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Relationship between degree of order and magnetic moments in spin-gapless semiconductor CoFeMnSi Heusler alloy studied by XMCD

Jun Okabayashi[1], Lakhan Bainsla[2], Kazuya Suzuki[2], and Shigemi Mizukami[2]
[1]*Research Center for Spectrochemistry, The University of Tokyo, 113-0033 Tokyo, Japan*
[2]*WPI-Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan*

Half-metals exhibit fully spin-polarized band structures and therefore are suitable for spintronic applications. The half-metallicity is seen in different classes of materials, such as magnetic oxides, diluted magnetic semiconductors, and Heusler alloys. Cobalt-based Heusler alloys are very interesting due to their theoretically predicted half-metallic electronic structures and experimentally observed high spin polarization with high Curie temperatures. Recently, the quaternary Heusler alloys also have attracted much attention because of their half-metallic and/or spin gapless band structures [1]. Original and stoichiometric full-Heusler alloys have A_2BC in their chemical formulas, where A and B are transition-metal elements and C is a main group element and those alloys have a cubic $L2_1$ crystal structure. A quaternary Heusler alloy with a different structural symmetry is obtained when A in A_2BC partially is replaced by another element A', i.e., $AA'BC$. They also are named equiatomic quaternary Heusler alloys. We focus on the structural and magnetic properties for CoFeMnSi (CFMS) films, which is a candidate of spin-gapless semiconductors. We deduce the element-specific magnetic moments of Mn, Fe, and Co using x-ray magnetic circular dichroism (XMCD) and discuss the ordering types of CFMS.

The sample of 30-nm-thick CFMS were grown on MgO (001) substrates with Cr buffer. Sample surfaces were capped by MgO layer. The MgO(001) substrate was ushed thermally at 700°C. All of the layers were deposited at room temperature. The Cr layer was *in situ* annealed at 700°C for 1 h before the CFMS deposition. Samples with CFMS *in situ* annealing at temperatures (T_a) of 300, 400, 500, and 600°C were prepared [2].

XMCD was performed at BL-7A in the Photon Factory (KEK). Photon helicity was fixed, and a magnetic-field switching between ±10 kOe was performed along the incident polarized soft x-ray. A total-electron-yield mode was adopted. The measurements were carried out in a grazing incidence setup to the sample surface normal in order to detect the in-plane spin and orbital magnetic moments. All the measurements were performed at room temperature.

Figure 1 shows the x-ray absorption spectra (XAS) of Mn, Fe, and Co $L_{2,3}$ edges, respectively, for T_a =600°C. XAS are normalized by the photon fluxes. Clear metallic peaks are observed, which confirms that there is no mixing of oxygen atoms in the thin CFMS 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. Element-specific hysteresis curves taken at L_3-edge photon energies are also plotted, which indicates the in-plane easy axis in 30-nm-thick CFMS film. The spin and orbital magnetic moments are estimated by applying the magneto-optical sum rules. The magnetic moment summing both spin and orbital components of each element is estimated to be 0.94, 0.90, and 2.22 μ_B for Co, Fe, and Mn, respectively. Total magnetic moment is 4.05 μ_B in this sample, which is similar to the value for type-I ordered case in the calculation [3]. We deduced the magnetic moments depending on the annealing temperature. The results clearly indicate the increase of magnetic moments with annealing temperature.

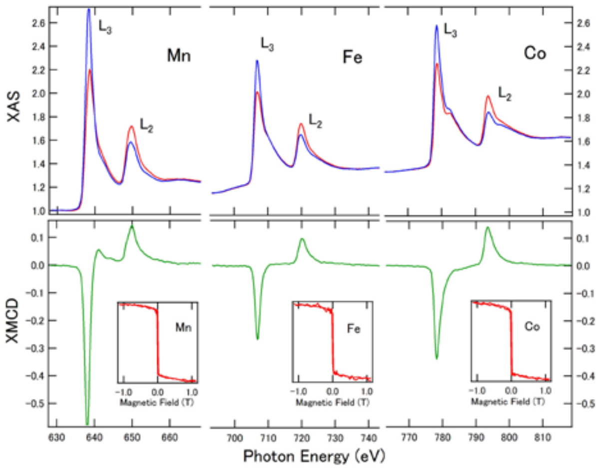

Fig. 1, The x-ray absorption spectra with different magnetic fields for the sample annealed at T_a = 600°C measured at the Mn, Fe, and Co $L_{3,2}$ edges. The XMCD spectra for the corresponding elements are also shown. Insets show the element-specific hysteresis curves taken at each L_3-edge photon energy.

References

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*jun@chem.s.u-tokyo.ac.jp