Antiferromagnetic layer thickness dependence of mangnetoelectric switching condition of perpendicular exchange bias

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Perpendicular exchange bias (PEB), appeared at the antiferromagnetic (AFM)/ferromagnetic interface, is of vital importance to realize modern spintronic devices. Using a magnetoelectric (ME) AFM Cr_2O_3 enabled the electric field control of PEB [1,2]. In the previous research, we have reversibly, isothermally switched the PEB in typical Cr_2O_3/Co stack films. We found the relationship between the applied magnetic field and threshold electric field for the ME switching of PEB (*EH* curve) with a contribution of AFM moments to the total free energy of the system [3]. In this study, to get a deeper understanding of the ME switching, we further investigated the dependence of the energy condition on the thickness of the AFM layer (t_{AFM}).

The stacked films Pt(1.2 nm)/Co(0.4 nm)/Au(0.5 nm)/Cr_2O_3(t_{AFM} = 115 nm, 130 nm, 147 nm, 169nm, 170 nm, 212 nm)/Pt(20 nm) were fabricated by using DC magnetron sputtering. Using a reversible isothermal electric tuning approach, the ME switching was investigated by the anomalous Hall effect measurements at the similar reduced temperature T/T_N = 0.987 in order to exclude the thermal effect in the ME switching process (T_N is the Néel temperature determined from the temperature dependence of the PEB field). Based on the previously proposed energy condition, i.e. $\alpha(E\text{-}E_0)H = \pm\ 2K_{AFM}\ \text{-}\ J_{INT}/t_{AFM}$ (where α is a ME coefficient of Cr_2O_3) [3], we estimated the t_{AFM} dependence of the magnetic anisotropy energy (K_{AFM}), the interface exchange coupling (J_{INT}), and the critical electric field (E_0). K_{AFM} decreases as t_{AFM} increases, which suggests a magnetic domain wall process (Fig. 1a). The asymmetry of the switching condition is also quantitated by J_{INT}. J_{INT} and the unidirectional magnetic anisotropy energy J_K (=$H_{EB}\times M_S\times t_{FM}$) are correlated well, suggesting that the asymmetry is caused by the unidirectional nature of the interfacial exchange coupling. The critical electric field E_0 decreases with the increase of Cr_2O_3 thickness, which indicated that the E_0 is originated from the interface uncompensated AFM moments.

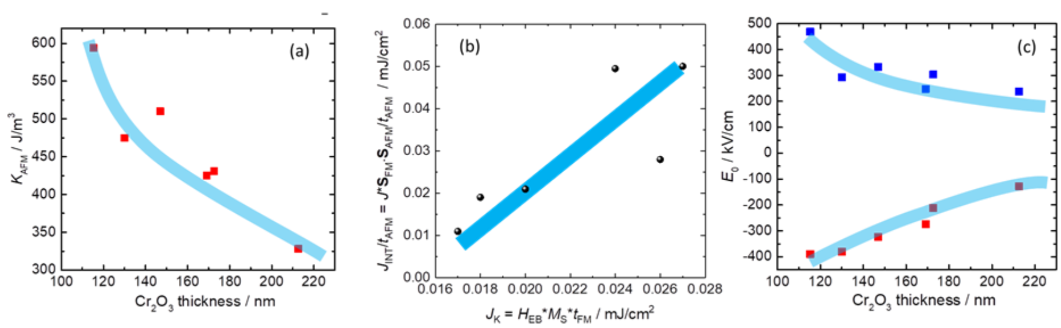

Fig. 1: (a) t_{AFM} dependence of K_{AFM}, (b) correlation between J_{INT} and J_K, (c) t_{AFM} dependence of E_0.

References: (1) X. He et al., Nature Mat. **9**, 579, (2010); (2) Y. Shiratsuchi et al., Appl. Phys. Express. **6**, 123004, (2013); (3) T. V. A. Nguyen et al., J. Appl. Phys. **122**, 073905, (2017);