Effects of Pt Seedlayer and Ar Pressure on Magnetic and Structural Properties of Sputtered CoNi/Pt Multilayers

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Abstract—CoNi/Pt multilayers were prepared by magnetron sputtering using Ar gas. Effects of Pt seedlayer and Ar sputtering pressure on magnetic and structural properties are investigated. Microstructures of multilayers were analysed using XRD and TEM. It was found that perpendicular magnetic anisotropy and coercivity increase with increasing either the thickness of Pt seedlayer or Ar pressure. The causes of increases in perpendicular anisotropy and coercivity are discussed in relation to the interface roughness, the curvature of layers and the columnar structures.

I. INTRODUCTION

It has been reported that CoNi/Pt multilayers provide high write sensitivity and high number of write/erase cycles for MO recording due to their lower Curie temperature compared with Co/Pt multilayer media [1]. We previously reported upon magnetic properties of CoNi/Pt multilayers, especially the dependence of Curie temperature on CoNi and Pt layer thickness [2]. The properties of thermomagnetic written domains in CoNi/Pt multilayers have been investigated [3]. In this paper, the magnetic properties, especially the perpendicular magnetic anisotropy and the coercivity will be discussed as a function of Pt seedlayer thickness and Ar sputtering pressure.

II. EXPERIMENTAL

CoNi/Pt multilayers were deposited on Si (001) substrates by magnetron sputtering using Ar gas. The base pressure was lower than 5×10^{-8} mbar. The distance between the target and the substrate was 10 cm. There was neither heating nor cooling applied to the substrate during the deposition. The Ar pressure and the electric power were kept constant during the deposition. A Co-Ni composite target or a $\text{Co}_{0.5}\text{Ni}_{0.5}$ alloy target was used for the deposition of the CoNi layer with a rf power of 100w or 50w, respectively. A dc-power of 50w was used for Pt sputtering. The composition of the CoNi layer was 50:50 at% as measured by EDX (Energy Dispersive X-ray) and XRF (X-ray Fluorescence). The multilayer structure was designed as *Si-substrate/Pt-seedlayer/(CoNi/Pt) × n*. Individual layer thickness t_{CoNi} and t_{Pt} were estimated from the product of the deposition time and deposition rate and confirmed by low and high angle XRD (X-ray diffraction) measurements. Saturation magnetisation M_s and coercivity, H_c were obtained from perpendicular

VSM loops. Effective perpendicular anisotropy constant, K_{eff} (including the demagnetisation energy) was measured using a torque magnetometer.

III. RESULTS AND DISCUSSION

Fig. 1 shows a typical microstructure of a CoNi/Pt multilayer on Si substrate. The curvature of the layers and the columnar structures become clear with the film growing. The roughness of the film surface and interfaces as shown in this image will be used in the following discussion with regard to XRD patterns. Low and high angle XRD patterns demonstrate a well defined periodic modulation of the chemical composition in multilayers and a fcc-(111) orientation along the film growth direction as shown in Fig. 2 and Fig. 4.

Fig. 1. A typical cross-sectional TEM image of a $\text{Co}_{0.5}\text{Ni}_{0.5}/\text{Pt}$ multilayer deposited at $P_{\text{Ar}} = 1.6 \times 10^{-2}$ mbar with a composition of $\text{Si}/24 \text{ nm Pt}/(3.8 \text{ nm CoNi}/1.5 \text{ nm Pt}) \times 17$.

A. Effects of Pt Seedlayer

One series of $\text{Co}_{0.5}\text{Ni}_{0.5}/\text{Pt}$ multilayers was deposited with varying the Pt seedlayer thickness and the number of CoNi/Pt bilayers. The designed thickness and magnetic characteristics are listed in Table I. The low and high angle XRD patterns of this series are shown in Fig. 2. There is no fcc-(111) peak of the Pt in the patterns of the samples A and B because their "Pt seedlayers" are only about 1 nm. The intensity of the first order periodic modulation peak ($m=1$) and CoNi/Pt crystalline main peak ($n=0$) of the sample A are higher than B because of more bilayers in A. The high angle patterns of the samples C and D display the fcc-(111) peak of the Pt

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TABLE I
DESIGNED THICKNESS AND MAGNETIC CHARACTERISTICS OF CoNi/Pt MULTILAYERS

Sample	Ar pressure (10^{-2} mbar)	Pt seedlayer (Å)	CoNi layer (Å)	Pt layer (Å)	Number of bilayer	Total thickness (Å)	M_s (CoNi/Pt) (kA/m)	M_r/M_s	$H_c(L)$ (kA/m)	K_{eff} (CoNi/Pt) (kJ/m ³)
A	1.6	10	5.8	10	33	531	305	0.8	20	135
B	1.6	10	5.8	10	17	279	303	1	24	150
C	1.6	264	5.8	10	17	533	288	1	46	165
D	1.6	528	5.8	10	17	797	307	1	55	165

because of their thicker Pt seedlayers. With those enhanced Pt peaks, the intensities of main peaks ($n=0$) of the CoNi/Pt increase and their satellite peaks ($n=-1$) become visible. This implies that the degree of fcc-(111) texture is enhanced by the thicker Pt seedlayer. However, with increasing Pt seedlayer thickness, the intensities of " $m=1$ " peaks of C and D in the low angle patterns decrease, which indicates that interfaces between CoNi and Pt layers become rougher due to the curvature of the layers and the columnar structures because of the thicker films (see Fig. 1). The oscillation peaks before the " $m=1$ " peak are caused by the total film thickness including the Pt seedlayer. The difference in the amplitude of those peaks gives an indication of the difference

in the roughness or the flatness of the film surface. Their surface roughness can be determined in an order as $B < A < C < D$, which has been confirmed by AFM (Atomic Force Microscopy).

As shown in Table I, the perpendicular anisotropy, K_{eff} and the coercivity, H_c increases with increasing Pt seedlayer thickness. This is attributed to the enhanced fcc-(111) texture and the columnar structures. The enhancement of the fcc-(111) texture results in an increased K_{eff} . The increased K_{eff} contributes to the increase in H_c and improves the squareness ratio M_r/M_s , which is clearly revealed by the difference in M_r/M_s and K_{eff} between the samples A and B. The difference of their K_{eff} is attributed to the difference in their interfacial roughness. The increase in H_c is also attributed to the columnar boundaries according to the mechanism of domain wall pinning [4, 5]. In Table I, the magnetisation M_s of C is smaller because the real CoNi thickness could be thinner than designed thickness as shown by the position of its " $m=1$ " peak at the low-angle XRD pattern (see Fig. 2 (a)).

B. Effects of Ar Pressure

Fig. 3 shows perpendicular VSM loops of a series of $Co_{0.5}Ni_{0.5}/Pt$ multilayers deposited at different Ar pressures. It shows that H_c increases with increasing Ar pressure. At 4.0×10^{-2} mbar, a maximum H_c of about 100 kA/m is achieved. With increasing P_{Ar} up to 4.8×10^{-2} mbar, H_c and M_r/M_s degrade. Fig. 4 shows low and high angle XRD patterns of this series. As can be seen, intensities of the main peak ($n=0$) and satellite peak ($m=1$) decrease with increasing P_{Ar} . This indicates that the degree of fcc-(111) texture and the sharpness of interfaces degrade due to the higher P_{Ar} , which implies that the perpendicular anisotropy, K_{eff} might decrease. However, K_{eff} does not decrease but increases from 77 to 124 and 145 kJ/m³ (per unit CoNi/Pt volume) with increasing P_{Ar} from 0.8 to 1.6 and 4.0×10^{-2} mbar, respectively and then decreases to 99 kJ/m³ at 4.8×10^{-2} mbar. This agrees quite well with the variation in H_c and M_r/M_s as shown in Fig. 3. In order to understand this unexpected increased K_{eff} , the microstructure of a $Co_{0.5}Ni_{0.5}/Pt$ multilayer deposited at 4.0×10^{-2} mbar was investigated using TEM. The cross sectional TEM image shows that the interfaces between the CoNi and Pt layers still exist within the columns and the curvature of the layers is enhanced, which could contribute to the increased K_{eff} because of the enhanced strain anisotropy at the interfaces.

Fig. 2. XRD patterns of CoNi/Pt multilayers as indicated in Table I. " $m=1$ " indicates the first order periodic modulation peaks; " $n=0$ " the CoNi/Pt main peaks and " $n=-1$ " the satellite peaks. The measurement conditions were the same for these four samples. ($\lambda=1.5415$ Å)

Fig. 3. Perpendicular VSM loops of CoNi/Pt multilayers deposited at different Ar pressures as indicated in the figure. The composition is Si/24 nm Pt/(0.5 nm CoNi/1.5 nm Pt)×17.

The roughness determined by XRD gives an indication of the interfacial roughness over a large area including many columns. It does not provide any information about the local interfaces within the columns because the column size is only about 10 or 20 nm. However, when P_{Ar} was too high ($>4.8 \times 10^{-2}$ mbar), the interfaces and the crystalline structure of layers became very poor so that K_{eff} and H_c were reduced as shown in Fig. 3 (d).

Furthermore, the plane-view TEM image of a Co/Pt multilayer which was deposited at the higher P_{Ar} (4.0×10^{-2} mbar) shows the large voids at the grain boundaries [3]. The voids can act as domain wall pinning sites which contribute to the larger H_c [6]. However, the large voids could cause the readout noise which is not desirable for MO application.

Fig. 4. XRD patterns of CoNi/Pt multilayers as indicated in Fig. 3. “m=1” “n=0” and “n=-1” have the same meaning as shown in Fig. 2. The measurements conditions for these four samples were the same.

IV. CONCLUSION

Perpendicular magnetic anisotropy and coercivity of CoNi/Pt multilayers can be enhanced by using thicker Pt seedlayer and higher Ar sputtering pressure. The increase in perpendicular anisotropy at higher Ar pressures is attributed to the enhanced strain anisotropy at the interfaces because of the enhanced curvature of the layers. The increase in H_c is attributed to the columnar structure and the voids due to the domain wall pinning.

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