R/W CHARACTERISTICS OF RING HEAD/Co-Cr MEDIA WITH SOFT MAGNETIC UNDERLAYER

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Abstract--- Read/write characteristics of a combination of a ring head and a Co-Cr medium with a very thin soft-magnetic underlayer are experimentally studied in terms of saturation magnetization of the Co-Cr layer and spacing between head and medium. At narrow spacing, optimum saturation magnetization is in the range of 300-400 emu/cc. Reproduced voltage at low recording density in the double-layered media is always larger than that in single-layer media in the range of 20-200 nm-thick protective layer. However, recording density characteristics of double-layered media, particularly at large spacing, are inferior to those of single-layer media because recording density characteristics at large spacing are strongly affected by a slight deterioration in the Co-Cr layer's magnetic properties. Computer simulation shows that reproduced output is remarkably enhanced by using double-layered media, particularly at a recording density below 100 kFCI.

INTRODUCTION

Perpendicular magnetic recording is suitable for high density recording, since the demagnetizing field becomes smaller as recording density increases. However, reproduced voltage must be further improved to achieve high density recording systems.

In a ring-head/Co-Cr medium combination, some Co-Cr films with low coercivity initial growth layers show higher output signals than highly oriented films^{1,2,3}. We thought the reason to be an effect of decreasing the demagnetizing field by forming horse-shoe magnetization. Therefore, to improve reproduced voltage, a soft-magnetic underlayer was intentionally deposited to replace an initial layer. It has been found that a medium with a Co-Cr layer directly deposited onto a very thin (10 nm) Ni-Fe underlayer, produced a 1.3 times higher output signal than a single-layer medium^{4,5}. However, when using a thicker underlayer, magnetic properties of the Co-Cr layer were deteriorated and recording density characteristics were affected. Inserting a Ti interlayer between the Co-Cr layer and underlayer is one method of improving perpendicular anisotropy of Co-Cr film. With this method, an 80nm thick underlayer resulted in 1.5 times higher output without affecting recording density characteristics. However, medium noise became much larger, and signal to noise ratio was lowered⁶.

This paper reports dependence of read/write characteristics on saturation magnetization and spacing for double-layered media with

a very thin underlayer, which is most advantageous experimentally for signal to noise ratio. Effects of decreasing the demagnetizing field by using a soft-magnetic underlayer are also discussed, based on results of computer simulation.

EXPERIMENTS

Samples were prepared by vacuum evaporation onto polyimide substrates. Thicknesses of the Co-Cr layer and the soft-magnetic underlayer were 200 and 10 nm, respectively. The saturation magnetization ranged from 200 to 500 emu/cc by change of the Cr contents. Read/write characteristics were evaluated using a metal-in-gap head. An effective gap length of 0.35 μm was selected to ensure saturation recording, even at large spacing. The spacing between the head and recording layer of the medium was varied by the protective layer thickness, which ranged from 20 to 200 nm.

EXPERIMENTAL RESULTS

Magnetization of the Co-Cr layer with soft-magnetic underlayer is enhanced by forming horse-shoe magnetization. Therefore, increasing the saturation magnetization of the Co-Cr layer is expected to be effective in improving the output signal. Saturation magnetization (Ms) dependence of reproduced voltage at 2 kFCI and -6 dB recording density (D_{50}) is shown in Fig.1. Magnetic properties of the samples are listed in Table 1. Thickness of the protective layer

was 20 nm. Reproduced voltage is increased by increasing M_s and it saturates at around $M_s=400$ emu/cc. On the other hand, D_{50} decreases when M_s exceeds about 300 emu/cc. In this experiment, D_{50} of a small M_s medium (sample A) is low, but this may be because the coercivity of sample A is smaller than that of the other samples. M_s dependence of dipulse ratio in reproducing an isolated magnetization transition is shown in Fig.2. Dipulse ratio lowers and the waveform changes from dipulse to single pulse with increasing M_s . This indicates that as M_s increases, it becomes so difficult to record perpendicular magnetization with a ring head that D_{50} degrades. The increase in in-plane squareness (M_r/M_s) with increasing M_s is one reason for degradation of the dipulse ratio and D_{50} . From these results it is concluded that optimum saturation magnetization is in the range of 300 to 400 emu/cc. Optimum saturation magnetization for a system which requires higher output is about 400 emu/cc, while for a system which requires higher resolution, about 300 emu/cc is optimum.

Spacing dependence of reproduced voltage at 2 kFCI is shown in Fig.3. Horizontal axis indicates the thickness of the protective layer ($\delta_{pro.}$). Effective spacing between the head and the medium recording layer is about 50 nm larger than the protective layer thickness. Magnetic properties of the samples are given in Table 2. Saturation magnetization of the Co-Cr layer is controlled in the range of 300 to 350 emu/cc. Single-layer media have highly oriented Co-Cr layers deposited onto Ge underlayers. The table shows that magnetic

Fig.1 Saturation magnetization dependence of reproduced voltage and D_{50} .

Table 1 Magnetic properties of sample media.

#	δ_{pro} (nm)	δ_{CoCr} (nm)	δ_{NiFe} (nm)	M_s (emu/cc)	$H_c(0e)$		M_r/M_s	
					$\perp$	$\parallel$	$\perp$	$\parallel$
A	20	200	10	200	530	160	0.19	0.10
B	20	200	10	310	800	330	0.19	0.14
C	20	200	10	380	890	360	0.20	0.21
D	20	200	10	500	830	370	0.14	0.25

Fig.2 Saturation magnetization dependence of dipulse ratio.

Fig.3 Spacing dependence of reproduced voltage.

properties of single-layer and double-layered media are similar except that in-plane M_r/M_s of the double-layered media is a little larger than that of single-layer media. 2 kFCI reproduced voltage of double-layered media is always larger than that of single-layer media in the range of 20-200 nm-thick protective layer, as shown in Fig.3. However, D_{50} decrease of the double-layered media with increasing spacing is more severe than that of the single-layer media, as shown in Fig.4. D_{50} decrease is about 60 kFCI for double-layered media when the protective layer thickness is increased from 20 to 200 nm, while it is about 40 kFCI for single-layer media. Spacing dependence of dipulse ratio is shown in Fig.5. Dipulse ratio, as well as D_{50} , of double-layered media decreases more rapidly than that of single-layer media, with increasing spacing. The waveform of a double-layered medium with a

Table 2 Magnetic properties of sample media.

Sample	δ_{CoCr} (nm)	δ_{NiFe} (nm)	M_s (emu/cc)	$H_c(\text{Oe})$		M_r/M_s	
				$\perp$	$\parallel$	$\perp$	$\parallel$
Single-layer	200	—	300	780	300	0.20	0.09
			350	840	310	0.22	0.10
Double-layer	200	10	310	800	310	0.19	0.14
			340	1000	360	0.23	0.18

Fig.4 Spacing dependence of D_{50} .

Fig.5 Spacing dependence of dipulse ratio.

200 nm-thick protective layer is a single pulse. This indicates that perpendicular recording is so difficult with spacing that the longitudinal magnetization component becomes larger.

From these results it is concluded that a small deterioration in perpendicular anisotropy, caused by inserting a soft-magnetic underlayer, produces a change in magnetization mode and seriously damages recording density characteristics at large spacings. Therefore, a future subject of double-layered media is to establish a technology which makes it possible to deposit highly oriented Co-Cr film directly onto soft-magnetic underlayers to improve recording density characteristics in large spacing regions. On the other hand, when using a non-magnetic interlayer between recording layer and soft-magnetic underlayer, decreasing medium noise will be a subject, as reported before⁵⁾.

DISCUSSIONS

The effect of decreasing the demagnetizing field in the Co-Cr layer by using a soft-magnetic underlayer was studied by computer simulation. In this simulation, perpendicularly recorded magnetization was calculated by taking self-demagnetization in a medium into account. At first, M-H loops of a highly oriented single-layer Co-Cr medium were matched with experimental data using a modified Stoner - Wohlfarth magnetization reversal model^{6,7)}. Next, remanent magnetization distribution with a self-demagnetization was solved self-consistently using the finite element method. In this simulation, saturation

magnetization in the perpendicular direction was initially set to each bit cell of the Co-Cr layer. Finally, magnetization distribution was solved again in the presence of a soft-magnetic block which corresponded to a ring head with an infinitely small gap, and reproduced voltage was calculated from magnetic flux induced in the head. Thickness of the Co-Cr layer was 200 nm, and permeability of the head was set at 1000. An example of the M-H loops obtained by the computer simulation, along with measured M-H loops, is shown in Fig.6. The loop measured in the perpendicular direction was corrected by a demagnetizing field, which was calculated by the demagnetization factor estimated from the slope of the perpendicular M-H loop at the coercivity.

Recording density characteristics of single-layer and double-layered media are shown in Fig.7. Permeability, saturation induction and thickness of the underlayer were 1000, infinity and 100 nm, respectively. Saturation magnetization of the Co-Cr layer was 400 emu/cc. Spacing between head and medium was 50 nm. The effect of decreasing the demagnetizing field by a soft-magnetic underlayer is remarkable, particularly at a recording density below 100 kFCI. Reproduced voltage of a double-layered medium is 1.7 times larger than that of a single-layer medium at a low recording density. At a recording density above 200 kFCI, since the demagnetizing field is small even in a single-layer medium, the difference in reproduced voltage between single-layer and double-layered media is diminished.

M_s dependence of reproduced voltage at a recording wavelength of 20 μm is shown in Fig.8. The condition of the underlayer was the same as above. Reproduced voltage of the double-layered medium increases linearly with M_s , while that of the single-layer medium saturates at $M_s=400$ emu/cc. This indicates that remanent magnetization of single-layer medium reaches constant at smaller M_s , compared with that of double-layered medium, because the demagnetizing field in single-layer medium is larger than that in double-layered medium.

Spacing dependence of reproduced voltage at 2 kFCI for single-layer and double-layered media is shown in Fig.9. M_s of the Co-Cr layer was set at 300 emu/cc to be the same as in the experiment. The underlayer parameters were the same as above. As shown in this figure, at large spacing, the reproduced voltage of the double-layered medium is much larger than that of the single-layer medium, and spacing loss

Fig.6 Measured and calculated M-H loop of Co-Cr layer.

Fig.7 Recording density characteristics.

Fig.8 Saturation magnetization dependence of reproduced voltage.

of the double-layered medium is approximately the same as that of the single-layer medium. It corresponds to the experimental results in Fig.3. However, in narrow spacing regions, spacing loss of the double-layered medium is smaller than that of the single-layer medium. This is because, in a single-layer medium, the effect of recovering perpendicular magnetization caused by interaction between the head and Co-Cr layer becomes larger than for a double-layered medium in a very narrow spacing region.

These simulation results were obtained by assuming ideal perpendicular magnetization was recorded. However, from Fig.2 and Fig.5, it is proved that magnetization mode in double-layered medium changes as increasing M_s or spacing. Therefore, measured dependences of reproduced voltage on M_s and spacing differs from calculation results. For instance, actual increase of reproduced voltage with increasing M_s is larger than that calculated. It seems to be because in the experiment longitudinal magnetization component becomes larger as M_s increases.

Perpendicular magnetization distribution at the bottom of Co-Cr layer is shown in Fig.10. In this calculation, permeability and saturation induction of the underlayer were 1000 and infinity, respectively. It is found that magnetization recovery is limited to the region near the magnetization reversal. The relation-

Fig.9 Spacing dependence of reproduced voltage.

ship between low-density output and underlayer thickness is shown in Fig.11. Recording wavelength was $20 \mu\text{m}$. In this calculation, saturation induction of the underlayer was 1.0 T, the same as that of Ni-Fe film used in the experiment. In the region where the underlayer thickness is sufficient, reproduced voltage depends little on underlayer permeability. However, optimum permeability exists in thinner underlayer regions. This is caused by magnetic saturation of the underlayer near the magnetization reversal region. Therefore, to

Fig.10 Perpendicular magnetization distribution of isolated transition.

Fig.11 Underlayer thickness dependence of reproduced voltage.

increase reproduced voltage effectively, it is very important to choose an unsaturated underlayer condition (B_s , thickness and permeability). In the experiment, reproduced voltage of a double-layered medium with only a 10 nm thick underlayer is 1.3 times that of a single-layer medium. This result does not agree with calculation results using magnetic properties ($\mu=1000$, $B_s=1.0$ T) which were measured in the condition of a Ni-Fe film alone. This discrepancy may be because an actual underlayer is not easily saturated, for two probable reasons. One is that permeability of the underlayer in double-layered state is lower than $\mu=1000$. The other is that remanent magnetization in the experiment is smaller than that calculated, because of imperfect perpendicular recording.

SUMMARY

Read/write characteristics of a combination of a ring head and a Co-Cr medium with a very thin soft-magnetic underlayer were experimentally studied in terms of saturation magnetization and spacing, and the following results were obtained:

- 1) At small spacing, optimum saturation magnetization was in the range from 300 to 400 emu/cc;
- 2) Reproduced voltage at low density of a double-layered medium was always larger than that of a single-layer medium for a 20-200 nm-thick protective layer;
- 3) However, recording density characteristics of double-layered medium were greatly affected at large spacing, because of a slight deterioration in perpendicular anisotropy of Co-Cr film caused by inserting a soft-magnetic underlayer.

The effect of decreasing the demagnetizing field by the use of a double-layered medium was investigated by computer simulation. The following results were obtained:

- 1) Improvement in reproduced voltage of double-layered media was remarkable, particularly at a recording density lower than 100 kFCI;
- 2) Double-layered media were less dependent on spacing than single-layer media in a very narrow spacing region;
- 3) To effectively improve reproduced voltage, it is very important to choose an unsaturated underlayer condition.

ACKNOWLEDGEMENT

The authors thank to Dr. H. Fujiwara of Tsukuba Research Laboratory of Hitachi Maxell, Ltd. for his helpful discussions.

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