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Valence-band ordering restored by ferromagnetism in GaMnAs

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The origin of the ferromagnetism and the band structure are the central issues in the ferromagnetic-semiconductor GaMnAs. In the previous model of the ferromagnetism, the RKKY-like interaction was believed to be the origin of the ferromagnetism, where the scattering by the spin-dependent *p-d* hybridized orbital plays an essential rule and results in the disordered valence band (VB) [1]. However, we have successfully observed the resonant tunneling effect even in the ferromagnetic GaMnAs quantum well (QW) [2,3], which means that the ferromagnetic GaMnAs has the well-ordered VB. Therefore, the change of the order in the VB by means of doping the Mn impurities is important to understand the mechanism of the ferromagnetism. Here, we report the Mn concentration (x) dependence of the resonant tunneling effect in the GaMnAs QW, and discuss the change of the order in the VB.

Figure 1 shows the device structure of the double-barrier (DB) $Ga_{1-x}Mn_xAs$ QW studied here. The QW thickness d is varied from 4 - 15 nm on the same wafer. Figure 2(a)-(c) show the resonant tunneling spectroscopy in Sample A (x~0.3%), B (x~0.7%), and C (x=1.0%) at 3.5 K, respectively. In the paramagnetic x region (x < 1%), the resonance becomes weak with increasing x, which is attributed to the strong scattering in the VB due to doping of Mn impurities. However, with further increasing x ($x \geq$ 1.0%), clear resonance appears with the onset of ferromagnetism, which indicates that the ferromagnetic transition induces the well-ordered energy region around the VB top. In terms of the change of the scattering, we will discuss the origin of the ferromagnetism and the formation of the impurity band.

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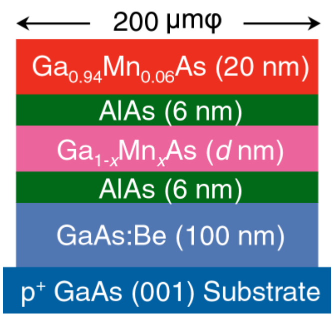

Figure 1 Device structure of the DB $Ga_{1-x}Mn_xAs$ QW.

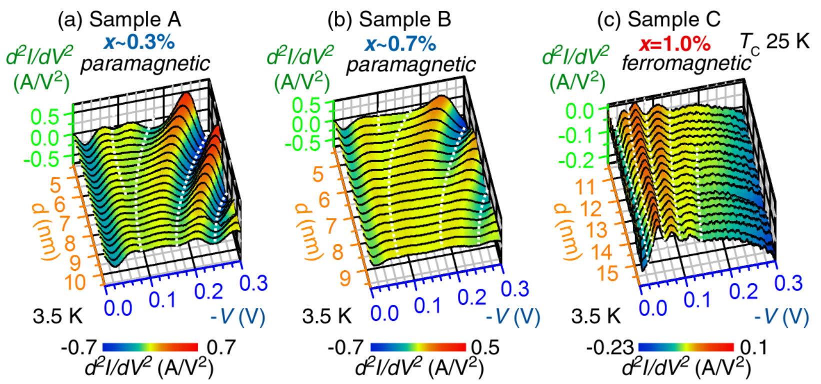

Figure 2 d^2I/dV^2-V characteristics with various d in (a) Sample A (x~0.3%), (b) B (x~0.7%), and (c) C (x=1.0%) at 3.5 K.

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