Bulk and near-interface magnetic properties of $Co_2Fe(Ga_{0.5}Ge_{0.5})$ Heusler alloy explored by magnetic circular dichroism in hard x-ray photoelectron spectroscopy

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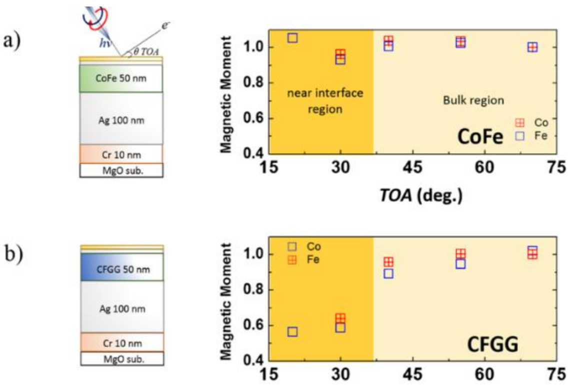

Fig. 1 Sketch of sample structure of CoFe and CFGG films. The normalized magnetic moments with Co and Fe elements in the case of a) CoFe and b) CFGG films

Co-based Heusler alloys have attracted attention for the applications as ferromagnetic (FM) electrodes in spintronic devices. In particular, large magnetoresistance (MR) ratios over 50% at room temperature have been demonstrated in the current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) devices using Co-based Heusler alloys with the $L2_1$ structure[1)], which are one order of magnitude larger than those using conventional FMs such as CoFe. In general, however, the MR ratio in the CPP-GMR devices using Heusler alloys largely decreases with increasing temperature compared to the CoFe-based CPP-GMR, whose origin has not been understood sufficiently. One possibility for the origin of the large MR degradation at elevated temperature is the weak magnetic exchange stiffness at the interface between Heusler alloy and non-magnetic spacer, which is considered to lead to a large thermal fluctuation of the magnetization near the interface. In order to understand the mechanisms of such large temperature dependence of CPP-GMR, we performed *in-situ* hard x-ray photoelectron spectroscopy (HAXPES)-magnetic circular dichroism (MCD) experiment at beamline BL09XU of SPring-8. The HAXPES-MCD is a powerful method for investigating the element-specific magnetic properties in thin magnetic films and buried layers of multilayers.[2)] By varying the take-off angle (TOA) of photoelectron by using a rotatable sample stage, it is possible to control the probing depth of circularly polarized x-rays from near-interface (lower TOA) to bulk (higher TOA) region. We performed HAXPES-MCD measurements for two kinds of samples: CoFe(50 nm) and CFGG(50 nm) thin films, which were grown epitaxially on a MgO (001) single-crystal substrate buffered by Cr (10 nm)/Ag (100 nm). Thin Ag (2 nm)/Ta (2.5 nm) were deposited on top of films to prevent surface oxidation. Before the measurement, we confirmed atomically flat interface between CFGG and Ag by STEM/HAADF. The HAXPES-MCD experiments with an excitation energy of 8003.58eV by circularly polarized x-ray were performed. Fig. 1 shows the normalized magnetic moments resulting from the normalized peak intensities at each Fe and Co $2p_{3/2}$ states for the CoFe and CFGG samples, as TOA is varied from 20^{o}-70^{o} form sample normal, which corresponds to an effective probing depth variation of 8-22 nm. The normalized intensities were calculated from different MCD intensities of opposite helicity divided by their sum of total intensities after subtracting a Shirley-type background. In the case of CFGG sample, the normalized intensities reduce with decreasing TOA, indicating large thermal fluctuation with smaller magnetic moment compared to that of bulk CFGG. On the other hand, for the CoFe case, the magnetic moment did not exhibit marked changes by changing TOA. Consequently, this result suggests that an improvement of exchange stiffness at near interface is the key to reduce temperature dependence of MR ratio in Heusler alloy-based CPP-GMR.

Reference

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2) X. Kozina *et al*., Phys. Rev. B **84**, 054449 (2011).