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

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Voltage-controlled magnetic anisotropy (VCMA) in magnetic heterostructures [1] are expected to be a key for approaching next generation low-power consumption spintronic devices such as voltage-controlled magnetoresistive random access memories (MRAMs). For practical high-density memory applications, large interface perpendicular magnetic anisotropy (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 required. To achieve such a large VCMA effect, investigating the origin of the VCMA effect using ideal PMA heterostructures without any interfacial defects appears to be necessary. 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 (t_{Fe} = 0.70, 0.84, 0.98→ 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 magnetometer incorporated with superconducting quantum interference device (SQUID). After microfabrication (5×10 μm scale), magneto-transport 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 measured normalized TMR curves with different Fe thicknesses. The in-plane component of magnetization could be calculated and areal PMA energy density $K_{eff} \times t_{Fe}$ 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. 2, $K_{eff} \times t_{Fe}$ values for both the samples show complicated bias voltage dependence. Further detailed t_{Fe} dependence measurement reveals the spin-dependence resonant tunnel (SDRT) effect plays a role due the existence of quantum wells in ultrathin-Fe layer. Importantly, the shape of $K_{eff} \times t_{Fe}$ curve 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

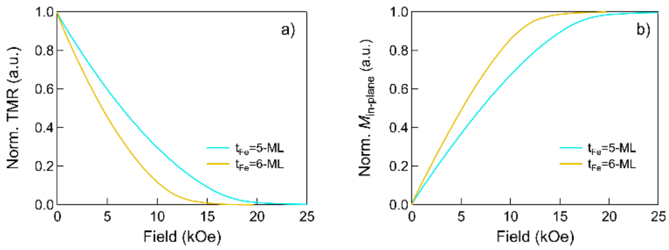

Fig. 1. (a) Normalized TMR a function of in-plane magnetic fields for ultrathin-$Fe/MgAl_2O_4$/CoFeB MTJs with 5- and 6-ML thick Fe; (b) calculated in-plane magnetization component of ultrathin-Fe.

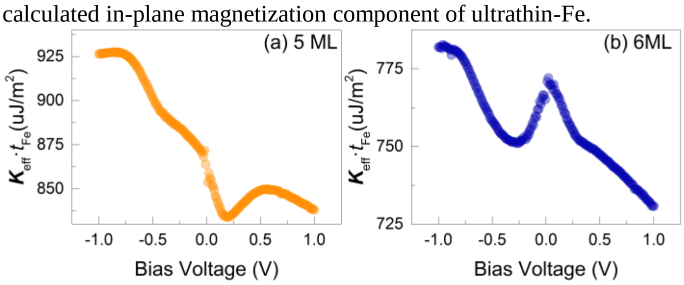

Fig. 2. Bias voltage dependences of $K_{eff} \cdot t_{Fe}$ for (a) 5-ML and (b) 6-ML Fe sample.

References
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