DEPENDENCE OF POWER DENSITY OF Ar BOMBARDMENT ON PROPERTIES OF Fe FILMS BY DOUBLE ION BEAM SPUTTERING

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ABSTRACT

Fe films have been deposited by double ion beam sputtering with Kaufman type ion source. For the Ar bombardment ion source, the voltage V_A was varied in the range of 80-2000 V. The current density J_A was fixed at 0.49 and 0.049 A/m², that is, the power density of Ar bombardment P_A , the product of V_A and J_A , was changed in the range of 3.9-980 W/m². The P_A dependence of the magnetic properties of the Fe films has been investigated in detail.

Fe films with the coercivity H_C below 5 Oe were deposited on the substrates ion-bombarded at P_A in the range of 30-70 W/m². The saturation magnetization $4\pi M_s$ of the films was 21.5 kG at P_A of 9.6 and 96 W/m². The electric resistivity ρ took the maximum value of 80 $\mu\Omega\text{cm}$ at P_A of 980 W/m². This value was 2.7 times as large as that without Ar bombardment. These results imply that the bombardment by Ar ions with an optimum power density is very useful technique to obtain the Fe films with good magnetic properties and the high electric resistivity for a backlayer of perpendicular recording media.

I. INTRODUCTION

Fe thin films seem to be hopeful material for large $4\pi M_s$ backlayer of Co-Cr media for perpendicular magnetic recording. As recording density is high, the unit of recording is small to nano-scale. In the range, the uniformity of composition may be important for the alloy films like NiFe or Co based material. Because the uniformity of backlayer relates to the noise of media and the film growth of perpendicular magnetic layer. Pure Fe films, which are uniform composition have excellent properties for the backlayer. However, it is very difficult to prepare Fe films with a good soft magnetism, since magnetic properties of these are significantly influenced by preparation methods, as listed in Table 1.

Table 1 Magnetic properties of Fe films

Sputtering method	$4\pi M_s$ (kG)	H_C (Oe)	
FTS (Facing Target System)	-	30 - 60	[3]
FTS + bias voltage	16 - 21.5	8-20	[4]
Sputter beam	-	10-40	[5]
Ion beam	14 - 21.5	4 - 13	[1][6]
Double ion beam	11 - 21.5	1.5 - 50	[2]

In sputtering, the film surface is always bombarded by the ions from the plasma and the atoms recoiled from the target plane. It is very useful to bombard the films during the film growth in the case of a bias sputtering [4] and an ion-assisted deposition. Therefore, the technique of Ar bombardment can be applicable to control the magnetic properties of the Fe films.

So far, the energy of the Ar bombardment to the substrate has been only emphasized [1]. However, the relationship between the bombardment effect and the power density has not been mentioned in detail for deposition of Fe films. Taking the density of the energetic particles into consideration, this parameter is very important for the film deposition. Especially, the parameter influences the film temperature.

In this study, Fe films have been deposited by the ion beam sputtering with Ar bombardment as a parameter of the power density P_A . The dependence of the crystallographic and magnetic characteristics of the Fe films on P_A and the temperature has been investigated in detail.

II. EXPERIMENT

A double ion beam sputtering apparatus was used in this study. Both ion sources were Kaufman-type. Specimen films were deposited on water-cooled glass substrates by double ion beam sputtering using an Fe target of 99.9% in purity. On the other hand, heated specimen films were deposited on glass substrates by ion beam sputtering without Ar bombardment. After the chamber was evacuated to the residual gas pressure lower than 6×10^{-5} Pa, Ar gas of 99.999% in purity was introduced through the sputtering ion source and used as the sputtering gas. Ar pressure was as high as 3.6×10^{-3} Pa by setting the gas flow rate at 2 sccm. The voltage V_s for sputtering and the current were kept at 1200V, and 50 mA, respectively.

For the assisting Ar ion source, the voltage V_A for Ar bombardment was varied from 80 to 2000V. The current density J_A fixed at 0.49 and 0.049 A/m² to change P_A , which was the product of V_A and J_A . The relationship of P_A and V_A as a parameter of J_A is shown in figure 1. P_A varied from 39 to 980 W/m² at J_A of 0.49 A/m² and from 3.9 to 98 W/m² at J_A of 0.049 A/m².

The thickness of as-deposited Fe films was in the range of 300-350 nm. The crystal structure was analyzed by X-ray diffractometry. The electrical resistivity ρ was measured by

means of four-terminal method. The saturation magnetization $4\pi M_s$ and the coercivity H_c were measured using a vibrating sample magnetometer.

Fig. 1. The relationship between the power density of Ar bombardment P_A and the bombardment voltage V_A for J_A of 0.49 and 0.049 A/m².

Fig. 2. P_A dependence of the deposition rate R_D and the substrate holder temperature T_S for J_A of 0.49 and 0.049 A/m².

III. RESULTS AND DISCUSSION

A. Deposition rate and substrate temperature

Figure 2 shows the P_A dependence of the deposition rate R_D and the surface temperature T_S of the substrate holder as a parameter of J_A equal to 0.49, 0.049 and 0 A/m². J_A of 0 means that the film was deposited without Ar bombardment and R_D was 0.036 nm/sec. For J_A of 0.49 and 0.049 A/m², R_D decreased in proportion to P_A . The gradients of the line for J_A of 0.49 and 0.049 A/m² were -2.0×10^{-14} and -1.8×10^{-14} m³/Wsec, respectively. These values were almost same. The sputtering yield was in proportion to the sputtering voltage in the range from 100 to 10000V. In this experiment, P_A was product of V_S and J_A . Therefore, the difference from R_D for J_A of 0 shows the rate of re-sputtering from the film by the bombardment.

On the other hand, T_S also increased with an increase of P_A . For P_A below 39 W/m² at J_A of 0.049 A/m², the variation of T_S was very small. T_S was about 45°C. For P_A over 39 W/m² at J_A of 0.49 A/m², T_S increased in proportion to P_A . The maximum value of T_S was 120°C, even though the substrate holder was cooled by water. The difference between J_A of 0.49 and 0.049 A/m² at P_A in the range from 39 to 98 W/m² was caused by the heat from the filaments of the assisting ion source. Therefore, the increase of T_S was mainly due to the bombardment effect and the thermal emission from the ion sources. The surface temperature of the deposited films may be higher than T_S as measured at the substrate holder.

B. Crystallographic characteristics

X-ray diffraction diagrams of the as-deposited Fe films as a parameter of P_A were measured. The crystallographic characteristics changed remarkably with P_A . The X-ray diffraction peaks corresponding to the (110) and (200) planes of α -Fe crystallites were observed.

Figure 3 shows the P_A dependence of the lattice constant "a" and the ratio in (200)/(110) integral peak intensity $R_{(200)/(110)}$ in X-ray diffraction diagrams of the as-deposited Fe films for J_A of 0.49 and 0.049 A/m². These values were larger than that of the bulk pure Fe 2.8664 Å. "a" was 2.886 Å for J_A of 0. For J_A of 0.049 A/m², "a" increased in proportion to P_A . However, for J_A of 0.49 A/m², "a" decreased with an increase of P_A . The decrease of "a" for J_A of 0.49 A/m² may be caused by the elevation of the film temperature as shown in Fig. 3.

On the other hand, $R_{(200)/(110)}$ with Ar bombardment was smaller than that without Ar bombardment. $R_{(200)/(110)}$ for J_A of 0.49 A/m² was smaller than that for J_A of 0.049 A/m². $R_{(200)/(110)}$ took the minimum value at P_A of 96 W/m² for J_A of 0.49 A/m² and at P_A of 20 W/m² for J_A of 0.049 A/m².

In order to investigate the dependence on the substrate temperature, the substrate holder was heated in the range of 50 to 400°C using the filament without water-cooling. Figure 4 shows the dependence of "a" and $R_{(200)/(110)}$ on T_S by the heater. "a" decreased with an increase of T_S . "a" over 300°C was smaller than that of the bulk pure Fe 2.8664 Å. $R_{(200)/(110)}$ took the minimum value at T_S of 100°C. The variations of "a" and $R_{(200)/(110)}$ corresponded to that of P_A for J_A of 0.49 A/m². Therefore, Ar bombardment with the elevation of T_S by the high P_A appeared the only effects of the elevation of T_S by the heater. The effects of pure Ar bombardment based on the collisions between the atoms of the films and Ar ions may be obtained for J_A of 0.049 A/m².

Fig. 3. P_A dependence of the lattice constant a and the ratio of (200)/(110) integral peak intensity $R_{(200)/(110)}$.

Fig. 4. Dependence of a and $R_{(200)/(110)}$ on T_S by the heater.

Fig. 5. P_A dependence of the electric resistivity ρ .

C. Electric resistivity

The electric resistivity of backlayer was very important parameter to the performance for high density recording of perpendicular media. When the data transfer rate was over 200 MBit/sec, the eddy current loss of magnetic field was necessarily occurred. Namely, the backlayer of perpendicular media must have a higher electric resistivity for achieving the high density recording. Figure 6 shows the P_A dependence of the electric resistivity ρ of the films. ρ was 30 $\mu\Omega\text{cm}$ for J_A of 0. ρ was almost constant at P_A below 9.6 W/m². At P_A over 9.6 W/m², ρ was higher than that of J_A of 0. At P_A of 98 W/m², which was the product of V_A of 200 V and J_A of 0.49 A/m², ρ decreased abruptly. At P_A in the range of V_A higher than 200 V for both J_A of 0.49 and 0.049 A/m², ρ increased with increasing V_A . The variation of ρ for J_A of 0.49 A/m² was larger than that for J_A of 0.049 A/m². ρ took the maximum value of 80 $\mu\Omega\text{cm}$ at P_A of 980 W/m². This value was about 2.7 times as high as that of J_A of 0. The electric resistivity of the films depended on the bombardment power density rather than bombardment voltage.

D. Magnetic Properties

Figure 6 shows the P_A dependence of $4\pi M_S$ and H_C of the Fe films. At P_A of 9.6 and 96 W/m², which was the product of V_A of 200 V and both J_A , $4\pi M_S$ took the maximum value of 21.5 kG. The variation of $4\pi M_S$ for J_A of 0.049 A/m² was smaller than that for J_A of 0.49 A/m².

On the other hand, H_C was also almost 5 Oe at P_A below 9.6 W/m². At P_A in the range of 9.6 to 200 W/m², H_C was below 5 Oe, except the value of V_A of 80 V for J_A of 0.49

mA. At P_A higher than 380 W/m^2 , H_C increased drastically with increasing P_A . H_C took the minimum value of 2 Oe at P_A of 39 W/m^2 , which was the product of V_A of 800 V and J_A of 0.049 mA. These results show the power density of Ar bombardment in the range of 38 to 96 W/m^2 was available to obtain the good soft magnetism of the Fe films.

Fig. 6. P_A dependence of the saturation magnetization $4\pi M_S$ and the coercivity H_C .

Fig. 7. Dependence of $4\pi M_S$ and H_C on T_S by the heater.

Since the decrease of $4\pi M_S$ corresponded to the increase of ρ , the variation of both $4\pi M_S$ and ρ may be caused by Ar included in the Fe films and the formation of the mixing layer between deposited film and substrate in the range of the high energy bombardment.

Figure 7 shows the dependence of $4\pi M_S$ and H_C on T_S by the heater. $4\pi M_S$ was an almost constant value of 21 kG. At T_S below 300°C , H_C gradually increased with increasing T_S . At T_S of 300°C , H_C of the film was 40 Oe. The elevation of the film temperature had the effect of the increase of H_C . Therefore, the high density Ar bombardment led the increase of H_C . The Ar bombardment without the strong elevation of temperature was effective to decrease of H_C .

IV. CONCLUSION

Varying the power density of the Ar bombardment technique, the magnetic properties and electric resistivity of the Fe films were controlled. The Fe films with good soft magnetism can be deposited at the optimum power density in the range of 38 to 96 W/m^2 . Moreover, it was necessary for the films with high resistivity to deposit at high energy bombardment. At P_A of 38 W/m^2 , which is V_A of 800 V and J_A of 0.049 A/m^2 , $4\pi M_S$ was 21.5 kG and ρ was $50 \mu\Omega\text{cm}$. These values were twice as high as one of $\text{Ni}_{80}\text{Fe}_{20}$ alloy. Therefore, the Fe films deposited with high energy bombardment can be expected for the excellent backlayer for the perpendicular recording media.

REFERENCES

- [1] M. Nagakubo, A. Kadokura and M. Naoe, "Preparation and Gas addition of Soft Magnetic Pure Iron Thin Film by Dual Ion Beam Sputtering", *Mat. Res. Soc. Vol. 80*, pp. 415 (1987)
- [2] M. Naoe, Y. Yamaga, N. Terada, "Deposition of Rust Proof Iron Thin Films with Soft Magnetic Properties by Dual Ion Beam Sputtering", *IEEE Trans. Magn.*, MAG-21, 1900 (1985)
- [3] Y. Hoshi, N. Naoe, S. Yamanaka, "Uniaxial Magnetic Anisotropy of Iron Thin Films Deposited by Targets Facing Type of Sputtering", *IECE, J65-C(11)*, 921 (1982) [in Japanese]
- [4] A. Fukizawa, N. Naoe, "Sputtered Pure Iron Film for Soft Magnetic Layer in Perpendicular Recording Media", *IEEE Trans. Magn.*, Vol. 24, No. 6, 3078 (1988)
- [5] S. Okamoto, Y. Shimada, M. Suzuki, "Crystal Structure and Magnetic Properties of Fe Films Produced by the Sputter Beam Method", *J. Mag. Soc. Japan Vol. 17*, No. 1, 43 (1993) [in Japanese]
- [6] N. Ishiwata, C. Wakabayashi, T. Matsumoto, "Zero Magnetostriction Iron Films", *IEEE Trans. Magn.*, Vol. 24, No. 6, 3078 (1988)