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Contact magnetoresistive head for perpendicular magnetic recording

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Contact-type magnetoresistive (MR) inductive head designs and recording characteristics have been discussed in perpendicular magnetic recording. The shielded-type MR head offered a high D_{50} of 100–135 kFRPI, and the unshielded MR head had the largest output in a low density region. However when the recorded bit length became shorter than the shield-to-shield spacing, the shield had little effect and the output of the shielded head was no longer almost equal to that of the unshielded MR head. In result, the shielded-type and even unshielded-type MR heads have good high density recording characteristics in the head-to-medium contact state. © *1996 American Institute of Physics.* [S0021-8979(96)08608-7]

I. INTRODUCTION

Magnetoresistive (MR) head technology makes it possible to perform high areal density magnetic recording over 1 Gbit/in.^{2} (Refs. 1 and 2). The MR head is expected to offer a high density response as well as the large output for the sensor in future high linear and track density recording system. In a high linear density recording design, the low head-to-medium clearance and a high resolution medium have to be developed. On the other hand, extremely high resolution recording over 600 kFRPI has been characterized by using a perpendicular medium and a single-pole head in the head-to-medium contact state.[3] Consequently the introduction of the contact perpendicular recording is expected to be an important technology in the high density design. A MR head for perpendicular recording is also a key element to a sensitive read head. However a few reports[4,5] have been presented on readback performance of a MR head combined with a perpendicular medium. In this work the characteristics of perpendicular magnetic recording are described, obtained by the combination of contact MR heads and a perpendicular double-layered disk.

II. HEAD DESIGN

Generally a conventional MR head is optimized for longitudinal recording, which is combined with an inductive ring head and has a shielded MR element for the improvement of high density response.[6] When a MR head is adopted for the read element in perpendicular magnetic recording, the single-pole head is preferable to the ring head from the view point of the write performance. Moreover the shield effect in the MR head is not sufficiently investigated for the perpendicularly recorded mode. Consequently the MR head for perpendicular recording has to be newly designed. Here we designed and fabricated three kinds of contact MR heads for perpendicular recording.

The schematic cross sections of the MR heads and the illustrations for the read/write elements used in the following experiments, are shown in Fig. 1. These heads have a writing single pole, an auxiliary core, and a read MR element. The auxiliary core is wounded with a 26 turn coil, and the read/write elements are connected with the core.

Each MR element has a 25-nm-thick Ni_{80}–Fe_{20} film biased by a soft adjacent layer (SAL). The sensor height of a conventional flying MR head is typically 1–2 μm for high read sensitivity. However a sliding contact hard disk system[7] gives rise to the wear of the air bearing surface (ABS) due to the head-to-disk contact, and here every MR sensor height is adjusted to approximately 10 μm. The sense current was set at 20 mA (current density: 0.3×10^7 A/cm^2) in accordance with the output wave form asymmetry.

A. Unshielded-type MR head

The unshielded-type MR head Fig. 1(a) is composed of a MR read element and an inductive write element. These elements are arranged at intervals of 50 μm and magnetically separated from each other. The write pole is made of 0.4-μm-thick Co–Zr–Nb amorphous film. This pole, the MR element, and the lead line are exposed on the ABS. The track width of the MR read sensor is 3 μm, and the height is 10 μm.

B. Shielded-type MR head

The head shown in Fig. 1(b) has a MR element shielded on both sides. The shields made of Co–Zr–Nb film are 0.4

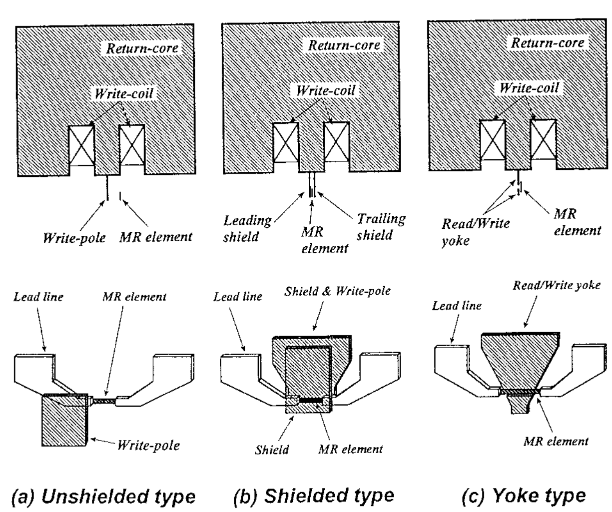

FIG. 1. The upper figures are the schematic cross sections of contact MR heads for perpendicular magnetic recording. The lower figures are schematic illustrations of the read/write elements of the MR heads.

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TABLE I. Properties of the double-layered hard disk for the experiments.

Parameters	Values
Thickness of Co–Cr	50 nm
M_S of Co–Cr	496 emu/c
$H_{c_{(\perp)}}$ of Co–Cr	1480 Oe
Thickness of Ni–Fe–Nb	0.5 μm
Thickness of SiO_2	4 nm
Substrate	Glass

μm thick, and are thinner than that of a conventional MR head. The trailing shield plays a part in the recording as an inductive write pole and defines the write track width. The shield-to-shield spacing, without the thickness of the MR and the SAL films, is 0.7 μm. The shields are also exposed on the ABS in addition to the MR element and lead line. The read width and height of the MR sensor are 3 and 10 μm, respectively.

C. Yoke-type MR head

A MR sensor is inserted into the yoke of the head shown in Fig. 1(c). The head construction is simple since the yoke performs the read and write operations as a flux guide, all in one. The yoke material is Fe–Si/SiO_2 multilayered film, and the yoke is only exposed on the ABS. The front yoke, whose thickness and width are 0.25 and 10 μm, respectively, guides the medium surface flux through the MR sensor. Both the front yoke width and height are 10 μm, and this track width is wider than those of the above-described MR heads.

III. MEASUREMENT CONDITIONS

The contact MR heads were evaluated on a Co–Cr/Ni–Fe–Nb double-layered hard disk. Table I shows properties of the medium for the following experiments. The disk was fabricated by sputtering a Cr underlayer, a Ni–Fe–Nb backlayer, a Co–Cr recording layer, and a SiO_2 protective layer on a flat glass substrate. The surface was given a coat of liquid lubricant (PFPE), which kept the electric insulation between the exposed MR element, the lead lines, and the disk surface. The measurements were performed at a relative velocity of 2 m/s, then the head-to-disk clearance was 30 nm.

Every head had adequate write performance, and especially in the shielded type, good overwrite characteristics were obtained since the leading shield operates as a shield from the stray field of the prewritten region.[8] The readback performance of the MR heads was tested after the saturation recording. The mechanical rubbing noise and the thermal asperity were not detected in the contact state combined with the medium.

IV. READBACK PERFORMANCE

Figure 2 shows readback wave forms of the three types of heads at 10 kFRPI density. These wave forms were different from the one produced by longitudinal recording. Even in the unshielded MR head Fig. 2(a), the output had a very sharp slope at the rear side of a magnetic transition, and was gradually attenuated after the peak due to the medium demagnetization state and the high passage filter of 20 kHz cutoff frequency in the read amplifier.

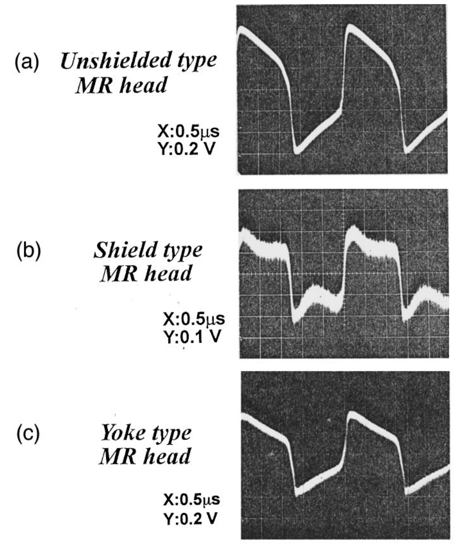

FIG. 2. Readback wave forms of MR heads at a linear density of 10 kFRPI. (a) Unshielded-type, (b) shielded-type, and (c) yoke-type.

On the other hand, the shielded MR head Fig. 2(b) had the wave form emphasized not only at the rear but also at the front of a transition. Since the surface demagnetization field is relieved in the vicinity of the transition, the peak appears at the front of the transition, too.

The yoke-type MR head Fig. 2(c) had almost the same wave form as the unshielded type, since the head did not have a shield. The wave form did not have the peak at the front side of the transition like the unshielded type head because of the stray field from the neighboring recorded region. These wave forms are related to the medium demagnetization state and the surface field gathering range by each contact MR head. However every wave form approached sine waves with increasing recording density.

We also measured the recording density characteristics. The rolloff curves differed according to the type of MR head, as shown in Fig. 3. In the unshielded-type head, the largest output of low density was obtained. This is because the MR sensor is situated on the medium surface and gathers the

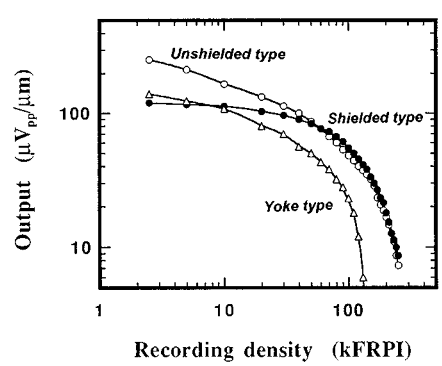

FIG. 3. Density rolloff curves of MR heads with a sense current of 0.3×10^7 A/cm^2.

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medium field widely. This stray field decreased and the output gradually decreased with increasing recording density. However this output decrease was smaller than the theoretical MR height loss,[9] considered just nonmagnetic space. The actual MR height loss must be quite tiny.

On the other hand, the shielded-type MR head gathered only the medium surface field of the shield-to-shield region and the output was lower than that of the two heads in low density. However the head showed the highest D_{50} of 100 kFRPI, and it was increased to 135 kFRPI by adopting a 0.5 μm shield-to-shield spacing. However the experimental result was not in agreement with the theory characterized by spacing loss and gap loss, and the output of the shielded head was almost equal to that of the unshielded MR head in high density region. This is because the shielded MR head cannot be always regarded as two back-to-back ring heads,[6] and the MR element must operate independently, particularly in high density region.

The yoke-type MR head also gathered the surface stray field far from the recorded region and showed large output in low density, though its MR element was remote from the medium surface. However the output decreased gradually in low density and rapidly in the range over 50 kFRPI with increasing recording density, because of the yoke thickness loss and the decrease of the stray field. The thinner front yoke must be adopted for high density response.

Both the shielded- and unshielded-type MR heads have high read sensitivity in a high density recording region. In fact, the 500 kFRPI signal was confirmed in these MR heads.

V. SUMMARY

We designed and fabricated the newly developed contact MR heads for perpendicular magnetic recording. They were evaluated with a double-layered hard disk in order to examine the operation of the MR element and the shield in the contact state. The shielded-type, unshielded-type, and yoke-type heads offered square waves with the sharp slope at the transition. Though the construction of the yoke-type MR head was simple, the head showed poor high density resolution because of the yoke thickness loss. In contrast, each read element of the unshielded and shielded MR heads is so thin that the thickness loss can be practically negligible. The shielded-type and even unshielded-type MR head had good high density characteristics. The shield, which was considered necessary for a high density response, had little effect when the recorded bit length became shorter than the shield-to-shield spacing. The output of the shielded-type head was almost as large as that of the unshielded type in the high density region in the case of the head contact, because of the independent operation of the MR element in both heads. We conclude that the combination of a contact MR head and a perpendicular medium offers the possibility of a future high density storage system.

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