BB04

III-V- Semiconductor-Based Ferromagnetic Heterostructures

Shinobu Ohya[1,2], Pham-Nam Hai[1]*, and Masaaki Tanaka[1,2]
[1]Department of Electrical Engineering and Information Systems,
The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[2]Japan Science and Technology Agency, 4-1-8 Honcho, Kawaguchi-shi, 332-0012, Japan
*Corresponding author: ohya@cryst.t.u-tokyo.ac.jp, masaaki@ee.t.u-tokyo.ac.jp

Semiconductor-based magnetic heterostructures are one of the hopeful candidates for future spintronic materials and devices. Especially, III-V-based ferromagnetic semiconductor GaMnAs and metallic MnAs nano- nanoparticles embedded in GaAs (*GaAs:MnAs*) are ideal systems owing to their excellent monocrystalline quality and compatibility with existing III-V systems. Here, we review our recent progress on GaMnAs and its quantum heterostructures, and a huge magnetoresistance up to 100,000% and the electromotive force (emf) induced by a static magnetic field in the zinc-blende (ZB) MnAs nano-magnets in magnetic tunnel junctions (MTJs).

1. Properties of heavily Mn-doped $Ga_{1-x}Mn_xAs$ (x: 12.3-21.3%) [1]

We have successfully grown heavily Mn-doped GaMnAs thin films with a Mn concentration of 12.3-21.3% by low-temperature molecular-beam epitaxy. Transmission electron microscopy analyses showed that they are zinc-blende-type single crystal alloys without precipitation of any other phase. Magneto-optical, magnetotransport, and magnetization measurements revealed that these heavily Mn-doped GaMnAs films are intrinsic ferromagnetic semiconductors with a Curie temperature up to 172.5 K. We found that the Curie temperature linearly increases with the substitutional Mn concentration without saturation.

2. Spin-dependent resonant tunneling in GaMnAs quantum heterostructures [2]

We have grown double-barrier quantum heterostructures composed of GaMnAs (20 nm) / GaAs (1 nm)/ $Al_{0.5}Ga_{0.5}As$ (4 nm)/ GaAs (1 nm)/ GaMnAs (d = 3.8 - 20 nm)/ GaAs (1 nm)/ AlAs (4 nm)/ GaAs:Be on p+GaAs(001) substrates. dI/dV-V and tunneling magnetoresistance vs. bias voltage characteristics showed clear oscillations at resonant peak bias voltages. These resonant levels are well explained by the coherent tunneling model with the 4×4 Luttinger-Kohn $k{\cdot}p$ Hamiltonian and the p-d exchange Hamiltonian. In these analyses, we found that the Fermi level position should be in the bandgap for explaining the quantum levels observed in the GaMnAs QWs. This result contradicts the mean-field Zener model [3] commonly used for describing GaMnAs, where the Fermi level is assumed to exit in the valence band, suggesting that a more appropriate model may be needed for understanding the electronic properties of GaMnAs heterostructures.

3. Spin-dependent transport in ZB MnAs nanoparticles / GaAs hybrid structures [4]

Studied here are MTJs comprising NiAs-type MnAs(20 nm)/ GaAs (1 nm)/ AlAs(2.1 nm)/ ZB MnAs nanoparticles embedded in GaAs. ZB MnAs nanoparticles ($T_C > 300^o$) are promising, since they are expected to be haft-metallic. We observed a huge magnetoresistance up to 100,000% at certain bias voltage. This huge magnetoresistance is a consequence of the Coulomb blockade effect of the ZB MnAs nanoparticles and an emf emerging from the MTJ. Transport measurements showed that this emf is induced by spin effects associated with spin-dependent tunneling of carriers and macroscopic quantum tunneling of ZB MnAs nano-magnets occurring simultaneously. Our results demonstrate the potential of granular materials as important resources for semiconductor-based spintronics.

This work was partly supported by PRESTO/SORST of JST, Grant-in-Aids for Scientific Research, Next-Generation IT Program, the Special Coordination Programs for Promoting Science and Technology, and the Global COE Program “Secure-Life Electronics” of MEXT.

REFERENCES

[1] S. Ohya, K. Ohno, and M. Tanaka, Appl. Phys. Lett. **90**, 112503 (2007).
[2] S. Ohya, P. N. Hai, Y. Mizuno, and M. Tanaka, Phys. Rev. B **75**, 155328 (2007).
[3] T. Dietl *et al*., Phys. Rev. B **63**, 195205 (2001).
[4] P. N. Hai, B. H. Yu, S. Ohya, M. Tanaka, S. E. Barnes and S. Maekawa, submitted.

BB05

Spin-polarised Photoexcitation with a Tunnel Contact

K. Y. Lee[1]*, T. Trypiniotis[1], H. Kurebayashi[1], S. N. Holmes[1,2], W. S. Cho[1], J. A. C. Bland[1], C. H. W. Barnes[1], and K. H. Shin[3]
[1]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
[2]Toshiba Research Europe Limited, Cambridge Research Laboratory, United Kingdom
[3]Nano Device Research Centre, Korea Institute of Science and Technology, Seoul, South Korea
*Corresponding author: K. Y. Lee, e-mail: kl315@cam.ac.uk

Spin injection and extraction through GaAs have been widely studied in both theories and experiments and are recognised as a prerequisite for future device applications. [1] Although several groups have demonstrated spin injection experiments via all electrical methods, efficient extraction of spin-polarised current is still elusive. Thus a fundamental understanding of the transport and the scattering mechanism of the spin polarised carriers across the interface is very crucial to realise a practical device as the theory predicted. Here we present the result of the spin filtering effects in a simple system which includes a tunnel barrier between interfaces using the optical excitation of spin polarised carriers in GaAs. All the structures were prepared by DC/RF sputtering, accompanied by the plasma oxidation method for alumina tunnel contact. As evidenced by conventional current-voltage characteristics, the property of tunnel barrier was assessed with relatively high resistance. After film deposition, the mesa structure was defined by conventional photolithography and electrically isolated from the adjoining region by subsequently depositing TaOx films. Conventional current-voltage measurements represent that the devices show clear Schottky diode characteristics, and thus tunnelling transport is expected to be the dominant process for the filtering of spin-polarised carriers. [1] The measured helicity-dependent photocurrent (HDPC) reveals that the degree of spin filtering depends on the magnetic alignment of the FM layers as well as the applied bias. Furthermore, the HDPC, corrected for MCD, shows the expected behaviour for a single FM/barrier structure. [2] In case of p-GaAs, the HDPC is purely dependent on the tunnel barrier since the band bending at the interface is totally different with the one in n-doped semiconductor. By varying the thickness of the tunnel contact, spin-dependent tunnelling across the interface will be further investigated. We discuss these results by considering spin-dependent transmission within the structure, supported by the results of relevant electrical measurement.

This work is supported by Cavendish Laboratory and Magdalene College in Cambridge, U. K.

REFERENCES

[1] A. Fert and H. Jaffres, Phys. Rev. B 64 184420 (2001).; J. D. Albrecht and D. L. Smith Phys. Rev. B **68** 035340 (2003).
[2] A. Hirohata, S. J. Steinnmueller, and J. A. C. Bland *et al*. Phys. Rev. B **66** 035330 (2002).