A Soft X-Ray Magnetic Circular Dichroism Study of Co_2MnGe/MgO Interfaces

We studied the magnetic states of Mn and Co atoms in Co-rich Co_2MnGe (CMG) Heusler alloy thin films facing an MgO barrier by soft X-ray magnetic circular dichroism (XMCD). The CMG film-thickness dependent XMCD revealed that Mn atoms were oxidized in the 1-monolayer (ML) samples, in contrast to samples thicker than 4 ML. On the other hand, Co atoms in the 1-ML sample were not oxidized and were more strongly spin-polarized. The Co spin magnetic moment larger than theoretical values and the Co-rich film composition implied the presence of Co antisites that would lower the spin polarization at the Fermi level.

Co_2MnGe (CMG) and Co_2MnSi (CMS) Heusler alloys are promising candidates for ferromagnetic electrodes in magnetic tunnel junctions (MTJ) because of the possible half-metallicity. Recently, tunnel magnetoresistance (TMR) ratios of several hundred percent in $Co_2Mn_{0.77}Ge_{0.42}$ (Co-rich CMG) facing an MgO tunnel barrier have been reported [1]. In order to further improve the performance of CMG/MgO MTJ, it is very important to understand the interfacial electronic and magnetic states because high-quality interfaces are the key for obtaining a high TMR ratio, which is closely related to spin polarization at the Fermi level. We studied the magnetic and electronic structures of Mn and Co atoms in a Co-rich CMG/MgO barrier [1] using soft X-ray magnetic circular dichroism (XMCD) [2]. The CMG-film-thickness dependences of XMCD and magnetic moments of CMG/MgO samples with various CMG thicknesses ranging from 1 to 172 monolayers (ML) were investigated.

Fully epitaxial CMG/MgO thin films were fabricated by the combined use of magnetron sputtering for CMG and electron beam evaporation for MgO [1, 2]. XMCD measurements were performed at BL-16A and BL-11A. The photon helicity (h) was fixed on BL-11A and reversed on BL-16A. The total-electron yield method was employed in the X-ray absorption spectroscopy (XAS) and XMCD measurements. Using a superconducting-magnet XMCD apparatus, magnetic fields of $B = \pm 3$ T were applied to the sample parallel or antiparallel to h. All the measurements were made at room temperature.

As the Co_2MnGe film thickness was decreased to 1–2 monolayers (ML), the spin magnetic moment of Mn, m_{spin}(Mn), decreased and the Mn $L_{2,3}$-edge XAS showed a Mn^{2+}-like multiplet structure in MnO, in contrast to samples thicker than 4 ML (Fig. 1). Furthermore, the O K-edge XAS for the 1-ML sample (not shown) showed a pre-edge structure characteristic of MnO [2]. Therefore, the Mn atoms of the 1- and 2-ML samples were

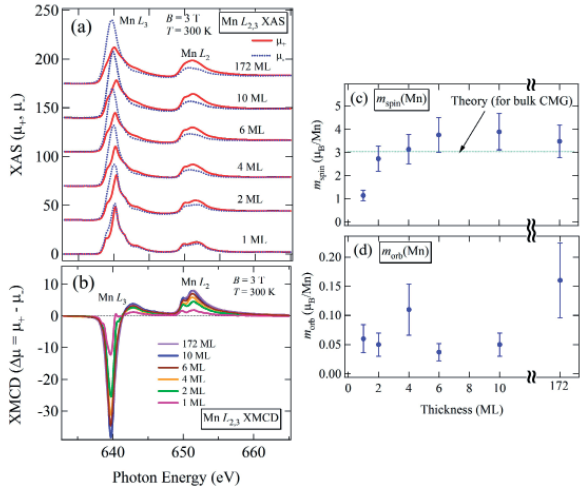

Figure 1
Normal-incidence Mn $L_{2,3}$-edge XAS and XMCD of Co-rich Co_2MnGe (CMG) samples with various CMG thicknesses. (a) XAS measured at 300 K and $B = \pm 3$ T. μ_+ and μ_- are the absorption coefficients for the photon helicity parallel and antiparallel to the Mn 3d majority spin, respectively. (b) XMCD spectra given by $\Delta\mu = \mu_+ - \mu_-$. Film-thickness dependences of (c) Mn spin magnetic moment (m_{spin}) and (d) Mn orbital magnetic moment (m_{orb}). These were determined using the spin and orbital sum rules [6, 7]. The theoretical m_{spin} was taken from Ref. 5.

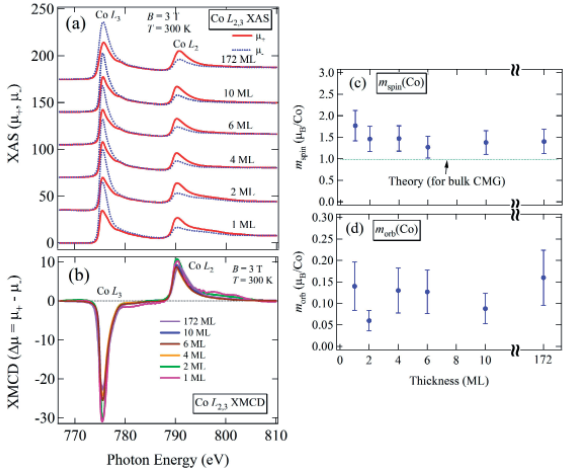

Figure 2
Normal-incidence Co $L_{2,3}$-edge XAS and XMCD of Co-rich Co_2MnGe (CMG) samples with various CMG thicknesses. (a) XAS measured at 300 K and $B = \pm 3$ T. μ_+ and μ_- are the absorption coefficients for the photon helicity parallel and antiparallel to the Co 3d majority spin, respectively. (b) XMCD spectra given by $\Delta\mu = \mu_+ - \mu_-$. Film-thickness dependences of (c) Co spin magnetic moment (m_{spin}) and (d) Co orbital magnetic moment (m_{orb}). These were determined using the spin and orbital sum rules [6, 7]. The theoretical m_{spin} was taken from Ref. 5.

oxidized. The orbital magnetic moment, m_{orb}(Mn), was found to be 0.05–0.10 μ_B for all the samples [Fig. 1(d)], that is, m_{orb}(Mn) did not show any clear film-thickness dependence. Comparing m_{spin}(Mn) for 1 ML with that for 10 ML, we found that about 70% of the Mn atoms in the 1-ML sample were oxidized. In CMS-film-thickness dependent XMCD and theoretical studies on Co-rich CMS/MgO [3], the m_{spin}(Mn) of CMS was reduced only for the 1-ML sample but the XAS and XMCD spectra for the 1-ML sample did not show any Mn^{2+}-like multiplet structure, indicating the absence of oxidation [3]. On the other hand, the present experimental results on the Co-rich CMG/MgO showed reduced m_{spin}(Mn) due to the oxidation of Mn atoms in the 1- and 2-ML samples. The quality of the crystal structure of the ultrathin Co-rich CMG samples should not be as good as that of the slightly Co-rich 1-ML CMS. The structural difference would be related to the different oxidation tendencies.

The Co spin moment m_{spin}(Co) increased slightly with decreasing thickness (Fig. 2). A Co^{2+}-like multiplet structure in CoO was not observed in all the Co $L_{2,3}$-edge XAS and XMCD (Fig. 2), indicating that, even in the ultrathin samples, the Co atoms were not oxidized, and were more strongly spin-polarized than those in the thicker samples. The Co orbital moment, m_{orb}(Co), was about 0.10 μ_B for all the samples. The existence of Co antisites is suggested by considering theories on Co antisites [4] and the observed m_{spin}(Co) of 1.40–1.77 μ_B, which was larger than theoretical values for ideal compounds [5]. The nonstoichiometry of the Co-rich CMG samples is also consistent with the existence of Co antisites. When Co antisites were present, in-gap states were predicted to exist within the Co minority-spin band gap, which would lower the spin polarization at the Fermi level [4]. The consideration is consistent with the fact that the TMR ratio of the Co-rich CMG/MgO MTJs was 185% at 4.2 K and 83% at RT [1].

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BEAMLINES

16A and 11A

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