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

II. EXPERIMENTAL PROCEDURE

FeCoN films were synthesized through reactive RF diode
sputtering in an argon and nitrogen atmosphere. The target com-
position 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 ap-
plied 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 magnetiza-
tion (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 be-
havior was also observed in the saturation magnetization of the
as-deposited (FeCoC10)N 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/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/Ar gas flow rate ratio of 5 \%\%--6\%\% , then the coercivity increases with the increment of the gas flow rate ratio. Similar relation between coercivity and N/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/Ar gas flow rate ratios, 0\%, 12.5\%, and 19.6\%, are shown in Fig. 3. At low N/Ar gas flow rate ratio, the FeCoN films have a BCC \(\alpha\)-Fe(Co, N) structure with a strong \{110\} fiber texture; while a significant amount of Fe\(_2\)N phase appears in the film at a high N/Ar gas flow rate ratio of 19.6\%. In addition, the \(\alpha\)-Fe(Co, N) \{110\} diffraction peak is shifted to lower angles and is much broader at higher N/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/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/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/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 saturation magnetization of around 24.5 kG and low coercivity of around 5 Oe can be realized at a N/Ar gas flow rate ratio of 5 \%\%\%--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 result in this dramatic change in the soft magnetic properties of the FeCoN films will be detailed in reference [9].
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\cdot cm. The data indicate that the FeCoN films are very good candidates as future write head materials.

REFERENCES