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Magnetic Properties of (CoFe₂O₄)-(Co-CoO) Composite Films for Perpendicular Magnetic Recording

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Abstract: Cobalt ferrite films were prepared by facing targets sputtering, and then post-annealed at various temperatures ($T_a=200\text{--}500^\circ\text{C}$) in air. Their magnetic properties and fine structure were investigated. A coercivity ($H_{c\perp}$) measured in a perpendicular direction to the film surface of a film deposited at the oxygen gas pressure (P_{O_2}) of 0 mTorr and post-annealed at 300°C was 1.5 kOe. The value was 3.5 times greater than a coercivity ($H_{c\parallel}$) measured in a parallel direction to the film surface. This high coercivity ratio ($H_{c\perp}/H_{c\parallel}$) showed that this film had the perpendicular magnetic anisotropy. It was investigated by the SEM observation that the perpendicular magnetic anisotropy was mainly caused by the columnar structure of the film. Moreover, the film was found to be made up of a (CoFe₂O₄)-(Co-CoO) composite by the XPS measurement of the binding energies of Co_{2p} and Fe_{2p} electrons of the film.

1. Introduction

The low noise magnetic recording media are required for high density recording system. It was reported that in a high density region the SNR of iron oxide recording media are higher than that of metal recording media [1-2]. Moreover, the oxide recording media have benefits such as long media lifetime, high resistance to damage and excellent corrosion. In these reasons, the barium ferrite thin film media have been studied for high density recording media [3-4]. But barium ferrite thin film media need high temperature annealing to crystallize. On the other hand, Cobalt ferrite thin film which has spinel structure is prepared with low temperature annealing. We therefore fabricated (CoFe₂O₄)-(Co-CoO) composite thin film media with high squareness, and investigated magnetic properties and fine structure of them.

2. Experimental

Cobalt ferrite films were prepared by a facing targets sputtering system. Targets were iron and cobalt metal plate with the Fe/Co ratio of 2. After the chamber was evacuated to a pressure below 2×10^{-5} Torr, the films were deposited on glass substrates at O₂ partial pressures (P_{O_2}) of 0 and 0.2 mTorr, and total pressure ($P_{O_2}+P_{Ar}$) of 15 mTorr. Applied power remained at 44 W during deposition. Then the films were post-annealed at various temperatures (T_a) ranging from 200°C to 500°C for 5 hours in air. The film thickness was in the range from 3000 to 5000 Å.

3. Results and Discussion

Figure 1 shows x-ray diffraction patterns of the films deposited at $P_{O_2}=0$ mTorr and post-annealed at various temperatures. The diffraction line from Fe(110) plane was observed for the as-deposited film. The CoFe₂O₄ phase crystallized with the increase of annealing temperatures. When the film annealed at $T_a=200\text{--}300^\circ\text{C}$, α -Co and CoO phase coexisted with CoFe₂O₄ phase.

Figure 2 shows x-ray diffraction patterns of the films deposited at $P_{O_2}=0.2$ mTorr and post-annealed at various temperatures. CoO phase added with α -Fe phase was observed in the as-deposited film. CoO and Co phase crystallized at lower annealing temperature compare with the films deposited at $P_{O_2}=0$ mTorr.

Figure 3 shows annealing temperature(T_a) dependence of magnetization and coercivity measured in perpendicular direction to the film surface for the $P_{O_2}=0$ (▲,●) and 0.2 mTorr (△,○) films. The magnetization of the films of $P_{O_2}=0$ mTorr decreased with increase of T_a . Because a spinel phase was formed, instead of α -Fe phase which formed in an as-

deposited film. The coercivity of the films which annealed at 400°C were the highest. The hysteresis loop of the film deposited at $P_{O_2}=0$ mTorr and then annealed at $T_a=300^\circ\text{C}$ had excellent squareness of 0.78 (compensated with demagnetizing field).

Figure 4(a) and (b) show the cross-sectional views of the $P_{O_2}=0$ mTorr and 0.2 mTorr films post-annealed at 300°C , respectively. The $P_{O_2}=0$ mTorr film (a) had a good columnar structure. In contrast, the columnar structure was not observed clearly for the $P_{O_2}=0.2$ mTorr film (b). Therefore the strong perpendicular magnetic anisotropy of the $P_{O_2}=0$ mTorr film was due to this columnar structure.

Moreover, to investigate the fine structures of these films, the ion states of Co ions in the films were measured by XPS. Figure 5 and figure 6 show annealing temperature dependence of the binding energy of the Co_{2p} electrons of the $P_{O_2}=0$ mTorr and 0.2 mTorr films, respectively. In the as-deposited films Co metal ($\text{Co}_{2p_{3/2}}=778$ eV) exists. The amounts of Co^{2+} ions increased with the increase of post-annealing temperature. In the $P_{O_2}=0$ mTorr film annealed at $T_a=300^\circ\text{C}$ which showed excellent perpendicular magnetic anisotropy Co metal coexists with large amounts of Co^{2+} ions. From this XPS spectrum and XRD pattern (fig.1), it is considered that the $P_{O_2}=0$ mTorr film annealed at $T_a=300^\circ\text{C}$ was made up of a $(\text{CoFe}_2\text{O}_4)\text{-(Co-CoO)}$ composite.

4. Conclusion

- (1) The film deposited at $P_{O_2}=0$ mTorr and then annealed at $T_a=300^\circ\text{C}$ showed excellent perpendicular anisotropy.
- (2) The origin of perpendicular magnetic anisotropy of the film was mainly shape anisotropy due to its columnar structure.
- (3) The $P_{O_2}=0$ mTorr film annealed at $T_a=300^\circ\text{C}$ was made up of a $(\text{CoFe}_2\text{O}_4)\text{-(Co-CoO)}$ composite.

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Figure 1: X-ray diffraction patterns of $P_{O_2}=0$ mTorr films post-annealed at various temperatures.

Figure 3: Annealing temperature dependence of the magnetization and coercivity for $P_{O_2}=0$ (▲, ●) and 0.2 mTorr (△, ○) films.

Figure 5: Annealing temperature dependence of the binding energy of the Co_{2p} electrons for the $P_{O_2}=0$ mTorr film.

Figure 2: X-ray diffraction patterns of $P_{O_2}=0.2$ mTorr films post-annealed at various temperatures.

Figure 4: Cross-sectional SEM micrographs of (a) $P_{O_2}=0$ and (b)0.2 mTorr films post-annealed at 300°C .

Figure 6: Annealing temperature dependence of the binding energy of the Co_{2p} electrons for the $P_{O_2}=0.2$ mTorr film.