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RECORDING CHARACTERISTICS OF PERPENDICULAR MAGNETIC HARD DISK MEASURED BY NON-FLYING SINGLE-POLE HEAD

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Abstract - A contact recording experiment using perpendicular magnetic hard disks was made by a non-flying single-pole type magnetic head to investigate the practical possibility of an extremely high density magnetic recording in future. A single-pole head produces an ideally sharp field distribution because of a strong head-medium magnetic interaction, so an isolated magnetization transition in perpendicular magnetic recording becomes much sharper than that in the longitudinal recording at a narrower head-medium spacing. A much better durability of hard disks and heads due to much smoother surface of the disk was also confirmed.

INTRODUCTION

A head-medium spacing must be as narrow as possible to realize an extremely high density magnetic recording. We already confirmed experimentally by a contact recording using perpendicular magnetic flexible disks that information can be stored and detected by a single-pole type magnetic head at an ultrahigh bit density over 500 kFRPI (20 kFRPM) on a double-layered medium composing of a Co-Cr layer and a soft magnetic back-layer [1]. This fact was also proved theoretically by the computer simulation [2].

However, a Co-Cr flexible disk made by a sputtering on a polymer film substrate shows a poor durability in a contact running with a head, because the alloy disk is not flexible perfectly and has some microscopic roughness on the surface [3]. The microscopic surface roughness is due to the mismatch of the thermal expansion coefficient and the Young's modulus between the alloy and the substrate. To investigate a practical possibility of an extremely high density perpendicular magnetic recording in future, therefore, we tried a contact hard disk recording by a non-flying head.

EXPERIMENTAL

Perpendicular magnetic hard disks were made by sputtering on non-texturing glass substrates of 3.5" in diameter. In Fig. 1, a section of a perpendicular magnetic hard disk is illustrated. After an 0.025 microns thick Cr underlayer was sputtered on the substrate to make a better crystallinity and a higher adhesion strength of a magnetic layer, a Ni-Fe-Nb soft magnetic underlayer, a Co-Cr perpendicular recording layer and a SiO$_2$ protective layer were successively deposited by 1 micron, 0.1 microns and 0.002 to 0.03 microns in thickness, respectively.

The possibility of a contact hard disk recording was investigated first by a conventional flying head slider but the disk was immediately damaged after the head touched. We have therefore introduced a novel head supporting method so that a single-pole head runs on the disk without flying by its own-weight even at a higher head-disk speed. Fig. 2 shows the schematic illustrations of (a) the apparatus for a contact hard disk recording experiment and (b) the structure of a non-flying single-pole head.

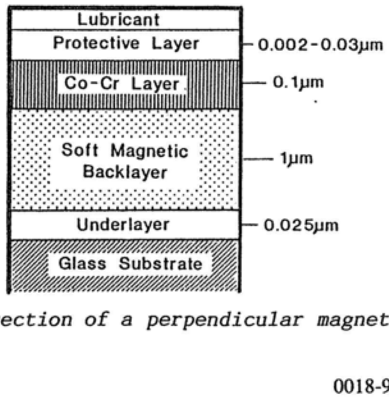

Fig. 1 A section of a perpendicular magnetic hard disk.

The structure of a single-pole head for the hard disk is the same as that used for perpendicular magnetic flexible alloy disks [1]. A main-pole of the head was made of a Co-Zr-Nb or a Fe-Si film [4] of 0.2 to 0.3 microns in thickness and held between glass-ceramic substrates, and its tip was finally polished so that the curvature becomes about 10 mm in the head running direction. The weight of the head itself was 40 mg but the total weight including a removable guide pin made of a brass was about 600 mg.

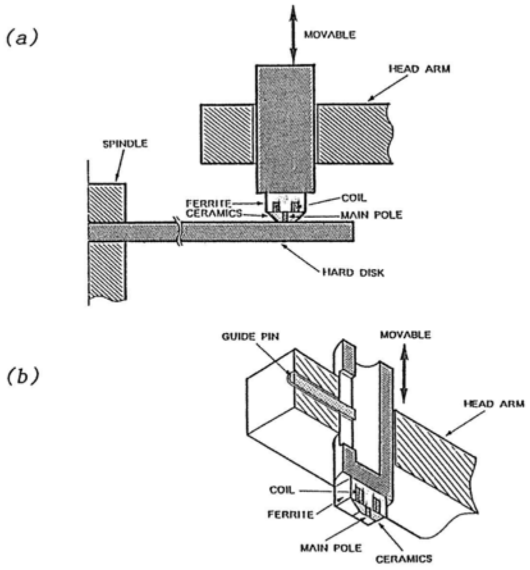

Fig. 2 Schematic illustrations of (a) a contact hard disk recording apparatus and (b) a structure of a non-flying single-pole head.

RESULTS

Fig. 3 shows that stable and lower flying heights of about 300 to 400 angstroms was observed for various head-disk velocities by the non-flying head. The flying height was measured by a light interferometer and compensated by a refractive index of the protective layer [5]. A much better durability of more than 5 millions passes was also obtained without any damage on the disk and the head in an ordinary room environment. This is due to the one order smaller surface roughness of the rigid disk than that in the flexible alloy disk [3]. The surface roughness measured by a mechanical surface profilometer using a stylus was about 35 angstroms in the average and about 180 angstroms in the maximum. Fig. 4 shows an envelope of the reproduced voltage at a bit density of 100 kFRPI and a disk revolution of 1800 rpm. The head never floated even though a head-medium speed was increased up to about 15 m/sec, so the amplitude of the reproduced voltage was proportion to the head-medium speed.

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Fig. 5 shows the increasing of D_{50} with decreasing an actual head-disk spacing which is the sum of a protective layer thickness and a head flying height. The spacing dependency of D_{50} measured by a 0.3 microns thick main-pole for both rigid and flexible disks agrees well with that measured by Tanabe et.al. using a conventional flying head slider [6]. A head-disk spacing should be narrower than 0.05 microns to make good use of the ability for ultrahigh bit density recording in perpendicular magnetic recording.

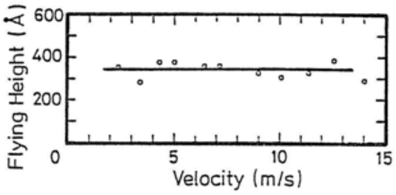

Fig. 3 Flying heights of a non-flying head for various numbers of the disk revolution.

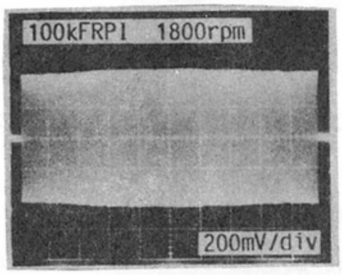

Fig. 4 An envelope of voltage reproduced by a non-flying single-pole head at 1800 rpm.

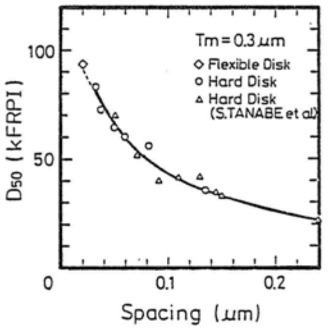

Fig. 5 Dependency of D_{50} on actual head-disk spacings in perpendicular magnetic recording.

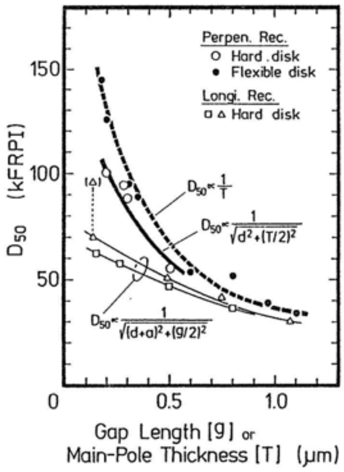

Fig. 6 Dependencies of D_{50} on main-pole thicknesses and gap lengths in perpendicular and longitudinal recordings.

In Fig. 6, the dependencies of D_{50} on the main-pole thicknesses of single-pole heads measured for both rigid and flexible disks are plotted by white and black circles, respectively. The perpendicular coercivities were about 1250 Oe in the rigid disks and 500 to 1250 Oe in the flexible disks, and both the saturation magnetization was about 370 emu/cc. From the result that the D_{50}'s in the flexible disk recording were higher than those in the rigid disk recording, it presumed that the spacing in the later is still slightly larger than that in the former.

For comparison, the gap length dependency of D_{50} in Co-system alloy thin film disks for longitudinal magnetic recording are also plotted by rectangles and triangles. The rectangles were measured by us using ring heads attached to the same non-flying head supporter for an 0.055 microns thin disk whose longitudinal coercivity was 900 Oe. The triangles were measured by Tanaka et.al. at the flying height of 0.1 microns for an 0.03 microns thin disk whose coercivity is 640 Oe [7]. In the later, the triangle increases to near 100 kFRPI when the thickness of the recording layer decreases to 0.01 microns and the coercivity increases over 1000 Oe, as shown in the figure.

DISCUSSIONS AND CONCLUSIONS

Transition Width

In longitudinal magnetic recording, D_{50} can be calculated by the following equation when an isolated magnetization transition can be approximated with an arctangent function [8],

$$D_{50} = K/\sqrt{\{(d+a)^2 + (g/2)^2\}} \qquad (1).$$

Here '2a', 'g' and 'd' are a transition length, a gap length and a spacing in microns. The measured results agree well with a solid thin curves calculated as shown in Fig. 6, if relatively wider transition widths 'a' of 0.14 and 0.2 microns at the respective spacing 'd' of 0.1 and 0.07 microns are assumed for both Tanaka's and our results. Therefore the limit in longitudinal magnetic recording is determined by the transition width.

On the other hand, in perpendicular magnetic flexible disk recording, a transition width reaches 0.05 microns or less which corresponds to the size of several crystalline particles in a Co-Cr layer [2]. In the rigid disk recording, if an extremely narrow transition width of about 0.07 microns can be assumed at an actual head-disk spacing of about 0.06 microns, which is the sum of an 0.02 microns thick protective layer and an 0.04 microns high flying height, the measured D_{50}'s agree well with a thick solid curve calculated by replacing a gap length 'g' with a main-pole thickness 'T' in Eq. (1). Consequently the limit in perpendicular magnetic recording is determined by the sharpness of the head field distribution and sensitivity function [9], because D_{50} only depends on a main-pole thickness and a head-disk spacing.

Head Field Distributions

In Fig. 7 and 8, the magnetic fields around a main-pole of a single-pole head and a gap of a ring head are compared at the spacings of (a) 0.02 and (b) 0.2 microns. The distributions of magnetization in a recording layers are also shown by arrows. They were calculated by the FEM incorporating a magnetization model of fine magnetic particles composing recording layers [10]. In the calculations, a single-pole head was combined with a double layer medium having a perpendicularly anisotropic recording layer having a higher saturation magnetization of 400 emu/cc, but a ring head was combined with a longitudinally anisotropic single layer medium having a lower saturation magnetization of 120 emu/cc. They are the conditions for high density recording in each heads. As a magnetomotive force, the values giving the sharpest field

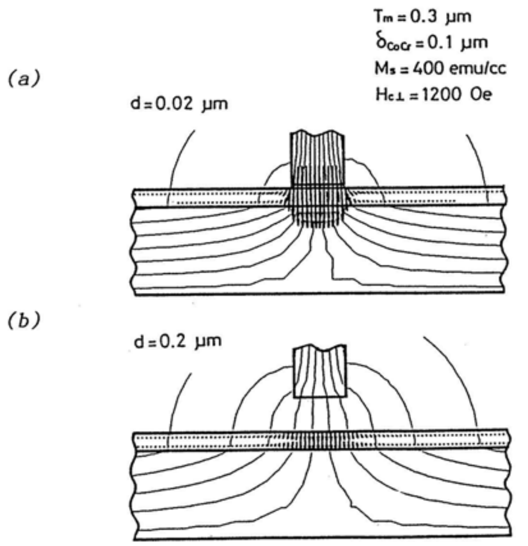

Fig. 7 The configurations of lines of magnetic force around a main-pole of a single-pole head and the distributions of magnetization in a perpendicularly anisotropic recording layer.

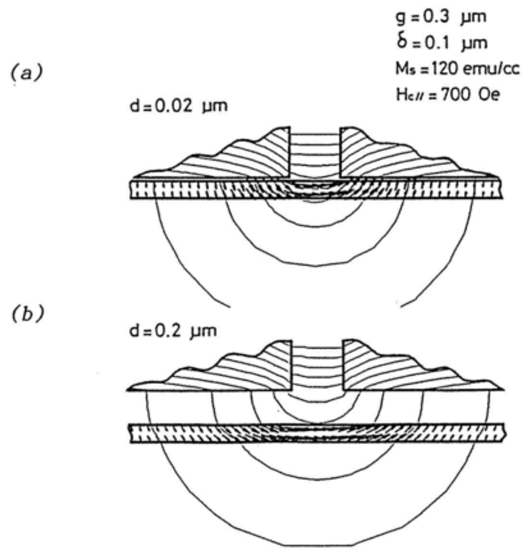

Fig. 8 The configurations of lines of magnetic force around the gap of a ring head and the distributions of magnetization in a longitudinally oriented recording layer.

distribution at the spacing of 0.02 microns was chosen for each head. In Fig. 9, both the field distributions on the medium surfaces are compared at various head-medium spacings 'd'.

When a single-pole head is combined with a double layer perpendicular recording medium having a recording layer whose saturation magnetization is as high as those of a soft magnetic back-layer and a main-pole of a head, the perpendicular field component becomes much steeper and the longitudinal component becomes negligibly smaller at a narrower head-medium spacing because of a stronger head-medium magnetic interaction [9]. Moreover both the distributions is hardly broadened with increasing the spacing.

On the other hand, the longitudinal component in the ring head becomes much broader with increasing head-medium spacing, as compared with the perpendicular component in the single-pole head. Moreover the perpendicular component is smaller but more widely distributed than the longitudinal component. This feature does not change in a ring head combined with a perpendicularly oriented medium [9], though a perpendicularly oriented medium is desired to materialize a higher bit density recording even for a ring head.

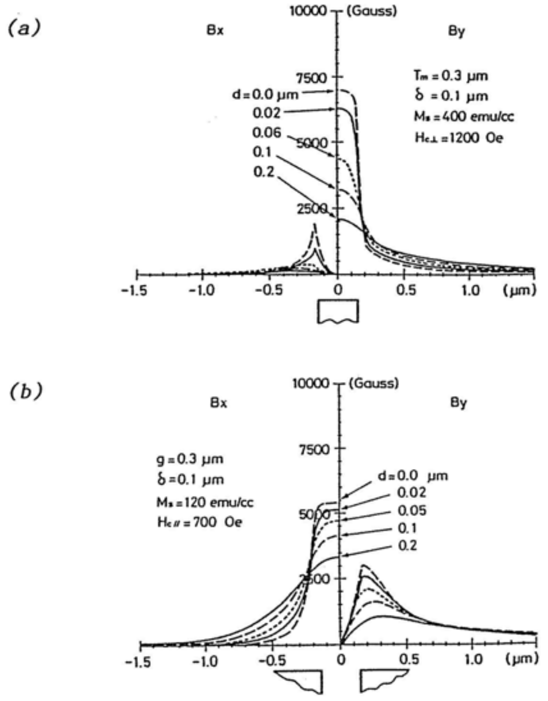

Fig. 9 Comparison of the field distributions of both the (a) single-pole type and (b) ring type heads on the medium surfaces at various head-medium spacings 'd'.

In conclusion, from the viewpoint of the head field distribution, we can say that a single-pole head is the most suitable to realize ultrahigh density magnetic recording if a much narrower head-disk spacing is practically materialized using a non-flying head slider on a perpendicular magnetic hard disk.

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