III-V- Semiconductor-Based Ferromagnetic Heterostructures

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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,MnAs (x = 12.3-1.3)% [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, magneto-transport, and magneto-navigation 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) / AlAsGaAs (4 nm) / GaMnAs (1 nm) / GaAs (1 nm) / AlAs (4 nm) / GaAs on p-type (GaAs:O) substrates. dI/dV -2 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 effective Hamiltonian and the p-d exchange Hamiltonian. In these analyses, we found that the Fermi level position for the barrier was in the band gap for resonant tunneling levels. The results of resonant tunneling in the GaMnAs QWs. This result constrains the mean-field Zener model [3] commonly used for describing GaMnAs, where the Fermi level is assumed to exist in the valence band, suggesting that a more appropriate model may be needed for understanding the electronic properties of GaMnAs heterostructures.


Studied here are MTJs comprising NAs-type MnAs/20 nm GaAs (1 nm) / AlAs(2.1 nm) / ZB MnAs nanoparticles embedded in GaAs. ZB MnAs nanoparticles (IE > 300) are promising, since they are expected to be half-metallic. We observed a huge magnetoresistance up to 100,000% at resonant bias voltages. 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 magneto-ionic quantum tunneling of ZB MnAs nano-magnets occurring simultaneously. Our results demonstrate the potential of granular materials as important resources for semiconductor-based spintronics.

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REFERENCES