Voltage-controlled magnetic anisotropy of $Co_{1-x}Ni_x$ ultrathin alloy at interface with MgO

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Voltage-controlled magnetic anisotropy (VCMA) has been intensively studied for establishing ultra-low power memory device. However, the amplitude of VCMA has to be increased significantly. In ultra-thin ferromagnetic metal, the VCMA effect arises from a charge-doping to 3*d*-orbital occupation of interfacial magnetic atoms by a bias-electric field [1-3]. Hence, the manipulation of 3*d*-orbital state of interfacial ferromagnetic layer can be a key to obtain a high VCMA value. In this study, we focused on the difference of number of *d*-orbital-electron between Co and Ni, and investigated the VCMA effect of Fe/$Co_{1-x}Ni_x$/MgO multilayer using spin-wave spectroscopy.

Multilayer film structure was grown onto NaCl-type single-crystal MgO(001) substrate as depicted in Fig. 1. The Co and Ni atomic layers were inserted in between Fe/MgO sandwich. By employing wedges shape, the fraction of Ni layer (x) was controlled. Then, the multilayer was pattern into rectangular shape. Two microsize antennae were grown onto it. An in-plane external magnetic field was applied to excite magneto-static surface spin-wave (MSSW). The characterization of VCMA effect was performed through vector network analyzer, by acquired the modulation of scattering parameter (S_{21} and S_{12}) with and without bias-voltage. The bias-electric-field amplitude was 8 mV/nm. Figure 2 shows the Ni fraction (x) dependence of $Co_{1-x}Ni_x$/MgO VCMA coefficient. x = 0 and x = 1 are represent 100%-Co and 100%-Ni, respectively. It is seen that the increasing of Ni fraction (x) decrease the VCMA energy significantly. The highest VCMA of 280 fJ/Vm was obtained in Fe/Co(0.28 nm)/MgO (x = 0). In the presentation, voltage-induced *i*DMI change and the influence of heavy metal layer of Pd will be also discussed. This work was partially supported by ImPACT program and JSPS KAKENHI (JP18H03880, JP26103002).

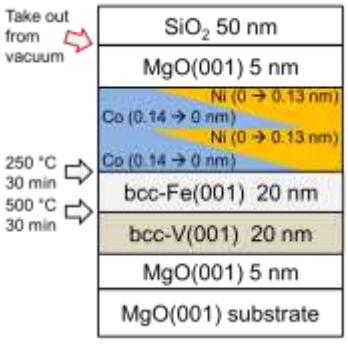

Fig. 1 Sample structure schematic

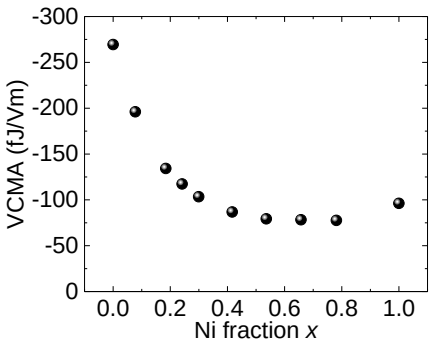

Fig. 2 VCMA energy of $Co_{1-x}Ni_x$/MgO as function of x

[1] S. Miwa *et. al.*, Nat. Commun. **8**, 15848 (2017). [2] T. Kawabe *et. al.*, Phys. Rev. B **96**, 220412(R) 2017. [3] J. Zhang *et. al.*, Phys. Rev. B **96**, 014435 (2017).