Sputter Deposition of Ferrite Films and Application for High Density Rigid Disk Media in Contact Mode

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Abstract. Co-Zn ferrite and BaM ferrite films were deposited on silicon wafer disks with thermally oxidized surface layer without annealing process, and their read/write characteristics in contact mode have been investigated by using a MIG and Mn-Zn ferrite head with gap length of 0.2-0.4 μm . The highest linear recording density D_{50} of Co-Zn ferrite and Ba ferrite films were 105 and 190 kFRPI, respectively. Clear dipulse was observed for isolated wave form of Ba ferrite disks and then dipulse ratio was 0.65. It was concluded that the Co-Zn ferrite films and Ba ferrite films have high potential as an isotropic and a perpendicular recording layer, respectively, in contact recording mode at ultra-high density

1. INTRODUCTION

The spacing between magnetic head and rigid disk media has being decreased with increasing of recording density and a contact recording media have to be investigated for achieving ultra-high recording density above 20 Gbit/inch². The sputtered ferrite films seem to be superior candidates for contact recording layer because of their excellent chemical stability, high corrosion resistance, well wear pass durability and so on. Moreover, the media noise of ferrite disks are low and almost constant even at high recording density, it would be a superior merit to conventional Co-based alloy disks[1]. Especially both films of a spinel type of Co-Zn ferrite films with (111) orientation and a magnetoplumbite type of Ba(BaM) ferrite films with c-axis orientation seemed to be very suitable for isotropic[2] and perpendicular magnetic recording layer, respectively, because they possessed excellent surface smoothness and highly dense cross-sectional morphology as well as excellent magnetic properties. Therefore, in this study, Co-Zn ferrite and BaM ferrite films were deposited on silicon wafer disks with thermally oxidized surface layer without psot-annealing process, and their read/write characteristics in contact mode have been investigated by using a MIG and Mn-Zn ferrite head.

2. EXPERIMENTAL PROCEDURE

Prior to the fabrication of specimen disks, several Co-Zn ferrite($\text{Co}_{0.5}\text{Zn}_{0.5}\text{Fe}_{2.0}\text{O}_{4.0}$) and BaM ferrite($\text{Ba}_{1.0}\text{Fe}_{12.0}\text{O}_{19.0}$) films were deposited by a facing targets sputtering(FTS) apparatus and a conventional RF diode sputtering apparatus, respectively, to optimize the surface smoothness, crystallographic characteristics and magnetic properties. Various deposition conditions for Co-Zn ferrite and BaM ferrite films were shown in Table 1. The FTS system can realize damage-free deposition and there is no discrepancy of film composition between the target and the deposited films[3]. The plates which have the same stoichiometric composition of $\text{Co}_{0.5}\text{Zn}_{0.5}\text{Fe}_{2.0}\text{O}_x$ were used

Table 1 : Deposition Conditions

	Co-Zn ferrite	BaM ferrite
Sputtering Apparatus	Facing Targets	RF Diode
Target Composition	$\text{Co}_{0.5}\text{Zn}_{0.5}\text{Fe}_{2.0}\text{O}_x$	$\text{Ba}_{1.7}\text{Fe}_{12.0}\text{O}_x$
Ar gas pressure	1.98 mTorr	3.68 mTorr
O ₂ gas pressure	0.02	0.002 - 2.0
Substrate Temperature	90-500°C	620°C
Film Thickness	200 nm	200 nm
Substrate-target distance	90 mm	35-77 mm

as the targets. On the other hand, since there is serious plasma damage to surface of the growing film in a conventional RF diode sputtering system and Ba content is likely to be insufficient compared with stoichiometric composition of BaM ferrite ($\text{Ba}_{1.0}\text{Fe}_{12.0}\text{O}_{19.0}$)[4], the target with Ba enriched composition of $\text{Ba}_{1.7}\text{Fe}_{12.0}\text{O}_x$ was used. The substrate temperature T_s measured at substrate surface using thermocouple was varied in the range from 90 to 500°C for the deposition of Co-Zn ferrite films. On the other hand, the dependences of crystallographic characteristics and surface morphology on the distance between target and substrate d_{t-s} and the partial oxygen gas pressure P_{O_2} were investigated for the deposition of BaM ferrite films. Film thickness of both ferrite films was set at about 200 nm. A silicon wafer chips and 2 inch disks with thermally oxidized surface layer were used as substrates.

The surface texture and cross-section morphology were observed by scanning electron microscopy (SEM). The crystallographic characteristics, such as the full width of half maximum $\Delta\theta_{50}$ and the quality factor for the c-axis orientation f_c , were calculated on X-ray diffraction diagrams(XRD), and magnetic characteristics such as the saturation magnetization $4\pi M_s$ and the in-plane and perpendicular coercivities $H_{c//}$ and $H_{c\perp}$ were determined from the $M_{//}$ - $H_{//}$ and $M_{\perp}$ - $H_{\perp}$ hysteresis loops, respectively, which were measured by using a vibrating sample magnetometer (VSM).

3. RESULTS AND DISCUSSION

3.1 Co-Zn ferrite films

Co-Zn ferrite film deposited at T_s of 90°C revealed a flat surface and uniform morphology as shown in Fig. 1 and it was composed of crystallites with (111) orientation. This diffraction intensity of (111) increased with increase of T_s up to 250°C. Since the easy and hard axes of spinel ferrite crystallite with Co ions are $\langle 100 \rangle$ and $\langle 111 \rangle$, respectively, and $\langle 100 \rangle$ are distributed in a circular cone whose generation line canted at an angle of 35.3° to the film plane, magnetization vector $\mathbf{M}$ seemed to be oriented isotropically in Co-Zn ferrite film with (111) orientation as shown in Fig.2. Figure 3 shows typical hysteresis loops measured in in-plane and perpendicular direction and they revealed almost the same shape due to isotropic orientation of magnetization vector $\mathbf{M}$.

Fig.1 SEM photograph of Co-Zn ferrite film deposited at T_s of 90°C.

Fig.2 Magnetization vectors $\mathbf{M}$ of (111) oriented Co-Zn ferrite crystallite.

Fig.3 Typical hysteresis loops of Co-Zn ferrite film measured in in-plane and perpendicular directions.

Fig.4 T_s dependences of $4\pi M_s$ and $H_{c//}$ and $H_{c\perp}$ of Co-Zn ferrite film

The maximum $4\pi M_s$ of 4.8 kG was obtained at T_s of 250°C and it was almost equal to that of bulk Co ferrite as shown in Fig.4. The films in specimen disk was deposited at T_s of 200°C and $4\pi M_s$ and H_c were estimated to be as large as 4.0 kG and to be as moderately high as about 2.0 kOe, respectively.

Since Co-Zn ferrite films with (111) orientation possessed a flat surface and strong adhesion to disk substrate as well as sufficient hardness, the read/write characteristics of the specimen magnetic disks were evaluated without protective and lubricant layers. A MIG type head with gap length of 0.27 μm was used for evaluating read/write characteristics, where the coil turn number and relative velocity were 31 and 2.3 m/s, respectively. Although actual flying height has not been measured, it was estimated at the value less than 300 Å. Figure 5 shows the dependences of output voltage on linear density. The normalized output has a 'shoulder' at linear density from 5 to 20 kFRPI and high recording density D_{50} of 105 kFRPI was attained. Since the 'shoulder' was generally observed for the measurement of perpendicular recording media, it was seemed that the recorded magnetization vector $\mathbf{M}$ has perpendicular component as shown in Fig.2.

3.2 BaM ferrite films

Figure 6 shows the surface appearance of BaM ferrite films deposited at partial oxygen gas pressure P_{O_2} in the range from 0.003 to 3.7 mTorr. Although the films deposited at quite low P_{O_2} of 0.003 mTorr and below were only composed of spinel phase crystallites and possessed bumpy surface texture due to excessive growth of crystallites, the film deposited at P_{O_2} of 0.02 mTorr exhibited very smooth surface and seemed to be suitable for high density recording media. However, the film deposited at P_{O_2} of 0.3 mTorr revealed irregularities at surface and it changed to fiber structure at P_{O_2} higher than 2.0 mTorr.

Figure 7 shows the dependence of $\Delta\theta_{50}$ and f_c of c-axis orientation on the distance between target and substrate d_{t-s} . The values of $\Delta\theta_{50}$ were determined from the rocking curve of (008) plane for BaM crystallites and the value of f_c was determined from ordinary x-ray diffraction diagram, as proposed by Lotgering[5], where f_c of 1.0 corresponds to the complete c-axis orientation and $f_c < 1.0$ means that the film includes crystallites with other orientation. The value of f_c increased steeply with increase of d_{t-s} in the range of 35-50 mm and reached about 1.0 when it is longer than 65 mm and $\Delta\theta_{50}$ decreased from 10 to 3° with increase of d_{t-s} . It seemed that, since the bombardment of high energy particles, such as γ -electrons and negative oxygen ions from plasma and the recoiled particles from target surface was suppressed, crystallinity was improved in appropriately low P_{O_2} and enough long d_{t-s} . It was clarified that the suppression of plasma damage to the film surface is intrinsically necessary for the deposition of BaM ferrite films with good c-axis orientation using a conventional RF diode sputtering apparatus.

Ba ferrite film had almost perpendicular magnetic anisotropy as shown in Fig.8. The read/write characteristics of BaM ferrite disk media were also evaluated without protective and lubricant layers by a Mn-Zn ferrite head whose head gap g , track width

Fig.5 Dependences of output voltage on linear recording density of Co-Zn ferrite disks.

Fig.6 SEM photographs of BaM ferrite films deposited at various P_{O_2} .

Fig.7 Dependences of $\Delta\theta_{50}$ and f_c on d_{t-s} .

Fig.8 Typical hysteresis loops of BaM ferrite film measured in in-plane and perpendicular directions.

Fig.9 Dependences of output voltage on linear recording density of BaM ferrite disks and an isolated wave form at 7 kFRPI.

and coil turn number were 0.2 μm , 27 μm and of 34 turn, respectively. The relative velocity was 1.0 m/s. Very high linear recording density D_{50} of 190 kFRPI was obtained as shown in Fig.9. High dipulse-ratio of 0.65 in isolated wave form at the density of 7 kFRPI and clear 'shoulder' at linear recording density from 50 to 120 kFRPI implied that perpendicular magnetic was successfully performed in the BaM ferrite disk.

4. CONCLUSION

Co-Zn ferrite and BaM ferrite films were deposited by using a facing targets sputtering(FTS) apparatus and by a conventional RF diode sputtering apparatus, respectively. Their surface texture, crystallographic and magnetic characteristics, and read/write characteristics in contact mode were investigated.

Co-Zn ferrite films with (111) orientation and BaM ferrite films with excellent c-axis orientation deposited in this study have high potential as the isotropic and perpendicular recording layers, respectively.

Although the D_{50} of Co-Zn ferrite disks and Ba ferrite disks to date were still lower than that of conventional Co-Cr/Cr disks, it may be possible to increase it by optimizing of the magnetic characteristics of both ferrite films and by the usage of MR head for reading.

REFERENCES

- [1] S. Tsuboi, T. Korenai, N. Ishiwata, K. Yamada and K. Tagami; *J. Mag. Soc. Japan*, vol. 18, No. S1, pp. 95-98, 1994.
- [2] J. U. Lemke; *IEEE Trans. on Magn.*, vol. 15, No. 6, pp. 1561-1563, 1979.
- [3] M. Naoe, S. Yamanaka and Y. Hoshi; *IEEE Trans. on Magn.*, vol. 16, No.5, pp.646-648, 1980.
- [4] M. Naoe, S. Hasunuma, Y. Hoshi and S. Yamanaka; *IEEE Trans. on Magn.*, vol. 17, No.6, pp.3184-3186, 1981.
- [5] F. K. Lotgering; *J. Inorg. Nucl. Chem.*, vol. 9, pp.113-123, 1959.