5–8 Unmasking the Ferromagnetism in Magnetically-Doped Topological Insulators

— Toward Ultra-Low Power-Consumption Spintronic Devices —

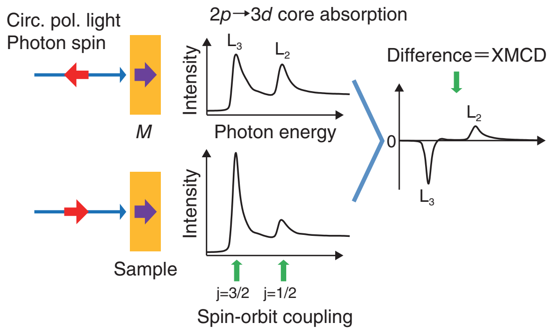

Fig.5-22 XMCD schematics in core-level absorption
The XMCD is defined as the difference in absorption intensity between left- and right-polarized light.

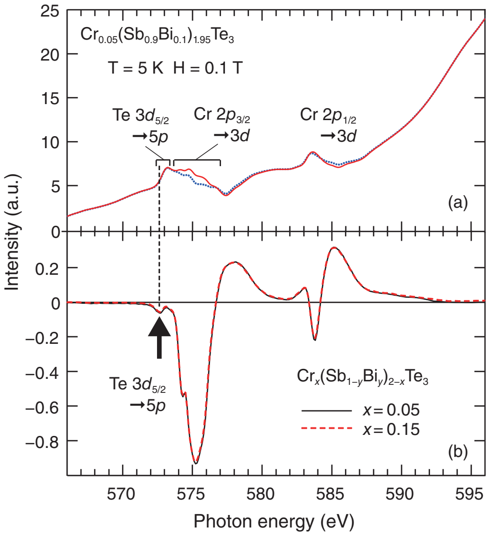

Fig.5-23 Experimental spectra of $Cr_x(Sb_{1-y}Bi_y)_{2-x}Te_3$ at the Cr 2*p*→3*d* and Te 3*d*→5*p* edges
XAS (a) and XMCD (b) spectra measured at 5 K and 0.1 T.

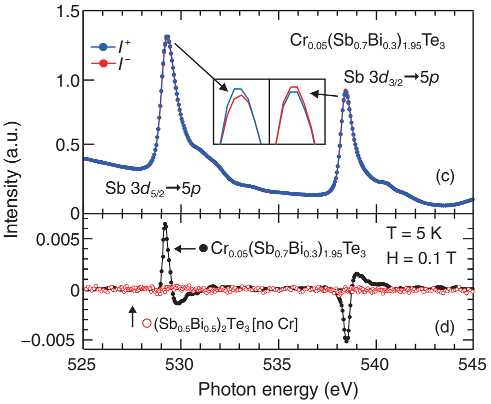

Fig.5-24 Experimental spectra of $Cr_x(Sb_{1-y}Bi_y)_{2-x}Te_3$ at the Sb 3*d*→5*p* edges
XAS (c) and XMCD (d) spectra measured at 5 K and 0.1 T.

Recently, topological insulators (TIs), characterized as bulk insulators with conducting states on their surface, have attracted attention globally owing to the quantum-anomalous Hall effect (QAHE) discovered in ferromagnetic Cr-doped $(Sb,Bi)_2Te_3$ TI at very low temperatures. The QAHE enables electric currents to flow with little energy consumption. To realize QAHE at room temperature, unmasking the underlying physics behind the ferromagnetism is required. We have performed an X-ray magnetic-circular dichroism (XMCD) experiment at the BL23SU of SPring-8 and revealed the origin of ferromagnetism by detecting not only the magnetic moment of Cr 3*d* electrons but also those of "nonmagnetic" Sb and Te 5*p* electrons. The XMCD spectrum is defined as the difference between the core-absorption spectra (XAS) of the left- and right-handed circularly polarized light, as schematically shown in Fig.5-22.

Fig.5-23(a) shows the Cr 2*p*→3*d* XAS spectra of $Cr_x(Sb_{1-y}Bi_y)_{2-x}Te_3$ (x = 0.05, y = 0.1, T_C = 15 K) measured at a magnetic field of 0.1 Tesla and a temperature of 5 K. Fig.5-23(b) shows the XMCD spectra for two different Cr contents (x = 0.05, 0.15). We find that the signals are negative and positive at the $2p_{3/2}$→3*d* and $2p_{1/2}$→3*d* edges, respectively, which signifies that the Cr 3*d* electrons are responsible for ferromagnetism. As indicated by an arrow in Fig.5-23(b), a negative signal at the Te $3d_{5/2}$→5*p* edge below the Cr $2p_{3/2}$ edge is observed. This tells us that the magnetic moments of the Te 5*p* and Cr 3*d* electrons are coupled in an antiparallel manner.

Fig.5-24 shows the Sb 3*d*→5*p* XAS (c) and the associated XMCD (d) spectra for $Cr_{0.05}(Sb_{0.7}Bi_{0.3})_{1.95}Te_3$. Here, we find positive and negative signals at the $3d_{5/2}$→5*p* and $3d_{3/2}$→5*p* edges, respectively. No XMCD spectrum is found for the sample without Cr doping [$(Sb_{0.5}Bi_{0.5})_2Te_3$]. The result tells us that the Sb 5*p* moment is aligned parallel to the Cr 3*d* magnetic moment. Therefore, we confirm that the Cr 3*d* magnetic moments are mediated by the Te and Sb 5*p* holes, which work as a glue for the largely separated Cr spins in the crystal and should be a key to the ferromagnetism of magnetic TI $Cr_x(Sb_{1-y}Bi_y)_{2-x}Te_3$.

Our results will open the way to the future material design of QAHE systems and may provide a guideline for practical application of next-generation ultra-low power-consumption devices using TIs.

Reference

Ye, M., Saitoh, Y. et al., Carrier-Mediated Ferromagnetism in the Magnetic Topological Insulator Cr-Doped $(Sb,Bi)_2Te_3$, Nature Communications, vol.6, 2015, p.8913-1-8913-7.