Estimation of Interlayer Exchange Coupling Constant in $Nd_2Fe_{14}B$/ $Ni_{80}Fe_{20}$ Thin Film: A TRMOKE Study

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Enhancement of coercivity in Nd-Fe-B magnet without using heavy rare-earth element is one of the most important topics in the permanent magnet community. Recent study on microstructure analysis of hot-deformed Nd-Fe-B magnets revealed that one possible way to achieve high coercivity is to isolate each $Nd_2Fe_{14}B$ grains magnetically by forming non-ferromagnetic (NF) intergranular phase. Grain boundary diffusion process (GBD) using Nd-rich eutectic alloy [1, 2] in sintered and hot-deformed Nd-Fe-B magnets is one solution to form the NF intergranular phase. However, no experimental method to evaluate exchange coupling between $Nd_2Fe_{14}B$ grains is established. In order to estimate the exchange coupling constant (J_{ex}), here we chose a model sample of Nd-Fe-B/Mo (t)/Ni-Fe magnetic multilayer thin film structure.

The stacking structure of Mo (20 nm)/$Nd_2Fe_{14}B$ (16 nm)/Mo (t nm)/$Ni_{80}Fe_{20}$ (5 nm)/Mo (20 nm)/SiN (65 nm) were deposited on MgO [001] single-crystalline substrate by magnetron sputtering with a base pressure of 4×10^{-7} Pa. The thickness (t) of the Mo layer was varied from 0 to 3 nm. The magnetization curve (Fig.1 (c) and (d)) shows that for Mo ($t > 0$ nm) the coercivity increases and remanence decreases. To evaluate J_{ex} at the interface between the Nd-Fe-B and Ni-Fe layers, resonance frequency (f_r) was measured using time-resolved MOKE microscope. An external static bias magnetic field ($\mu_0 H_b$) upto 2 T was applied at an angle of $\theta_H = 50°$. The f_r of a single layer Nd-Fe-B thin film is studied first. Then we studied the magnetization dynamics of coupled multilayer film structure. The f_r of Nd-Fe-B/Ni-Fe resembles with the value of f_r of a single layer Ni-Fe thin film with addition of a strong anisotropic field originated from the Nd-Fe-B thin film. A model calculation [3] of f_r *vs.* H_b is done using a macro-spin approximation for this bi-layer model (Fig.1 (a), (b)). The total magnetic energy of the system is assumed as a summation of Zeeman, magneto-crystalline anisotropy, magneto-static energy in each layer and the interlayer exchange-coupling energy. Fig.1 (e) shows the fitting of calculated and measured resonance frequencies at different bias magnetic fields. The calculated resonance frequency curve shows that the exchange-coupling constant (J_{ex}) of Nd-Fe-B (16 nm)/Ni-Fe (5 nm) is 4×10^{-3} J/m^2. But insertion of a very thin (t = 1~3 nm) Mo layer can totally decouple the exchange-coupled system.

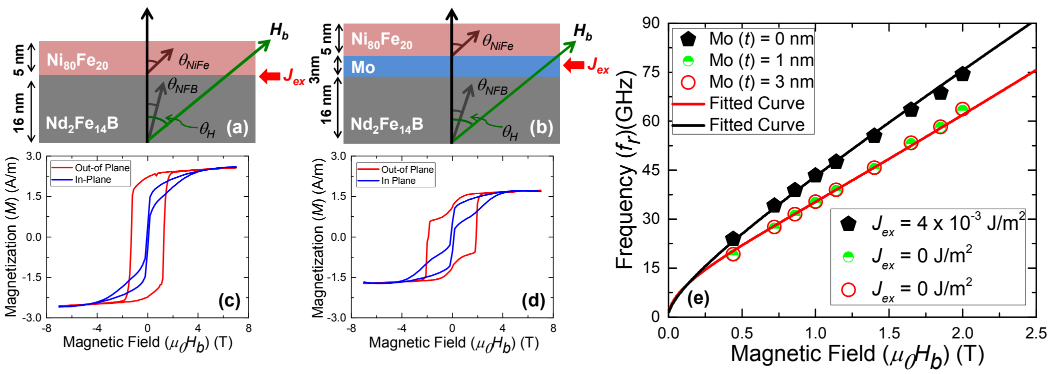

Figure 1: Schematic diagram of Nd-Fe-B/Ni-Fe bilayer coupled system and their corresponding magnetization curve Mo (t = 0 nm) (a), (c) and Mo (t = 3 nm) (b), (d). (e) Calculated and observed f_r as a function of $\mu_0 H_b$ for Mo (t = 0, 1 and 3 nm).

Reference

1) H. Sepehri-Amin *et al.*, *Acta Mater.*, **61**, 6622 (2013). T. Akiya *et al.*, *J. Appl. Phys.*, **115**, 17A766 (2014).
2) H. Kato *et al.*, *IEEE Trans. Magn.*, **37**, 2567 (2001).