Electronic Structure of the $p$-type Ferromagnetic Semiconductor (Ga,Fe)Sb

Shoya Sakamoto 1, Nguyen Thanh Tu 1, Yukihiro Takeda 2, Shin-ichi Fujimori 2, Pham Nam Hai 3, Le Duc Anh 1, Yuki K. Wakabayashi 1, Goro Shibata 1, Masafumi Horio 1, Keisuke Ikeda 1, Yuji Saitoh 2, Hiroshi Yamagami 2,4, Masaaki Tanaka 1, Atsushi Fujimori 1

E-mail: shoya@wyvern.phys.s.u-tokyo.ac.jp

Fe-doped GaSb is a newly synthesized $p$-type ferromagnetic semiconductor, which exhibits ferromagnetism at a relatively high temperature of 340 K [1-3].

In order to reveal the mechanism of the ferromagnetism, we have studied its electronic structure and magnetic properties by soft x-ray resonance photoemission spectroscopy (RPES), x-ray absorption spectroscopy (XAS), and x-ray magnetic circular dichroism (XMCD). The measurements were performed at BL23SU of SPring-8. Figure 1(a) shows the RPES spectra of an Fe 13.7%-doped sample ($T_C = 180$ K) taken with the photon energies across the Fe $L_3$ absorption edge from 705 eV to 715 eV. The color and the baseline positions represent the photon energies as depicted by triangles on the XAS spectra shown in Fig. 1(c). Here, the off-resonance spectrum taken with the photon energy of 704 eV shown in Fig. 1(b) has been subtracted to emphasize the resonance behavior. One can see a strong normal Auger peak dispersing with incident photon energy, and we observed an enhancement of the photoemission intensities at $E_F$, both of which suggest the itinerant nature of the Fe 3$d$ electrons. On the other hand, one can also see resonantly enhanced non-dispersive structures around 1.7 eV and 10.3 eV, denoted by $\alpha$ and $\beta$, respectively, indicating the localized nature of the Fe 3$d$ electrons as well. This kind of non-dispersive structures were not seen in the previous measurements on Fe-doped Ge, suggesting stronger localization of Fe 3$d$ electrons in (Ga,Fe)Sb than in Ge:Fe. From XMCD measurements, the magnetic moment of Fe was found to be $\approx 1.5 \mu_B$ at $H = 7$ T and $T = 5$ K, much smaller than the ionic value of Fe$^{3+}$, indicating the existence of paramagnetic or antiferromagnetically coupled Fe atoms.