Submicron Trackwidth Recording Utilizing a Novel Single Pole Head

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Abstract --- A concept of a submicron width multi-track head for ultra high track density perpendicular magnetic recording is discussed. Very narrow track of 0.4 μm in width is confirmed, judging from a measurement with a magnetic force microscopy. The head configuration for multi-track high areal density recording has been proposed, which consists of submicron-trackwidth write-heads and a high resolution wide-track read-head. C/N ratio of low density signal exceeds 30 dB. D₀ is 100 kFRPI; high linear density of perpendicular magnetic recording is not degraded in this scheme. Areal density of 6 Gbit/inch² is demonstrated, and the potential for 13 Gbit/inch² is suggested.

I. INTRODUCTION

Areal density of magnetic recording rapidly increases year by year. Recently the write trackwidth as narrow as 1 μm has been already demonstrated[1]. The trackwidth of less than 1 μm will be required in order to meet the demand for recording in the next generation[2]. For this goal, one of the most critical problems is the writing resolution at track edges. Perpendicular magnetic recording will play an important role because of not only high linear density but also the capability for super-narrow track recording. Contact or near contact perpendicular magnetic recording has been demonstrated well-defined recorded track edges in narrow track recording[3].

However, servo accuracy may be a limitation for such submicron trackwidth recording; it would be preferable if very precise servo tracking were not required. The resolution of the conventional lithography for mass-production is another difficulty for narrow track recording, which resolution may be insufficient for fabrication of a submicron trackwidth head.

From this viewpoint, we have developed a new single pole head that enables submicron trackwidth recording. In this paper, its recording performance and the possibility for multi-track recording is described.

II. NEW SINGLE POLE HEAD

a. Head Structure

The schematic structure of the new single pole head is indicated in Fig 1. While in conventional perpendicular magnetic recording the travelling direction of the medium is normal to the plane of the main pole film (Fig 1, left-hand), in the new single pole head the direction of the medium motion was changed to the plane of the main pole, as drawn in right-hand. In this case, the trackwidth is determined by the main pole thickness. Since the thickness is easy to control accurately by sputtering deposition, the trackwidth of the head can be precisely determined. This structure does not need the severe resolution of lithography in head fabrication.

b. Head Field Distribution

The head field distributions of the new head and a narrow track ring head were calculated by our three-dimensional computer simulation. The result for the single pole head is shown in Fig 2 (a), in which the field of the head steeply decreases within less than 0.1 μm along both the main pole width and main pole thickness directions, which result means that a single pole head has the same recording resolution in
both directions. In contrast, field distribution for the ring head is not the same in these two directions; there is broader distribution outside of track and near the track edges.

In a ring head whose trackwidth is less than 1 \( \mu m \), since the trackwidth is comparable with gap length, generated magnetic flux spreads out of track. Its head field strength therefore becomes weaker as indicated in Fig 3. In a conventional single pole head of submicron trackwidth, its field strength also becomes weaker. The maximum field of a single pole head is determined by the head-to-medium magnetic interaction[4], which depends on the cross-sectional area of a main pole under condition of finite head-to-underlayer spacing. However, when a main pole is turned as shown in Fig 1(a), the field strength can be the same for a narrow track head as that of a wide track head, even for less than one micron trackwidth. Because the main pole width

![Fig 3 Dependece of maximum head field strength on trackwidth for a ring head and a single pole head. The arrow and filled circle show a case of a new submicron trackwidth single pole head.](image)

outside a track at least 0.3 \( \mu m \) on each side. Since the boundary of the recorded area is not straight, written transitions will be bent across the track.

c. Computer Simulation of Stand-still Recording

The difference of the head field distribution between the ring head and single pole head, mentioned above, was examined theoretically. Stand-still recording with two kinds of submicron trackwidth heads, a ring head and a single pole head, was simulated in order to investigate the recorded pattern on a medium. Our two-dimensional calculation using a magnetization model of a Co–Cr medium based on the curling-type switching mode[5] was extended to a three-dimensional model. The results of the simulation are shown in Fig 4. The track written with a single pole head is almost the same width as the trackwidth of the head, which is determined by the main pole thickness. The calculation predicted the trackwidth on a medium, written with a head of 0.3 \( \mu m \) trackwidth, will be about 0.4 \( \mu m \); indicating that submicron trackwidth recording is possible with the new single pole head. In contrast, a ring head magnetized the area

![Fig 4 Comparison of recorded magnetization of stand-still recording between with a single pole head and a ring head. Open circles in (a) indicate switched magnetization. Shaded area shows trackwidth.](image)

d. Recorded Bit Observation

The recorded tracks were observed with a high resolution Magnetic Force Microscopy (MFM) by Mr. S. Porthun and Professor J. C. Lodder in the University of Twente. Here, the trackwidth, or the thickness of the main pole of a write-head, was 0.3\( \mu m \). The MFM image is depicted in Fig 5, where the recorded tracks of 20, 50, 100 and 200 kFRPI with the track pitch of 5 \( \mu m \) are visualized. This image indicates that the trackwidth was about 0.4 \( \mu m \). Although the measured trackwidth was slightly wider than that of the head, the trackwidth of less than half micron was certainly realized. In addition, since the image of 200 kFRPI could be observed, the head also maintains the high recording resolution along the travelling direction.

The track edges were also examined; there were no
noticeable irregular transitions that are more than a half micron in size near the track edges. The smallest bit in this observation corresponds to a bit area of 0.05 \mu m^2, or areal density of 13 Gbit/in^2.

III. READ/WRITE PERFORMANCE

The new head of 0.3 \mu m trackwidth was used for both writing and reading. A Co-Cr/Fe-Ni-Nb double layer disk was used in sliding contact recording[6]. The read–back signal waveform and its spectrum are depicted in Fig 6 and 7. Here, the same head was also used for recording. Although the pulse shape was distorted a little at the bottom of the waveform through filtering, the observed single peak pulse suggested that perpendicular magnetization mode was surely formed in a medium with the head. The carrier to noise ratio of the low density signal was about 30 dB. However, the head output has minima where the integral multiple of the recorded wavelength are equal to the main pole length along the medium traveling direction, which is seen in the roll-off characteristics, Fig 8 with open circles. In order to get rid of this disadvantage, the standard single pole head was utilized as the dedicated read head. As shown in Fig 8 with closed circles, D_{50} was drastically improved to 100 kFRPI. We could conclude that the new single pole head is effective as a recording head with a high resolution dedicated read–head. In this case, areal density of more than 6 Gbit/in^2, or linear density of 100 kFRPI and trackwidth of 0.4 \mu m, was demonstrated in the actual write/read experiment.

IV. MULTI-TRACK RECORDING

This new head will have the possibility of the parallel-processing recording or two–dimensional recording; the close–packed multiple submicron tracks are simultaneously recorded with a submicron trackwidth integrated head, and they are read at once with a dedicated head of wider trackwidth. Fig 9 schematically explains the idea of this parallel recording heads. Reading of the recorded multiple...
tracks by a single wide pole head has an advantage for the servo tracking technique, because the total trackwidth of the multiple tracks is not submicron width any more; no severe precision tracking is required. However, to introduce this new recording, the thin film head technique should be applied in order that each main pole is independently excited by a thin film coil. At the same time, in order to stack the main poles as close as possible, it is preferable that the single layer coils are put between the main poles; the "off" and "on" of the main pole excitation is controlled by the direction combination of the recording currents of the coils. A main pole put between a set of opposite current directions is excited (on-state), and it is not excited in same current directions (off-state). As a fundamental experiment, a head with two independent thin film single-turn coils along both sides of a main pole was prepared and evaluated. In Fig 10, the signal waveform of the "off" and "on" conditions are shown. The signal under the "off" condition, in which no signal appeared in the figure, reduced its amplitude by 20 dB compared with the "on" condition, which result proves the potential of this method.

As mentioned above, we can obtain a sort of multi-level output from the wide track dedicated read-head shown in Fig 9. For example, when three tracks are recorded with the integrated write-heads and are read with the dedicated-read head, head output is a multi-level signal of +3, +2, +1, 0, −1, −2, −3, because magnetization levels in each track can be positive saturation (+1), erased or sufficiently high frequency (0), and negative saturation (−1). Thus, the read output contains information of 7 bits in binary at each detection point. We will utilize multi-value algebras for this recording channel, instead of binary algebras.

V. CONCLUSION

We have suggested the fundamental possibility of very high areal density multi-track recording utilizing perpendicular magnetic recording and the newly developed single pole head. The experiments demonstrated high areal density of 6 Gbit/inch², and suggested the potential of 13 Gbit/in². Grouped-track-recording will further expand the possibility because of its advantages in tracking servo and high data rate, though practical head design and signal coding method must be established.

ACKNOWLEDGMENT

The authors wish to thank Mr. S. Porthun and Professor J.C. Lodder in the University of Twente for their outstanding contribution of MFM observation.

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