HIGH-DENSITY MAGNETIC RECORDING PROPERTIES OF EVAPORATED Co-Ni-O THIN FILM

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Abstracts

The Co-Ni-O thin film formed by the CVI process has a columnar structure that slants diagonally in relation to the substrate. It is known that, for the reasons described above, the film has no easy-to-magnetize direction within the plane and that there is a directionality in output reproduction. [1],[2] The orientation of the easy-to-magnetize direction of Co-Ni-O thin film has been analyzed.

The head has also been studied with the objective of fully exploiting the potential capability of the recording medium. In addition, a method for reducing magnetic noise, a problem involving the recording medium itself, has been discussed.

INTRODUCTION

It is well known that metallic magnetic thin films suitable for high-density magnetic recording can be formed by evaporating Co-Ni in an O_2 atmosphere using the Continuous-Variation-of-Incidence (CVI) method. Such Co-Ni-O thin films have a columnar structure that is slanted and bent in relation to the in-plane. As a result, their easy-to-magnetize direction is tilted in relation to the in-plane. This results in a difference in output with respect to the tape running direction. We have discussed the three topics: (1) the orientation of the Co-Ni-O thin film, (2) the recording/playback characteristics when using a narrow-gap head, and (3) the output vs. noise in columnar structures.

EXPERIMENT

After a vacuum chamber was evacuated to 1×10^{-5} Torr or less, Co(80)Ni(20) was melted using an electron beam and allowed to evaporate. The deposit formed on a 10 μm thick PET substrate by the CVI process as O_2 was introduced created the Co-Ni-O thin film.

To determine the orientation of the Co-Ni-O thin film, two sample tapes having a minimum incidence angle ($\theta_{min.}$) of 25° and 45° , respectively, were prepared. Details regarding these sample tapes and the reference sample tapes appear in Table 1. After magnetizing these tapes in direction θ as shown in Fig. 1, the residual magnetization direction ϕ was measured on the VSM. The direction ϕ was measured by determining the direction at which the magnitude of the residual magnetization at $\phi + 90^\circ$ became zero.

Sample B shown in Table 1 was used to measure high-density recording characteristics. Using the head shown in Table 2, square-wave signals were recorded and reproduced at a relative speed of 1.57 m/sec.

Fig.1 Illustration of direction

For noise analysis, tapes shown in Table 4 having four types of columnar structures (shown in Table 3) were prepared. Each of the samples was set at the minimum incidence angle $\theta_{\min} = 25^\circ$. To prevent differences in their spacing losses, their surface roughness and the

thickness of the surface oxidation layer were made identical. Using an amorphous head with a GL length of $0.23 \mu\text{m}$, a sine wave signal of $0.54 \mu\text{m}$ in the recording waveform was recorded on the tapes and reproduced at a relative speed of 3.8 m/sec.

Table 1. Tapes used for determining the direction of magnetization

Tape	A	B	Ref. 1	Ref. 2
Magnetic layer	Co-Ni-O	Co-Ni-O	Metal-particle	Co-Cr
Thickness of the magnetic layer	160 nm	160 nm	$3 \mu\text{m}$	160 nm
Minimum incidence angle $\theta_{\min}$.	25°	45°	—	—
Easy-to-magnetize direction	Diagonal	Diagonal	In-plane	Vertical

Table 2. High-density recording heads

Head	A	B
Material	Single-crystal ferrite, S303U	←
Track width	$28 \mu\text{m}$	←
Number of turns	16	←
Gap length	$0.12 \mu\text{m}$	$0.22 \mu\text{m}$
Gap depth	$45 \mu\text{m}$	←

Table 3. Types of columnar structures

Type	1	2	3	4
Columnar structure

Table 4. Tapes for noise analysis

Tape	C	D	E	F
Type (Table 3.)	1	2	3	4
Per-layer thickness (nm)	150	75	75	50
Number of layers	1	2	2	3
Total thickness (nm)	150	150	150	150
Hc (Oe)	1080	1090	1080	1120

RESULTS AND DISCUSSION

Magnetization Characteristics

Fig. 2 shows the relationship between the direction θ of the magnetic field applied on the VSM and the direction ϕ of the residual magnetization. The MP, a kind of in-plane media, has an orientation which is very much close to that of an ideal in-plane medium. The Co-Ni-O thin film has its easy-to-magnetize direction in the diagonal direction inside the plane, indicating that it has an exceptionally good orientation comparable to that of the MP. The film's easy-to-magnetize direction is slanted in plane by about 20° , and this angle of inclination is dependent on the minimum incidence angle $\theta_{\min}$ by the CVI process. In the case of Co-Ni-O thin film, asymmetric results were observed, as shown in Fig. 2, in the vicinities of $\theta = 90$ to 110° and of $\theta = 110$ to 130° , with steeper changes being observed in the vicinity of $\theta = 90$ to 110° . This asymmetry is not a problem coming from the measuring techniques involved, e.g. due to the phenomenon of hysteresis. This may be because the columnar structure of the Co-Ni-O thin film is not of a simple diagonal column but bent in shape as shown in Fig. 3.

For reference, the Co-Cr film, a vertical magnetic recording medium, is shown. As seen in Fig. 2, the characteristic is closer to that of an isotropic

Fig.2 Direction of apply field v.s. Direction of magnetization

Fig.3 SEM cross-section micrograph of film produced by CVI method

medium rather than the vertical recording medium. The Co-Ni-O film has a much stronger orientation.

It has been reported that the spacing loss is very high $-(50 \text{ to } 70) \text{ d}/\lambda \text{ dB}$ [3] even in the recording process of the Co-Cr film. In contrast, the spacing loss of Co-Ni-O film is very low, measuring $-(5 \text{ to } 10) \text{ d}/\lambda \text{ dB}$. This low spacing loss may be due to the fact that the Co-Ni-O film's total thickness is thin, which allows the head to maintain sufficient recording ability even with some spacing occurred. It may also be pertinent that the direction of magnetization is maintained constant at the direction inclined in-plane by about 20° even when the direction of the magnetic field changes somewhat.

Narrow gap head and recording properties

Fig. 4 shows the recording/reproducing characteristics of a narrow-gap head, with emphasis placed on the high-density recording characteristic. Fig. 4 reveals that the narrow-gap head substantially improves the output reproduction in the high-frequency range although there is some reduction in output reproduction in the low-frequency range. Tape B in Table 1 was used for the measurement; 130 Kbpi

Fig.4 Frequency characteristics of Co-Ni thin film with narrow-gap ring head

was achieved with D50 by making the GL length $0.12 \mu m$. Due to processing technique limitations, a ferrite head of $0.12 \mu m$ (the GL length) was used. Our conclusion is that the recording characteristic of Co-Ni-O thin film has not yet been fully exploited. In the future, we will conduct studies to finalize the optimal length of the GL, to determine the best material for the head, to design separate heads for recording and playback, etc. The noise level measured at this time has not yet been accurately evaluated. Our studies will continue.

Columnar structure and noise level

Table 5 summarizes the relationship between the three different types of columnar structures and the respective noise levels of the reproduced outputs. For the RF outputs, the direction in which the head strokes the column in the normal fashion is the higher direction. The direction in which the head strokes the column in the reverse fashion is the lower direction. The directionality in the reproduced outputs is greatly influenced by the layer which does not directly contact the head. Little directionality is observed with type II. From Table 5, we can see that directionality is not a problem of a mechanical nature, like the floating of the tape away from the head, but that of magnetic orientation. On the other hand, it is known that the noise level falls when a double-layer structure is adopted. This is true irrespective of the column's directionality. Fig. 5 shows the C/N improvement effect achieved by the adoption of a multi-layer structure. An improvement by 2.5 dB in the C/N over the single-layer construction is achieved with the double-layer construction and an improvement by 3.5 dB is achieved with the three-layer structure. In the case of the single-layer construction (type I), improvements in the surface property and H_c , Br or Br/Bs composition may enhance the RF output performance. However, when the noise of the medium itself is at issue and the noise levels of the peripheral equipment are sufficiently low, an RF

Table 5. Columnar structure and recording properties

Tape		C	D	E
Type (Table 3.)		1	2	3
Relative output (dB)	Higher direction	0	-0.9	-0.2
	Lower direction	-2.8	-1.7	-2.6
Output difference		2.8	0.8	2.4
Relative noise level		0	-2.6	-2.1
C/N		52.3 (± 0)	54.0 (± 1.7)	54.8 (± 2.5)

Fig.5 Columnar structure v.s. C/N ratio

output improvement by 1 dB will accompany a 0.7 to 1.0 dB increase in noise over the entire band. This will result in only a nominal improvement of 0 to 0.3 dB in the C/N.

Even with Co-Ni-O thin films formed by the CVI process, the presence of zig-zag type domains can be observed in low H_c (500 to 600 Oe) film. The Lorentz image is not clearly visible under the condition of 1000 Oe, though. From a qualitative point of view, noise levels can be improved using a multi-layer construction through the synergism of the reduced domain size and the effective compensatory action of the zig-zag pattern. As shown in Fig. 3 (a) and Fig. 3 (b), a reduction in the domain size can be expected when the size of the columnar

structure is reduced through multi-layer construction. However, further study of this matter may be required.

SUMMARY

The following knowledge has been obtained regarding the magnetic and magnetic recording properties of the Co-Ni-O thin film formed by the CVI process:

- i) The easy-to-magnetize direction of Co-Ni-O thin film is in the slanted direction in-plane, showing a very high degree of orientation comparable to that of the MP.
- ii) By using a narrow-gap head, it is possible to record 130 Kbp with D50.
- iii) By adopting a three-layer construction, the C/N can be improved by 3.5 dB, allowing a C/N of 54.8 dB at a recording wavelength of $0.54 \mu\text{m}$.

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