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# Perpendicular Exchange Bias and Thermal Stability of $[Pd/Co]_N/FeMn$ Films

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**Perpendicular magnetization curves and crystal textures of $[Pd(0.8\ nm)/Co(0.8\ nm)]_5/FeMn$ multilayers having an exchange-biased perpendicular magnetic anisotropy as a function of FeMn thickness and annealing temperature were measured. As FeMn thickness increases from 0 to 21 nm, the perpendicular exchange biasing field ($H_{ex}$) obtained the maximum value of 130 Oe at FeMn thickness 12 nm. As the annealing temperature increases to 240 °C, the $H_{ex}$ increased from 115 Oe to 190 Oe and the exchange-biased perpendicular magnetic anisotropy disappeared at 330 °C.**

**Key words :** Perpendicular exchange bias, Pd/Co, Thermal stability

## 1. Introduction

In the past most studies of exchange biasing have been reported for exchange-biased multilayers with the film plane where the magnetic easy axis of ferromagnetic normally lies in plane due to the shape anisotropy. Recently, perpendicular exchange biasing has been observed in ferromagnetic Co/Pt and Co/Pd multilayers with perpendicular magnetic anisotropy when multilayers are in contact with an antiferromagnetic layer such as NiO, FeMn and CoO. From a more applied point of view, perpendicular magnetic phenomenon can be quite useful for magnetic field sensors and magnetic recording technique, especially integrated planer sensors, or for magnetic random access memory devices. Although exchange biased thin films have found applications in magnetic thin film sensors, a satisfying micromagnetic description that explains all observed phenomena has not, as yet, been developed [1-4].

In the present study, we have investigated the effects of deposition order and antiferromagnetic layer thickness on coercivity ($H_c$) and exchange biasing field ($H_{ex}$) of exchange-coupled $[Co/Pd]_5/FeMn$ multilayers with perpendicular magnetic anisotropy and annealing temperature dependence of these samples.

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## 2. Experiments

The $Ta/[Pd/Co]_N/FeMn/Ta$ multilayers were deposited using DC magnetron sputtering system at room temperature on Corning glass 1737. The samples were deposited in a vacuum system without an applied magnetic field to induce unidirectional anisotropy. The background pressure in sputtering system was kept below $8.0 \times 10^{-7}$ Torr and Ar pressure was $2.0 \times 10^{-4}$ Torr., respectively. The deposition condition of the Ta, Pd, Co, and FeMn layers were 0.1 nm/s, 0.14 nm/s, 0.17 nm/s, and 0.1 nm/s, respectively. The samples were annealed up to 330 °C in a vacuum ($< 2.0 \times 10^{-6}$ Torr) for 1 hour. Perpendicular magnetization curves were obtained by out-of-plane Hall measurement. The samples were patterned into six terminal Hall bars. The four electrodes were used for $I_+$, $I_-$, $V_+$ and $V_-$ terminals, respectively, in the Hall voltage measurement [5, 6]. The crystallography of the films was studied by X-ray diffraction (XRD) with $CuK_\alpha$ radiation.

## 3. Results and Discussion

Fig. 1 shows normalized hall voltage (NHV) curves of $[Pd(0.8\ nm)/Co(0.8\ nm)]_5$ multilayers exchange biased by top and bottom FeMn(15 nm) layer. As shown the curves, top FeMn sample has an exchange biasing with perpendicular magnetic anisotropy, and its $H_{ex}$ and $H_c$ were 127 Oe and 225 Oe, respectively. However, bottom FeMn sample disappeared an exchange biasing with perpen-

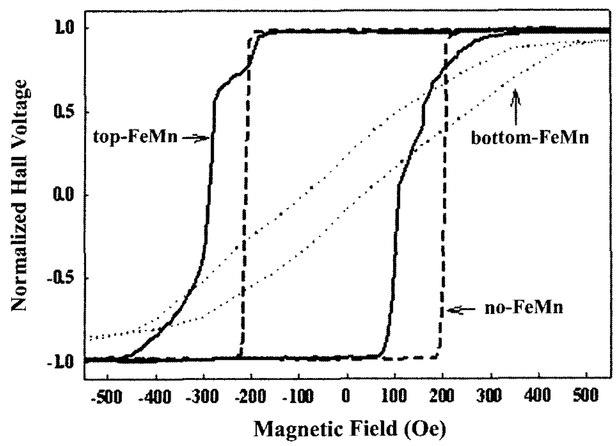


**Fig. 1.** NHV curves of [Pd(0.8 nm)/Co(0.8 nm)]$_5$ multilayer exchange biased by top and bottom FeMn (15 nm) film.

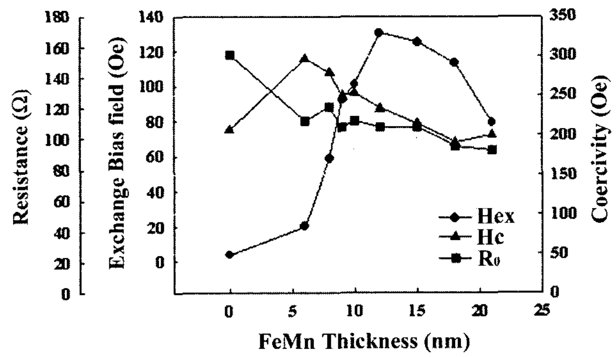


**Fig. 2.** Resistance $R_o$, $H_{ex}$ and $H_c$ as a function of FeMn thickness in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_5$/FeMn($t$ nm)/Ta(1.9 nm) multilayers.

dicular magnetic anisotropy due to the unstable crystal texture of [Pd/Co] above FeMn layer. Fig. 2 shows resistance, $H_{ex}$ and $H_c$ as a function of FeMn thickness in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_5$/FeMn($t$ nm)/Ta(1.9 nm) multilayers. As the FeMn thickness $t$ increases to 12 nm, the $H_{ex}$ increased up to 130 Oe. Howerver, the $H_{ex}$ decreased 90 Oe in 21 nm FeMn thickness. The $H_c$ decreases gradually from 300 Oe to about 200 Oe as

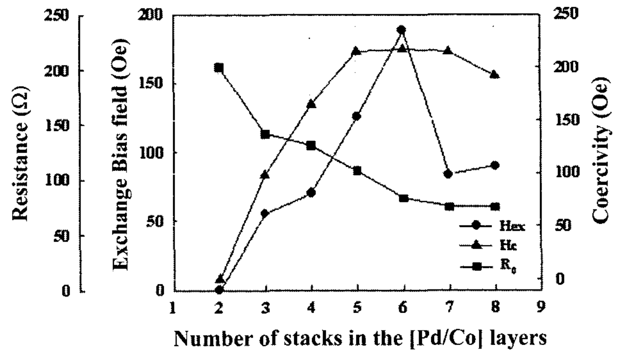


**Fig. 3.** Resistance $R_o$, $H_{ex}$ and $H_c$ as a function of the number of stacks $N$ in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_N$/FeMn(15 nm)/Ta(1.9 nm) multilayers.

FeMn thickness increase.

Fig. 3 shows resistance $R_o$, $H_{ex}$ and $H_c$ as a function of the number of stacks $N$ in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_N$/FeMn(15 nm)/Ta(1.9 nm) multilayers. When the number of stacks in the exchange-biased [Pd/Co] multilayers is larger than 3, the samples appeared exchange bias with perpendicular magnetic anisotropy. The exchange bias field $H_{ex}$ increased rapidly from 55 Oe to 190 Oe as the $N$ increases from 3 to 6. However, the $H_{ex}$ above $N$ = 7 decreased to 90 Oe. The $H_c$ was increased up to 220 Oe and saturated at $N$ = 5. The increase in the coercivity ($H_c$) could be understood by the enhancement of perpendicular uniaxial anisotropy due to the possible accumulation of the structural defects at interfaces with increasing the $N$ [7].

Fig. 4 shows (a) resistance $R_o$, $H_{ex}$, $H_c$ and (b) XRD as a function of the annealing temperature in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_5$/FeMn(15 nm)/Ta(1.9 nm) multilayers. The $H_{ex}$ increased from 115 Oe to 190 Oe as the annealing temperature rises up to 240 °C, afterwards, the $H_{ex}$ deceased rapidly. The perpendicular magnetic anisotropy disappeared above 330 °C. Fig. 5 shows the perpendicular magnetization curves as a function of (a)

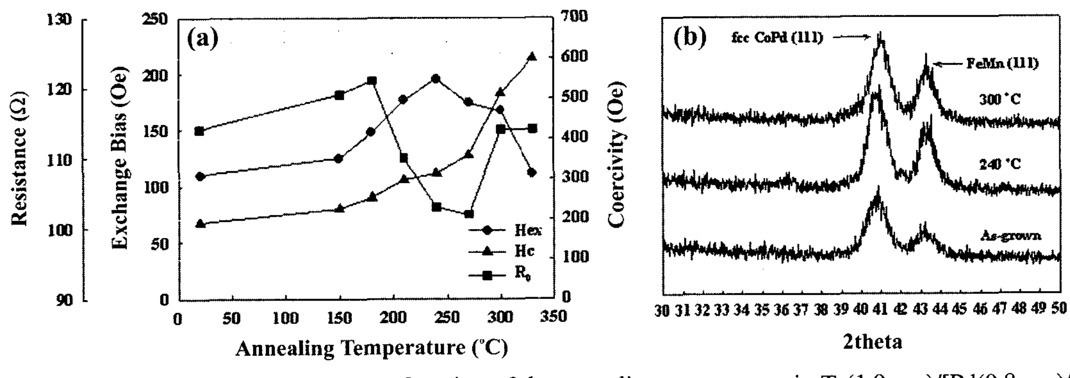


**Fig. 4.** (a) Resistance $R_o$, $H_{ex}$, $H_c$ and (b) XRD as a function of the annealing temperature in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_5$/FeMn(15 nm)/Ta(1.9 nm) multilayers.

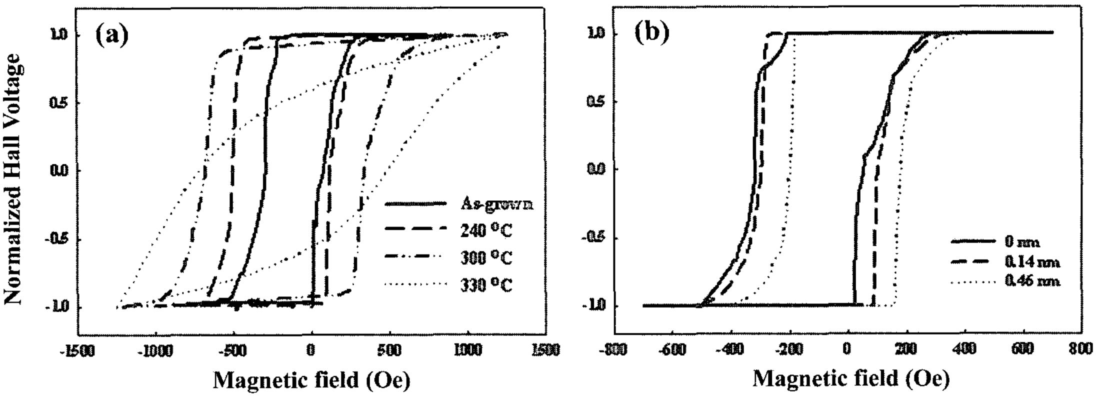


**Fig. 5.** Perpendicular magnetization curves as a function of (a) annealing temperature and (b) Pd thickness in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_5$/Pd($t$ nm)/FeMn(15 nm)/Ta(1.9 nm) multilayers.

annealing temperature and (b) Pd thickness in Ta(1.9 nm)/[Pd(0.8 nm)/Co(0.8 nm)]$_5$/Pd($t$ nm)FeMn(15 nm)/Ta(1.9 nm) multilayers. The curve of as-grown sample shows an asymetric square type at upper corner as shown in the case of the top FeMn sample of Fig. 1. The asymetric step at upper corner of the curve is caused by the difference of magnetic properties between the bottom Co layer exchange-coupled directly by FeMn and the top Co restricted weakly from FeMn layer. It can be established from the insertion of Pd layer at the Co/FeMn interface, as shown Fig. 5(b). The asymetric step was disappeared by the insertion of 0.14 nm Pd at the Co/FeMn interface. The $H_{ex}$ of 0.14 nm Pd sample increased slightly from 125 Oe to 145 Oe, and vanished at 0.5 nm Pd.

The increase in the $H_{ex}$ and $H_c$ with annealing temperature can be explained as a realignment of spins through the suitable mobility of Co and Pd atoms and the flattness of interface layer by annealing process. This was confirmed that the strength of a peak of FeMn (111) increased in 43.4° ($2\theta$) by the XRD measurement, as shown in figure 4(b). Also, the decrease in the $R_0$ between 180 °C and 270 °C may be considered as a result of the smooth interfaces by annealing, and the increase of the $R_0$ above 270 °C is caused by an interdiffusion of Pd and Co atoms and also a fast diffusion Mn atom toward the top Ta layer [8-10].

## 4. Conclusion

We carry out a comprehensive study of thermal stability and thickness dependences of perpendicular magnetic anisotropy in the exchange-biased [Pd/Co]$_N$/FeMn multilayers. Top FeMn sample has a perpendicular magnetic anisotropy, however, that of bottom FeMn one did not observed. The $H_{ex}$ was maximized at 12~15 nm FeMn thickness and the stack number of 6. The $H_{ex}$ increased from 115 Oe to 190 Oe as the annealing temperature rises up to 240 °C, afterwards, the $H_{ex}$ deceased rapidly and disappeared above 330 °C. The increase in the $H_{ex}$ by annealing was explained to the suitable mobility of Co and Pd atoms and the flattness of interface layer. The asymetric step at upper corner of the magnetization curve in as-grown sample was vanished by the insertion of Pd layer at the Co/FeMn interface.

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