MAR11-2010-002390

Abstract for an Invited Paper
for the MAR11 Meeting of
the American Physical Society

Valence-band structure of the ferromagnetic semiconductor GaMnAs investigated by resonant tunneling spectroscopy

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The origin of ferromagnetism in the prototype ferromagnetic semiconductor GaMnAs is still controversial due to the insufficient understanding of its band structure and Fermi level position. Here, we investigate the valence-band (VB) structure of GaMnAs by analyzing the resonant tunneling levels of the GaMnAs quantum well (QW) in double-barrier heterostructures. The resonant levels including the heavy-hole first state (HH1) are clearly observed in the metallic GaMnAs QW with the Curie temperature (T_C) of 60 K, which indicates that no holes reside in the VB of GaMnAs in the equilibrium condition. Clear enhancement of tunnel magnetoresistance induced by resonant tunneling is demonstrated. We find that the resonant levels formed in the GaMnAs QW are well explained by using the transfer matrix method with the 6x6 kp Hamiltonian and small $p-d$ exchange Hamiltonian. The VB structure of GaMnAs is well reproduced by that of GaAs with a small exchange splitting energy of 3-5 meV and with the Fermi level lying at $\sim$30 meV higher than HH1 in the bandgap. Furthermore, we show our more recent results of resonant tunneling spectroscopy on various surface GaMnAs films (Mn concentration: 6-15%, T_C: 71-154 K) grown on an AlAs layer, where the resonant levels are formed by confinement of the VB holes by the surface Schottky barrier and the AlAs barrier. We systematically investigate the thickness dependence of the resonant levels in GaMnAs by precisely etching the surface of GaMnAs. We find that the p-d exchange interaction is negligibly small (3-5 meV) and that the Fermi level exists in the bandgap. This work was performed in collaboration with I. Muneta, P. N. Hai, K. Takata, and M. Tanaka, and partly supported by Grant-in-Aids for Scientific Research, the Special Coordination Programs for Promoting Science and Technology, and FIRST Program by JSPS.

[1] S. Ohya et al., Phys. Rev. Lett. 104, 167204 (2010).
[2] S. Ohya et al., arXiv:1009.2235.