Temperature dependence of mangnetoelectric switching condition of perpendicular exchange bias

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Recent progress in electric field induced switching of the perpendicular exchange bias (PEB) at the magnetoelectric (ME) Cr_2O_3/ferromagnetic interface has achieved the isothermally reversible PEB even for the all-thin-film systems [1,2]. To realize the application in spintronics devices, it is essential to clarify the energy condition of the ME switching of the PEB. So far, the relationship between the applied magnetic field H and threshold electric field E for the ME switching of PEB was suggested: $\alpha(E-E_0)H = \pm 2K_{AFM} - J_{INT}/t_{AFM}$ (eq.1) (where α is a ME coefficient of Cr_2O_3, K_{AFM} and t_{AFM} are magnetic anisotropy energy and thickness of the Cr_2O_3 layer, J_{INT} is the interface exchange coupling, and E_0 is the interfacial magnetization - induced electric field) [3]. While the previous researches on the ME switching were normally conducted at a certain temperature below the Néel temperature (T_N), in this study, to obtain a deeper understanding of the effect, we examined the temperature dependence of the energy condition for ME switching of PEB.

The Pt(1.2 nm)/Co(0.4 nm)/Au(0.5 nm)/Cr_2O_3(173 nm)/Pt(20 nm) stacked film was fabricated by using DC magnetron sputtering. The electric-field induced ME switching was investigated at different temperatures T (from 284 K to 296 K) by the anomalous Hall effect measurements, following the reversible isothermal approach. Using eq.1, we estimated the temperature T dependence of K_{AFM}, J_{INT}, E_0. Fig. 1 shows that K_{AFM}, J_{INT}, E_0 decrease as T increases. We compared the T dependence of J_{INT} with that of J_K, where J_K was calculated using the exchange bias field and the saturation magnetization per unit area (Fig. 1b). The result shows a bifurcated tendency between them at J_{INT} ~ 0.02-0.03 mJ/m^2, suggesting a clear restriction of J_K by the magnetic domain wall energy of the AFM layer.

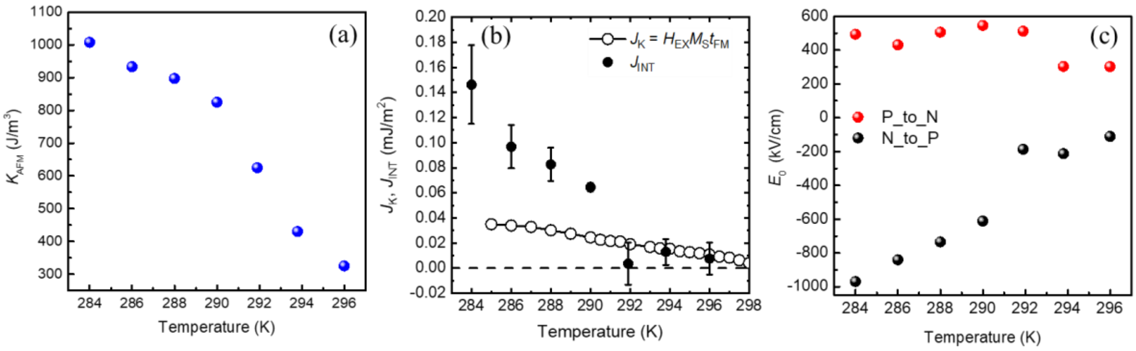

Fig. 1: Temperature dependence of (a) K_{AFM}; (b) J_{INT} and J_K; (c) E_0

References: (1) T. Ashida et al., Appl. Phys. Lett. **106**, 132407, (2015).; (2) K. Toyoki et al., Appl. Phys. Lett. **106**, 162404, (2015).; (3) T. V. A. Nguyen et al., J. Appl. Phys. **122**, 073905, (2017);