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Enhanced CPP-GMR effect by improved B2 order of $Co_2(Mn_{0.6}Fe_{0.4})Ge$ Heusler layer deposited on amorphous CoFeBTa underlayer: a quantitative estimation of site-disorder by anomalous x-ray diffraction

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Improving the chemical order of Heusler alloy films under relatively low annealing temperatures (<400 °C) is important for achieving large output in current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) polycrystalline devices for practical sensor applications such as HDD read sensors. We studied the effect of amorphous CoFeBTa (CFBT) underlayer on the site-disorder in $Co_2(Mn_{0.6}Fe_{0.4})Ge$ (CMFG) Heusler alloy films, by which an enhanced CPP-GMR effect was recently reported [Choi *et al.* Appl. Phys. Express **10**, 013006, (2017)]. Polycrystalline pseudo spin-valve films with the stacking structure of thermally oxidized $Si_{substrate}$ /Ta/Cu/Ta bottom electrode /Ru (2 nm)/CoFe (1 nm)/CFBT (*t* nm)/CMFG (5 nm)/CoFe (0.4 nm)/AgSn (4 nm)/ CoFe (0.4 nm)/CMFG (5 nm)/ CoFe (1 nm) /Ru cap were prepared by magnetron sputtering, and annealed at 300 °C for 3 h. Fig. 1 shows magnetoresistance-area product (*ΔRA*) of the CPP-GMR devices with various thickness of CFBT insertion, showing a clear enchantment of *ΔRA* with increasing CFBT thickness. A large MR ratio of 25% (insert of Fig. 1) was observed at room temperature. We performed anomalous x-ray diffraction study in the synchrotron facility of Spring-8 to investigate the site disorder in CMFG. Fig. 2(a) and (b) shows the integrated intensity of (200) B2-sputterlatice diffraction of the 30 nm-thick CMFG films deposited on the CFBT underlayer from experiment and simulation with assumption of various Co-Mn disorder, respectively. By comparing the experimental result to the simulation result, we can estimate the quantity of the Co-Mn or Co-Fe site-disorders as show in Fig. 2(c) and thus lead to a quantitatively estimation of B2 order in the CMFG layers as a function of thickness of the CFBT seed layer as shown in Fig. 2(d). The degree of B2 order in the CMFG layers increased from ~47% to ~76% after inserting a 1.2 nm-thick CFBT underlayer, which is the reason for the enhancement of *ΔRA* in CPP-GMR device after inserting CFBT underlayer below CMFG layers.

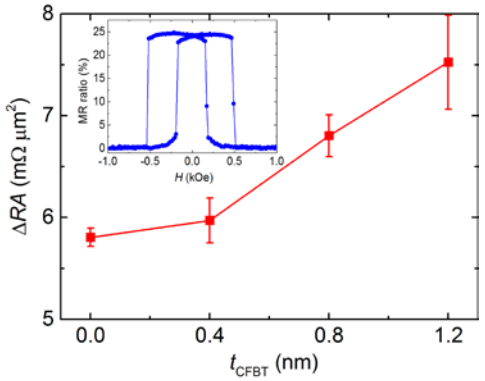

Fig.1 Δ RA as function of thickness of CFBT underlayer in CMFG-based CPP-GMR devices.

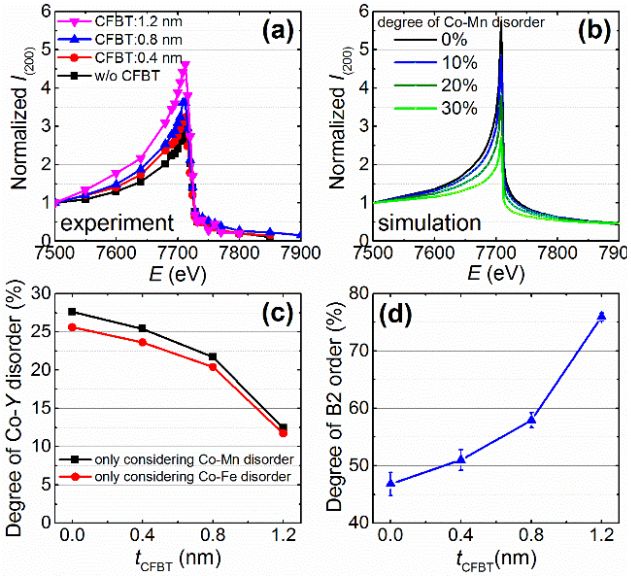

Fig. 2 (a) x-ray energy dependence of I_{200} of CMFG layer deposited on CFBT underlayer with various thickness t_{CFBT}; **(b)** Simulation result with various degree of Co-Mn disorder; **(c)** Estimated Co-*Y* disorder in CMFG layer as function of t_{CFBT}; **(d)** Quantitative estimation of B2 order in CMFG layer as a function of t_{CFBT}.