Magnetic Properties of Co/Pd Multilayers Sputter-Deposited at High Ar Gas Pressures

L. Wu, S. Yanase, N. Honda, and K. Ouchi

Akita Research Institute of Advanced Technology, 4-21 Sanuki, Araya, Akita 010-16

Sputter-deposition at high Ar pressures was investigated with the aim of reducing the medium noise of Co/Pd multilayer films for perpendicular magnetic recording media. A large increase in perpendicular coercivity was obtained in samples prepared at Ar pressures above 10 Pa. Angular variations of the coercivity suggested that the magnetization reversal process was dominated by domain wall motion in the samples prepared at Ar pressures below 5 Pa, while it seemed rotational in samples prepared at Ar pressures above 10 Pa. Through recording performance tests with a ring head, it was found that a sample prepared at a high Ar pressure of 70 Pa showed a lower medium noise level and higher recording resolution than a sample prepared at 1 Pa.

Key words: Co/Pd multilayers, perpendicular magnetic recording, medium noise, sputter-deposition, high Ar pressure

1. Introduction

Co/Pd multilayer films have been found to show large perpendicular magnetic anisotropy when the Co layer thickness is below several atomic layers, and studies of their application as perpendicular magnetic recording media have been reported.^{1)–3)} Although high perpendicular coercivity and high remanent magnetization were obtained in Co/Pd multilayers, a higher medium noise than that in conventional Co–Cr media was found in this new kind of perpendicular magnetic recording media.⁴⁾ This was thought to be due to a relatively strong magnetic interaction between Co grains along the lateral direction, which resulted in a large magnetic domain size, and the magnetization reversal process was dominated by a domain wall motion. In those former studies, however, the Co/Pd multilayers were prepared by sputtering under low gas pressures.^{2), 4)} Recently we reported that it is effective to decrease the magnetic domain size by increasing the sputtering gas pressure in preparation of conventional Co–Cr media.⁵⁾ In this work, Co/Pd multilayers were sputter-deposited at high Ar pressures up to 70 Pa, and effects of the Ar pressure on their magnetic properties were studied.

2. Experiments

Co/Pd multilayers were prepared using magnetron sputtering on glass disk substrates. The background

pressure of the sputtering system was about 4×10^{-5} Pa. An underlayer of Ti (100 nm) was deposited at an Ar pressure of 1 Pa with dc magnetron sputtering for obtaining enough adhesion strength between the glass substrate and the metallic films, followed by deposition of a Pd (25 nm) buffer layer under the same condition as that for the Ti underlayer. Co/Pd multilayer films were then formed on the Pd buffer layer by rotating the substrate to expose alternatively to Co (ac magnetron sputtering) and Pd (dc magnetron sputtering) targets, while sputtering Ar pressure was varied from 1 Pa to 70 Pa. The Co layer thickness (t_{Co}) was around 0.40 nm and fluctuated within 10% between samples. The Pd layer thickness (t_{Pd}) was in the range between 0.50 nm and 1.00 nm. The stacked number was 20 in all the samples. The substrates were cooled with water during the preparation.

X-Ray diffraction profiles were measured using an X-ray diffractometer with a Cu- K_{α} radiation. Angular variation of coercivity was measured at room temperature using a vibrating sample magnetometer (VSM), and saturation magnetization was measured with an alternating gradient force magnetometer (AGFM). The perpendicular magnetic anisotropy field ($H_{k\perp}$) of each sample was estimated from the area surrounded by the saturation magnetization level and the initial in-plane magnetization curve. The magnetic domain structures were observed using a magnetic force microscopy (MFM). Furthermore, medium noise and recording performance were measured for two samples prepared at 1 Pa and 70 Pa.

3. Results and Discussions

A. Ar pressure dependence of the magnetic properties

Figure 1 shows the perpendicular magnetization loops for Co/Pd multilayers prepared at 1, 5, 10, and 70 Pa. A loop with a very small $H_{c\perp}$ value and shoulders was obtained for the sample prepared at 1 Pa. While a higher $H_{c\perp}$ was obtained when the Ar pressure was increased to 2 and 5 Pa, however, shoulders on the loops were still observed as shown in Fig. 1 for the sample prepared at 5 Pa. In such samples showing shoulders, the reversal of the magnetization was thought to be made mainly through a rapid domain wall motion after the nucleation of reversed domains, which was not suitable for magnetic recording media.⁶⁾

Fig. 1 Perpendicular magnetization loops for Co/Pd multilayer films prepared at 1, 5, 10, and 70 Pa.

On the other hand, the magnetic properties were significantly changed when the Ar pressure during the sputtering was raised up to 10 Pa or above. The loops for the samples prepared at high Ar pressures above 10 Pa showed rounded shoulders and high $H_{c\perp}$ values as shown in Fig. 1.

The changes of $H_{k\perp}$, $H_{c\perp}$, and $H_{c\perp}/H_{k\perp}$ with the increase of Ar pressure are shown in Fig. 2. $H_{k\perp}$ increased with the increase of Ar pressure up to 10 Pa and then decreased with further increase of Ar pressure. The reason for such dependence of $H_{k\perp}$ on Ar pressure has not been clarified. On the other hand, $H_{c\perp}$ and $H_{c\perp}/H_{k\perp}$ which are the very important parameters for magnetic recording media, was found to increase monotonously when Ar pressure was increased up to 10 Pa.

The change of $H_{c\perp}/H_{k\perp}$ with Ar pressure may imply changes in the mechanism of magnetization reversal process which can be elucidated from the measurement of the angular variation of coercivity. Figure 3 shows the angular variation of $H_c/H_{k\perp}$ for Co/Pd multilayers prepared at various Ar pressures. For the samples prepared at 1 and 2 Pa, H_c decreased monotonously from the in-plane to the perpendicular direction, which suggested that the magnetization reversal was dominated by domain wall motion. For the sample prepared at 5 Pa, H_c increased at first when applied field was turned out of film plane and then decreased to the perpendicular direction, exhibiting a maximum H_c at around 30 degrees from the film plane. As the Ar pressure was further increased above 10 Pa, H_c increased rapidly at first from the in-plane, but exhibited no peaks.

For an infinite cylindrical magnetic particle with only a shape anisotropy ($H_{k\perp} = 2\pi M_s$), if the magnetization switches in a curling mode, the reduced radius, S , can be estimated using,⁷⁾

$$S^2 = 1.08 H_{k\perp} / H_{c\perp} \quad (1)$$

Fig. 2 Dependences of the perpendicular coercivity, perpendicular anisotropy field, and $H_{c\perp}/H_{k\perp}$ on the Ar pressure.

Fig. 3 Angular variation of coercivity for Co/Pd multilayer films prepared at various Ar pressures.

As an approximation for our Co/Pd multilayers, S was estimated using eq. (1) and $H_{c\perp}/H_{k\perp}$ values shown in Fig. 2. It is obvious that S decreased with the increase of Ar pressure.

B. Micro and magnetic structure of Co/Pd multilayers

In the small angle region X-ray diffraction measurements, only the first order diffraction peak was observed for all the samples. Figure 4 shows two small angle X-ray diffraction patterns for the samples prepared at 1 and 70 Pa. The peak intensity dropped when the Ar pressure was raised above 10 Pa, indicating some deterioration in the multilayer structure. In high angle region, no satellite peaks from the multilayer structure was observed and the X-ray diffraction patterns were similar to each other. The full width at half maximum ($\Delta\theta_{50}$) for the rocking curve of Co/Pd (111) peak was around 4° for all the samples. This could be

Fig. 4 Small angle X-ray diffraction patterns for Co/Pd multilayer films prepared at 1 and 70 Pa.

ascribed to the fact that the buffer layers in all the samples were prepared under the same conditions.

The changes in the film structures in the lateral direction was investigated through sample surface observations with a SEM. Figure 5 shows the surface microstructures for the samples prepared under 1 Pa, 2 Pa, 10 Pa, and 20 Pa. The in-plane grain size was around 25 nm in diameter and exhibited little change with the increase of Ar pressure. However, clearer grain boundaries were observed in the samples prepared at high Ar pressures than that at low Ar pressures, implying an enhanced physical separation between grains or grain clusters along the lateral direction.

Figure 6 shows MFM images of the surface for the samples prepared under 2 Pa and 70 Pa at dc remanent and ac demagnetized states. From the images, it is clear that the magnetic domains are smaller in the sample prepared at the high Ar pressure. However, the ac erased domain size was still of several times the grain size observed in the SEM pictures in Fig. 5. Thus, the domain size seemed to be determined by clusters composed of several grains. Nevertheless, it can be concluded that the preparation at high Ar pressures weakens the magnetic interactions between grain clusters, and reduces effective magnetic domain size, which in turn should lead to the aforementioned significant

Fig. 5 SEM surface images for Co/Pd multilayer films prepared at 1, 2, 10, and 20 Pa.

Fig. 6 MFM-observed magnetic domain structures of dc remanent (a, b) and ac erased states (c, d) for samples prepared at 2 and 70 Pa.

change in magnetic properties.

The changes in the film structure with the increase of Ar pressure are due to that the incident atoms from Co and Pd targets bombard the substrate with a high kinetic energy in low pressure sputter-depositions, resulting a dense and homogenous film structure and a strong magnetic interaction between grains; while in case of preparation at high pressures, incident atom energy is reduced by frequent collisions with Ar atoms before reaching the substrate, resulting films with a rather clear microstructure by a shadowing effect and a weak magnetic interaction between grains.

C. Recording performance

Recording tests were performed for the Co/Pd multilayer media prepared at 1 Pa and 70 Pa. As discussed above, the $H_{c\perp}$ was too small for the sample prepared at 1 Pa, while it was too high for that prepared at 70 Pa. Proper $H_{c\perp}$ values were obtained through adoption of a thinner t_{Co} (0.20 nm) for 1 Pa preparation, and a thicker t_{Co} (0.48 nm) for 70 Pa preparation by referring to the result of the change in $H_{k\perp}$ with t_{Co} .⁸⁾ The magnetic properties for the two media are summarized in Table 1. A protection layer of 10 nm thick carbon was coated on the sample surface. A metal in gap (MIG) ring head with a gap length of 0.26 μm was used in the test. For comparison, results for a Co₈₀Cr₂₀ medium (film thick-

Table 1 Magnetic properties of Co/Pd multilayer media prepared at 1 and 70 Pa

Ar pressure (Pa)	d (nm)	$H_{c\perp}$ (kOe)	$H_{c\perp}/H_{k\perp}$	M_s (emu/cm ³)
1	23.3	1.5	0.07	447
70	18.2	3.1	0.4	686

Fig. 7 Recording density characteristics for two Co/Pd multilayer media prepared at 1 and 70 Pa, and a Co-Cr medium.

ness = 100 nm, $H_{c\perp} = 1.3$ kOe, $H_{k\perp} = 6$ kOe, $M_s = 500$ emu/cm³) measured under the same conditions were also plotted.

Figure 7 shows the recording density characteristics for the two Co/Pd multilayer and a Co-Cr media. Up to the third peak in the reproduced voltage was confirmed for both media. However, the medium prepared under 1 Pa showed a fast drop in reproduced output at high densities. On the other hand, the medium prepared under 70 Pa maintained a higher output even at higher densities, indicating a higher recording resolution. The evaluated $D_{50}^{\%}$ value increased from 200 kFRPI for the medium prepared under 1 Pa to 260 kFRPI for the medium prepared under 70 Pa.

Figure 8 shows the recording density dependence of medium noise for the three media. At the dc remanent state, the noise level was lower for the sample prepared at 1 Pa than that for the sample prepared at 70 Pa. However, the inverse was true when signals above 40 kFRPI were recorded as shown in Fig. 8. Moreover, the medium noise level increased with the increase of recording density for the sample prepared at 1 Pa, while it decreased with the increase of recording density for the medium prepared at 70 Pa.

The drastic difference in medium noise characteristics was considered to be stemmed in their difference in magnetic properties, which has been described in Section 3.B that the sample prepared at 1 Pa showed a very large magnetically coupled domain, but it decreased with the increase of Ar pressure. The medium noise for the sample prepared at 1 Pa with a large magnetically coupled domain was mainly attributed to the transition noise which increases with the increase of recording density, while the noise source for the sample prepared

Fig. 8 Medium noise characteristics for two Co/Pd multilayer media prepared at 1 and 70 Pa, and a Co-Cr medium.

at 70 Pa was bulk noise.

In conclusion, Co/Pd multilayers have been sputter-deposited in a wide Ar pressure range. It was found that sputter-deposition at an Ar pressure higher than 10 Pa was essential for obtaining a low noise medium. However, further reduction of medium noise for Co/Pd multilayer media is still required for future high density recording.

Acknowledgments. The authors gratefully acknowledge Professor Emeritus S. Iwasaki, Tohoku University, for instruction throughout this work. They are also indebted to J. Ariake, S. Watanabe, K. Saito, and K. Harada for their assistance in the experiments.

References

- 1) P. F. Carcia, A. D. Meinhardt, and A. Suna: *Appl. Phys. Lett.*, **47**, 178 (1985).
- 2) B. M. Lairson, J. Perez, and C. Baldwin: *IEEE Trans. Magn.*, **30**, 4014 (1994).
- 3) L. Wu, N. Honda, K. Ouchi: *Technical Report of IEICE*, **95** (No. 383), 63 (1995).
- 4) S. Yanase, L. Wu, K. Saito, N. Honda, and K. Ouchi: *Proceeding of the IEICE General Conference*, 1996, C-437 (in Japanese) (1996).
- 5) N. Honda, S. Yanase, and K. Ouchi: *J. Appl. Phys.*, **79**, 5362 (1996).
- 6) J. R. Barnes, S. J. O'Shea, M. E. Welland, J. Y. Kim, J. E. Evetts, and R. E. Somekh: *J. Appl. Phys.*, **76**, 2974 (1994).
- 7) S. Shtrikman and D. Treves: *J. de Phys. et Rad.*, **20**, 286 (1959).
- 8) F. J. A. den Broeder, H. C. Donkersloot, H. J. G. Draaisma, and W. J. M. de Jonge: *J. Appl. Phys.*, **61**, 4317 (1987).

Received Oct. 16, 1996; Accepted Jan. 16, 1997