Journal of Korean Institute of surface Engineering
Vol. 29, No. 6, Dec., 1996

SOFT MAGNETISM OF Co-Zr AND Fe-Co FILMS WITH LARGE SATURATION MAGNETIZATION

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ABSTRACT

Large saturation magnetization 4pM$_s$ is essentially required for soft magnetic thin layers used in magnetic recording devices. Amorphous Co-based alloys and Fe-Co alloys may be regarded as one of the candidates for soft magnetic materials which possess large $4\pi M_s$. Some preparation process to improve soft magnetism of these films were performed in this study. Addition of Ta seemed to be effective to change the magnetostriction constant λ from positive value to negative one. The magnetoelastic energy K_e is strongly dependent on λ. $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ films with K_e of negative value have sufficiently soft magnetic characteristics. $Fe_{90}Co_{10}$ alloy exhibits extremely large $4\pi M_s$ of about 24 kG. Addition of N and Ta to $Fe_{90}Co_{10}$ films improved the soft magnetism of them.

The $Fe_{82.0}Co_{7.6}Ta_{10.4}$:N/Ti multilayered films exhibit better soft magnetic properties and better thermal stability than Fe-Co-Ta:N singlelayer films.

INTRODUCTION

Magnetic thin films with soft magnetic properties are used for core layers in magnetic recording heads and the backlayers in doublelayered perpendicular magnetic recording media.[1] Since soft magnetic films have to pass sufficient magnetic flux, the soft magnetic films with large saturation magnetization are desired. Amorphous Co-based alloys and Fe-Co alloys may be regarded as one of the candidates for soft magnetic materials which possess large $4\pi M_s$. Some preparation processes to improve soft magnetism of these films were performed in this study. By changing Ta content χ of $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ films, the relationship among χ, magnetostriction constant λ and coercivity H_c were clearly observed. The magnetostriction constant λ of Co-based alloy films should be minimized to attain soft magnetism. Fe-Co alloy has the largest saturation magnetization $4\pi M_s$ of all the magnetic alloys. The addition of N and Ta to $Fe_{90}Co_{10}$ sputtered thin films prepared by facing targets sputtering apparatus were effective to improve soft magnetic properties.[2] These soft magnetism seemed to be caused by the fine granulation in the films. The as-deposited films of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N possessed relatively large 4pM$_s$ and high relative permeability m$_r$ of 17kG and 400, respectively. Moreover, $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films possessed not only high permeability μ_r without annealing process but also excellent thermal stability.

EXPERIMENTAL PROCEDURE

All the specimen films were prepared by the facing targets sputtering (FTS) apparatus as shown Fig.1, where two targets were located face-to-face. Permanent magnets were installed behind the targets to confine the plasma in the space between the targets. This FTS apparatus has four kinds of target materials and can deposit thin layers of them continuously. The substrates were polyethlene naphtalate tape or silicon. They were positioned on a can roll, which was located out of the plasma. Therefore the substrates were almost free from plasma. The substrate temperature T_s was kept at room temperature (R.T.). Kr was used in place of Ar as sputtering gas in depositing $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ and Ti films to minimize damage of films by recoiled particles. $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N films were deposited by reactive sputtering method using mixture gas of N_2 and Kr. Total pressure of the mixture gas was set at 1 mTorr. N_2 partial pressure P_{N2} was adjusted to control the N content from 0.02 mTorr to 0.34 mTorr.

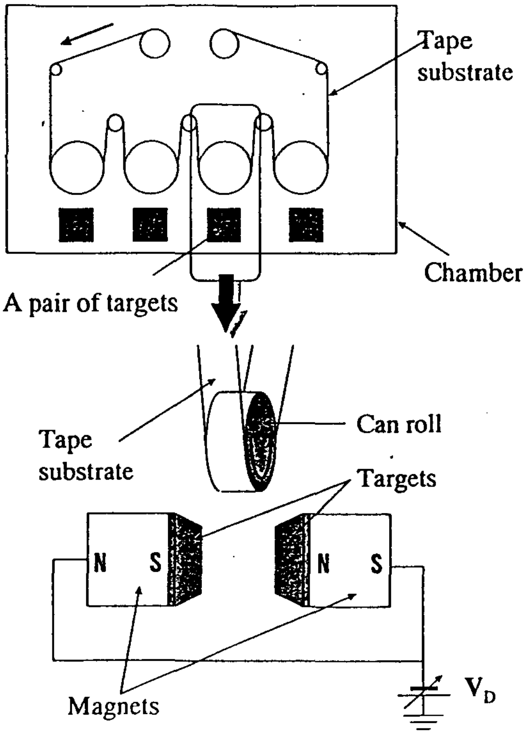

Fig. 1 Schematic figure of facing targets sputtering(FTS) appuratus

Crystallographic characteristics of the films were analyzed by X-ray diffractometry(XRD), and magnetic properties were measured by vibrating sample magnetometer (VSM). Internal stress s was evaluated from the degree in curling of the sheet substrates with the deposited films. Films composition was analyzed by inductively coupled plasma (ICP) analysis. Relative permeability of magnetic films were measured by shunt core method at 1MHz. Magnetostriction constant l of $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ films were evaluated by the method which will be described below.

Measurement of magnetostriction constant λ of $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ films

Since the magnetostriction constant λ of Co-Zr alloy thin films are so small below 110^{-6}, it is difficult to measure l of the films with small thickness around 0.1㎛. Schematic configuration of the measurement system used in this study were shown in Fig. 2. Two pairs of coils were installed to measure M-H loop. Outer coils were used to apply AC magnetic field H to $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ films, and inner coils were used to detect magnetization M of $(Co_{95.7}Zr_{4.3})_{100-x}Ta_x$ films. When the tensile stress F was applied to the films, the anisotropic tensile stress was induced in the soft magnetic films. By applying the tensile stress F to the films, anisotropy field H_k in the films

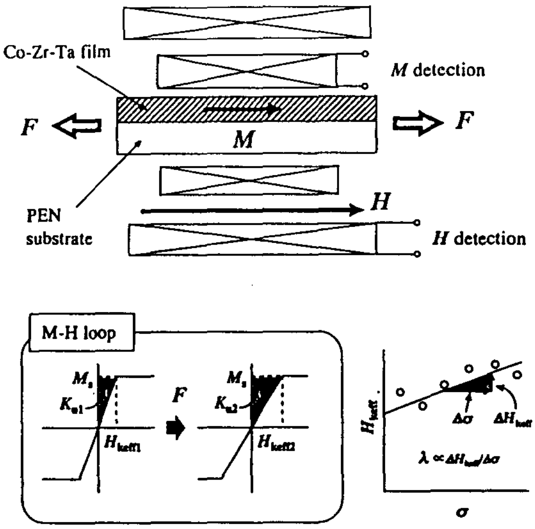

Fig. 2 Schematic configuration of the system to measure magnetization constant λ

changed due to the reverse magnetostrictive effect. The change of anisotropic field DH_{keff} by applying anisotropic stress σ to the films is

$$\Delta H_{keff}=2\Delta K_u'/M_s \qquad (1)$$

where ΔK_u' and M_s are the change of anisotropy energy K_u and saturation magnetization, respectively. Anisotropy energy K_u induced due to reverse magnetostrictive effect caused by the applied anisotropic stress s is

$$K_u^* = (-3/2)\lambda\sigma \qquad (2)$$

ΔK_u^*, the change of anisotropy energy K_u to anisotropic stress $\Delta\sigma$, is

$$\Delta K_u^*=(-3/2)\lambda\Delta\sigma \qquad (3)$$

Assuming that the change of anisotropic field is induced due to reverse magnetostrictive effect, $DK_u'=\Delta K_u^*$. Then l is calculated as follows;

$$\lambda=(-1/3)M_s\Delta H_{keff}/\Delta\sigma \qquad (4)$$

where $\Delta H_{keff}/\Delta\sigma$ is determined by the gradient of H_{keff} vs. σ characteristic curve.

RESULT AND DISCUSSION

Co-Zr-Ta films

Fig. 3 shows the dependence of magnetostriction constant λ on the Ta contents χ for the $(Co_{96.7}Zr_{4.3})_{100-x}Ta_x$ films with various thickness and prepared at various P_{Kr}. λ decreased monotonously from positive value to negative one as x increased. λ seems to take the value of nearly zero at χ around 6 at.%. Fig. 4 shows the change of coercivity H_c as a function of magne-toelastic energy K_e. Since Ds depended weakly on x and were in the range from -2 to -6 $\times 10^8$ (dyne/cm^2) for films deposited at P_{Kr} of 1mTorr, K_e seemed to be strongly dependent on λ. It was confirmed that lower H_C was observed at K_e of negative value.

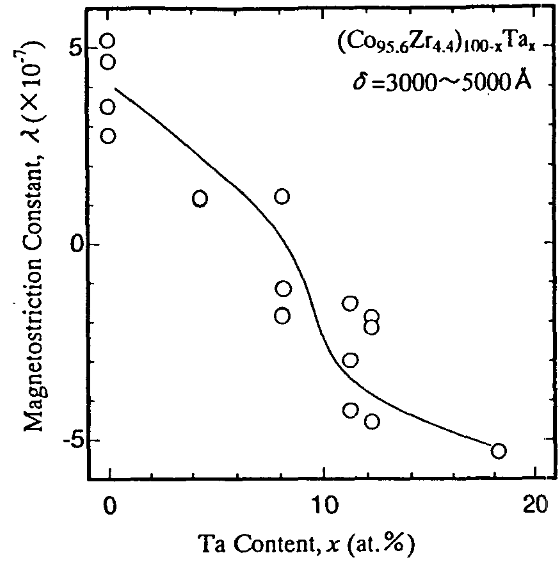

Fig. 3. Dependence of λ of$(Co_{96.7}Zr_{43})_{100-x}Ta_x$ films on Ta content χ.

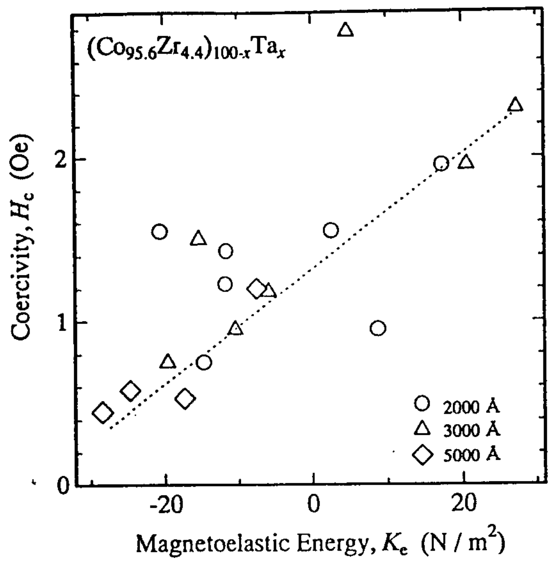

Fig. 4 Change of Hc as a function of K_e

Fe-Co-Ta:N films

Fe-Co alloy has the largest saturation magnetization $4\pi M_s$ among all the magnetic alloys.

The addition of N and Ta to $Fe_{90}Co_{10}$ reduced the grain size <D>. These soft magnetism seemed to be caused by the fine granulation in the films. Fig. 5 shows the dependence of saturation magnetization $4\pi M_s$ and relative permeability μ_r of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N films on P_{N2}. $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N films prepared of P_{N2} at 0.06 mTorr exhibited relatively large $4\pi M_s$ and high relative permeability m_r of 17kG and 400, respectively.

$Fe_{82.0}Co_{7.6}Ta_{10.4}$: N films thicker than 2000, however, did not have soft magnetic properties. So it was attempted to improve their soft magnetism by depositing $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N layers thinner than 1000Å. In this study, $Fe_{82.0}Co_{7.5}Ta_{10.4}$: N singlelayer film (specimen A) and $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films (specimens B and C) were prepared as shown in Fig. 6. Total thickness of magnetic layers in these specimens were 2000Å. P_{Kr} and PN_2 in depositing $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N layers are 0.84mTorr and 0.16mTorr, respectively. P_{Kr} in depositing Ti layers was set at 1mTorr. These films were annealed for 2 hours in vacuum at temperature T_A of 150, 220℃ and 300℃.

Fig. 7 shows the dependence of relative permeability μ_r of $Fe_{82.0}Co_{7.6}Ta_{10.4}$ singlelayer film and $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films on annealing temperature T_A. Specimen A exhibited low relative permeability μ_r of about 50 in as-deposited state. After annealing at high T_A of 220℃, μ_r of it could be higher than 400℃.

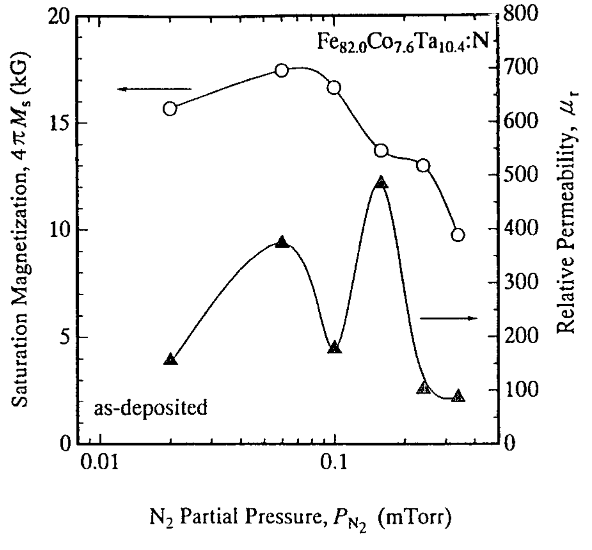

Fig. 5 P_{N2} dependence of $4\pi^M$ and μ_r of Fe-Co-Ta : N films

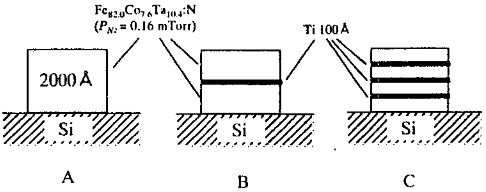

Fig. 6 Schematic configuration of $Fe_{82.0}$ $Co_{7.6}Ta_{10.4}$: N singlelayer film and $Fe_{82.0}Co_{7.6}Ta_{10.4}$:N/Timultilayered films.

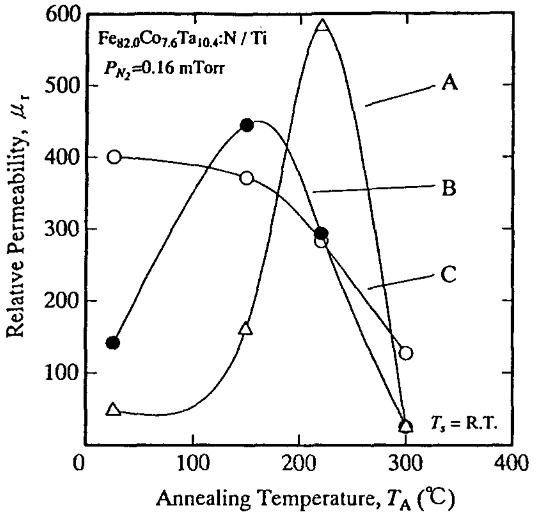

Fig. 7. T_A dependence of μ_r of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N singlelayer film and $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/ Timultilayered films.

Specimen C exhibited high μ_r of about 400 in as-deposited state. Deposition of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films seems to be effective to improve soft magnetism. And the $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered film divided into four magnetic layers by Ti layers maintained μ_r of about 150 after annealing at 300℃ though μ_r of the other specimens were less than 30.

Fig. 8 shows the dependence of $4\pi M_{s(\mathrm{annealed})}/4\pi M_{s(\mathrm{as-deposited})}$ of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N singlelayer film and $Fe_{82.0}Co_{7.6}Ta_{10.4}$:N/Timultilayered films on annealing temperature T_A. As T_A became high, $4\pi M_s$ gradually decreased. $4\pi M_s$ of singlelayer film annealed at 300℃ were about 40% of that of as-deposited film. But $4\pi M_s$ of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films was not so small as that of singlelayer film annealed at 300℃. It seemed to be due to that ferromagnetic ε-Fe_3N and γ'-Fe_4N crys-tallites were formed in multilayered films by annealed at 300℃ and that nonmagnetic ζ-Fe_2N crystallite were formed mainly in singlelayer film since N atoms in magnetic layers of multilayered films were diffused into Ti layers. Deposition of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films seems to be effective to prevent $4\pi M_s$ from decreasing by annealing at high T_A.

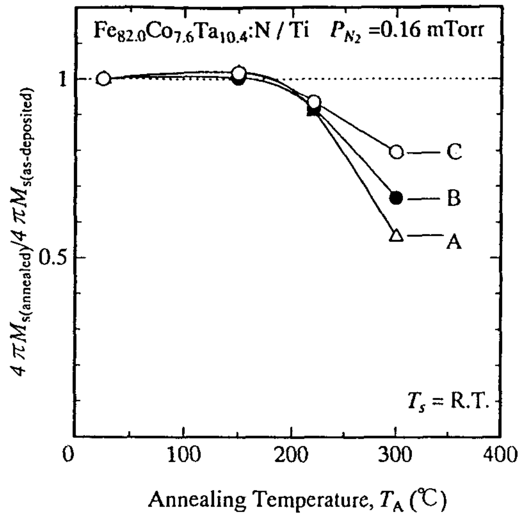

Fig. 8 T_A dependence of $4\pi M_s$ of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N singlelayer film and $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N /Timultilayered films

CONCLUSION

Ta was added to $Co_{96.7}Zr_{4.3}$ to minimize magnetostriction constant λ. λ of $(Co_{96.7}Zr_{4.3})_{100-x}Ta_x$ films decreased monotonously from positive value to negative one as χ increased. λ seems to take the value of nearly zero at x around 6 at.%. K_e seemed to be strongly dependent on λ. It was confirmed that H_c was lower at K_e of negative value. Soft magnetic properties of Fe-Co alloy films were improved by adding both Ta and N to $Fe_{90}Co_{10}$ films. These soft magnetism of Fe-Co alloy films seemed to be caused by the fine granulation in the films. $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N films possessed relatively large $4\pi M_s$ and high relative perme-ability μ_r of 17kG and 400, respectively.

Deposition of $Fe_{82.0}Co_{7.6}Ta_{10.4}$: N/Ti multilayered films seems to be effective to improve soft magnetism and to prevent $4\pi M_s$ from decreasing by annealing at high T_A.

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