Orbital hybridization of Fe 3*d* orbitals with the host InSb bands in *n*-type ferromagnetic semiconductor (In,Fe)Sb

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Ferromagnetic Semiconductors (FMSs) are materials which show the properties of both semiconductors and ferromagnets, and are considered to be promising materials for spintronics that utilizes both charge and spin degrees of freedom. Recently, Fe-doped III-V FMSs such as *n*-type (In,Fe)Sb have been successfully grown by molecular beam epitaxy (MBE) [1]. The Curie temperature (T_C) of (In,Fe)Sb increases with the concentration of Fe, and reaches 385 K at 35% of Fe concentration [2]. However, the mechanism of ferromagnetism behind the high T_C is unclear. In order to clarify the origin of the ferromagnetism, it is necessary to investigate the microscopic state of the Fe atoms in (In,Fe)Sb. In this study, we investigate the local electronic state of Fe in (In,Fe)Sb by x-ray magnetic circular dichroism (XMCD). A 15 nm-thick $(In_{0.94},Fe_{0.06})Sb$ thin film was grown on a *p*-type GaAs(001) substrate by MBE. The sample was covered with a thin amorphous As capping layer after the growth of the $(In_{0.94},Fe_{0.06})Sb$ layer. The value of T_C was estimated to be 100 K by using the Arrott plot of magnetic circular dichroism (MCD) intensity - magnetic field characteristics at various temperatures.

The obtained x-ray absorption spectroscopy (XAS) and XMCD spectra at the Fe $L_{2,3}$ edge on the (In,Fe)Sb film indicate that there are an Fe component substituting the cation site in (In,Fe)Sb and an extrinsic oxidized Fe component. Our spectral decomposition analysis indicates that the XMCD spectrum of the doped Fe ions is similar to that of other Fe-doped III-V FMSs such as (Ga,Fe)Sb [3]. This result suggests that the electronic state related to the magnetism of Fe in (In,Fe)Sb is nearly identical to that in other Fe-doped III-V FMSs. The ratio between spin and orbital magnetic moments M_{orb}/M_{spin} estimated by the XMCD sum rules [4] is a finite positive value, implying that the Fe 3*d* orbitals of the doped Fe ions hybridizes with the ligand Sb bands. Figure 1 shows the magnetic field (H) dependence of the magnetization (M - H curve) estimated from the XMCD and the normalized MCD - H curve. The two curves show the same behavior, suggesting that the local magnetic moment of the doped Fe ions is proportional to the Zeeman splitting of the ligand Sb bands. These results indicate that the magnetism of (In,Fe)Sb originates from the hybridization of the Fe 3*d* orbitals with the InSb bands.

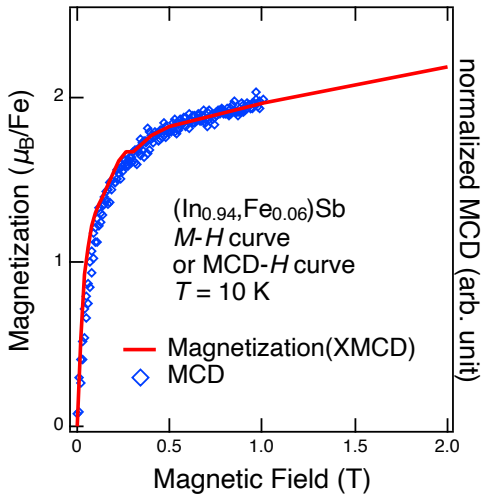

Fig. 1. *M-H* curve and MCD-*H* curve for the $(In_{0.94},Fe_{0.06})Sb$ thin film at 10 K. The magnetic field was applied perpendicular to the sample plane.

References [1] N. T. Tu *et al*., Appl. Phys. Express **11**, 063005 (2018). [2] N. T. Tu *et al*., Appl. Phys. Express **12**, 103004 (2019). [3] S. Sakamoto *et al*. Phys. Rev. B **100**, 035204 (2019). [4] C. T. Chen *et al*., Phys. Rev. Lett. **75**, 152 (1995).