PERPENDICULAR MAGNETIC RECORDING WITH A COMPOSITE ANISOTROPY FILM

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ABSTRACT

For a recently proposed perpendicular recording system, a composite anisotropy medium has been developed to improve the recording sensitivity of the perpendicular recording head. The medium is composed of a Fe-Ni soft magnetic film and a Co-Cr perpendicular anisotropy film, which are successively deposited on a base by an r. f. sputtering. By using the new double layer medium, an extremely high recording sensitivity could be obtained, compared with the single layer Co-Cr medium. The recording current needed to saturate the double layer film decreased to one-tenth of that for the single layer Co-Cr film. Although the Fe-Ni layer was soft magnetic material, neither deterioration of the frequency response nor peak shift was observed for the double layer film. The reproduction with a perpendicular head was also investigated, and a high output voltage and a high signal-to-noise ratio were obtained.

INTRODUCTION

It was pointed out that an extremely high density recording can be realized by a new perpendicular magnetic recording system. A perpendicular head,[1,2] proposed by the authors, has the main pole of magnetic thin film which contacts perpendicularly with the recording medium to record signal. The recording medium is a Co-Cr perpendicular anisotropy film prepared by an r.f. sputtering.[3]

It is expected that, from a theoretical analysis of the demagnetization mechanism, the perpendicular recording has the magnetization mode essentially suitable for high density digital recording.[1] However, a large amplitude of record current (or magneto-motive force) is needed as compared with a conventional ring head, since the perpendicular head has an open structure in its magnetic circuit.[2] To decrease the saturation record current, therefore, the double layer recording medium composed by thin films of Co-Cr and Fe-Ni alloy was developed. The Fe-Ni film with the anisotropy in plane was deposited by an r.f. sputtering between the base material and the Co-Cr perpendicular anisotropy film. It was ascertained that the saturation record current can be decreased markedly by using the medium. The remanent magnetization will be deduced as a horseshoe type magnetization mode[1] in the cross section of the recording medium. In this paper, the perpendicular recording characteristics of the composite anisotropy film are presented. The reproduction of signal by the perpendicular head is also discussed.

A COMPOSITE ANISOTROPY RECORDING MEDIUM

Fig.1 a) shows a method of the perpendicular magnetic recording on the composite anisotropy recording medium. M(//) and M(⊥) in the figure represent the thin films of the Fe-Ni and the Co-Cr alloys which are deposited successively by an r.f. sputtering on the non-magnetic base material. The Fe-Ni film sputtered on the base material has an easy axis of magnetization lying in the film plane. The Co-Cr film sputtered on the top surface of the medium is a perpendicular anisotropy film[1,3] that realizes a perpendicular magnetic recording. Both films are 0.5 $\sim$ 1 μm in thickness and 500 $\sim$ 600 emu/cc in saturation magnetization. Recording was made by the main pole which is in contact with the Co-Cr film and magnetized by the auxiliary pole excitation.[1,2]

The head has practical merits that the perpendicular field can always be applied to the medium, and that the effect of the recording demagnetization in short wavelengths is very small.[2] However, it was obtained that, for the single layer Co-Cr recording medium, the amplitude of saturating record current for digital signal is about 10 times larger as compared with the ordinary longitudinal recording by a ring-type head.[2] The fact is reflected by a large magnetic reluctance of the head due to the presence of an air gap between the main and the auxiliary poles.

A composite anisotropy recording medium has been developed with the aims of the decrease of the magnetic reluctance of the air gap, and of the increase of the recording sensitivity of the perpendicular head. By a presence of the Fe-Ni film at the bottom surface of the perpendicular anisotropy Co-Cr film, the following effects may be deduced.

a) In the recording process, the Fe-Ni film acts to decrease the magnetic reluctance of the head, since a part of the magnetic path is made for the flux induced by the auxiliary pole as shown in Fig.1 a). The fact means that the composite anisotropy film is effective in reducing the amplitude of record current for perpendicular recording. The result means also that, from the reciprocity theorem, the reproducing sensitivity of the perpendicular head can be improved by using such recording medium.

b) In the remanent state as shown in Fig.1 b), the Fe-Ni film acts to rotate the magnetization vector to establish a horseshoe type magnetization mode[1] in the medium. The result means that the remanent magnetization is increased, since the demagnetizing field in the mode is decreased, as compared with the pure perpendicular magnetization mode for the Co-Cr film alone.

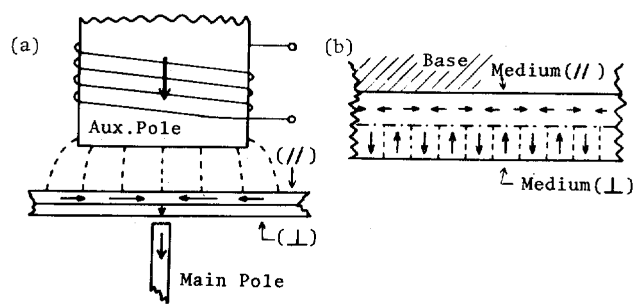

Fig.1 Effect of Fe-Ni layer in perpendicular recording process (a) and remanent state (b).

Fig.2 shows a cross-sectional view of the composite anisotropy film which was observed by using a scanning electron microscopy(SEM). The specimen was prepared by ripping the film after dissolving the polyimide base in hydrazine hydrate. Reffering to Fig. 2, it is seen that the crystallite structure of the lower Co-Cr layer is quite different from that of the upper Fe-Ni layer. The former has a columnar structure composed of closed packed fine particles, which grow perpendicularly from the surface of the Fe-Ni layer. The column diameter was estimated from the SEM image to be about 0.1 μm for the film of thickness 1.0 μm. The fact agrees very well with the result of transmission electron microscopy.[3] The columnar structure is closely related to the c-axis orientation of hcp structure of the Co-Cr, which is the origin of the perpendicular anisotropy. On the other hand, the Fe-Ni layer has a fcc structure, and exhibits no micro-structure, sug-

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gesting homogeneity in the layer of relatively large thickness of 0.5 μm. Therefore, the Co-Cr layer behaves as a perpendicularly magnetizable medium and the Fe-Ni layer acts as highly permeable back layer to improve the recording sensitivity.

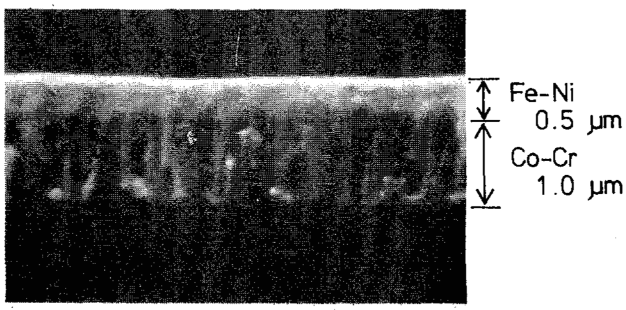


Fig.2 Scanning electron micrograph of cross-section of composite anisotropy medium.

PERPENDICULAR RECORDING CHARACTERISTICS

(i) Reproduction by ring-type head

Fig.3 is the reproduced voltage vs. recording magneto-motive force characteristics in all 1's NRZ recording at the densities of 0.2 kBPI and 45 kBPI. In the figure, the solid and the dotted lines are measured curves for the composite anisotropy medium (double layer medium) and the single layer medium, respectively. Both the Co-Cr and the Fe-Ni layers of the composite anisotropy medium are 0.5 μm in thickness, and the Co-Cr single layer medium is 1 μm in thickness. The coercivity and the saturation magnetization of Co-Cr layer in both media are about 1200∼1300 Oe. and 600 emu/cc, respectively. The recording was made with the perpendicular head having the main pole of a Fe-Ni electro-deposited film of 1 μm thick and the auxiliary pole of Mn-Zn ferrite of 0.7 mm thick. The reproduction was made with a ring-type head having the effective gap length of 0.67 μm. As shown in the figure, the recording sensitivity in the composite anisotropy medium becomes about 10 times larger in comparison with the single layer medium and reaches almost the same order as the ordinary longitudinal recording. Moreover, it is observed that the reproduced voltage scarcely drops after the saturation in high densitites. The fact means that the recording demagnetization does not take place even for the double layer medium.

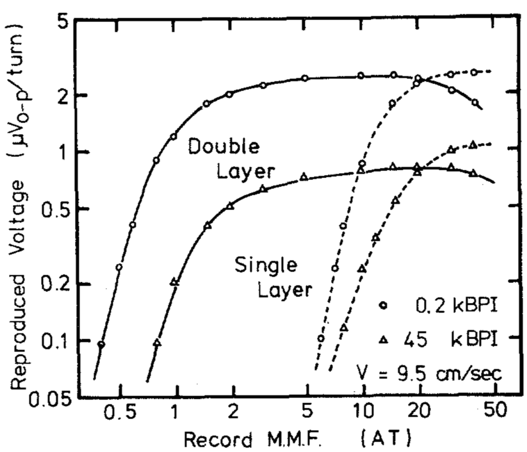


Fig.3 Reproduced voltage vs. Recording magneto-motive force characteristics.
(linear velocity: 9.5 cm/sec.)

Fig.4 shows the reproduced voltage vs. bit density characteristics measured for the double layer (solid line A) and the single layer (dotted line B) media in the saturation recording of all 1's NRZ signals. Nevertheless soft Fe-Ni film is included, the frequency response curve of the double layer medium is almost the same as the single layer medium. In both curves, the null point and the second peak in the amplitude of the reproduced voltage appear at about 75 kBPI and 100 kBPI, respectively. The wavelength of the null point corresponds to the effective gap length (Gpe=0.67 μm) of the ring-type reproducing head. The maximum recording densities (D_{50}) for both curves are about 40 kBPI, but the result shows that the recording density has been limited by the gap loss of the reproducing head.

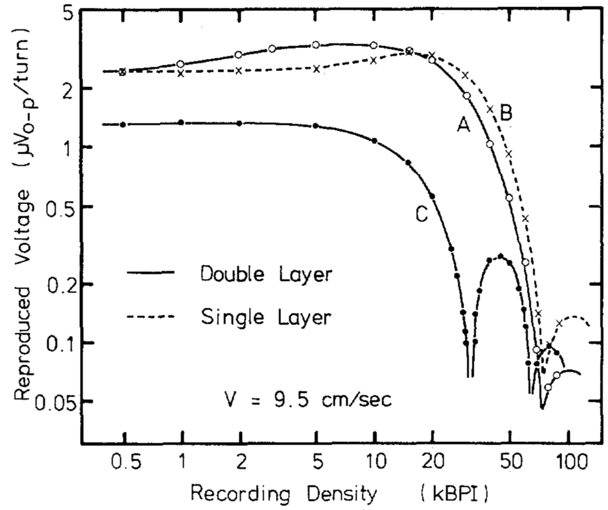


Fig.4 Recording density characteristics reproduced by ring head (curves A and B) and perpendicular head (curve C). (velocity: 9.5 cm/sec.)

Fig.5 is a measured result of the peak shift ΔX_p, which is obtained as an increase of the reproduced bit interval X to the original bit inerval X_o in the recording of 2-bit pattern, that is $\Delta X_p = X - X_o$. To obtain the peak shift, the output pulses of a ring-type head were once differentiated and the distance between two pulses was measured.[4] In the figure, it is found that the peak shift in perpendicular recording is very small in quantity as compared with the ordinary longitudinal recording and it mostly depends on the reproducing head gap. Moreover, the peak shift scarcely depends on the recording conditions, such as the recording magneto-motive force, the medium thickness and the main pole thickness of perpendicular head.

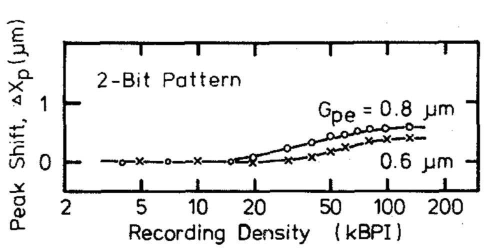


Fig.5 Peak shift vs. bit density characteristics for various gap length (Gpe.).

Fig.6 a) is the reproduced waveform in low density (0.2 kBPI) of all 1's NRZ signals. The reproduced waveform is quite different from the conventional one, but it is readily interpreted by reciprocity theorem using the head field function of the ring-type head and the step change perpendicular magnetization in the medium.

Fig.6 b), c) and d) are the reproduced waveforms for 2-bits,3-bits and 4-bits NRZ signals at the density of 30 kBPI. Although the reproduced waveforms becomes sinusoidal because of the limitation of the gap loss of the reproduce head, the amplitude of each pulses are still constant even for the 3-bit and 4-bit signals. Moreover, it is seen from the figures that the superposition principle is applicable in determining the waveforms of a finite number of bits. The result corresponds to the fact that any severe recording demagnetization does not take place in perpendicular magnetization as has been shown in Fig.3.

(a) all 1's NRZ at 0.2 kBPI

(b) 2-bit pattern at 30 kBPI

(c) 3-bit pattern at 30 kBPI

(d) 4-bit pattern at 30 kBPI

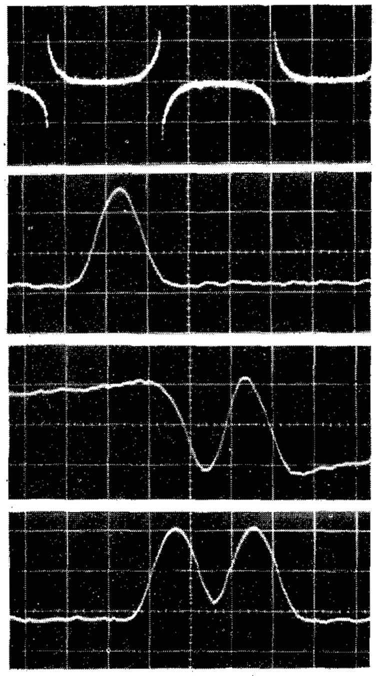
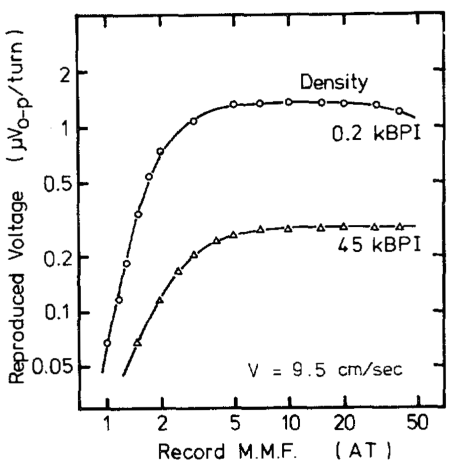


Fig.6 Reproduced waveforms observed by ring head for double layer medium.

(a)



(b)

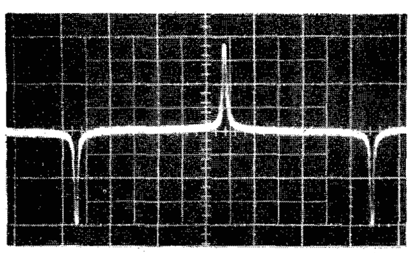


Fig.7 (a) Reproduced voltage vs. recording magnetomotive force measured by perpendicular reproducing head. (b) Reproduced waveform at 0.2 kBPI. (velocity: 9.5 cm/sec.)

(ii) Reproduction by perpendicular head

Most successful effect of the composite anisotropy medium lies in the fact that the reproduction by the perpendicular head becomes possible. Fig.7 (a) is the reproduced voltage vs. recording magneto-motive force measured by using the perpendicular head for both record and reproduction. The perpendicular head is the same as the recording head used in Fig.3 and the detection of the signal was made with a coil wound around the auxiliary pole. The amplitude of the reproduced voltage by the perpendicular head has been reached about a half of the ring head reproduction, as shown by comparison with Fig.3 and Fig.7 (a).

In Fig.7 (b), the reproduced waveform at low density(0.2 kBPI) is shown, which is similar to the waveform in the conventional longitudinal recording by ring-type head. The half pulse width is very narrow ($W_{50} \leq 3$ μm) and almost constant in wide range of the recording magneto-motive force.

The curve C in Fig.4 represents the reproduced voltage of perpendicular head vs. recording density characteristics in saturation recording of all 1's NRZ signals. The first and the second null points are observed at the densities of 32 kBPI (wavelength 1.6 μm) and 65 kBPI (wavelength 0.8 μm), respectively. These null points can be shifted to higher density by using a thinner main pole. From the results, it is evident that the practical high density recording and reproducing system will be realized by using the perpendicular head and the composite anisotropy medium.

CONCLUSIONS

The foregoing results indicate that;

a) The saturation magneto-motive force for the composite anisotropy medium can be decreased markedly as compared with the Co-Cr single layer medium. At present, the sensitivity of perpendicular recording has been reached to about a half of the longitudinal recording with a ring-type head and the γ-Fe_2O_3 magnetic tape.

b) The amplitude of the reproduced voltage of a perpendicular head can be increased by using the composited anisotropy medium. Since the thickness of the main pole of the head corresponds to the gap length of the ring-type head, a thinner main pole must be developed for the reproduction of signals in high densities.

c) Although the composite anisotropy medium includes the Fe-Ni film of low coercivity, the deterioration of the reproduced voltage vs. recording density characteristics is very small. It was ascertained experimentally that the recording characteristics in high densities deteriorate markedly when the recording was made with a ring-type head on the same medium. Therefore, the superior frequency response curve may be interpreted by the strong interaction[2] between the main pole and the composite anisotropy medium.

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