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Writer Materials for High Performance Hard Disk Drives

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ABSTRACT

We have investigated the magnetic properties of FeCoAlO films and FeCo films deposited on Ruthenium underlayer. An O/W improvement of about −10 dB was observed, when the pole tip materials applied to both gap sides were changed from the B_s ~20 kG material to the B_s ~24 kG FeCoAlO material. Accordingly, it is confirmed that the FeCoAlO film is effective for improving the write performance. However, compared with FeCo binary films, a little decrease of B_s for the FeCoAlO films cannot be prevented due to the added nonmagnetic elements, such as aluminum and oxygen. To solve this problem, we developed FeCo films with a Ruthenium underlayer. A several Å-thick Ruthenium underlayer contributes to the appearance of uniaxial magnetic anisotropy and the low coercivity for the FeCo films maintaining high B_s. Further write performance improvement is expected by applying the FeCo films with a Ruthenium underlayer.

Key words: FeCoAlO film, FeCo binary alloy, write head, overwrite, Ruthenium underlayer

1. INTRODUCTION

A narrower write track width and a stronger writing field without side erasure are required of an increase of areal recording density in hard disk drives. Therefore the soft magnetic materials with high magnetic induction, B_s, are required as pole tip materials to expand writing field. FeCo binary alloys are well known as a material with the highest value of B_s =24.5 kG among thermal equilibrium alloys [1]. However, it is difficult to induce magnetic softness in this system because of large magnetocrystalline anisotropy and magnetostriction. In fact, the isotropic magnetic properties and high coercivity are observed in FeCo binary alloys with the thickness of about 100 nm [2,3]. In order to enhance a writing field, it is preferable that the soft magnetic properties are shown with the thickness of 100 nm or more. Although Ohnuma *et al.* have succeeded in appearance of the magnetic softness and anisotropy control maintaining high B_s by other elements addition of the very small quantity to FeCo binary alloys [4, 5], the fact of some B_s reduction cannot be denied. On the other hand, Sun and Wang obtained soft magnetic properties from Fe-Co-N thin films with B_s of 24 kG by sandwiching a Fe-Co-N film layer between two permalloy thin layers[6, 7]. They proposed so-called "exchange induced ripple reduction mechanism", which means that the induction of magnetic softness in the Fe-Co-N film deposited onto the permalloy underlayer is caused by exchange-coupling with the permalloy underlayer during the growth. In spite of this proposal, Shimatsu *et al.* have achieved a result that even when the nonmagnetic NiFeCr underlayer is used, the magnetic softness in FeCo films is improved[8, 9]. This fact means that the improvement of the FeCo magnetic properties cannot be explained by the magnetic coupling of FeCo films. As mentioned above, the addition effect of other elements and the underlayer effect to the magnetic properties in the FeCo films are still unknown. Therefore we evaluated the magnetic properties, the thermal stability, and the corrosion resistance in the FeCoAlO films to examine the additional effects. And then we investigated the characteristics of the write heads, which actually arranged the FeCoAlO films as pole tip materials. Moreover, in order to examine the underlayer effects, magnetic properties of the FeCo films on the Ruthenium underlayer are investigated. The Ruthenium is well known as a material used for synthetic antiferromagnetic spin-valve structure or synthetic ferromagnetic media. We also investigated the influence of Ruthenium underlayer on the magnetic properties of FeCo films.

2. EXPERIMENTS

FeCoAlO films were deposited on glass and Al_2O_3-TiC substrates by RF sputtering in Ar atmosphere. The target composition was $Fe_{70}Co_{30}$ (at.%) alloy and Al_2O_3 powders, using hot-press equipment. The target of Al_2O_3 content was about 0.4 wt%. During sputtering, the magnetic field was not applied to the substrates. The film thickness was about 0.3 μm. The film was annealed under the atmospheric pressure of 8 x 10^{-5} Pa in the temperature range 230 °C – 280 °C for 3 hours. The magnetic properties were evaluated using a *B-H* loop tracer. The corrosion resistance was evaluated from the anodic polarization curve. In this measurement, the specimens were exposed to a 0.01 N KCl electrolyte at room temperature. A saturated calomel electrode (SCE) was used as the reference electrode. The film structure was characterized by means of a transmission electron microscope (TEM), an electron probe microanalyzer (EPMA), and an X-ray diffractometer (XRD) using Cu-Kα radiation. The overwrite (O/W) for the write head with pole tips composed of FeCoAlO films with B_s of ~24 kG was measured using a spin stand.

The Ruthenium underlayer and the FeCo film layer were deposited onto Si wafers by RF sputtering at an Ar pressure of 0.6 Pa. Purity of the target of Ruthenium and $Fe_{70}Co_{30}$ was set to 99.9 % or more respectively. The Ruthenium layer thickness was changed by means of the depositing time control. The FeCo film thickness was fixed at about 0.2 μm. For the film thickness identification, fluorescent X-ray spectrometric analysis was used. Magnetic properties were evaluated using *B-H* loop tracer. The structural analysis was done using XRD and TEM.

3. RESULTS AND DISCUSSION

In order to prevent degradation of the magnetic properties by thermal treatment in head fabrication processes, the materials which have the magnetic thermal stability of more than 230 °C as soft magnetic materials for heads are desirable. Fig. 1 shows the B-H curves of as-made FeCo, as-made FeCoAlO films and FeCoAlO film annealed at 280 °C made under the same sputtering conditions. In the as-made FeCo film, the easy-axis and hard-axis coercivities show 60 Oe or larger values, and clear uniaxial,

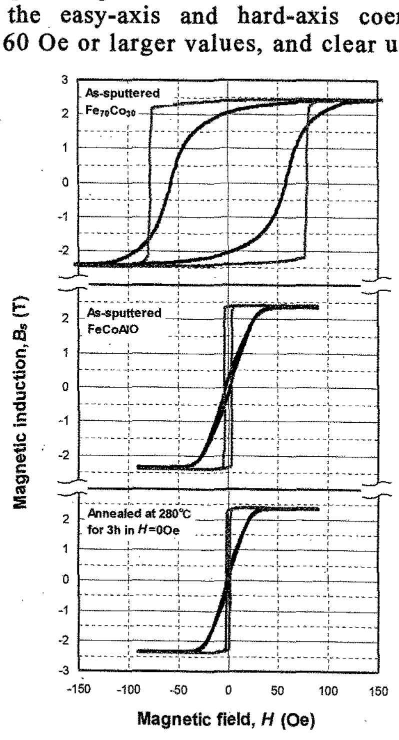

Fig.1. *B-H* curves measured along easy and hard axis for as-sputtered $Fe_{70}Co_{30}$, as-sputtered FeCoAlO films, and FeCoAlO film annealed at 280°C for 3 hours.

anisotropy is also not observed. On the other hand, in an as-made FeCoAlO film, the easy-axis and hard-axis coercivity show H_{ce}~5 Oe, H_{ch}~3 Oe respectively, and also clear uniaxial anisotropy of H_k~35 Oe. It can be said that the addition of nonmagnetic elements, such as aluminum and oxygen to a FeCo alloy is obviously effective for improving the magnetic softness. Moreover, in the thermal treatment up to 280 °C, degradation of the magnetic softness was not observed in our FeCoAlO films. This result shows that our FeCoAlO films have sufficient magnetic thermal stability to withstand head fabrication processes.

It is known that the uniaxial magnetic anisotropy of FeCo-based granular films containing an oxygen element strongly depends on the directional order induced by an applied field during sputtering, and furthermore the direction of the easy axis can be controlled by means of the field applied during annealing[4]. However, the uniaxial anisotropy was obtained in our FeCoAlO films without applying the magnetic field during sputtering. That is, induced magnetic anisotropy is not dominant in our FeCoAlO films. Therefore, it is concluded that the origin of the anisotropy in our films is different from that in the films described above. Also, It is known that the appearance of magnetic anisotropy and magnetic softness in sputtered films are closely related to the film's morphological characteristics, such as grain shape and texture[10, 11, 12]. The in-plane TEM observation was performed to consider the appearance of the uniaxial anisotropy and the magnetic softness in our FeCoAlO films in detail. An in-plane TEM image of the as-made FeCoAlO film is shown in Fig. 2 (a), and that of the FeCo film sputtered under the same conditions is shown in Fig. 2 (b) in comparison. These TEM images show fine grains when aluminum and oxygen elements are added to the

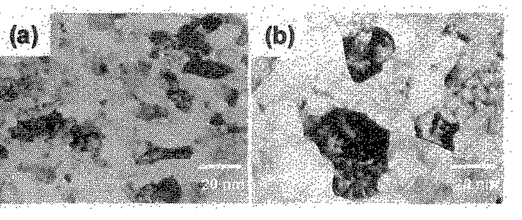

Fig.2. In-plane TEM images for (a) as-made FeCoAlO ; (b) as-made $Fe_{70}Co_{30}$ films.

FeCo film. In addition, some formations of the elongated grains, which are considered to have originated in the carousel-type sputtering, are also observed. Accordingly, it is thought that the origin of the uniaxial magnetic anisotropy in our FeCoAlO films is related to the film structure having morphological characteristics such as elongated grains. On the other hand, it seems that grain refining such as FeCoAlO film structures may lead to a reduction in coercivities.

The anodic polarization curves for the as-made FeCoAlO and $Fe_{70}Co_{30}$ films are shown in Fig. 3. The rest potential (RP) and pitting potential (PP)

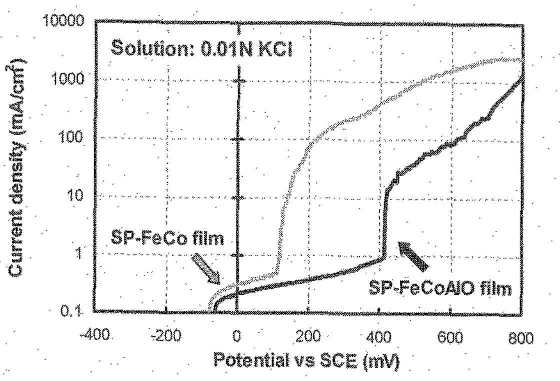

Fig.3. Anodic polarization curves for sputtered FeCoAlO and $Fe_{70}Co_{30}$ films.

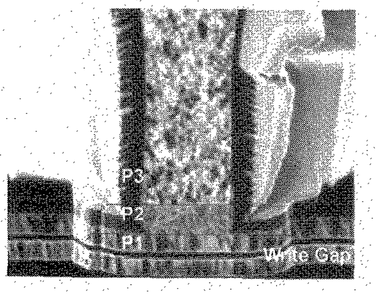

Fig.4. SEM image of the realized pole tips with FeCoAlO/CoNiFe/50NiFe trilayer structure before trimming by ion milling.

of a $Fe_{70}Co_{30}$ film are –76 mV vs. SCE and +115 mV vs. SCE, respectively. In contrast, the RP and PP of a FeCoAlO film are –60 mV vs. SCE and +410 mV vs. SCE, respectively. Although there is no difference in the RP when aluminum and oxygen are added into a $Fe_{70}Co_{30}$ film, V vs. SCE of PP becomes higher by about 300 mm. That is, stable passivity is formed. From the above results, it is thought that FeCoAlO films have sufficient corrosion resistance for magnetic head fabrication. In fact, no corrosion of FeCoAlO films is observed after electroplating and polishing in the head fabrication processes.

Fig. 4 shows a SEM image of the realized pole tips for air bearing surface before trimming by ion milling. The composite pole tips which consist of P1, P2 and P3 were applied to both sides of the write gap. The 0.3 μm-thick FeCoAlO film with B_s of 24 kG was used as P1 material, and electroplated CoNiFe and $Ni_{50}Fe_{50}$ films were used as P2 and P3 materials respectively. The O/W performance of the write head, which consists of this structure, was measured. The dependence of O/W performance on the effective write core width, WCWe, is shown in Fig. 5. The tB_r and H_c of the media used for measurements are 35 Gμm and 3500 Oe, respectively, and measurements were performed under conditions with write current I_w=37 mA and signal frequency f=133 MHz. The O/W performance improvement by about –10 dB was observed when the pole tip materials applied to both gap sides were changed from the material with B_s of 20 kG (open triangles) to the FeCoAlO material with B_s of 24 kG (solid

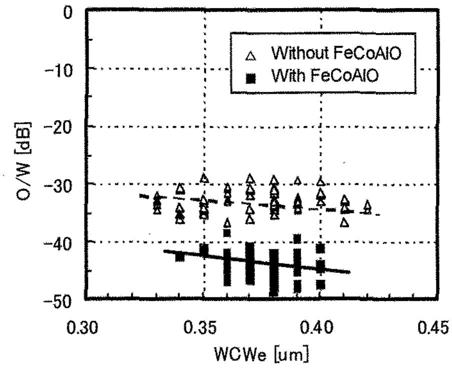

Fig.5. Dependence of the O/W on the WCWe for write heads applied to FeCoAlO film with B_s of 2.4T.

squares). The above results confirm that the FeCoAlO film is effective in improving the write performance.

However, compared with FeCo binary films, a little decrease in B_s for the FeCoAlO films cannot be prevented due to the added nonmagnetic elements such as aluminum and oxygen. Then the magnetic properties of the FeCo films in which do not contain nonmagnetic elements are measured with and without a Ruthenium underlayer. The hard axis and easy axis coercivities of the FeCo thin films with different Ruthenium underlayer thicknesses are shown in Fig. 6. It is clear that the easy axis and hard axis coercivities drop from about 60 Oe to about 10 Oe and from about 47 Oe to about 3 Oe respectively when a Ruthenium underlayer as thin as 5 Å is put under the FeCo film, and then they stay between 10-15 Oe, 3-4 Oe respectively when the Ruthenium thickness is larger than 5 Å.

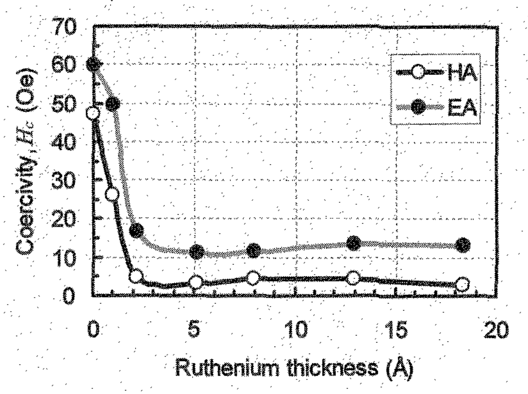

Fig.6. Coercivity for the FeCo film on Ruthenium underlayer.

Fig. 7 shows representative XRD patterns in FeCo films with and without a Ruthenium underlayer. The diffraction peaks corresponding to bcc (110) and (211) are observed. The peak intensity of (110) decreases with the increase in the Ruthenium thickness, in contrast, the peak intensity of (211) becomes higher. Accordingly it seems that a Ruthenium underlayer tends to suppress (110) orientation, and promote (211) orientation in the FeCo thin films.

In order to examine the structures in detail, TEM observation and the corresponding selected

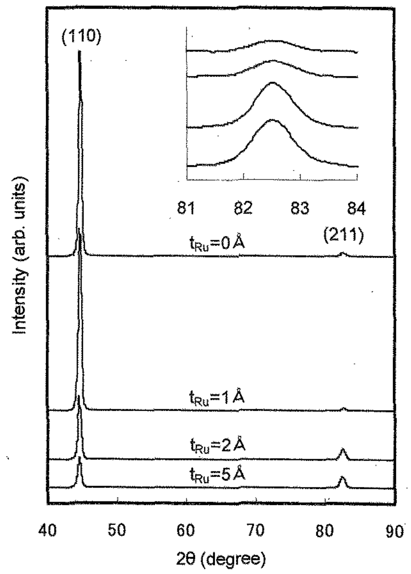

Fig.7. XRD patterns for FeCo films with different Ruthenium underlayer thickness.

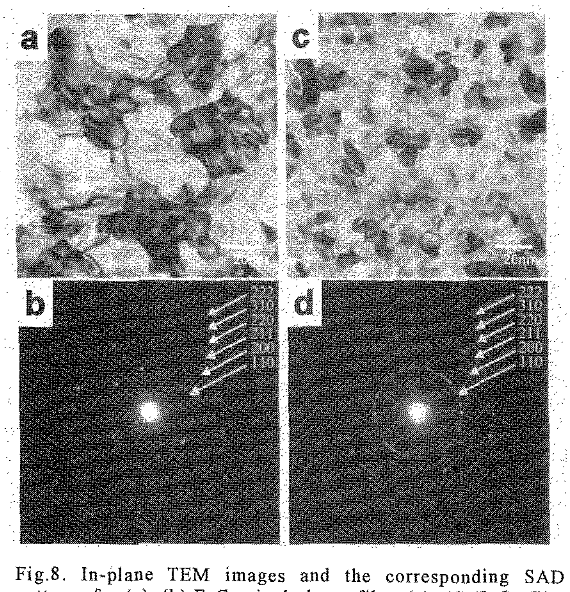

Fig.8. In-plane TEM images and the corresponding SAD patterns for (a), (b) FeCo single layer film, (c), (d) FeCo film on Ruthenium underlayer.

area diffraction (SAD) observation were performed in FeCo films with and without Ruthenium underlayer. Figs. 8 (a) and (b) show the FeCo film without the Ruthenium underlayer and (c) and (d) show the FeCo film with the Ruthenium underlayer in the TEM image and in the SAD patterns. In Fig. 8 (a), the grain size is estimated to be about 10-50 nm, which is not uniform and the formation of circular and elongated grains is observed in some places. Furthermore, in Fig. 8 (b), the strong diffraction rings corresponding to the bcc α-Fe phase appear as indexed in the SAD pattern, and this SAD pattern indicates the presence of a crystallographic texture. On the other hand, in Fig. 8 (c), circular uniform crystalline grains about 10 nm in diameter are observed everywhere. In Fig. 8 (d), the preferential orientation of (110) like the FeCo single layer films is not observed, and a weak halo ring can be observed indicating the formation of an amorphous phase in connection with refinement of crystal grains. Therefore, it seems that the appearance of low coercivity in FeCo films with the Ruthenium underlayer is due to randomly oriented nanograins and the decrease in local magnetic anisotropy by reducing the grain size.

4. CONCLUSIONS

We have developed soft magnetic FeCoAlO materials with B_s of 24 kG. The film microstructures such as anisotropic grains are critical factors for controlling the uniaxial magnetic anisotropy of the FeCoAlO films. The films have magnetic thermal stability up to 280 °C and high corrosion resistance to withstand magnetic head fabrication processes. An O/W improvement of about −10 dB is observed when the FeCoAlO materials are applied to the pole tip materials. Moreover, the Ruthenium underlayer with the thickness of several Angstrom contributes to a decrease in coercivity in the FeCo films, which have the highest B_s of 24.5 kG among ferromagnetic materials. As the FeCo films on the Ruthenium underlayer have the structural feature of suppressed bcc (110) orientation, it seems that the low coercivity is due to the randomly oriented nanograins. Therefore, by applying Ru/FeCo layer to the pole tip materials of a write head, further improvement in O/W performance can be expected.

5. REFERENCES

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