Evaluation of higher order magnetic anisotropy in a perpendicularly magnetized epitaxial ultrathin Fe layer modified by applied voltage

AIST, °A. Sugihara, T. Nozaki, H. Kubota, H. Imamura, A. Fukushima, K. Yakushiji, and S. Yuasa

E-mail: a.sugihara@aist.go.jp

Recently, voltage-controlled magnetic anisotropy (VCMA) effect at an interface between a ferromagnetic metal layer and a dielectric layer attracts much attention as the key technology for voltage-torque magnetic random access memory (MRAM). For the stable operation, VCMA coefficient ξ is important factor and required to be 600-1500 fJ/Vm.[1)] However, demonstrated ξ value (≤290 fJ/Vm) in magnetic tunnel junctions (MTJs) is much lower than the required value and its improvement is the current main issue. To make a strategy to improve ξ value, we need more systematic studies focusing on the relationship between magnetic anisotropy and VCMA effect which give clues to clarify the mechanism of VCMA effect. In this study, we investigated the thickness and applied voltage dependences of first and second order magnetic anisotropy, K_1 and K_2 respectively, in an ultrathin Fe film.

A fully epitaxial MTJ consisting of Cr buffer/ultrathin Fe free layer (t_{Fe})/MgO barrier (2.3 nm)/Fe pinned layer (10 nm) was grown on an MgO(001) single crystal substrate. In this film, easy axis of the ultrathin Fe free layer is perpendicular and that of the Fe pinned layer is in-plane. The film was fabricated into micrometer-sized devices to measure tunnel magnetoresistance (TMR) curves under the application of in-plane magnetic fields and various electrical voltages at room temperature. K_1 and K_2 were evaluated with Sucksmith-Thompson method[2)] from magnetization curves given from the TMR curves.

Figure 1 shows applied voltage dependence of K_1, K_2, K_1+K_2, intrinsic K_1 (K_{1int}), and effective uniaxial magnetic anisotropy $K_{u,\,eff}$ evaluated by the area method for t_{Fe} of (a) 0.40 nm and (b) 0.64 nm. They show clearly different trend that all the magnetic anisotropy constants have strong dependence on applied voltage at t_{Fe} = 0.40 nm while have virtually no dependence on applied voltage at t_{Fe} = 0.64 nm. We can also find that anisotropy change in K_1 term is partly compensated by that of K_2 term at t_{Fe} = 0.40 nm. VCMA coefficient in the K_1 term reaches -600 fJ/Vm, being two times larger than that of effective ξ value observed in the Cr/Fe/MgO systems.[3)] These results imply that individual control of K_1 and K_2 is the key factor for enhancement of the VCMA coefficient.

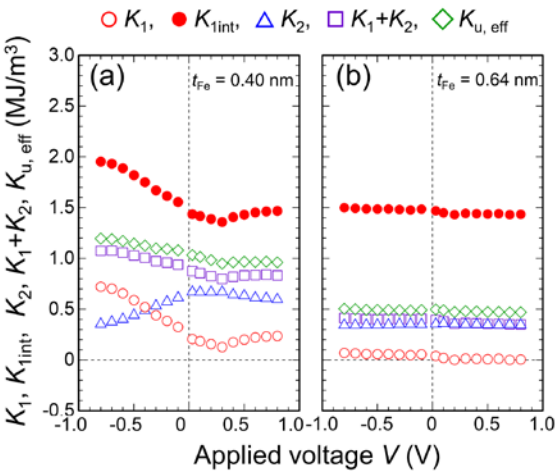

Fig. 1 Applied voltage dependence of K_1, K_2, K_1+K_2, K_1 (K_{1int}), and $K_{u,\,eff}$ for t_{Fe} of (a) 0.40 nm and (b) 0.64 nm.

1) T. Nozaki et al.: Micromachines 10 (2019)327.

2) W. Sucksmith et al.: Proc. R. London A 225(1954) 362.

3) T. Nozaki et al.: Phys. Rev. Appl. 5(2016) 044006.