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Identification of impurity band and valence band in GaMnAs by tunneling anisotropic magnetoresistance spectroscopy

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Long time investigations have been conducted to clarify the complex band structures in GaMnAs, which is mainly motivated by scientific interest in the origin of hole-mediated ferromagnetism in III-V semiconductors. Furthermore, from the viewpoint of device applications, understanding the electronic structures that mediate the ferromagnetism is important for the design and control of magnetism. The recent progress of the investigations yields the results that an impurity band (IB) is around the valence band (VB) top and has overlap with it [1,2], and that IB is the origin of the ferromagnetism because the Fermi level is located in IB [1-3]. Although these studies indicate that IB does exist, there is no study providing the detailed features of IB, which are clues to full understanding of the band structure and ferromagnetism.

Tunneling anisotropic magnetoresistance (TAMR) on a tunnel junction with a GaMnAs electrode [4] can provide important features of IB because the magnetization-angle-dependence of tunnel resistance has symmetry that is different in orbitals, bands, or the charge distribution of the orbitals. Also, TAMR when applying different bias voltages is tunneling spectroscopy that provides the energy-dependent DOSs of IB and VB in a spectroscopic way. Together with TAMR, quantum confinement is a useful auxiliary for identifying IB and VB because the quantum-size effect is induced only in VB, not in IB.

Here, we successfully distinguish VB and IB of GaMnAs by capturing the symmetry of these bands using simultaneous spectroscopy of TAMR and resonant tunneling. Figure 1 shows the bias-voltage dependence of the symmetry of dI/dV-θ curves for tunnel junction devices, consisting of $Ga_{0.94}Mn_{0.06}As$ (d nm, T_C 134 K) / AlAs (5 nm) / GaAs:Be (100 nm). Region A corresponding only to IB shows 2-fold symmetry, which is almost the same in device A-D. On the other hand, device A-D show different symmetry in region B corresponding to the overlap region of IB and VB. As the thickness d of GaMnAs is varied from 22 nm to 9 nm (device D to A), the symmetry in region B changes from 2-fold to 4-fold, which is caused by the quantum-size effect in GaMnAs VB. These results indicate that the symmetry of IB is 2-fold, the symmetry of 2-dimensional VB is 4-fold, and 3-dimensional VB does not show TAMR. The results of the symmetry of IB and VB will help to understand the hole-mediated magnetic anisotropy, which leads to develop the electrical control of the magnetization by means of spin orbit torque.

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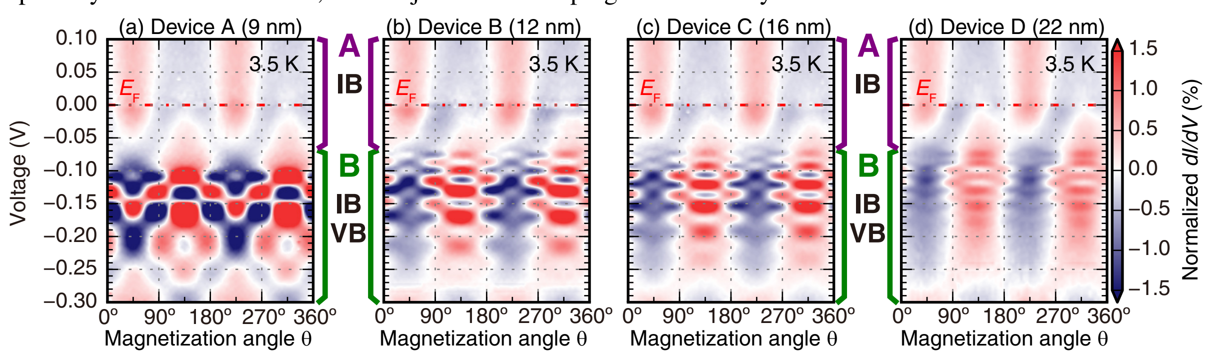

FIG. 1: Contour maps representing the symmetry of dI/dV-θ curves as a function of V measured on a same wafer but different devices at 3.5 K. The heterostructure consists of $Ga_{0.94}Mn_{0.06}As$ (d nm, T_C 134 K) / AlAs (5 nm) / GaAs:Be (100 nm). The thickness d of GaMnAs electrode was varied by chemical wet etching after the growth.

[1] I. Muneta *et al.*, APL **103**, 032411 (2013). [2] M. Kobayashi, I. Muneta *et al.*, PRB **89**, 205204 (2014).
[3] S. Ohya *et al.*, Nat. Phys. **7**, 342 (2011). [4] C. Gould *et al.*, PRL **93**, 117203 (2004).