Element-specific magnetic properties of compensated ferrimagnet
Mn$_2$Co$_{1-x}$V$_x$Al Heusler alloy films

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Half-metallic antiferromagnets or fully compensated ferrimagnets have attracted much attention for spintronics. They have no stray magnetic field and may significantly reduce switching current of spin-torque due to no net magnetization. Such intriguing materials have been originally proposed theoretically [1]. One of the candidates for such materials is the Heusler alloy. Some of the elemental compositions are believed to be half-metals and those magnetisms can be tuned by valence electrons according to the well-known Slater-Pauling-like rules in full Heusler alloys [2]. The rules lead the net magnetic moment $M_t = Z_t - 24$, where $Z_t$ is the total valence electron number and allows us to obtain half-metals with no net magnetic moments at $Z_t = 24$. The electronic structure for Mn$_2$(V$_{1-x}$Co$_x$)Z ($Z$=Al, Ga) has been anticipated as negligible magnetic moments as well as half-metallic band gap at the Fermi level for minority spin states. In this study, we investigate the element-specific magnetic states of Mn$_2$(V$_{1-x}$Co$_x$)Al with various compositions $x$ to understand the spin configuration of the magnetization compensation using x-ray absorption and magnetic circular dichroism (XAS/XMCD).

All samples were deposited on MgO(001) single-crystal substrates using a magnetron sputtering technique. The 30-nm-thick Mn$_2$(V$_{1-x}$Co$_x$)Al was grown with 2-nm-thick MgO capping. The XMCD were performed at BL-7A in PF. A magnetic field of ±1 T was applied along the incident polarized soft x-ray and magnetic field directions are switched, defining the absorption signals as $\mu^+$ and $\mu^-$. The total electron yield mode was adopted in the measurements at 80 K.

The XAS and XMCD spectra are displayed in Fig. 1 after the normalized divided by incident photon intensities. The XAS intensities of Mn remain almost unchanged and those of V and Co are systematically changed with regard to the element substitution. Clear metallic peaks are observed, which confirms preventing the mixing of oxygen atoms in the Mn$_2$Co$_{1-x}$V$_x$Al layer. Shoulder structures appear in the higher photon energy region of Co $L_3$ XAS peaks. These structures correspond to the Heusler alloys due to the Co-Co bonding states within the molecular orbital calculations and observed in the XMCD of ordered Co-based Heusler alloys.

XMCD line shapes shown in Fig. 1(b) are quite unique. The end compositions, Mn$_2$VAl and Mn$_2$CoAl, exhibit clear XMCD signals. In Mn$_2$CoAl, the spins of Mn and Co sites are coupled in parallel. On the other hand, the spins of Mn and V sites in Mn$_2$VAl are coupled in anti-parallel. Two kinds of components appear in Mn$_2$VAl, one has a peak at 638 eV and the other is 640 eV for $L_3$ edge. Former peak position is the same as that in the Mn XMCD of Mn$_2$CoAl. At the intermediate compositions, positive and negative signs in XMCD are observed for V, Mn, and Co $L$-edges and their systematic changes are also depicted. With increasing V composition into Mn$_2$CoAl, the Mn XMCD spectra clearly exhibit two kinds of sites with opposite sign. This clearly indicates the swapping for different atomic sites with different exchange coupling in Mn$_2$VAl, resulting in antiferromagnetic coupling between Mn and V sites. We found that the existence of anti-parallel coupled sites in both Mn and Co contributes to the antiferromagnetic compensation in $x = 0.5$ [3].

References

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