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Electronic structure of $Ga_{1-x}Cr_xAs$ studied by *in-situ* photoemission spectroscopy

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Introduction

Since the first reports of ferromagnetism in Mn-doped III-Vsemiconductors synthesized the "spinelectronics" research field using molecular-beam epitaxy (MBE), diluted magnetic semiconductors (DMS) have become key materials for the functional device application combining magnetic and semiconducting properties[1]. The Mn doping into GaAs leads to carrier-induced ferromagnetism because hole carriers introduced into the system mediate the ferromagnetic coupling between the Mn ions although its microscopic mechanism has been controversial until now. The Curie temperature (T_C) in $Ga_{1-x}Mn_xAs$ has not exceeded 150 K so far due to the solubility limit of Mn and the carrier self-compensation[2]. To overcome these problems in $Ga_{1-x}Mn_xAs$, the investigations for the chemical trends in III-V based DMS can bring us a new information about a functional material design. First-principle band-structure calculation predicts that the Cr doping into GaAs stabilizes the ferromagnetic states because the Cr 3*d* states are located near the Fermi level (E_F)[3]. The Cr doping into GaAs has a high potential to design the high-T_C ferromagnetic semiconductors. We have fabricated the $Ga_{1-x}Cr_xAs$ by MBE and discussed the electronic structure by the Cr doping into GaAs using *in-situ* photoemission spectroscopy. We focused on the transition-metal 3*d* states in $Ga_{1-x}Cr_xAs$ comparing with those in $Ga_{1-x}Mn_xAs$[4].

Experimental

$Ga_{1-x}Cr_xAs$ samples were grown by low-temperature (LT) -MBE methods on GaAs (001) substrates. The 100-nm $Ga_{1-x}Cr_xAs$ layer was grown on the GaAs buffer layer at 200°C and the evaporation temperature of Cr ions was changed from 1140°C to 1240°C to fabricate the different Cr-concentration samples. The MBE system used in this study was connected to the synchrotron-radiation photoemission spectroscopy chamber at BL-1C of Photon Factory, High-Energy Accelerator Research Organization (KEK). The samples grown by MBE were transferred into the photoemission chamber without breaking the ultrahigh vacuum. *In-situ* photoemission spectroscopy was performed at room temperature.

Results and discussion

Figure 1 shows the valence-band spectra of $Ga_{1-x}Cr_xAs$ depending on the Cr concentration. As references, spectrum for GaAs is also shown. Valence-band spectra taken at photon energy hν = 60 eV show new states near E_F derived from the Cr 3*d* states as shown by arrow in Fig. 1. One can see that the intensity in new states depends on the Cr concentration. These states appear by the hybridization between Cr 3*d* and As 4*p* states. Peak positions are shifted toward lower binding energy with increasing the Cr concentration, suggesting the Fermi-level shifts due to the hole doping. The Cr substitution into Ga site will derive the hole doping by $Cr^{3+} \rightarrow Cr^{2+}$ + *hole* through the hybridization between Cr 3*d* and As 4*p* states. Spectra for higher Cr concentrations than 11% doping show a clear Fermi edge. For $Ga_{1-x}Mn_xAs$, the Mn 3*d* states are located around ~4 eV and *p-d* exchange interaction through the hybridization Mn 3*d* and As 4*p* states is important for the ferromagnetic ordering[4]. On the other hand, the new states appearing by the Cr doping may be responsible for the double-exchange mechanism for the ferromagnetism.

References

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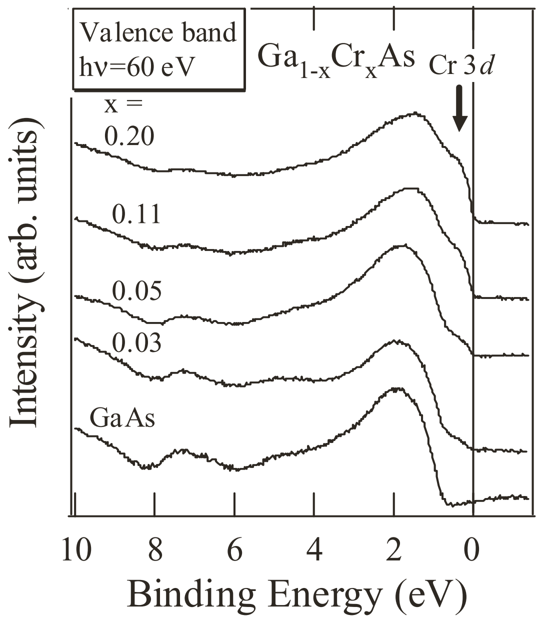

FIG. 1: Valence-band photoemission spectra of $Ga_{1-x}Cr_xAs$ depending on the Cr concentration.

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