Electronic Structure of $In_{1-x}Mn_xAs$ Studied by Resonant Photoemission Spectroscopy

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Diluted magnetic semiconductors (DMS) have attracted much attention because of the combination of magnetic and semiconducting properties and hence high potential for new device applications. Recently DMS based on III-V compounds have been extensively studied because of the success in doping high concentrations of transition-metal ions by molecular beam epitaxy (MBE). The Mn doping in GaAs and InAs leading ferromagnetism and interesting magneto-transport properties has attracted considerable interest in recent years. This behavior is generally called "carrier-induced ferromagnetism" because hole carriers are introduced into the system by Mn doping, however, its microscopic mechanism has been controversial until now. Better-known $Ga_{1-x}Mn_xAs$ has been extensively studied. On the other hand $In_{1-x}Mn_xAs$/GaSb is introduced as photo-carrier induced ferromagnetism [1]. Investigation of electronic structure give us a key for further functional material design.

Experiment was done at BL 18A, using a CLAM-II spectrometer. The total energy resolution was 100 meV because the measurements were done at room temperature. The *p*-type $In_{1-x}Mn_xAs$/GaSb grown by MBE were used [2], and samples have Curie temperature of $30-50$ K. To remove oxidized surface layers and other contamination, we repeated Ar-ion sputtering and annealing up to 200°C. The clear surfaces showed 1×1 LEED patterns.

Figure 1 shows the spectra taken using photon energy of $h\nu$=46−55 eV. Resonant effect occurs at $h\nu$=51 eV and off-resonant one at $h\nu$=48 eV. The difference between the two shows the Mn 3*d*-derived spectra. The spectral lineshapes are almost the same as that of $Ga_{1-x}Mn_xAs$ [3]. In the difference spectrum, there was little intensity at E_F and satellite structure was observed at 6−12 eV. These spectra indicate the strong hybridization between Mn 3*d* electrons and As 4*p* hole carriers. According to the electron paramagnetic resonance (EPR) measurement [4], the Mn 3*d* signals of both $Ga_{1-x}Mn_xAs$ and $In_{1-x}Mn_xAs$ showed the similar spectra and concluded that the dominant Mn impurities in the InAs show ionized state (Mn^{2+}, A^-) as an analogy of the $Ga_{1-x}Mn_xAs$. From the view of photoemission spectroscopy, the Mn 3*d* spectrum in Fig. 1 is analyzed in the Mn^{2+} model as $Ga_{1-x}Mn_xAs$. These results support that the Mn 3*d* electronic configuration is analogical in $Ga_{1-x}Mn_xAs$ and $In_{1-x}Mn_xAs$.

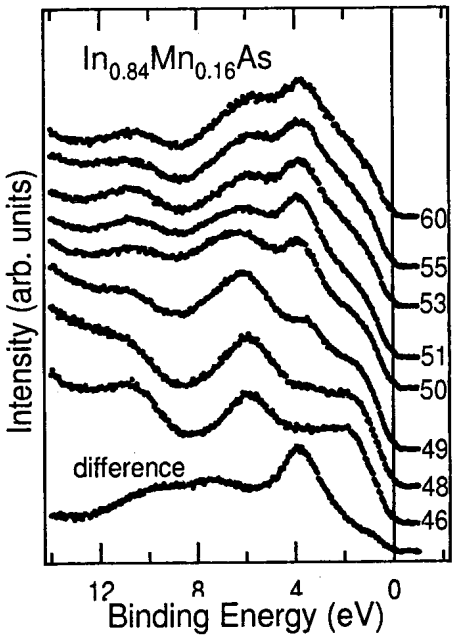

Figure 1: A series of photoemission spectra of $In_{1-x}Mn_xAs$ for various photon energies near the Mn 3*p* - 3*d* core excitation threshold. The difference spectra between the on-resonant ($h\nu$=51 eV) and off-resonant (48 eV) spectra, which is a measure of the Mn 3*d* partial density of states, is shown at the bottom.

References

[1] S. Koshihara *et al.*, Phys. Rev. Lett. **78**, 4617 (1997).
[2] H. Munekara *et al.*, Appl. Phys. Lett. **63**, 2929 (1993).
[3] J. Okabayashi *et al.*, Phys. Rev. B **59**, R2486 (1999).
[4] J. Szczytko *et al.*, Phys. Rev. B **63**, 085315 (2001).