Soft High Saturation Magnetization $(Fe_{0.7}Co_{0.3})_{1-x}N_x$ Thin Films For Inductive Write Heads

N. X. Sun and S. X. Wang

***Abstract*—$(Fe_{0.7}Co_{0.3})_{1-x}N_x$ (or FeCoN) alloy single layers and FeCoN film sandwiched between two very thin (5 nm) permalloy layers have been synthesized by RF diode sputtering. The saturation magnetization of the as-deposited FeCoN single layers was found to be around 24.5 kG, the same as the pure $Fe_{0.7}Co_{0.3}$ alloy; and the minimum hard-axis coercivity was 5 Oe. In contrast, the sandwiched FeCoN films have a hard axis coercivity of 0.6 Oe, an excellent in-plane uniaxial anisotropy with an anisotropy field of 20 Oe. The optimized FeCoN films exhibit a BCC structure with a strong $\{110\}$ fiber texture and the resistivity is 55 $\mu\Omega\cdot$cm. The combination of high saturation and low coercivity, makes the FeCoN films a very promising candidate for the write head materials for future magnetic recording.**

***Index Terms*—High saturation magnetization, iron cobalt nitrogen alloys, soft magnetic materials, write head materials.**

I. Introduction

THE AREAL density record of magnetic recording has been increasing at a compound annual growth rate of 80% much recently, and has reached 36.5 Gb/in^2 [1]. With such rapid progress of the areal density record, soft magnetic write head materials with high saturation magnetization are highly desired to write the high coercivity magnetic media. The unavailability of write head materials with higher saturation magnetization (>21 kG) has been an immediate bottleneck in limiting the growth of areal density.

It is well known that the binary Fe–Co alloys have a high saturation magnetization of 24.5 kG in the composition range of $Fe_{1-x}Co_x$ $(0.3 < x < 0.4)$ [2]. But the Fe–Co alloys are highly magnetostrictive, the saturation magnetostriction constant is about $40 \sim 65 \times 10^{-6}$ in the composition range of $30 \sim 40$ at % of cobalt [2]. The high saturation magnetostriction makes it very difficult to achieve low coercivity or in-plane uniaxial anisotropy [3]–[5].

The motivation of this work is to make the Fe–Co alloy based films soft, while keeping the high saturation magnetization at the same time. Introducing nitrogen has been shown to be very effective to lower the coercivity in the FeN [6], and FeMN (M: $5 \sim 10$ at % Al [7], Ta [8], etc.) alloy films. We studied the effects of introducing N into the $Fe_{70}Co_{30}$ alloy films, and also the effects of thin layer permalloy underlayer and overlayer on the FeCoN films, and successfully fabricate the soft FeCoN films with high saturation magnetization and low coercivity.

Manuscript received February 15, 2000; revised May 15, 2000. This work is supported in part by NSF under Grant ECS-9710223.

The authors are with the Department of Materials Science and Engineering at Stanford University, and also with the Center for Research on Information Storage Materials (CRISM), Stanford, CA 94305-2205 USA (e-mail: nxsun@stanford.edu).

Publisher Item Identifier S 0018-9464(00)07984-X.

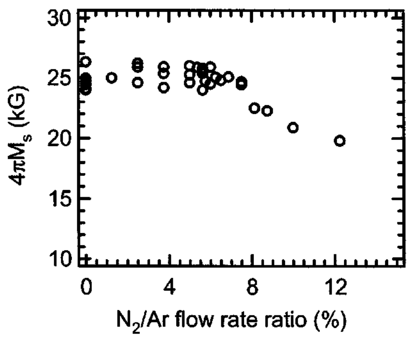


Fig. 1. $4\pi M_s$ versus N_2/Ar gas flow rate ratio in FeCoN.

II. Experimental Procedure

FeCoN films were synthesized through reactive RF diode sputtering in an argon and nitrogen atmosphere. The target composition was $Fe_{70}Co_{30}$ (at%) with the purity of 99.95%. Base pressure of the sputtering chamber was $\sim 2 \times 10^{-7}$ Torr. The gas flow rate of argon was set constant; while the flow rate of nitrogen was adjusted to get samples with different N contents in the films. A magnetic field of about 50 Oe was applied during deposition. The obtained films were characterized by vibrating sample magnetometer (VSM) and X-ray diffractometer (XRD), etc. Composition of the FeCoN films was analyzed by X-ray Photoelectron spectroscopy (XPS). A four-probe station was applied to measure the resistivity of the FeCoN films.

III. Results and Discussion

FeCoN films with the thickness of 1000 Å were deposited at different N_2/Ar gas flow rate ratio. The saturation magnetization ($4\pi M_s$) of the as-deposited FeCoN films is shown in Fig. 1 as a function of the N_2/Ar gas flow rate ratio. It is clear that the saturation magnetization values are almost the same as that of the pure Fe–Co alloy, about 24.5 kG, in a wide range of N_2/Ar gas flow rate ratio of $0\% \sim 7\%$. The corresponding nitrogen content in the FeCoN films was determined by XPS to be about 5 at % at a N_2/Ar gas flow rate ratio of 5.6%; the Fe/Co atomic ratio is around 2/1, and almost keeps constant for the FeCoN films at different N contents [9]. Similar behavior was also observed in the saturation magnetization of the

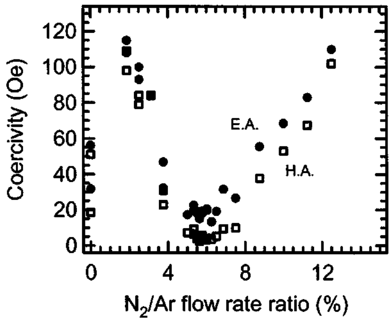


Fig. 2. H_c versus N_2/Ar gas flow rate ratio.

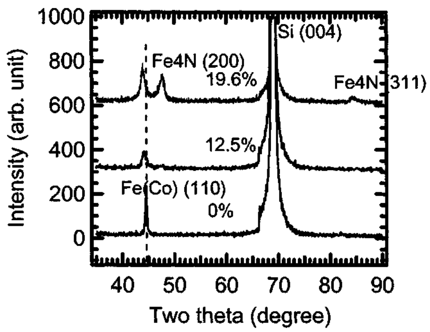


Fig. 3. XRD patterns of FeCoN films deposited at different N_2/Ar gas flow rate ratios.

as-deposited $(Fe_{90}Co_{10})_{1-x}N_x$ films when the nitrogen content is lower than 12 at %, and the observed saturation magnetization is in the range of $20 \sim 22.5$ kG [5].

The coercivity of these FeCoN films was measured and indicated in Fig. 2 as a function of the N_2/Ar gas flow rate ratio. The hard-axis coercivity first decreases quickly from about 100 Oe at a gas flow rate ratio of 2% to around 5 Oe at a N_2/Ar gas flow rate ratio of $5 \sim 6$%, then the coercivity increases with the increment of the gas flow rate ratio. Similar relation between coercivity and N_2/Ar flow rate ratio occurs in many FeMN alloy systems, and was believed to be a result of the decrease of grain size with the increase of N content in the film [5]–[9].

XRD patterns of the FeCoN films deposited at three N_2/Ar gas flow rate ratios, 0%, 12.5%, and 19.6%, are shown in Fig. 3. At low N_2/Ar gas flow rate ratio, the FeCoN films have a BCC α-Fe(Co, N) structure with a strong $\{110\}$ fiber texture; while a significant amount of Fe_4N phase appears in the film at a high N_2/Ar flow rate ratio of 19.6%. In addition, the α-Fe(Co, N) $\{110\}$ diffraction peak is shifted to lower angles and is much broader at higher N_2/Ar gas flow rate ratio, implying a higher N content incorporated and a much smaller grain size and/or micro- strain in the FeCoN films at higher N_2/Ar gas flow rate ratio. The resistivity of the FeCoN films is shown in Fig. 4. The resistivity increases as the increment of the N_2/Ar gas flow rate ratio. For the Fe–Co films, the resistivity is around 12 $\mu\Omega$·cm, while the resistivity increases almost linearly with the gas flow rate, reaching 55 $\mu\Omega$·cm at a N_2/Ar gas flow rate ratio of 5.6%, where the lowest coercivity is obtained.

Combining Figs. 1–4, we can clearly see that the high sat-

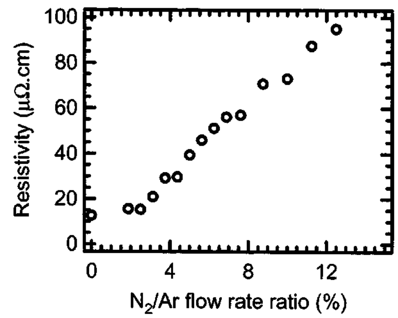
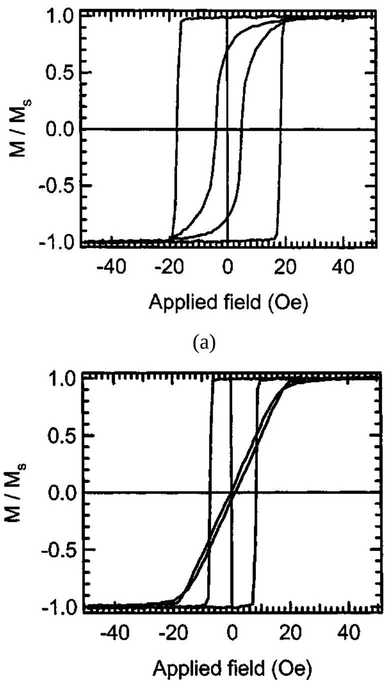


Fig. 4. Resistivity of FeCoN films deposited at different N_2/Ar gas flow rate ratio.



(b)

Fig. 5. (a) Typical hysteresis loop of the FeCoN single layer. (b) Hysterics loop FeCoN sandwiched between two permalloy layers.

of $5 \sim 6$%. However, the FeCoN single layer is not yet soft enough.

For the purpose of lowering the coercivity further, the FeCoN film was sandwiched with two very thin layers (5 nm) of permalloy $(Fe_{19}Ni_{81})$ as the underlayer and overlayer, respectively. The hysteresis loops of the single FeCoN layer, and sandwiched FeCoN film are shown in Fig. 5(a) and (b), respectively. It is clear the coercivity of the FeCoN single layer is about 5 and 18 Oe in the hard and easy axis, respectively; and is reduced to 0.6 and 7.8 Oe, respectively for the sandwiched FeCoN film.

Furthermore, the square easy loop, and an almost linear hard axis loop of the sandwiched FeCoN film indicate a very good in- plane uniaxial anisotropy. The anisotropy field can be determined by extrapolation to be 20 Oe, corresponding to ferromagnetic resonance frequency of about 1.9 GHz. Factors that may

IV. SUMMARY

We successfully deposited soft FeCoN single layers with a high saturation magnetization of 24.5 kG, and a coercivity of 5 Oe. A lower coercivity of 0.6 Oe, and an excellent in-plane uniaxial anisotropy with an anisotropy field of 20 Oe were achieved in the FeCoN films sandwiched between two very thin Permalloy layers. The obtained FeCoN films have a BCC lattice with strong $\{110\}$ fiber texture, and the resistivity is 55 $\mu\Omega$·cm. The data indicate that the FeCoN films are very good candidates as future write head materials.

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