Voltage control of perpendicular magnetic anisotropy in Fe/$MgAl_2O_4$ heterostructures

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Perpendicular magnetic anisotropy (PMA) and its voltage control in magnetic heterostructures [1] are expected to be a key for achieving low-power consumption spintronic devices such as voltage-torque magnetoresistive random access memories (MRAMs). For actual high-density memory applications, large interface PMA energy (K_i) and voltage control of magnetic anisotropy (VCMA) coefficient (β), i.e., $K_i > 2–3$ mJ/m^2 and $\beta > 1000$ fJ/(Vm), are needed. In order to achieve such a large VCMA effect, exploring the origin of the VCMA effect using ideal PMA heterostructures without any interfacial defects appears to be indispensable. Recently, large PMA energies were reported in lattice-matched Fe/$MgAl_2O_4$ [2] and Co_2FeAl/$MgAl_2O_4$ heterostructures [3]. In this study, we focused on the ultrathin Fe/$MgAl_2O_4$(001) epitaxial interfaces to achieve high K_i and β. Especially, we investigated the Fe thickness dependence of VCMA using Fe/$MgAl_2O_4$/CoFeB orthogonally magnetized MTJs. We report that only a monolayer thickness difference has a significant impact on the PMA energy and VCMA effect.

MTJ stacks of Cr buffer (30)/Fe (5, 6, 7 monolayers (MLs))/$MgAl_2O_4$ (2)/$Co_{20}Fe_{60}B_{20}$ (5)/Ru (10) (unit in nm) were epitaxially grown on an MgO(001) substrate by electron-beam evaporation. The top 5-nm CoFeB is the reference layer with in-plane magnetization for evaluating the VCMA effect of the bottom Fe. The Cr, Fe, $MgAl_2O_4$, and CoFeB layers were post-annealed to improve their crystallinity and flatness. Magnetic properties were investigated using a vibrating sample Superconducting QUantum Interference Device (SQUID) magnetometer. After microfabrication (5×10 μm scale), magnetotransport properties of MTJs were characterized by a Physical Property Measurement System (PPMS) at room temperature. The positive bias was defined with respect to CoFeB (electron tunneling from the bottom to top electrode).

Figure 1 shows the typical in-plane magnetization curves for the MTJ stacks with different Fe thicknesses. It was found that the 5- and 6-ML Fe layers had perpendicular magnetization. Areal PMA energy density, i.e. $K_{eff} \times t_{Fe}$, for the 5-ML (6-ML) Fe sample was determined to be 0.85 mJ/m^2 (0.77 mJ/m^2). We investigated the bias voltage dependence of $K_{eff} \times t_{Fe}$ for the 5- and 6-ML Fe samples using normalized tunnel magnetoresistance ratios as functions of both bias voltage and in-plane magnetic field. As clearly seen in Fig.1 c) and d), $K_{eff} \times t_{Fe}$ values for both the samples show complicated bias voltage dependence. Importantly, the $K_{eff} \times t_{Fe}$ curve shape significantly depends on the Fe thickness; a local minimum appears near +0.2 V for the 5-ML Fe sample, whereas a peak appears at the zero-bias voltage for the 6-ML one. This work was supported by the ImPACT Program of Council for Science, Technology and Innovation, Japan

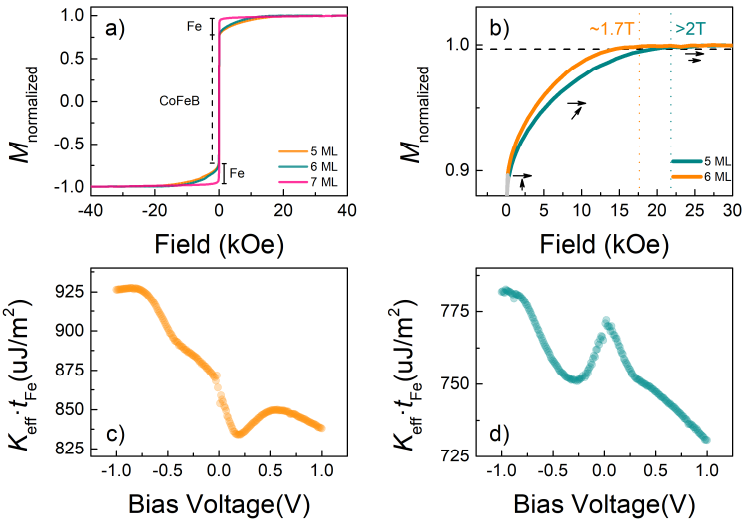

Fig. 1 a) Normalized magnetizations as a function of in-plane magnetic fields for ultrathin-Fe/$MgAl_2O_4$/CoFeB MTJs with 5-7 ML thick Fe; b) inplane component from ultrathin-Fe; bias voltage dependences of $K_{eff} \times t_{Fe}$ for c) 5-ML and d) 6-ML Fe sample.

References

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