Flattop-Type Writer Using Soft Magnetic Films with High Resistivity

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To improve write performance at high frequency, a flattop-type head consisting of a flat upper yoke and sputtered soft magnetic films is proposed. The sputtered FeAlO films used as yoke materials are magnetically soft, and have a resistivity $\rho$ of $\sim 100 \ \mu\Omega \cdot \text{cm}$, a saturation magnetic flux density $B_s$ of $\sim 1.8 \ T$, and an anisotropy field $H_k$ of $\sim 25 \ \text{Oe}$. All of these values for the FeAlO films are higher than those of conventional plated NiFe yoke materials. The yoke thickness and length are 2 $\mu\text{m}$ and 18 $\mu\text{m}$, respectively. A flattop-type head containing an FeAlO yoke at a high writing frequency of more than 540 $\text{Mfpr}$ has an O/W of around $\sim 30 \ \text{dB}$ and shows good NLTS ($\sim 15 \%$). Consequently, the improvement of the write performance at high frequency is confirmed when plated 45-50 NiFe films are replaced by sputtered FeAlO films as yoke materials.

Key words: writer, write performance, soft magnetic materials, high resistivity, high anisotropy field

1. Introduction

Increasing the transfer rate of an HDD induces a deterioration in the write performance due to eddy current loss. It is important to solve this problem, especially in enterprise-type HDDs, because a higher transfer rate is required for recording at high disk rotation speeds ranging from 10000 to 15000 rpm. To improve the writing property at high frequency, the write head design is optimized according to a principle whereby the yoke size is reduced drastically without changing either the current state or the yoke materials, such as NiFe$^{1)}$. Therefore, the yoke length is becoming shorter, and has currently reached about 10 $\mu\text{m}$. However, this trend increases the difficulty of exposure positioning and photoresist pattern formation with a high aspect ratio. Manufacturing processes have been devised for the simple fabrication of write heads$^{2)}$. On the other hand, increasing the resistivity of yoke materials has been proposed as a means of suppressing the high-frequency deterioration, in addition to head shape optimization. It is known that the resistivity of sputtered single layers and laminated films is higher than that of electroplated NiFe films$^{3-7)}$. In this study, we used sputtered FeAlO films as high-resistivity yoke materials, and investigated the frequency dependence of the write performance for flattop-type heads.

2. Experiments

FeAlO films were sputtered, using hot-pressed targets on $\text{Al}_2\text{O}_3/\text{TiC}$ substrates in an Ar atmosphere of 0.6 Pa. The rf-sputtering power was 2 kW. The film thickness was controlled by varying the deposition rate, calculated by the measuring the difference in level, and was fixed at 2 $\mu\text{m}$. The film's magnetic properties were evaluated by using a $B$-$H$ loop tracer and a SQUID magnetometer. The magnetic domain structure of a trimmed FeAlO dot pattern was observed by the Bitter method. The resistivity $\rho$ was measured by a dc four-point probe method. The film structure was characterized by transmission electron microscopy (TEM). The impedance of the write head was measured by using an impedance analyzer. Writing properties such as the overwrite (O/W) and nonlinear transition shift (NLTS) were evaluated by using a Guzik 1600 tester.

(a) Conventional writer

(b) Flattop-type writer

Fig. 1 Schematic illustrations of the cross-sections of conventional and flattop-type write heads.

chemical mechanical polishing (CMP) to suppress soft magnetic deterioration. Hereafter, such a yoke is called "flattop-type head." In this study, we used sputtered FeAlO films as high-resistivity yoke materials, and investigated the frequency dependence of the write performance for flattop-type heads.

(a) Conventional writer

(b) Flattop-type writer

Fig. 1 Schematic illustrations of the cross-sections of conventional and flattop-type write heads.
Fig. 2 Relationship between the saturation magnetic flux density and resistivity for FeAlO films with various alloy compositions.

3. Results and Discussion

3.1 Magnetic properties of FeAlO films

The addition of impurity elements in the parent phase is a general technique for increasing resistivity. On the other hand, $B_s$, inevitably decreases when the resistivity $\rho$ increases. Figure 2 shows the relationship between $B_s$ and $\rho$ for FeAlO films sputter-deposited while varying the Al$_2$O$_3$ contents of the targets. $B_s$ decreases linearly with increasing $\rho$. It is known that, for FeAlO granular alloys, oxide is formed in the intergrain\textsuperscript{4}). However, the analyzed results of XRD and EPMA in our FeAlO films show that the Al and O elements are dissolved in the bcc-Fe phase\textsuperscript{7}). It is guessed that there is a critical alloy composition at which the material changes from a solid solution to a granular state, and that the increase in the value of $\rho$ for our films is dominated by impurity scattering. In this study, the values of $B_s$, $\rho$, and the film thickness $t$ of the sputtered FeAlO films were set to $B_s \sim 1.8$ T, $\rho \sim 100 \ \mu\Omega$cm, and $t = 2 \ \mu$m, respectively. The reasons for these choices are as follows: (1) shortening of the deposition time; that is, the deposition rate ($\sim 20$ nm/min) of sputtering is much lower than that ($\sim 200$ nm/min) of electroplating; (2) fear of a deterioration in the dc soft magnetic properties of the thicker film; (3) control of the ac magnetic properties, such as the skin effect; and (4) suppression of an extreme decrease in the magnetic flux in the yoke. For instance, the thickness of 80 NiFe yoke ($B_s \sim 1$ T) used in conventional write head is approximately 4 - 5 $\mu$m.

Figure 3 shows the as-deposited FeAlO film's $B$-$H$ curves, which were measured by using an Al$_2$O$_3$-TiC wafer with a 5-inch diameter. The sputtering conditions for this film were similar to those for the sputtered FeAlO yoke material applied to the write head. For a 2-µm-thick FeAlO film, the anisotropy field and the coercivity measured along a hard axis show $H_{kh} = 25$ Oe and $H_{ch} = 1.0$ Oe, respectively. Accordingly, good magnetic softness with uniaxial anisotropy is realized, despite the large thickness of 2 $\mu$m. The resistivity of the FeAlO film is two to five times that of the electroplated NiFe films. Additionally, the $B_s$ and $H_k$ are larger than those of plated films with a similar film thickness ($B_s = 1 - 1.5$ T and $H_k = 2 - 5$ Oe). From these results, the use of FeAlO film in yoke materials can be expected to improve the high-frequency write performance by decreasing the magnetic resonance loss in addition to suppressing the eddy current loss.

Whereas a conventional yoke is formed by a process for lifting off the photoresist after the frame plating, the flattop FeAlO yoke in this study was trimmed by ion milling, and the photoresist pattern was used as a mask. As shown in Fig. 4, the Bitter pattern of the trimmed FeAlO dot makes a closure domain. This observed result reflects the uniaxial anisotropy in the as-deposited state. It is thought that FeAlO films can be used as yoke materials, because the FeAlO film preserves the uniaxial anisotropy after forming a fine pattern; that is, the magnetic flux inflow into the pole tip is caused by the magnetic behavior of the yoke, which uses a reversible and high permeability in a hard axis.
In accordance with the above-mentioned results, the soft magnetic properties and uniaxial anisotropy are still maintained in the 2-μm-thick film. As shown in Fig. 5, when the Al and O elements are added, the grain size is less than 5 nm and no obvious columnar grain is observed. Moreover, this film has a tensile stress $\sigma$ of $\sim+0.15$ GPa and positive magnetostriction $\lambda$ of $\sim+6.1 \times 10^{-6}$. It seems that these features relate to the appearance of soft magnetism with in-plane anisotropy.

### 3.2 Write performance of a flattop head

Figure 6 shows a cross-sectional SEM image of an actual flattop head. In this figure, the yoke Y1 and Y2 are composed of FeAlO films, and the yoke length YL is about 18 μm. Since the purpose was to investigate only the domination of the yoke materials with high resistivity, electroplated 45-50 NiFe was used for poles P1 and P2, and the optimum shape design of the pole tips was not reflected. The track width was 0.4 μm.

It is very difficult to measure the magnetic properties of fine patterns such as magnetic heads. However, the permeability corresponds to the inductance. Thus, the magnetic response of a magnetic head can be guessed by measuring the impedance. Figure 7 shows the frequency dependence of the impedance and resistance components for a flattop head in which FeAlO films are used. It is understood that because the inductance L is almost constant up to around 2 GHz, the magnetic response remains at a high frequency.

Since a good write performance at high frequency can be predicted from the results shown in Fig. 7, the write performance was measured by using a Guzik 1600 tester at a linear density 560 kFOI and write current $I_w = 40$ mA. In this measurement, the increase in the writing frequency corresponds to the increase in disk rotation speed. Therefore, a slider with low rotation speed dependence was selected, because the flying height depends on the disk rotation speed. The flying height was about 18 nm. In addition, to compare with the FeAlO flattop heads, the performances of the write head, consisting of a plated 45-50 NiFe yoke and having the same shape, were measured. Figure 8 shows the writing frequency dependence of the overwrite (O/W) for flattop heads when a medium with dynamic $H_c = 8000$ Oe was used. The $t_{Br}$ of the medium was 52 Gμm. The O/Ws of the FeAlO and NiFe yoke heads are almost equal at a frequency of less than 420 Mfrips. In the writing frequency range above 540 Mfrips, the flattop head with the...
FeAlO yoke maintains an O/W of about $-30$ dB, while the O/W of the NiFe yoke head gradually deteriorates with an increase in frequency. In addition, as shown in Fig. 9, the nonlinear transition shift (NLTS) for the flattop head with the FeAlO yoke takes a low value of less than 15%. The above experimental results confirm that the FeAlO films are effective for improving the O/W and realizing good NLTS. This may be attributed to the fact that the preservation of the O/W and the good NLTS at high frequency is closely related to the improvement of the magnetic flux response from the yoke into the pole tip, because the eddy current loss and the ferromagnetic resonance loss at high frequency are decreased by using FeAlO materials with high resistivity and anisotropy fields. The flattop head structure is necessary for maintaining good soft magnetic properties in the sputtered FeAlO films. However, further considerations are necessary concerning improvement factors, such as the head shape and yoke materials, of the high-frequency performance for these write heads.

4. Conclusions

FeAlO films sputtered using hot-pressed targets show soft magnetic properties with uniaxial anisotropy. The FeAlO films used as yoke materials, had $\rho$ of $\approx 100 \ \mu\Omega\text{m}$, $B_s$ of $1.8$ T, and $H_k$ of $\approx 25$ Oe, which are higher than the values of plated NiFe films. A flattop head composed of an FeAlO yoke at a high writing frequency of more than 540 Mfpr maintained an O/W of around $-30$ dB and showed good NLTS ($\approx 15\%$). Accordingly, use of the sputtered FeAlO yoke in a flattop head is effective in improving the frequency response of the write performance.

References


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