InAs homoepitaxy interfaces in the \(\beta\') and \(\beta\) reconstruction. On InAs, we find two relevant reconstructions: the familiar \(\beta\') (as on GaAs) and the less familiar \(\beta\), with excellent agreement between detailed atomistic-resolution STM and first-principles simulations. Images of these structures are shown in Figs. 1 and 2. The reconstructions 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 surface structure for InAs is remarkably different than for GaAs, where only the \(\beta\) reconstruction is present with relatively few defects under device growth conditions. These results presented in excellent qualitative agreement with an \(\beta\) initial-InAs Monte Carlo model that is being developed in parallel with the experimental effort to describe reconstructions and growth on this surface.

B.6 MAGNETIC POLARON IN CdMgTe UNDER HIGH-DENSITY EXCITATION. T. Kuroda, E. Mamin, 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 doped magnetic semiconductors, only a few results have been 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\(_{0.8}\)Mg\(_{0.2}\)Te (\(x = 0.1\)) bulk crystal, together with non-magnetic samples of a CdTe bulk and a CdMgTe thin film. Resonant \(\pi\) and \(\sigma\) pulses of 300-nJ pulse were used for excitation. The excitation density at the highest illumination was estimated to be \(6 \times 10^{15}\) cm\(^{-2}\), which is beyond the Mott density of \(2 \times 10^{16}\) cm\(^{-2}\). Major findings are as follows. In our film, the emission signal of MBE-grown CdMgTe has been observed. Even for well-known time-dependent Stokes shift reflecting the magnetic polaron formation. The formation energy with the lowest density (\(10^{16}\) cm\(^{-2}\)) is estimated to be \(\approx 6\) meV at 2 K. With increasing excitation power, it was found that the polaron shift significantly decreases, i.e., \(< 0.8\) meV at \(10^{18}\) cm\(^{-2}\). 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 carriers.

B.7 PHOTOELECTRON EMISSION ANOMALY FROM A TWO-DIMENSIONAL ELECTRON GAS IN CdTe/Cd\(_{1-x}\)Mg\(_x\)Te QUANTUM WELLS AT HIGH MAGNETIC FIELDS.
Hiroaki Yonei, Yozo Kakukune, Shuho Fujii, Takanori, Inst of Materials and Chemical Research, Tsukuba, JAPAN; Shigeru Takayama, C. Ural, Inst of Science, VII, Japan; Hidenori, Inst of Materials and Chemical Research, Tsukuba, JAPAN. K. Kim, Los Alamos National Laboratory, New Mexico Laboratory, NM, Gregorii Kurcawski, Tomasz Wojtowicz, Jack 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 development of the magnetic spin devices. By the spin-polarized light-exciton doping to CdMgTe barrier layer, a two-dimensional electron gas (2DEG) with mobility close to \(10^{6}\) cm\(^2\)/Vs and a sheet carrier density of about \(5 \times 10^{11}\) cm\(^{-2}\) was produced in a CdTe quantum well. Though the mobility is smaller than one order or more, they were those of high quality GaAs/GaAlAs quantum wells or heterojunctions, the modulation doped II-VI quantum structures exhibit photo-luminescence intensity enhanced to the quantum well effects. This feature is thought to originate from a large magnetic field enhancement of the g-factor in CdTe, which leads to evidence 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. In order to clarify how, we modulate the sample with the modified g-factor. The experiments were carried out at 2 K and to 30 T using a 2 sec long pulsed magnet. We discuss single dependence of the Zeeman gap anomaly in the vicinity of \(\alpha = 1\). Spectral anomalies at the fractional Landau filling will be also reported.

B.8 PHYSICAL PROPERTIES OF \(\text{La}_{0.6}\text{Sr}_{0.3}\text{MnO}_3\) (LSMO) GROWN ON GaN: A POSSIBLE CANDIDATE FOR SPIN-INJECTION INTO SEMICONDUCTORS. Dong-Wook Kim, Eunsook Oh, Dae Ho Kim, T.W. Noh, Seoul National University, Department of Physics, Seoul, KOREA.

\(\text{La}_{0.6}\text{Sr}_{0.3}\text{MnO}_3\) (LSMO) can be a candidate material for commercial applications, since it has the highest ferromagnetic transition temperature \(386\) K among manganese oxides showing colossal magnetoresistance since (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\(_2\)O\(_3\) 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 graphite 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.

B.9 SPIN-DEPENDENT ANDREEV REFLECTION IN MAGNETIC METAL OR SEMICONDUCTOR/INSULATOR/SUPERCONDUCTOR JUNCTIONS. D. Dimos, Institute for Scientific Research "DEMOKritos", Athens, GREECE.

Renewed interest [1] in ferromagnetic metal/insulator/ superconductor junctions has been stimulated by the need to accurately measure the spin-polarization parameter and develop new spin-injection devices. In this paper, the boundary conductivity 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 \(I_\text{bias}\) and the tunneling \(I_\text{exit}\) limits and helps extracting accurate values of the spin-polarization parameter by analyzing the dependence of the Andreev reflection signal of the junction on the barrier height, \(Z\). This work 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 expected that, in the presence of a finite barrier, Andreev reflection for electrons in the minority-spin band only, is induced and the value corresponding to perfectly transparent interfaces [2]. This new counterractive effect produces unique features (maximum) 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 which a magnetic metal/superconductor bilayer can be used as a spin-filtering device to inject more efficiently, spin-polarized carriers into a semiconductor. [1] Schön et al, Science 282, 85 (1998); [2] A. Dimos, Phys. Rev. B61, 9729 (2000).

B.10 FABRICATION APPROACHES FOR AlInAs/InGaAs HIGH ELECTRON MOBILITY SPIN FIELD EFFECT TRANSISTORS.
SESSION 14: SPIN INJECTION AND COHERENCE

Chair: Toshiaki Dietl

Wednesday Morning, November 29, 2000
Room 205 (Hyatt)

8:30 AM *H.1 ELECTRICAL SPIN INJECTION IN A FERROMAGNETIC HETEROSTRUCTURE
Daisuke Kuran 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 photons, 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 InAs.

Under forward bias, spin polarized holes from a p-type ferromagnetic semiconductor (Ga,Mn)As 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 ≈ 10 Oe. This is due to 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 to interfaces over distances greater than 200 nm. This work is supported by the AFSOR, DARPA, NSF, ONR, and JSPS.


9:00 AM *H.2 SPINTRONICS WITH DILUTE MAGNETIC SEMICONDUCTORS
Laurens W. Molenkamp, Physikalisches Institut (E13), Universität 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 ~ 180% spin-polarization. Both of these conditions 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 used as driven injectors into 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 *H.3 SPIN COHERENT TRANSPORT IN CARBON NANOTUBES
B.W. Alphenaar, M. Wegner, 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 magnetotransport measurements on ferromagnetically contacted carbon nanotubes that provide evidence for spin coherent electron transport. We observe hysteretic switching in the resistance of a number of carbon nanotubes as a function of magnetic field, with a maximum change of 5% 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 200 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 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/semiconductor device.

10:30 AM *A4.4 COHERENT SPIN TRANSPORT ACROSS A GaAs/ZnSe HETERointerface. I. Malajovich, J. M. Kikkawa, D.D. Awschalom. Center for Spintronics and Quantum Computation, University of California, 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. The samples consist of thin epitayers of \( \text{GaAs} (100), \text{ZnSe} \) grown by molecular beam epitaxy on \( \text{Si} \) and \( \text{n} \)-doped \( \text{GaAs} \) substrates. A pair of synchronized femtosecond laser pulses are used as sources of pump and probe pulses in this experiment. Pump pulses set at the \( \text{ZnSe} \) band gap \((1.5 \text{ eV})\) excite electron spin polarization solely in the substrate. As the polarized spins cross the interface to the \( \text{GaAs} \) epilayer, they are selectively measured with probe pulses tuned to the \( \text{ZnSe} \) absorption threshold \((2.8 \text{ eV})\) through the Kerr effect. The presence of a transverse applied magnetic field generates coherent spin precession, which permits the measurement of spin coherence times. Although \( \text{GaAs} \) and \( \text{ZnSe} \) have a factor of two difference in band gaps, and very different \( g \)-factors \((-0.45 \text{ and } 1.1 \text{ respectively})\), a coherent spin flow across the interface is observed at temperatures ranging from \( 5K \) to room temperature. The unusual changes in magnitude and phase shift of the Kerr rotation can be explained by dephasing resulting from the spin diffusion times (in conjunction with the decomposition of \( g \)-factors at the interface). In the absence of an applied magnetic field, the spins excited by the pump reach the probe, and the measured spin survival times are \( 20 \text{ ps} \) and \( 440 \text{ ps} \) for spins originating from \( \text{Si} \) and \( \text{n} \)-doped \( \text{GaAs} \) substrates, respectively. This spin diffusion process can be greatly enhanced by the application of a modest electric field across the structure. The data show that spin information can be preserved and transported to regions of lower spin dephasing, 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.


11:00 AM A4.5 BALLISTIC SPIN-DEPENDENT ELECTRON TRANSPORT IN FERROMAGNET/SEMICONDUCTOR SCHOTTKY BARRIER STRUCTURES AT ROOM TEMPERATURE. Atsafumi Hirohata, Yong-Bing Xu, Christian M. Guenter, L.C. Bland. Univ of Cambridge, Dept of Physics, Cambridge, UNITED KINGDOM; Stuart N. Holmes, Toshina Research Europe Ltd, Cambridge Research Lab, Cambridge, UNITED KINGDOM.

Proposed spin transistors analogous to conventional electronic devices, such as a spin-polarized field effect transistor (spin FET), have recently stimulated great interest [1]. In order to realize a spin FET, three major problems must be solved in order to be used to control the spin current at a ferromagnet (FM)/semiconductor (SC) interface, (i) spin transmission in the SC and (ii) spin filtering at the 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 electrons transmitted at the FM/SC interface. We produced samples of \( 3 \text{ nm} \) \( \text{Au}/5 \text{ nm} \) \( \text{NiFe} \) (\( \text{Co} \) and \( \text{Fe} \))\text{/GaAs} (100), \( n^+ = 10^{23} \text{ cm}^{-3} \) and \( p^+ = 10^{25} \text{ cm}^{-3} \) \()\) and attached two \( \text{Al} \) electrical contacts to the \( \text{Au} \) layer and one ohmic contact to the bottom of the substrate. \( \text{NiFe} \) and \( \text{Co} \) samples show Schottky characteristics, while \( \text{Fe} \) samples are almost ohmic according to \( \text{L} \)-measurements performed at \( 1.6 \text{ K} \leq T \leq 24 \text{ K} \). The samples were measured using \( \text{Hall} \) measurements showing a Hall mobility of \( 1 \text{ T} \text{cm}^2 / \text{Vs} \) for \( \text{Co} \) and \( \text{Fe} \) samples at room temperature. The \( \text{Au} \) layer was used to excite electrons with a spin polarization perpendicular to the film plane in the samples. A helicity-dependent photocurrent, dependent upon the magnetization configuration of the film \( (\sigma \ll \hat{\mathbf{M}} \text{ or } \sigma \parallel \hat{\mathbf{M}}) \) and the Schottky barrier height \( \phi_b \), was detected. With \( \text{NiFe} \) or \( \text{Co} \) as the metal contact and varying between the helicity-dependent photocurrent for the two configurations is observed at negative bias, which corresponds to a spin-dependent photocurrent passing from the SC to the FM, spin filtering. A change in the helicity-dependent photocurrent that photogenerated with \( \hat{\mathbf{M}} \) 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-polarized electron transport is not diminished as room temperature is approached.

11:15 AM A4.6 MAGNETO-TRANSPORT IN MnAs-BASED HYBRID FERROMAGNET/SEMICONDUCTOR HETEROSTRUCTURES. J.J. Berry, S.H. Chua, 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 thereby shifting 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 magnetoresistance and the Hall effect in ferromagnetic MnAs epilayers grown by molecular beam epitaxy on \( 100 \text{ GaAs} \) and \( 100 \text{ ZnSe} \). Electrical transport studies are carried out using mesa-etched Hall bars, over a temperature range \( 300 \text{ mK} \text{-} 100 \text{ K} \) and magnetic fields ranging up to \( 8 \text{ T} \). 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, whereas those grown on ZnSe buffer layers show reduced metallicity. In a parallel magnetic field, the magnetoresistance shows hysteretic behavior with switching at a characteristic coercive field \( (H_c \ll 1 \text{ T}) \), followed by a negative magnetoresistance due to domain formation. On the other hand, in a perpendicular magnetic field, the magnetoresistance is more complicated, with a non-monotonic behavior which varies with temperature. Hall effect measurements reveal a significant contribution of the nonmagnonic 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 applied magnetic fields are holes, while at cryogenic temperatures \( (T < 25 \text{ K}) \), 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 A4.7 IN-SITU FABRICATION OF EPITAXIAL METAL-SEMICONDUCTOR SCHOTTKY DIODES FOR SPIN INJECTION. D. Jaskovic, P.A. Crowell, School of Physics and Astronomy, L.C. Chen, D.M. Curr, 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 \( \text{Fe}_{x}\_\text{Co}_{1-x} \text{GaAs} \) \((011)\) /GaAs \((001)\) heterostructures by molecular beam epitaxy \((\text{MBE})\). 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 interface damage. 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 heterostructure properties. To test \( \text{Fe}_{x}\_\text{Co}_{1-x} \text{GaAs} \) quantum well as a spin detector, a similar approach has been used by Flederer et al. [Nature 402, 287 (1999)] and Ohno et al. [ibid., p. 289]. In this paper, 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 A4.8 SPIN COHERENCE AND DEPHASING IN GaN. E. Johnston, Halperin, B. Beschoten, J.E. Grinavich, 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 these dynamics is the behavior of spins as they scatter. Scattering from interfaces or impurities, which provides a practical limitation on the viability of such devices and applications. GaN epilayers grown by metal-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 using a technique of time-resolved Faraday rotation \((\text{TRFR})\). Three distinct
Spin lifetimes are observed in the decay of the THz signal ranging from ~200 ps to ~8 ns. The spin coherence is still viable at temperatures of at least 100 K. This phenomenon is observed despite the high density (~5 × 10^18 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 15: SPIN STATES, COHERENCE AND QUANTUM INFORMATION
Chair: David D. Awschalom
Wednesday Afternoon, November 29, 2000
Room 205 (Hynes)

1:30 PM #15.1
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, in GaAs/AlGaAs (110) quantum wells (QW), in which a predominant spin scattering mechanism is the 'non-perturbing' (DP) mechanism for conventional (100) QWs is substantially suppressed, while in (110) QWs was of nanosecond order, more than an order of magnitude longer than that of the (100) counterparts [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 dependence of . D The results suggest that the absence of DP interaction, electron-hole exchange interaction limits , in a wide temperature range. This work was done in collaboration with R. Tsuchi, T. Aida, F. Matsukura, and H. Ohno, and supported by Japan Society for the Promotion of Science (No. JSPS-RFTF9708219). [2] Y. Ohno et al., Phys. Rev. Lett. 83, 4186 (1999).

2:00 PM #15.2
SPIN DIFFUSION AND SPIN LIFETIMES IN mRNA CONDUCTORS. Michael E. Flatté, Wayne H. Lau, Jonathon T. Olesker, 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 semiconductors electronic devices. Recently, a broad 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 from the bulk behavior and non-perturbatively incorporating zincline 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, 1220 (2000).

2:30 PM #15.3
OPTICAL MANIPULATION OF NUCLEAR SPIN BY A TWO-DIMENSIONAL ELECTRON GAS. G. Saito, D.T. Vach, 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. The resulting signatures of all-optical NMR, as periodic QW spin excitation induces resonance from all three host nuclear isotopes and results in spatial focusing of the hyperfine interaction 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 #15.4
SPIN LIFETIMES IN SELF-ASSEMBLED InAs QUANTUM DOTS. R.J. Epstein, D.T. Vach, D.D. Awschalom, W.V. Schoenfeld, P.M. Petroff, Center for Spintronics and Quantum Computation, Univ California, Santa Barbara, CA; R. Knolle, 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 (QDs) 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 dephasing transverse spin lifetime, . We observe departures from this predicted form, suggesting that other factors such as spin diffusion as well as field-dependence of play a role in the dynamics. A reduced spin lifetime, , extracted from fits to the data, is lower bound on . Hanle measurements are taken as a function of detection energy, temperature (6-10K) and excitation intensity on samples with different dot sizes. Detection at the first excited state reveals to be a factor of two smaller than in the ground state. In the largest dots, the largest temperature dependence, dropping by 50% from 6K to 10K. In addition, sharply increases with decreasing excitation intensity at low intensities. This may be attributed to a transition from many excitations to less than one excitation per quantum dot, as seen through the vanishing of excited-state PL intensity, that eliminates the contribution of exciton-exciton spin scattering to . Chinmaya, time-resolved studies on these and strain-induced BH-VHE LD 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 #15.5
TUNABLE SPIN STATES IN TWO COUPLED QUANTUM DOTS. Sigei Tanaka, 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 true for the spin configuration, i.e., whether a higher spin state (triplet state) or a lower 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, it 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 states 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 symmetric and the antisymmetric states by the scissor 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 states and 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-blocked 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 #15.6
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-polarized quantum dot architecture as a quantum computer, by thereby indicating a variety of first generation nanosystems, as well as magnetic and electrical measurements which should be considered. I will discuss a spin fiber and spin detection mechanism based on manipulation of a single spin level which will be used for read-in and read-out in conventional as well as in quantum computer gates. Addressing the feasibility of quantum communication with entangled electrons [3,4] 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.
4:30 PM 15.7

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. Schom, 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.