U-9

THE MAGNETIC PROPERTIES OF Co-Ni-Fe-N SOFT MAGNETIC THIN FILMS

Y. M. Kim†, D. Choi†, K. H. Kim‡, J. Kim‡, S. H. Han and H. J. Kim

Thin Film Tech. Research Center, Korea Institute of Sci. and Tech., Seoul, 136-791, Korea

†Dept. of Physics, Myongji Univ., Yongin, 449-728, Korea

‡Dept. of Metallurgy and Material Science, Hanyang Univ., Ansan, 425-170, Korea

ABSTRACT Co-Ni-Fe-N thin films were fabricated by a N_2 reactive rf magnetron sputtering method. The nitrogen partial pressure (P_{N2}) was varied in the range of 0~10 %. As P_{N2} increases in this range, the saturation magnetization (B_s) linearly decreases from 19.8 kG to 14 kG and the electrical resistivity (ρ) increased from 27 to 155 μΩcm. The coercivity (H_c) exhibits the minimum value at 4% of P_{N2}. The magnetic anisotropy (H_k) are in the range of 20~50 Oe. High frequency characteristics of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films are excellent in the range of 3~5 % of P_{N2}. Especially the effective permeability of the film fabricated at 4% of P_{N2} is 800, which is maintained up to 600 MHz. This film also shows Bs of 17.5 kG, H_c of 1.4 Oe, resistivity of 98 μΩcm and H_k of about 25 Oe. Also, the corrosion resistance of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ were improved with the increase of N concentration.

I. INTRODUCTION

Recent developments in electronic devices have led to a demand for further miniaturization and higher frequency (f > 100 MHz) operation in magnetic devices such as magnetic heads and magnetic sensors. One of the important properties of magnetic materials for such applications is high permeability (μ) at high frequency which is limited by eddy current loss and ferromagnetic resonance. To improve high frequency characteristics of soft magnetic films, the films must have not only high electrical resistivity but also high saturation magnetization and magnetic anisotropy [1]. We recently have reported as-deposited Co-Ni-Fe soft magnetic thin films which have Bs of about 20 kG, H_c of 1.5~2.5 Oe and the effective permeability of about 1100 up to 100

MHz, respectively[2]. However, the high frequency properties rapidly deteriorate over 100 MHz due to low electrical resistivity and relatively small anisotropy field of these films.

In this study, it has, therefore, been investigated the effects of N_2 addition on high frequency characteristics of Co-Ni-Fe soft magnetic films by magnetic measurement and structural analysis.

Ⅱ. EXPERIMENTAL

As-deposited Co-Ni-Fe-N thin films were fabricated by rf magnetron sputtering using a composite target. The sputtering chamber was first pumped down to $\sim 1\times10^{-6}$ Torr. The deposition was then carried out under an $(Ar + N_2)$ atmosphere with the total gas pressure of 1×10^{-3} Torr. The input power was fixed at 450W, and the nitrogen partial pressure (P_{N2}) varied in the range of 0~10 % of total pressure. The thickness of Co-Ni-Fe-N thin films was measured about 500 nm. The structures of the films were analyzed by X-ray diffraction (XRD) and transmission electron microscopy (TEM) and the composition analyzed by electron probe microanalysis (EPMA). B_s, H_c, and H_k were measured by a vibrating sample magnetometer (VSM). The permeability and the electrical resistivity was measured the by a PMF 001 permeability measurement system and a four-point probe method, respectively. The corrosion resistance of Co-Ni-Fe-N thin films were performed using an EG & G Par 273A electrochemical test system. Table. 1 shows the sputtering condition of Co-Ni-Fe-N thin films.

Table 1. The sputtering condition of CoNiFeN thin films

Target	Composite Target Fe disc + (Co, Ni) chips
Substrate / Condition	Si (100) / Water cooling
Vacuum	$< 1 \times 10^{-6}$
Target – Substrate Distance	6.5 cm
RF Input Power	450 W
Total Pressure $(Ar + N_2)$	1 mTorr
Nitrogen Partial Pressure (P_{N2})	0 ~ 10 %
Film Thickness	500 ± 100 nm

Ⅲ. RESULTS AND DISCUSSION

As P_{N2} increases from 0 % to 10 % of P_{N2} , the B_s of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ thin films decrease continuously from 19.8 kG to 14 kG, as shown in Fig. 1(a). The H_c of these films initially decreases with the increase of P_{N2} and exhibits the minimum value at 4% of P_{N2} , and increases at P_{N2} higher than 5%, as shown in Fig. 1(b).

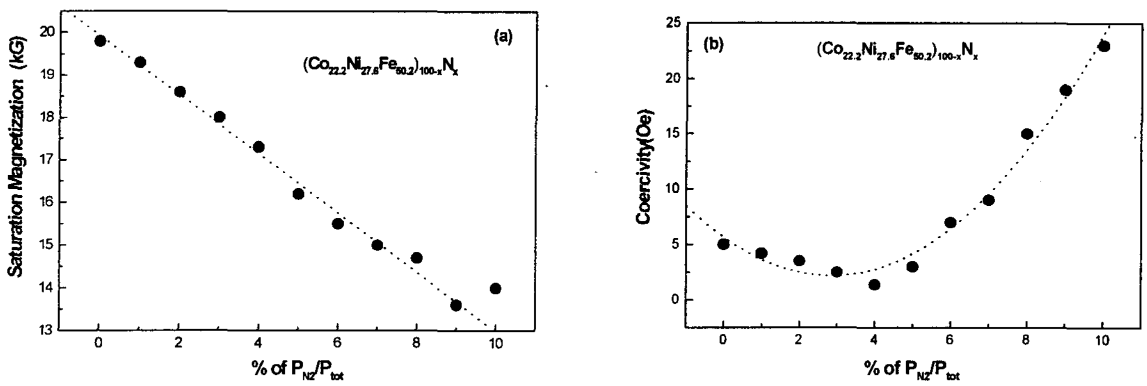

Fig. 1. Saturation magnetization (a) and Coercivity (b) for $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films.

The desirable high frequency characteristics for soft magnetic thin films are high permeability and low power loss. One of the sources of losses in ferromagnetic materials operated at high frequency is the eddy current loss. The eddy current loss increases in portion to the square of the frequency, which means that it plays an important role in high frequency. This eddy current effect can be minimized by the increase of the skin depth or electrical resistance in magnetic materials[3].

The easy and hard axis typical M-H loop of the $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ thin film deposited at 4% of P_{N2} is shown in Fig. 2. As shown in figure, the film is magnetically soft with the Hc of 1.4 Oe. From the hard axis M-H loop, the H_k is estimated to be about 25 Oe. By the M-H loops, H_k of CoNiFeN thin films with different N concentration are measured in the range of 20~50 Oe. These values are large than those of Co-Ni-Fe thin films, previously published in elsewhere[2].

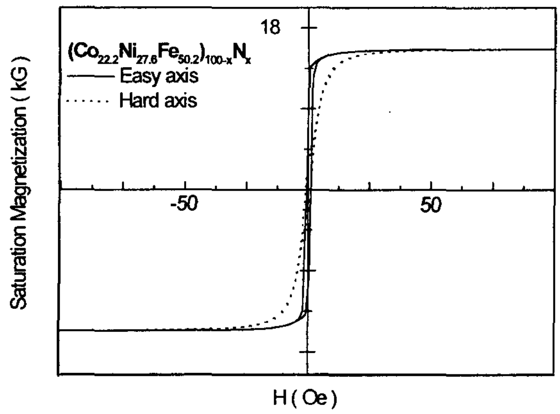

Fig. 2. Easy axis and hard axis M-H loop for $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ thin film deposited at 4 % of P_{N2}.

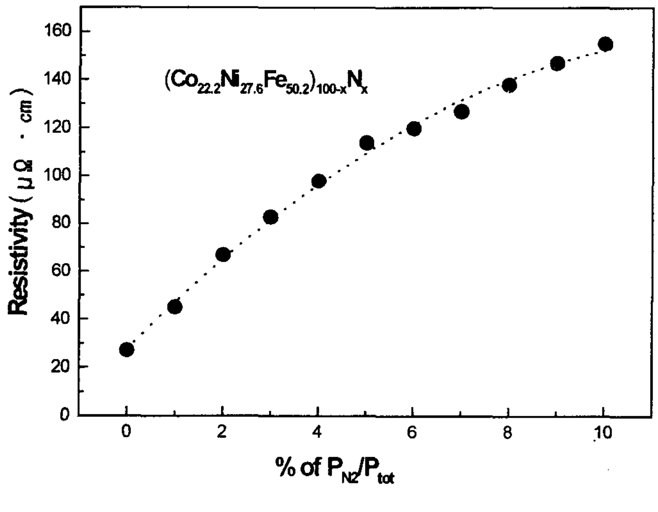

Fig. 3. Electrical resistivity of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ thin films with the variation of P_{N2}.

As shown in Fig. 3, the electrical resistivity of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films increases from 27 to 155 μΩ·cm with the increase of P_{N2}. These values are about 6 times larger than those of Co-Ni-Fe thin films. It indicates that the addition of nitrogen increases the resistivity of Co-Ni-Fe thin films significantly. Films fabricated in the range of 3 ~ 5 % of P_{N2} show the excellent high frequency characteristics, especially at 4 % of P_{N2}. Even though the electrical resistivity continuously increases over than 5 % of P_{N2}, the soft magnetic properties start to deteriorate, which results in the loss of excellent high frequency characteristics of these films. So, the high frequency properties of these films rapidly deteriorate over 100 MHz. Fig. 4 shows the frequency dependency of effective permeability for $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films deposited at 4 % of P_{N2}. Here the effective permeability is 800, and this value is maintain up to 600 MHz. This film also has Bs of 17.5 kG, H_c of 1.4 Oe, resistivity of 98 μΩ·cm, and H_k of about 25 Oe.

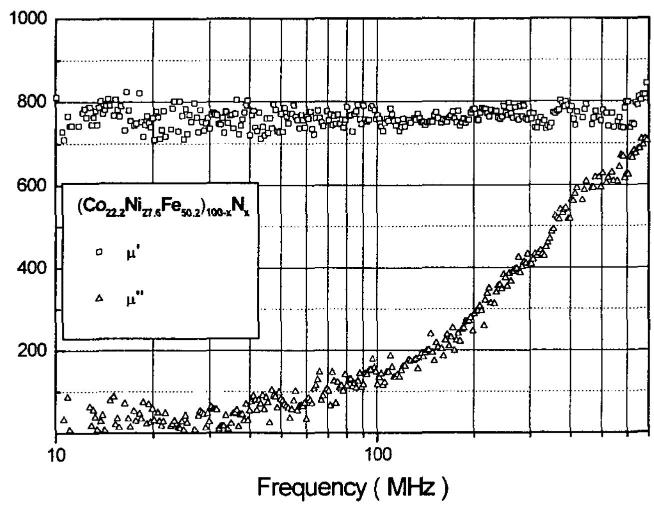

Fig. 4. Frequency dependency of effective permeability for $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films deposited at 4 % of P_{N2}.

In order to understand the changes of magnetic properties in these films, XRD was used to investigate the microstructures of the films. Fig. 5 shows the XRD patterns of the Co-Ni-Fe-N thin films at various P_{N2}. The grain size of Co-Ni-Fe-N thin films calculated by Scherer's equation is estimated around 10 ~ 40 nm. As P_{N2} increases to 4 %, the intensity of α-FeCo (110) peaks decreases but that of NiFe (200) peaks increases. Especially at 4 % of P_{N2}, only NiFe(200) single peak was observed. As P_{N2} increases above 5 %, NiFe (111) peak as well as NiFe(200) peak appears. These results confirm that the increment of P_{N2} results in the increase of NiFe phase instead of α-FeCo(110) phase, which is contributed to improve soft magnetic properties of Co-Ni-Fe-N thin films. Also, the appearance of NiFe (111) peak above 5 % of P_{N2} indicate the

(111) texture formation, which results in deterioration of soft magnetic properties[4].

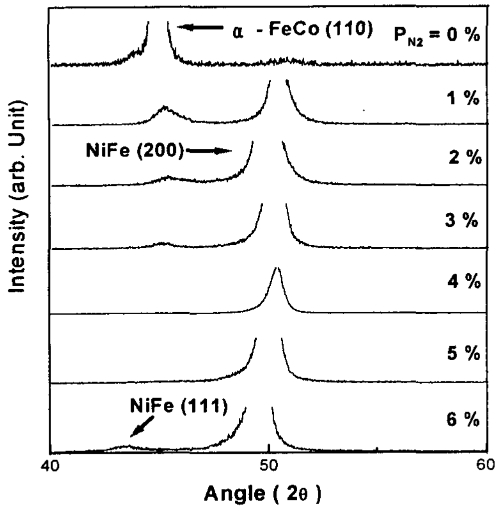

Fig. 5. Variations of XRD patterns with increasing of P_{N2} for the $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films

To ensure reliability in the magnetic device process using thin films, thin film materials must possess good corrosion resistance. Therefore, we investigated the corrosion resistance of these Co-Ni-Fe-N thin films. Electrochemical corrosion data were obtained using an EG & G Par 273A electrochemical test system and 352 Softcorr corrosion software. Potentiodynamic and cyclic polarization techniques were used to evaluate the localized corrosion resistance of the films with passive oxide layer. The measurements were carried out at room temperature in a EG & G flat cell where a circular area of 0.283 ㎠ of the films was exposed to the air saturated 0.5 M NaCl electrolyte at pH = 6 ± 0.1. Saturated Calomel Electrode (SCE) and 2.54 ㎝ × 1.27 ㎝ platinum net were used as a reference electrode and a counter electrode, respectively The scan rate was 5 mV below corrosion potential (E_{corr}). The testing condition emulates an extreme environment to which thin film heads are exposed during packaging, storage and subsequent applications.

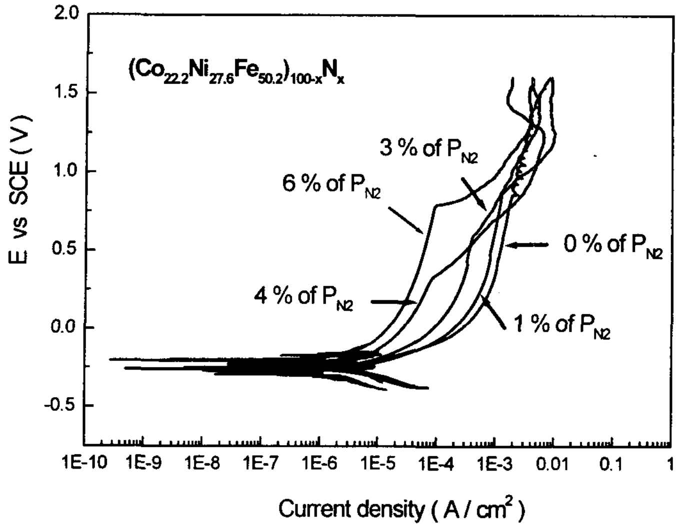

Fig. 6. Comparison of the anodic polarization curves of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ films in 0.5 M NaCl at pH = 6.

Fig. 6 shows the anodic polarization curves for $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ thin films with increasing the ratio (%) of P_{N2}. Their passivity currents are as low as 10^{-4} A/㎠ in the potential range of ~ 0.75 V. From this result, the corrosion resistance of $(Co_{22.2}Ni_{27.6}Fe_{50.2})_{100-x}N_x$ thin films improves with the increase in N concentration[5-6]. Therefore, Co-Ni-Fe-N thin films show better corrosion resistance than the Co-Ni-Fe thin films.

Ⅳ. CONCLUSIONS.

To improve the high frequency characteristics of CoNiFe thin films, we incorporated nitrogen into the CoNiFe alloy films. We investigated the magnetic properties and corrosion resistance of CoNiFeN thin films. As a result, the electrical resistivity and the anisotropy of CoNiFeN films increased significantly. The Co-Ni-Fe-N thin films deposited at 4 % of P_{N2}, have 17.5 kG of Bs, 1.4 Oe of H_c, 98 μΩ·cm of electrical resistivity, and about 25 Oe of H_k. Especially, this film has excellent high frequency characteristics that the effective permeability is about 800, which is maintained up to 600 MHz. The corrosion resistance of Co-Ni-Fe-N thin films improves with the increase in N concentration. In this result, we confirm that the Co-Ni-Fe-N thin films are the good candidates of a writing head material and high frequency devices.

REFERENCES

[1] H. Shibaya and I. Fukuda, IEEE Trans. Magn. **13**, 1005 (1997)
[2] Y. M. Kim, D. Choi, J. Kim, K. H. Kim, S. H. Han, H. J. Kim, J. Magn. Magn Mater., in press.
[3] H. Y. Wang, Y. J. He, and Z. W. Ma, J. Appl. Phys. **85**, 3745 (1999)
[4] Tetsuya Osaka, Mudoka Takai, IEEE Trans. Magn. **34**, 1432 ~ 1434 (1998).
[5] M. Kume, T. Tsujioka, Y. Abe, and A. Takasi, IEEE Trans. Magn. **23**, 3633 (1990)
[6] T. Kumura, K. Yamaguchi, and T. Kobayashi, J. Appl. Phys. **61**, 3844 (1987)