ANISOTROPY AND MAGNETO-OPTICAL PROPERTIES OF SPUTTERED Co/Ni MULTILAYER THIN FILMS

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***Abstract*—Several series of sputtered Co/Ni multilayer thin films have been investigated. The volume and interface contributions to the magnetic anisotropy were determined from magnetization measurements, and the interface anisotropy, $K_i = 0.23 \pm 0.03$ erg/cm^2, was found to support perpendicular magnetic anisotropy. The anisotropy constant, K, increased with the Au buffer layer thickness, indicating the buffer layer was crucial to the perpendicular magnetic anisotropy. The polar Kerr rotation and coercivity as a function of temperature, and room temperature magneto-optical figure of merit are presented in this paper.**

INTRODUCTION

Multilayered structures have attracted much attention in many fields of materials science owing to the possibility of creating new structures and physical properties. One interesting phenomenon observed in magnetic multilayered thin films is the preference for magnetization perpendicular to the film plane: perpendicular magnetic anisotropy (PMA). This property is displayed by several Co/X multilayers, where X is a noble non-magnetic metal such as Pd, Pt, Au, or Ir.[1],[2] Large perpendicular magnetic anisotropy shown in these multilayers makes them potential candidates for MO recording media.

Recently, Co/Ni multilayer thin films were also predicted to have perpendicular magnetic anisotropy,[3] and this was confirmed in e-beam evaporated[4] and sputtered[5] samples. The perpendicular magnetic anisotropy is due to the positive interface anisotropy[4], and is strongly buffer layer dependent[6]. Our previous paper showed perpendicular magnetic anisotropy for Co/Ni multilayers on Au buffer layers, while the same films on Ag buffer layers showed in-plane anisotropy.[5] This paper reports the anisotropy of sputtered Co/Ni multilayer thin films with Au buffer layers as a function of Co and Ni layer thicknesses. The effect of Au buffer layers is discussed in terms of the anisotropy constant and x-ray measurements. The polar Kerr rotation (as a function of temperature) and the magneto-optic figure of merit are also reported to investigate the possibility of using Co/Ni multilayer thin films as MO recording media.

Manuscript received April 4, 1994
The research is supported by National Science Foundation under Grant No. DMR-9222976.

EXPERIMENTS

Several series of Co/Ni multilayer thin films were prepared by magnetron sputtering. The system was evacuated to below 5×10^{-7} Torr before sputtering, and Ar gas (5×10^{-3} Torr for Au target and 15×10^{-3} Torr for Co and Ni targets) was used in the sputtering process. The source to substrate distances were fixed at about 10 cm. A series of 8 × (2 Å Co/ *t* Å Ni) multilayers was made with Ni thickness, *t*, ranging from 2 Å to 40 Å. A second series of 8 × (*t* Å Co/ 8 Å Ni) multilayers was made with Co thickness varying from 1.2 Å to 20 Å. These two series were deposited on 450Å thick Au buffer layers, which were deposited on glass substrates at room temperature. In the third series, 8 × (2 Å Co/ 8 Å Ni) multilayers were deposited onto Au buffer layers of varying thicknesses. (50 Å to 650 Å) The deposition rates for Co, Ni and Au were 0.9 Å/s, 1.3 Å/s and 3.4 Å/s, with corresponding input powers of 30W, 75W, and 40W respectively. Multilayered structures were realized by rotating the substrates above separate guns.

The magnetic anisotropy was determined from the area within the perpendicular (i. e. $\bar{H} \perp$ film plane) and parallel (i. e. $\bar{H}$ // film plane) magnetization curves[1]. An X-ray diffractometer was used to determined the sample and buffer layer textures. Kerr rotation, θ_k, and Kerr ellipticity, ε_k, were measured at normal incidence over the wavelength range from 3000 Å to 8000 Å.

RESULTS AND DISCUSSION

A. *Anisotropy*

Magnetic anisotropy can be written as:

$$KD = K_v^{Co} t_{Co} + K_v^{Ni} t_{Ni} + 2K_i, \qquad (1)$$

where K is the anisotropy of the sample, D is the bilayer thickness, K_v^{Co} and K_v^{Ni} are volume anisotropies corresponding to the Co and Ni layers respectively, K_i is the Co/Ni interface anisotropy constant, and t_{Co} and t_{Ni} are the Co and Ni layer thicknesses. It follows that KD changes linearly with t_{Co} when t_{Ni} is fixed; that is,

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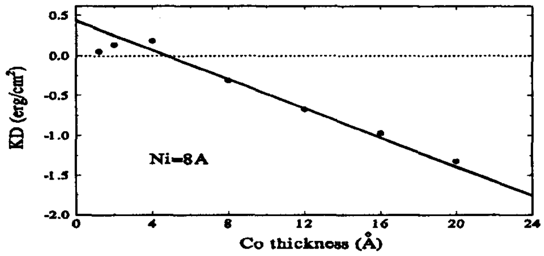

Fig. 1 Anisotropy constant times bilayer period as a function of Co thickness for 8 × (*t* Å Co/ 8 Å Ni) multilayers

$$KD = K_v^{Co} t_{Co} + K(t_{Ni}), \quad (2)$$

where $K(t_{Ni}) = K_v^{Ni} t_{Ni} + 2K_i$. (3)

Fig. 1 shows a plot of KD as a function of Co thickness with $t_{Ni} = 8$ Å. For this series, perpendicular magnetic anisotropy occurs for $t_{Co} < 5$ Å. Curve fitting gives $K_v^{Co} = -9.2 \times 10^6$ erg/cm^3 and $K(t_{Ni}) = 0.44$ erg/cm^2.

Fig. 2 shows the dependence of KD on Ni thickness for $t_{Co} = 2$ Å. Perpendicular magnetic anisotropy occurs over a wide range of t_{Ni}, and KD decreases in an approximately linear manner:

$$KD = K_v^{Ni} t_{Ni} + K(t_{Co}), \quad (4)$$

with $K(t_{Co}) = K_v^{Co} t_{Co} + 2K_i$. (5)

We get $K_v^{Ni} = -9.6 \times 10^5$ erg/cm^3 and $K(t_{Co}) = 0.22$ erg/cm^2 from fitting the data to a line.

Substituting K_v^{Ni} and $K(t_{Ni})$ data into Eq.(3) (or K_v^{Co} and $K(t_{Co})$ into Eq (5)), we obtain $K_i = 0.23 \pm 0.03$ erg/cm^2 without using any bulk Co and Ni anisotropy data. Positive K_i confirms that the perpendicular magnetic anisotropy of Co/Ni multilayer thin films at small Co and Ni layer thicknesses is due to the interface anisotropy. The K_v^{Co} and K_v^{Ni} values are comparable to published results[6],[7]. The K_i value is smaller than that for

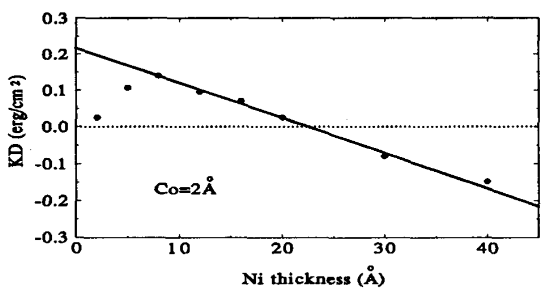

Fig. 2 Anisotropy constant times bilayer period as a function of Ni thickness for 8 × (2 Å Co/ *t* Å Ni)

the e - beam evaporated samples[4] , possibly because the samples made by e - beam evaporation have sharper interface boundaries.

The anisotropy constant, K, varied with sputtering conditions. With higher sputtering rate, K tends to increase.[6] This will lead to a larger anisotropy constant.

B. *Effect of Buffer Layers*

To obtain perpendicular magnetic anisotropy, a selected metallic underlayer was necessary,[6] since direct deposition on glass substrates gave strong in-plane anisotropy. We chose Au as the buffer layer. With variation of buffer layer thickness, the anisotropy constant changed dramatically as shown in the following table.

Variation of anisotropy constant K with Au buffer layers thickness for 8 × (2 Å Co/ 8 Å Ni) multilayers

Samples No.	Au buffer layer thickness (Å)	K (× 10^4 erg/cm^3)
Au–1	50	–37
Au–2	150	–3
Au–3	250	50
Au–4	350	60
Au–5	450	78
Au–6	550	89
Au–7	650	100

The 50 Å and 150 Å Au buffer layers could not provide sufficient (111) texture, so the films had in-plane anisotropy, similar to Co/Ni multilayers on Ag buffer layers.[5] Co/Ni multilayers on thick or annealed Au buffer layers[6] had perpendicular magnetic anisotropy , due to the buffer layer's better (111) texture.. X-ray measurements support this argument.

X-ray diffraction from Co/Ni multilayer samples showed Au (111) and Co/Ni (111) peaks. The Intensity of these peaks increased with increasing Au buffer layer thickness.

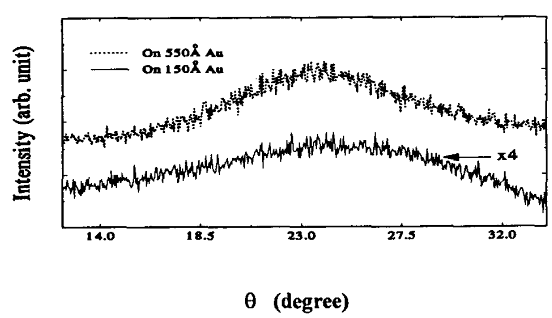

Fig. 3 Rocking curve measurement of Co/Ni multilayers

Fig.3 shows the rocking curve near the Co/Ni (111) peak. The peak intensity of the Co/Ni on the 550 Å film is much stronger, and the half width is smaller (less than 80%) than on the Au 150 Å film. This result is used to explain the increase in anisotropy constant, K, with increasing buffer layer thickness. Thicker Au buffer layers provide stronger <111> direction perpendicular to the film plane in the Co/Ni multilayer, which increases the perpendicular anisotropy ,K.

C. *Magneto-optical Properties*

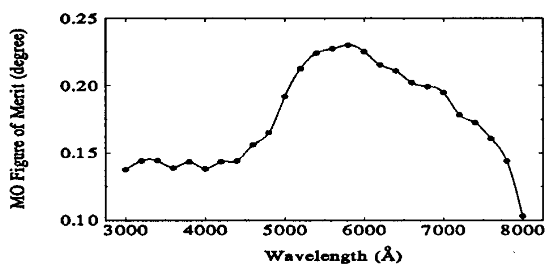

Fig. 4 Magneto-optical figure of merit

Fig. 4 shows the magneto-optical figure of merit ($\sqrt{(\theta_\kappa^2+\varepsilon_\kappa^2)R}$) at room temperature. The figure of merit is larger than 0.1 degree over the entire spectral region and the peak is as high as 0.22 degree at about 5500 Å. Note that the MO figure of merit for Co/Ni multilayers on Au buffer layers is larger than that of rare earth-transition metal alloys[8] at short wavelengths. The magneto-optical figure of merit from Co/Ni samples is larger than for both Co/Pt and Co/Pd for wavelengths λ =5000 ~ 6000 Å, and is smaller than for Co/Pt but larger than Co/Pd for λ =3000 ~ 4000 Å[9],[10]

The temperature dependence of Kerr rotation and coercivity in our samples was investigated The sample studied was $8 \times (4$ Å Co/ 8 Å Ni) and the temperature varied from 25 °C to 350 °C. The results are given in Fig. 5. This measurement was performed at 6328 Å. The Kerr rotation falls slowly as the temperature increases, and the coercivity dramatically drops at temperatures above 300 °C. These results are consistent with thermomagnetic writing measurements performed by den Broeder et al.[4]

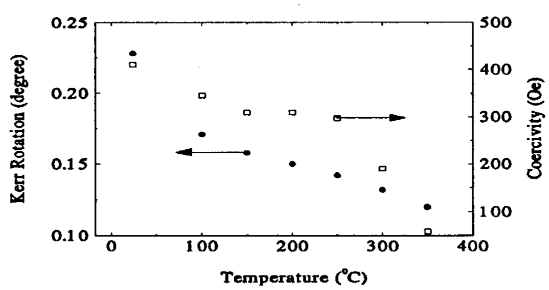

Fig. 5 Kerr rotation and coercivity as a function of temperature for $8 \times (4$ Å Co/ 8 Å Ni) multilayer thin film.

CONCLUSIONS

Sputtered Co/Ni multilayer thin films show perpendicular magnetic anisotropy when deposited on Au buffer layers. The perpendicular magnetic anisotropy arises from the interface anisotropy, where $K_i = 0.23 \pm 0.03$ erg/cm^2 for our sputtered samples. Thicker Au buffer layers have better (111) texture which improves the (111) texture of the Co/Ni multilayers, and consequently increase the perpendicular magnetic anisotropy. The measured magneto-optical properties indicate the Co/Ni multilayers on Au buffer layers are similar to those of other Co-based multilayers, but are not as large in the blue wavelength region as for Co/Pt multilayers.

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