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NiO Thickness Dependences of Perpendicular Magnetic Anisotropy in the [CoFe/Pt] Multilayers

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NiO thickness dependences of perpendicular magnetic anisotropy (PMA) in the NiO/$[CoFe/Pt]_5$ multilayers for exchange biasing and $[CoFe/Pt]_4$/Pt/$[CoFe/Pt]_4$ for interlayer exchange coupling were investigated. Perpendicular magnetization curve was obtained by out-of-plane extraordinary Hall measurement. Magnetic force microscopy (MFM) has been used for the investigation of magnetic domains on thin films. We confirmed that the interlayer exchange coupling (IEC) as a function of NiO thickness at room temperature existed with a period of two monolayers.

Key words : perpendicular magnetic anisotropy (PMA), interlayer exchange coupling (IEC), [CoFe/Pt] multilayers, extraordinary Hall-voltage

1. Introduction

Until recently, magnetic thin-film type storage cell that develop by social request by information storage technology extension had been studied being converged spin valve (spin valve; SV) and magnetic tunnel junction (MTJ) by structure that have (in-plane) magnetization in plane. Almost all MTJ devices thus far made public consist of in-plane magnetization films such as NiFe, Co, and Fe, and past studies of MRAM all use these in-plane MTJs. However, when these materials are patterned into submicron elements, magnetization curling occurs at the edge of the film, resulting in vortex magnetization. Therefore, in-plane magnetization films must have an aspect ratio (length/width) of 2 or more in order to ensure information storing. MTJ, with a high aspect ratio, decreases the density of MRAM, which in turn limits the possibilities of MRAM [1]. Finally, if it sustains high aspect ratio in MTJ element with in-plane magnetic anisotropy, it has limit to receive high degree of integration of MRAM. On the other hand, exchange biased perpendicular magnetic anisotropy films have a low saturation magnetization, preventing any magnetization curling at the film edge. Therefore, a MTJ with an aspect ratio of L/W = 1 can be realized using perpendicular magnetization. These films are also expected to resolve other difficulties in in-plane MTJ, such as MR curve offsets. Recently, out-of-plane exchange biasing has been observed in exchange biased Co/Pt and Co/Pd multilayers with a perpendicular anisotropy [2-4]. So far, magnetic layer is using [Co/Pt] and [Co/Pd] multilayer that is representative perpendicular magnetic anisotropy thin film, and antiferromagnetic layer to transfix vertical magnetic anisotropy thin film is using NiO and FeMn. Exchange biased field (H_{ex}) should be bigger than coercive field (H_c) to apply this phenomenon in practical devices, SV and MTJ. But, report until now shows result that exchange biased field and coercive field are similar almost [5]. Several researchers obtained exchange biased perpendicular magnetic anisotropy at room temperature.

We studied NiO thickness dependences of perpendicular magnetic anisotropy in the $[CoFe/Pt]_4$ multilayers exchange-coupled by NiO pinning layers at the top and bottom interfaces. Also, the characteristics of the interlayer exchange coupling (IEC) across of insulating AF spacer (NiO) in hetero-structures of type $[Pt/CoFe]_4$/AF/$[CoFe/Pt]_4$ was investigated.

2. Experimental

NiO/$[CoFe/Pt]_4$ and $[CoFe/Pt]_4$/Pt/$[CoFe/Pt]_4$ multi-

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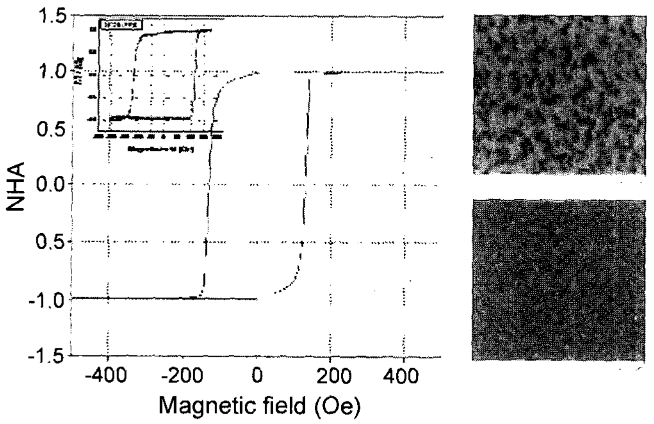

Fig. 1. (a) NHA curve of NiO(5 nm)/[CoFe(1 nm)/Pt(1.25 nm)]$_5$ multilayer. The insert shows the SMOKE magnetization curves of the multilayer. The field was applied perpendicular to the plane of the sample. (b) and (c) shows the MFM images of the sample. The scan size is 20×20 μm^2.

layers were deposited by dc and rf magnetron sputtering at RT on glass (Corning 7059) in a vacuum system with a base pressure of 1×10^{-6} Torr. Crystallographic structure of the bottom NiO sample was determined by X-ray diffraction (XRD) with Cu $K\alpha$ radiation ($\lambda = 1.541$ Angstrom). Normalized Hall amplitude (NHA) curves of the perpendicular magnetization Hysteresis were obtained by the out-of-plane extraordinary Hall measurement. Magnetic force microscopy (MFM) has been used for the investigation of magnetic domains on thin films.

3. Results and Discussion

Firstly, the XRD patterns of NiO(5 nm)/[CoFe(1 nm)/Pt(1.25 nm)]$_4$ multilayers revealed Pt (111) peak. The crystalline Pt (111) peak was reduced as increasing the Co thickness. As the thickness of NiO layer was changed form 0 to 20 nm, the peaks of Pt (111) intensity were almost a same amplitudes. No peaks corresponding to other crystallographic orientations are observed. Secondly, we obtained the normalized Hall amplitude (NHA) curve of the NiO/[CoFe/Pt]$_5$ multilayers. The NHA curves agreed with the values measured by a surface magneto Kerr effect (SMOKE). Both curves are fairly square, implying out-of-plane easy axes. The NHA curve does not show any shift, but does show the coercive field ***Hc*** = 260 Oe.

Figure 2(a) shows the NHA curves of NiO(0~37.5 nm)/[CoFe(1.0 nm)/Pt(1.25 nm)]$_5$ multilayers as a function of bottom NiO thickness. Figure 2(b) shows the NHA curves of NiO(7.5 nm)/CoFe(1.0 nm)/[Pt(1.25 nm)/CoFe(1.0 nm)]$_4$/NiO(0~7.5 nm) multilayers as a function of top NiO thickness. As the bottom NiO thickness

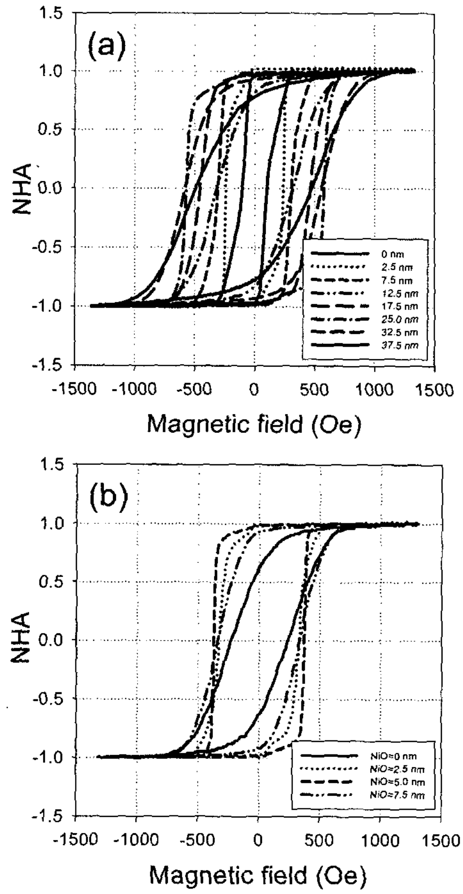

Fig. 2. (a) NHA curves of NiO(0~37.5 nm)/[CoFe(1.0 nm)/Pt(1.25 nm)]$_5$ multilayers and (b) NiO(7.5 nm)/CoFe(1.0 nm)/[Pt(1.25 nm)/CoFe(1.0 nm)]$_4$/NiO(0~7.5 nm) multilayers as a function of thickness of top NiO layer.

increases up to 37.5 nm, the perpendicular ***Hc*** increases 200 Oe to 650 Oe. However the top NiO sample did not influence by the NiO thickness and its Hc is less than that of bottom NiO sample. The increase in the ***Hc*** will be due to the exchange coupling by antiferromagnetic order and the increase of interface roughness.

On the other side, we have investigated the interlayer exchange coupling (IEC) as a function of NiO thickness at room temperature in glass/[Pt(1.25 nm)/CoFe(1.0 nm)]$_4$/NiO(0.5 nm)/[CoFe(1.0 nm)/Pt(1.25 nm)]$_4$ multilayers with an out-of-plane easy axis.

Two figures in Figure 3 depict the major Hall-voltage curve and MFM images at RT for 0.5 nm NiO thickness. The symmetric shift does not result from the exchange biasing (EB) due to the NiO layer, because the EB for a very thin NiO layer within 1 nm disappears completely at RT. However, in case of NiO having much high thickness above 10 nm, the exchange biasing mechanism at interface between Co layer and NiO layer is dominantly taken account the coercive field rather than exchange coupling

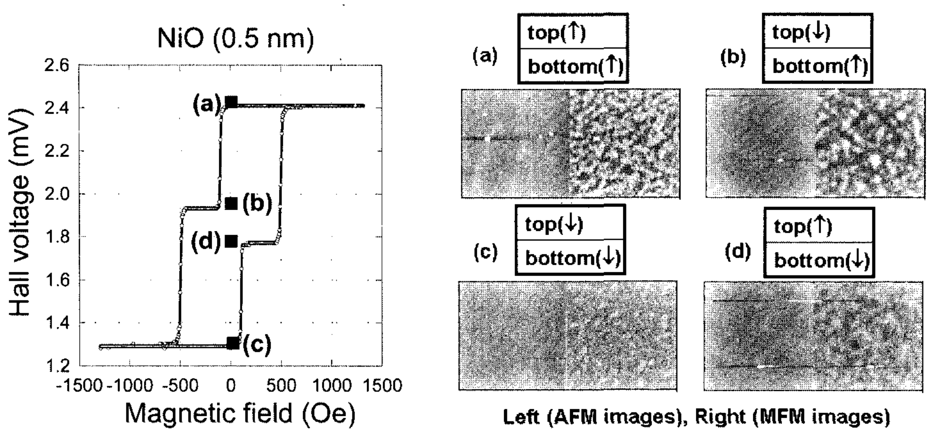

Fig. 3. The major anomalous Hall-voltage curve along the out-of-plane easy axis for the glass/[Pt(1.25)/CoFe(1.0)]$_4$/[NiO(0.5)/[CoFe(1.0)/Pt(12.5)]$_4$ (nm) multilayers. The magnetic force images at the four remanent states.

field. Therefore, it can be unambiguously attributed only to IEC between the two multilayers across the thin NiO spacer. In Fig. 3, the magnetization domains at four different remanent states (H = 0 Oe) showed (a) positive saturation (↑↑) of zero field, (b) positive saturation (↑↑), from −300 Oe (↑↓) to zero field, (c) negative saturation (↓↓) from +300 Oe (↓↑) to zero field. Those demonstrate the existence of 360 degree domain walls, identical to those observed an AF coupled Co/Ru/Co multilayers with perpendicular anisotropy. In the ac-demagnetized state, the multilayers display a fine labyrinthine domain structure.

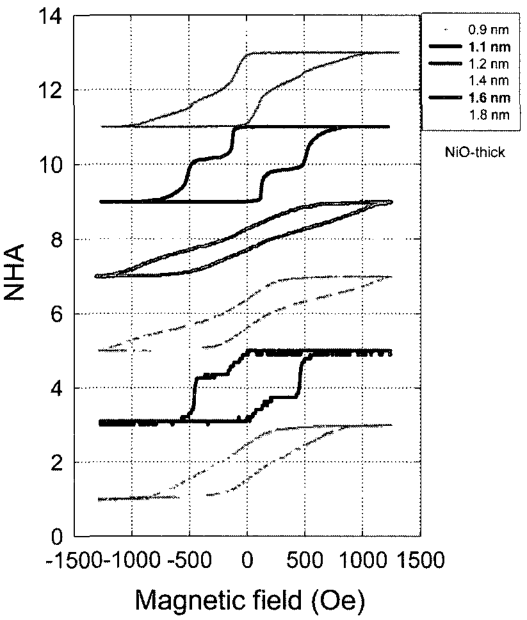

Fig. 4. Normalized Hall-voltage curves as a function of NiO thickness at room temperature. for the glass/[Pt(1.25)/CoFe(1.0)]$_4$/[NiO(t)/[CoFe(1.0)/Pt(12.5)]$_4$ (nm) multilayers. The bold lines and thickness values show a period of two nonolayers of NiO.

Figure 4 shows an normalized Hall-voltage curves as a function of NiO thickness at RT for the glass/[Pt(1.25)/CoFe(1.0)]$_4$/NiO(t)/[CoFe(1.0)/Pt(1.25)]$_4$ (nm) multilayers. Here the NiO thickness was above 0.5 nm. The bold line and thickness values show a period of two nonolayers of NiO. That is, it shows clearly that at RT the IEC oscillates between AF and ferromagnetic (FM) coupling as a function of NiO thickness with a period of ~0.5 nm. This unexpected oscillatory is quite different from the non-oscillatory decay of IEC strength expected by the models of Bruno [3, 7] and Slonczewski [8] for nonmagnetic insulating spacers and from recent experimental observations of coupling across a nonmagnetic insulating MgO spacer [3].

4. Conclusion

AF layer thickness dependences of PMA in the [CoFe/Pt]$_4$ multilayers exchange-coupled by NiO pinning layers at the top and bottom interfaces were investigated. Also, we confirmed that the IEC across of insulating AF space in heterostructures of type [CoFe/Pt]$_4$/AF/[CoFe/Pt]$_4$ as a function of NiO thickness with a period ~0.5 nm existed.

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