**Electric-field modulation of perpendicular magnetic anisotropy at MgO/Co$_2$FeAl interface**

Recently, the large perpendicular magnetic anisotropy (PMA) is found at the interfaces between ferromagnetic metals and oxides such as MgO/CoFeB [1]. The large PMA is also reported for the interfaces between MgO and Heusler alloy Co$_2$FeAl (CFA) [2], or Co$_2$FeSiAl [3]. These Heusler alloys are promising candidates for applications in spintronics due to the high spin polarization and low damping constant. Moreover, the magnetic anisotropy at the insulator/ferromagnet interface can be controlled by the electric field [4, 5]. This electric-field effect is a key technology for realizing the ultra-low energy consumption magnetization switching. In this work, we reveal the origin of the PMA at the MgO/CFA interface and explore the potential for the electric-field control of the PMA.

We have carried out first-principles electronic structure calculations based on the projector augmented-wave with plane wave basis set by using the Vienna ab initio simulation package [6]. We investigated magnetic anisotropy and its electric-field modulation in the MgO/CFA/Au junction. The magnetic anisotropy energy (MAE) is evaluated by using the force theorem.

The MAE is estimated to be 1.28 and 0.78 mJ/m$^2$ for the MgO/CFA/MgO junctions with Co- and FeAl-terminated interfaces, respectively. The Co-terminated (FeAl-terminated) interface has the perpendicular (in-plane) anisotropy. In MgO/CFA/Au junctions with both the Co- and the FeAl-terminated interfaces, the PMA is increased linearly with increasing negative electric field, which shows the same tendency with the experimental result in MgO/FeCo and MgO/CoFeB junctions [4, 5]. The variation of the MAE with respect to the electric field is 22fJ/Vm and 11fJ/Vm for the Co- and the FeAl-terminated interfaces, respectively. The variation is in the same order of magnitude with that in the MgO/Fe/Au junction.

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