Dependence of Recording and Reproducing Characteristics on Thickness of Co-Cr Layer in Perpendicular Recording

S. Yamamoto, I. Tagawa, Y. Nakamura and S. Iwasaki

Abstract

The influence of the thickness of the Co-Cr layer in a Co-Cr/Ni-Fe double-layer medium on the recording and reproducing characteristics, was investigated by computer simulation. In practice, perpendicular media with a relatively thin Co-Cr layer, about 0.1 μm thick, but still thicker than in longitudinal media, produced high playback voltages at high densities. This is because the sharp magnetic field distribution of a single-pole head is created for a thin Co-Cr layer by enhancing the head-to-medium magnetic coupling. As a result, the large residual magnetization remains in the recording process, and the high resolution of the single-pole head generates high playback voltages even at high densities.

I. Introduction

When taking self-demagnetization into account in perpendicular magnetic recording, we find a number of characteristic features: (a) If we assume as the initial condition an ideal steplike magnetization state in the medium, then the self-demagnetizing field acting at the magnetization reversal is zero; thus even for a thick magnetic layer, after self-demagnetization a sharp transition state can be maintained [1]. (b) In the thick Co-Cr layer of recording media, a large residual magnetic moment is obtained and this layer is also stable with respect to the magnetostatic energy [2]. Hence we may say that in perpendicular magnetic recording, a thick Co-Cr layer is in principle desirable.

In fact, when the authors first proposed the perpendicular recording method, they were using a double-layer medium consisting of a 0.5 μm thick Co-Cr layer and a 0.5 μm thick soft magnetic backing layer [1]. Thereafter, as we came to use increasingly thinner film media, recording densities continued to rise, and recently we have succeeded in recording and playing back signals at exceedingly high densities of several hundred kFRPI, using a medium with a Co-Cr layer of thickness about 0.1 μm and a backing layer 0.5 μm thick [3].

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From the Journal of the Magnetics Society of Japan (Nippon Oyo Jiki Gakkaishi), Vol. 12, No. 2, 1988, page 147-150.

In this report, we describe the results of investigations by computer simulation of the reasons for the increase in recording density in actual systems when the Co-Cr layer thickness is somewhat thin.

II. Computer Simulations

Computer simulations of read/write processes were performed for Co-Cr layer thicknesses of 0.10 and 0.20 μm.

Distribution of field from a single-pole head: The distribution of the magnetic field from a single-pole head was computed by a two-dimensional finite element method, for an infinitely large track width. The main pole thickness was 0.38 μm, with a relative permeability of 5000; the backing layer thickness was 0.5 μm, with relative permeability 1000. The head-medium spacing was taken to be 0.02 μm. These are essentially the conditions of actual read/write experiments performed by the authors. As we have already noted, in analyzing the field from a single-pole head, it is necessary to take into account not only the magnetic interaction between main pole and medium backing layer, but also the interaction between main pole and medium Co-Cr layer [4].

It may be that the head field should be calculated according to the medium magnetization state as the head and medium are in relative motion in the recording process; for simplicity, however, we have here set the relative permeability of the Co-Cr layer equal to 5, and have determined the field distribution based on an approximation to the interaction of the Co-Cr layer with the main pole. In head field calculations, we have not considered the effects of magnetic saturation in the head or in the backing layer.

Recording process: The model for magnetization in the Co-Cr layer was based on the curling model, modified to take into consideration the magnitude of the anisotropy field for Co-Cr crystal grains and dispersion in the easy magnetization axis [5]. Here we set the perpendicular coercivity at 400 Oe and the saturation magnetization at 400 emu/cc.

We assumed a Gaussian distribution for the magnitude of the perpendicular magnetic anisotropy field, with a mean of 5 kOe. We have obtained simulation results indicating that the smaller the dispersion in the perpendicular magnetic anisotropy, the stronger the residual magnetization in the medium at high recording densities. Here, we choose the half-maximum width of the distribution to be 1.5 kOe, so that the results of read/write simulations agree well with measurements.

In simulations of the recording process, we combined this medium magnetization model with the aforementioned head field distribution obtained through finite element analysis, computed the demagnetizing field due to the magnetic charge within the Co-Cr layer and the image charge in the backing layer, and used an iterative approximation technique to find the self-consistent magnetization state within the medium. In the course of these iterative calculations, when the change of magnitude of the magnetization from the preceding step at all points within the medium is equal within 1% of the saturation magnetization, the process was judged to have converged. In calculations, the Co-Cr layer was divided into six partitions in the depth direction, and was also partitioned into units of the same length in the head running direction. The permeability of the medium backing layer was assumed to be infinite.

Playback process: The playback voltage (in arbitrary units) was computed using the reciprocity theorem from the residual magnetization distribution in the medium as obtained from recording simulations, taking the head field distribution, as determined by the finite element method, as the sensitivity function.

III. Results and Discussion

A. The head field

Fig. 1 shows the head field distribution within the Co-Cr layer, as calculated by the finite element method. Here Y is the distance from the Co-Cr layer surface. The strength of the magnetic field is shown normalized by the magnetic field strength at the Co-Cr layer surface on the line passing through the center of the main pole. When the Co-Cr layer thickness is 0.1 μm (a), there is a strong magnetic coupling between the main pole and the medium backing layer, so that the distribution of the perpendicular field component (H_y) is sharp and almost the same at the bottom of the layer as at the top. But for a layer thickness of 0.2 μm (b), the

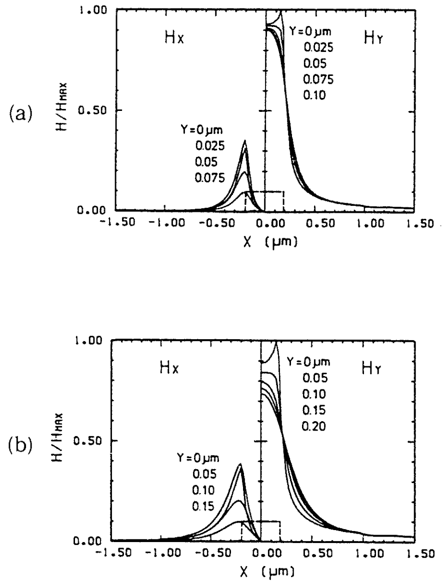

Fig. 1. Magnetic field distribution from single-pole head in the Co-Cr layer, calculated by the finite element method. The Co-Cr layer thickness is 0.1 μm in (a), 0.2 μm in (b).

field distribution is already broader at the surface, and at the bottom of the layer the field is broadened considerably.

When the same magnetomotive force is used to magnetize the medium, the field strength obtained at the surface of the Co-Cr layer, on the line passing through the center of the main pole, is about 20% greater for the medium with a Co-Cr layer 0.1 μm thick, than when the latter is 0.2 μm thick.

B. The recording process

Fig. 2 indicates the relation of the playback voltage to the magnitude of the perpendicular component of the head field at the Co-Cr layer surface, applied

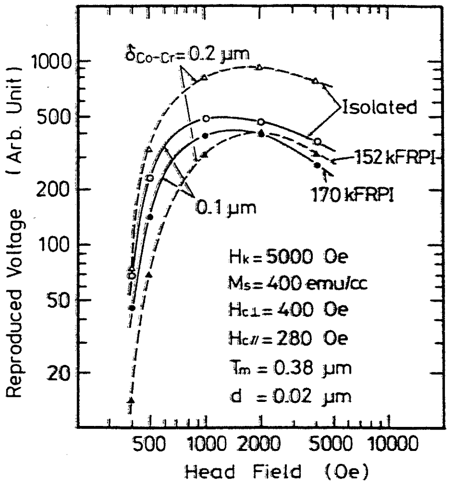

Fig. 2. Reproduced voltage vs. recording head field strength at surface of Co-Cr layer.

during writing. When the Co-Cr layer is thick, the difference between the head field strengths at the Co-Cr layer top and bottom surfaces is great. Hence in order to perform saturation recording, the field strength applied to the medium surface will have to be higher for thicker films.

In these simulations, it was found that if the field strength at the surface is about 2000 Oe, then the Co-Cr layer is sufficiently well magnetized all the way to the bottom of the layer when the layer thickness is 0.2 µm (the broken lines in the figure). Upon saturation recording, the largest playback voltage was obtained for both isolated magnetization transitions and under high-density (152 kFRPI) recording conditions. We therefore set the head field strength at the Co-Cr layer surface equal to 2000 Oe in our simulations of the recording process.

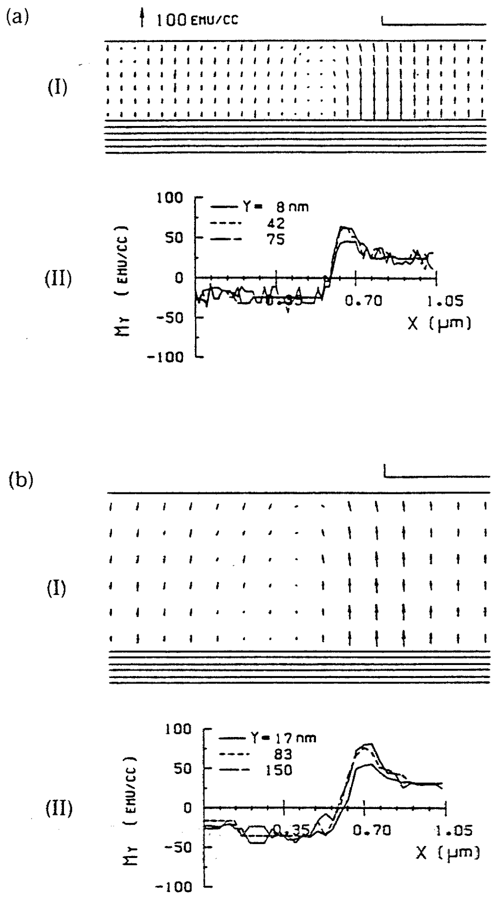

Fig. 3. Distributions of (I) the vectorial magnetization, (II) the perpendicular magnetization component, in the Co-Cr layer. The Co-Cr layer thickness is 0.1 µm in (a), 0.2 µm in (b).

Results of simulations of isolated magnetization transition recording appear in Fig. 3. Here (I) is the distribution of the residual magnetization vector within the Co-Cr layer, and (II) is the distribution of this vector's perpendicular component (M_y). In regions distant from the magnetization transition in

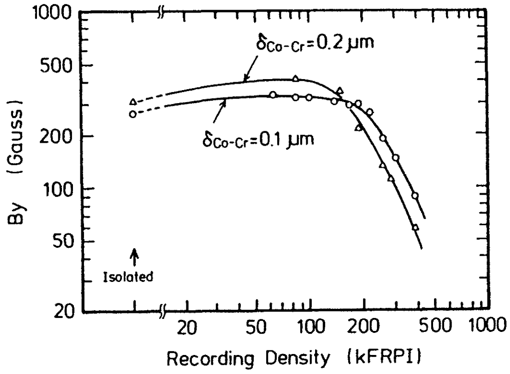

Fig. 4. Perpendicular component of the flux density at the Co-Cr layer surface, vs. recording density.

diagram (I), the demagnetizing field is strong in the perpendicular direction, and so it is somewhat difficult to obtain convergence of the magnetization in calculations of the self-consistent magnetization, and the latter is slightly disordered.

But near the magnetization transition the demagnetizing field is weak, convergence of the magnetization is readily obtained, and the result is correspondingly more reliable. When the Co-Cr layer thickness is 0.1 μm (a), the width of the transition is about 0.1 μm, or about half the width when the layer thickness is 0.2 μm (b). In perpendicular recording, there is only a small demagnetizing effect at the magnetization transition, and the sharpness of the transition is for the most part determined by the sharpness of the field distribution at the trailing edge of the head. Thus media with a smaller Co-Cr layer thickness have narrower magnetization transition widths.

Fig. 4 shows the recording density dependence of the perpendicular component (B_y) of the flux density at the medium surface. B_y reflects the magnitude of the perpendicular component of the residual magnetization near the surface of the Co-Cr layer. As the recording density is raised, the self-demagnetizing effect in the perpendicular direction diminishes and the magnitude of the residual magnetization increases; for these reasons, the flux density near the medium surface is larger than when isolated magnetization transitions are recorded.

But as the recording density is further raised, those areas which have once been written tend more to be overwritten by the trailing edge of the head field distribution during subsequent writing of magnetization transitions. Because of this, the residual magnetization, rather than being reinforced, is weakened. Hence the magnitude of the flux density at the medium surface first increases with rising recording density, and then begins to decline. Media with thinner Co-Cr layers (circles in the figure) are written by a head field with less of a trailing edge, and thus keep a stronger magnetization even at high recording densities than do media with a thicker Co-Cr layer (triangles).

As a consequence, media with a thinner Co-Cr layer are better able to maintain increases in flux density at high recording densities. From the figure, we also see that signals are

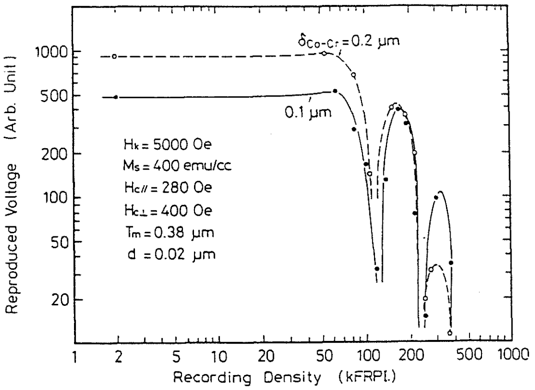

Fig. 5. Simulated recording density response curves. The solid and broken lines denote results for Co-Cr layer thicknesses of 0.1 and 0.2 μm respectively.

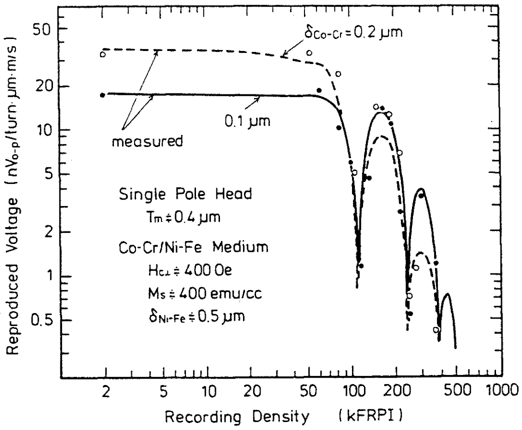

Fig. 6. Reproduced voltage vs. recording density. The solid and broken lines are measured results; data denoted by circles were obtained from simulations.

written up to a high density of about 400 kFRPI, the limit imposed by the dimensions of the mesh in the medium used for simulations.

C. The playback process

Fig. 5 shows the recording density characteristics of the playback voltage computed using the reciprocity theorem, taking the head field distribution of Fig. 1 as the playback sensitivity function, assuming the above-described dependence of the residual magnetization distribution on the recording density. In the figure, the solid and broken lines represent results for Co-Cr layer thicknesses of 0.1 and 0.2 μm respectively.

When the recording density is below 100 kFRPI, the medium with Co-Cr layer of thickness 0.2 μm delivers a playback voltage roughly twice that when the latter thickness is 0.1 μm. At recording densities near 100 kFRPI, the playback voltages are nearly the same; at 200 kFRPI and above, the trend is reversed, and the medium with the 0.1 μm Co-Cr layer delivers the higher playback voltage. This is both because a thinner Co-Cr layer results in formation of a stronger residual magnetization in the Co-Cr layer at high densities, and because a sharp head field distribution enables playback with higher resolution.

D. Comparison with measurements

Fig. 6 shows examples (the solid and broken lines) of recording density dependences of the playback voltage actually measured using a flexible disk drive. The solid line is for a Co-Cr layer 0.1 μm thick; the broken line, for a 0.2 μm thick layer. The results of these simulation calculations (empty and filled circles) can