ION BEAM DEPOSITION OF Co-Cr FILMS BY USING OPPOSED TARGETS SPUTTERING TECHNIQUE

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Abstracts---In order to deposit Co-Cr film with excellent c-axis orientation, ion beam deposition of the Co-Cr films has been attempted by using an opposed targets sputtering apparatus, since it can be operated at a gas pressure as low as 1×10^{-4} Torr and many metal ions are produced in the plasma during sputtering. The ions are extracted from the plasma through a grid and are deposited directly on a substrate. However, the ions in the plasma cannot reach to the substrate if the substrate is at earth potential, since the plasma is at a negative potential. Deposition rate R_d increases gradually as substrate potential V_{sub} decreases from 0 V and takes a maximum value of about 8 Å/min at a V_{sub} around -60 V. R_d decreases steeply as further decrease in V_{sub} from -70 to -90 V. Crystal structure and magnetic properties of the film are also changed with V_{sub} , though c-axis orientation is not observed.

INTRODUCTION

Ion beam deposition is one of the most attractive film deposition technique because of its high potential of low deposition temperature in the formation of the film with good crystallographic structure [1-4]. In opposed targets sputtering, high rate sputtering can be performed at a gas pressure as low as 1×10^{-4} Torr [5] and many metal ions are produced in the plasma during the high rate sputtering [6]. Therefore, if an ion extraction grid is arranged in the plasma and is applied a negative potential compared to the plasma, the metal ions in the plasma can be extracted through the grid and can be deposited directly on a substrate. Thus, it seems that ion beam deposition can be easily performed by utilizing the opposed targets sputtering apparatus, since the mean free path of the ions at a Ar gas pressure of 1×10^{-4} Torr is larger than 50 cm.

Co-Cr film should have excellent c-axis orientation to use for perpendicular magnetic recording media. So, the ion beam deposition method is very attractive to realize the Co-Cr film with excellent c-axis orientation. In this work, we

tried to deposit the Co-Cr film by the new ion beam deposition technique where an opposed targets sputtering technique was applied. In this paper, we will show the operating characteristics of the ion beam deposition system and the structure and magnetic properties of the Co-Cr film deposited by the method.

ION BEAM DEPOSITION SYSTEM

Figure 1 shows a schematic diagram of the opposed targets sputtering apparatus used in this work. Co-Cr alloy (21 at.%Cr-Co) plates of 13x18x0.5 cm in size were used as the targets. An ion extraction grid and a substrate were arranged as shown in the figure so that the ions in the plasma are extracted through the grid and are deposited directly on the substrate. The substrate is located at the position where the most of neutral sputtered particles emitted from the targets cannot be arrived directly.

Figure 2 shows typical discharge characteristics of this sputtering apparatus at various argon gas pressure. It is evident from the figure that the sputtering can be performed at a very low gas pressure as low as 0.15 mTorr where the

Fig.1 A schematic diagram of the ion beam deposition system utilizing an opposed targets sputtering system.

mean free path of the sputtered particles is much larger than the distance between the substrate and grid, though the applied voltage to the targets should be increased as the gas pressure decreased.

Figure 3 shows the changes in plasma potential with the position in the plasma at the various sputtering gas pressures. These plasma characteristics were measured with a conventional Langmuir probe method. The plasma potential $V_p(V)$ takes a negative value and increases as the sputtering gas pressure increases. Therefore, if the substrate is at a potential of $V_{sub}(V)$, the ion, incident to the substrate, is thought to have an energy about $e(V_p - V_{sub})$ (eV). Thus, the ions in plasma cannot reach the substrate if the substrate is at earth potential.

Figure 4 shows the energy distribution of ions incident to the substrate. A schematic diagram of the measuring system for the energy distribution is shown

Fig.2 Typical discharge characteristics of the opposed targets sputtering system at various gas pressures.

Fig.3 Changes in plasma potential V_p with the position in the space between the targets at various sputtering gas pressure.

Fig.4 Energy distributions of ions incident to the substrate.

Fig.5 A schematic diagram of the measuring system of the ion energy distribution.

in Fig.5. It is evident from the figure that the ions have an energy about -10 eV and the energy distribution depends little on the grid potential. This result i.e., the ion has negative energy, is caused by the fact that the plasma potential has a negative value as shown in Fig.3. However, it should be noted that Ar ions are also extracted together with metal ions in this deposition technique.

Fig.6 Changes in the ion current at substrate holder and the grid current with ion extraction grid voltage.

Figure 6 shows the changes in the ion current at substrate holder and grid current with applied grid voltage. The ion current increases gradually with an increase of grid voltage, though the ion current is less than 1/10 of the grid current. The ion current may be increased by enlarging the grid hole area.

FILM PREPARATION CONDITIONS AND MEASUREMENT

The films about 1000 Å thick were deposited on a silicon wafer substrate at the argon gas pressure of about 0.3 mTorr. In order to clarify the effect of the energy of the incident ions on the structure of the film, films were deposited at various substrate potential. Typical film preparation conditions are listed in Table 1. Figure 7 shows the changes in film deposition rate R_d with substrate bias voltage V_{sub} . R_d increases gradually as substrate potential V_{sub} decreases from 0 V and takes a maximum value of about 8 Å/min at a V_{sub} around -60 V. R_d decreases steeply as further decrease in V_{sub} from -70 to -90 V. The increase in the R_d as V_{sub} decreases from 0 to -30 V may be caused by the increase of arriving metal ions to the substrate. While, the decrease

Table I Film deposition conditions.

Sputtering gas pressure	0.3	mTorr
Target voltage	600	V
Discharge current	2	A
Ion extraction		
grid voltage	-400	V
Substrate bias voltage	+30 -90	V
Substrate	Silicon wafer	

Fig.7 Changes in film deposition rate R_d with substrate bias voltage V_{sub} .

in R_d as V_{sub} decreases from -60 V to -90 V should be attributable to the decrease in sticking probability of the arriving ions or an increase in resputtering because of the increase of the kinetic energy of the incident ions. The fact that films are deposited on the substrate even if the substrate potential is at a V_{sub} of 30 V suggests that some neutral atoms are arrived at the substrate.

Crystal structure and c-axis orientation was characterized with X-ray diffraction. The coercive force H_c and saturation magnetization M_s of the film were measured with a VSM.

STRUCTURE AND MAGNETIC PROPERTIES OF THE FILM

Figure 8 shows the changes in X ray diffraction diagrams of the film with substrate bias voltage. It is evident from the figure that the crystallites in all of the film has random orientation, though the crystallinity changes a little with V_{sub} . Especially, the film deposited at a V_{sub} around -50 V has amorphous like structure. But the reason is not clear till now.

Figure 9 shows the changes in coercive force H_c of the film with the substrate bias voltage. Coercive force takes a minimum value at a V_{sub} around -50 V. This can be attributable to the fact that the film deposited at the V_{sub} has inferior crystallinity. Saturation magnetization of these film is in the range from 300 to 400 emu/cc, though its dependence on the V_{sub} was not clear. Typical M-H loops of these films are shown in Fig.10. The M-H curves indicate that these films have very little perpendicular magnetic anisotropy.

Fig.8 Changes in X ray diffraction diagrams of the film with substrate bias voltage.

Fig.9 Changes in coercive force H_c of the film with substrate bias voltage V_{sub} .

Fig.10 Changes in M-H curves of the film with substrate bias voltage.

CONCLUSION

Ion beam deposition of the Co-Cr films has been attempted by using an opposed targets sputtering apparatus and following results are obtained.

(1) Ion beam deposition can be easily performed by utilizing the opposed targets sputtering technique.

(2) The ions extracted from the plasma cannot reach the substrate if the substrate is at earth potential, since the plasma is at a negative potential.

(3) Deposition rate R_d increases gradually as substrate potential V_{sub} decreases from 0 V and takes a maximum value of about 8 Å/min at a V_{sub} around -60 V. R_d decreases steeply as further decrease in V_{sub} from -70 to -90 V.

(4) Crystal structure and magnetic properties of the film are also changed with V_{sub} , though c-axis orientation is not observed.

However, we could not clarify the advantage of the ion beam deposition technique for the deposition of Co-Cr films. Therefore, further investigation must be continued.

REFERENCES

- [1] J.L.Vossen and W.Kern, "Thin Film process", Academic Press, pp.198-203 (1978)
- [2] J.Amano and R.P.W.Lawson; J. Vac. Sci. Technol., 14,831 (1977) and 14,836 (1977)
- [3] S.Aisenberg, and R.Chabot; J.Appl. Phys., 42,2953 (1971)
- [4] Y.Hoshi, M.Naoe and S.Yamanaka; Trans. IECE Japan, J65-C,490 (1982) (in Japanese)
- [5] N.Terada, Y.Hoshi, M.Naoe, and S.Yamanaka; Proc. Int'l Ion Engineering Congress-ISIAT'83 & IPAT'83, Kyoto (1983)
- [6] N.Terada, Y.Hoshi, M.Naoe, and S.Yamanaka; IEEE Trans. Mag., MAG-20,1451 (1984)