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Characterization of Thermal Response Induced by Head/Disk Interaction in Current TGMR Head

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***Abstract*—Recent developments in the tunneling giant magneto-resistive (TGMR) head technology incorporating an MgO barrier, is currently the most promising candidate for replacing a GMR head. The TGMR head whose junction utilizes an MgO barrier yields a higher performance with a lower areal resistance (RA) value. However, as the areal density increases, the actual flying clearance of the head above the media surface during read/write operations is reduced to less than 10 nm. The head/disk interaction under such conditions results in a thermal response, which causes a shift in the baseline of the readback signal and exhibits bi-polar magneto-striction on opposing DC (positive and negative) backgrounds. This magneto-striction causes the thermal response to look different from the classical thermal response that could distort the readback signal to the extent of causing a sector read failure. In this paper, we investigate and characterize the thermal response induced by the head/disk interaction in the TGMR head with an MgO barrier that is currently used in perpendicular magnetic recording systems.**

Keywords*– *MgO Barrier; Perpendicular recording; TGMR head; Thermal response.

I. INTRODUCTION

Tunneling giant magneto-resistive (TGMR) sensors have many advantages over the GMR sensors when implemented as a read element in a hard disk drive (HDD). These advantages include increasing an MR ratio [1], and reducing a RA (i.e., RA = resistance × area) value [1] and head noise. These advantages allow for an increase in data storage capacity.

The head-disk clearance in disk drives is being reduced continuously by current designs, in an effort to gain write/read performance. Recently, drives are being built with head-disk clearance close to 10 nm. Furthermore, head-disk clearance can become even less with decreased ambient air pressure. The reduction in head-disk clearance causes an increased sensitivity in the air bearing surface (ABS) altitude, resulting in variations in head flying characteristics. Therefore, head-disk interaction in real disk drive environments frequently occurs. As the amount of pole-tip protrusion increases, the gap between the head and the disk surface narrows. Thus, HDDs become more susceptible to shock and vibration during manufacturing and normal operation [2, 3]. The reduction in an effective fly height could cause the media surface and the read head to be interacted and heated easily. This heat will cause the resistive properties of the read head to change, resulting in a thermal response (or, equivalently, thermal transient) in the readback signal. This thermal response affects the performances of both recording and disk drive reliability. If precautions are not carefully taken, the string of errors in the detected data caused by the thermal response could easily exceed the correction capability of error correction code (ECCs), resulting in unrecoverable data. Therefore, the thermal response is a crucial problem in perpendicular recording systems.

With the current TGMR read head (using an MgO barrier), the thermal response no longer looks like the classical thermal response proposed by Stupp *et al.* [4]. Thus, the characteristic of the thermal response introduced by the current TGMR head is of importance, as studied in this paper.

II. CURRENT TGMR HEADS WITH MGO BARRIER

Currently, the TGMR head has been replaced the GMR one because the TGMR head has a higher MR ratio. The TGMR design implements the Current Perpendicular to Plane (CPP) architecture in the read head. The CPP is the most significant deviation from the Current In Plane (CIP) architecture implemented in the GMR head, as shown in Fig. 1.

The CPP architecture has many design advantages that allow for high data recording density. By flowing the current perpendicularly to the plane, the read element can be made physically smaller than that with CIP technology. As the read elements become smaller, the potential data recording density increases. From Fig. 1 (d), the top to bottom current flow within the CPP element allows for the removal of the insulator gap. Not having an insulator gap makes the read element more sensitive and can be used in higher Bit per Inch (BPI) designs. Furthermore, CPP architecture allows the shield to be placed in direct contact with the TGMR element. The shield will act as the upper and the lower terminals to the device. This layout prevents cross-talk with adjacent tracks, thus allowing an increased Track per Inch (TPI) density. In addition, to prevent shorting around the sensor, insulators are aligned under hard magnetic layers.

Futhermore, the TGMR heads are often made with barrier layers consisting of magnesium-oxitde (MgO). This increases the performance of the tunneling magneto-resistive sensor by

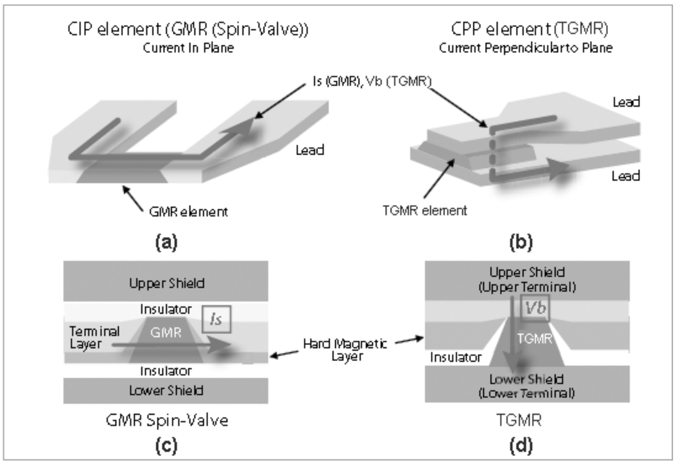


Fig.1. The difference between GMR and TGMR head designs [5].

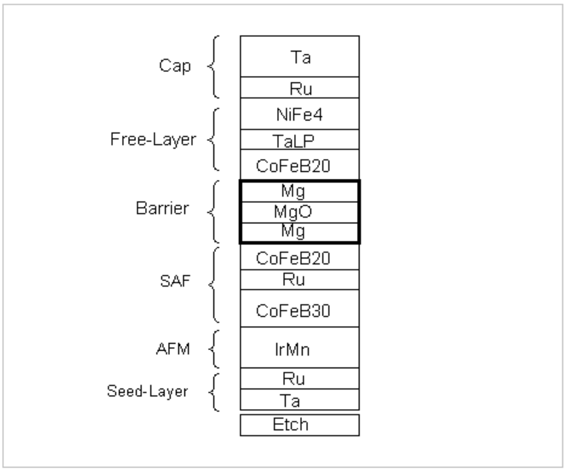


Fig. 2. Configuration of the TGMR head with an MgO barrier [1].

allowing increased amplitude when compared to conventional spin valve devices. The inclusion of MgO within the barrier layer also reduces the RA (resistance × area) value, thus reducing head noise, while maintaining a high MR ratio. Practically, the MR ratio is defined as dR/R where R is the minimum resistance of the TGMR sensor and dR is the change in resistance observed by changing the magnetic state of the free layer. A higher MR ratio improves the readout speed. Because of the smaller physical size and higher sensitivity of the TGMR head, high recording densities can be achieved. A high performance TGMR sensor is fabricated by incorporating a tunnel barrier consisting of a Mg/MgO/Mg configuration, as shown in Fig. 2.

The current TGMR stack technology is comprised of a seed layer (Ta/Ru) in a bottom spin valve configuration, an AFM layer (IrMn), a pined/symthetic antiferromagnetic (SAF) layer (CoFe/Ru/CoFeB), a barrier layer (Mg/MgO/Mg), a free layer (CoFe/NiFe), and a cap layer. All layers are sequentially formed on a bottom shield in the read head [1]. The TGMR stack technology differs from the GMR stack technology in the fact that the Cu layers have been replaced by oxide layers within the barrier layer. The lower Mg layer of 4 – 14 angstroms thick along with the upper Mg layer of 2 – 8 angstroms thick are deposited by a DC sputtering method [1]. The sandwiched MgO layer is formed by a process of natural oxidation (NOX). The natural oxidation of an MgO layer is the preferred method of formation because it can provide more uniformity than the conventional sputtering methods. The natural oxidation process involves pressurizing oxygen from 0.1 mTorr to 1 Torr (1 torr = 1 mm of Hg) and allowing exposure for 15 – 300 seconds. In practice, the NOX time and pressure may be varied to optimize the MR ratio.

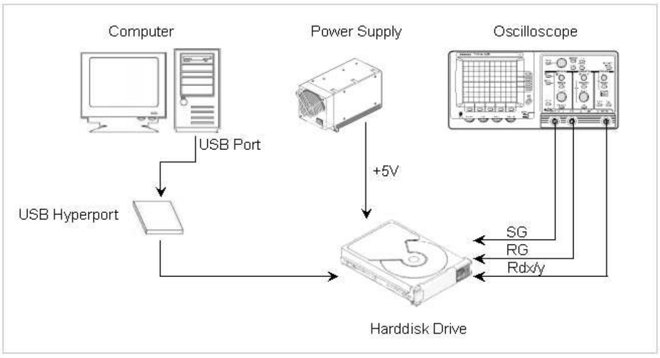


Fig. 3. Experimental setup.

III. EXPERIMENT AND DISCUSSION

This paper characterizes the behavior of the thermal response induced by head/disk interaction in the current TGMR head as a function of head/disk spacing, zone position, temperature, and writing polarity. To achieve this, we performed an experiment in the laboratory. We use the TGMR head with an MgO barrier whose structure is shown in Fig. 2 because it has a high MR ratio and a low RA value. Additionally, we also set parameters for this experiment as follows:

The interface is SATA , a drive capacity is 1500 GB, a track density is 191 KTPI average, a maximum linear density is 1293 KBPI, and the resistance of the head is approximately 300 Ω. The rotational speed of the disk is 7200 RPM. The magnetic spacing between the read gap of the head and the medium surface is controlled by adjusting the pole-tip protrusion directly from a computer. This computer will send a command via an USB Hyperport to a HDD as shown in Fig. 3. The voltage of the drive was +5 volts. We measure the readback signal from the RDx/y test points on the printed circuit board (PCB) of the HDD with a differential probe connected to an oscilloscope. The Servo Gate (SG) and Read Gate (RG) test points on the PCB are very important to indicate the exact reading location within the disk drive. The Servo Gate and Read Gate signals are monitored on the oscilloscope.

By design, the flying clearance of the drive under test is close to 10 nm. With this low clearance along with the decreased clearance due to reduction in ambient air pressure, head/disk interaction frequently happens in a normal disk drive environment. To prove that ambient pressure affects

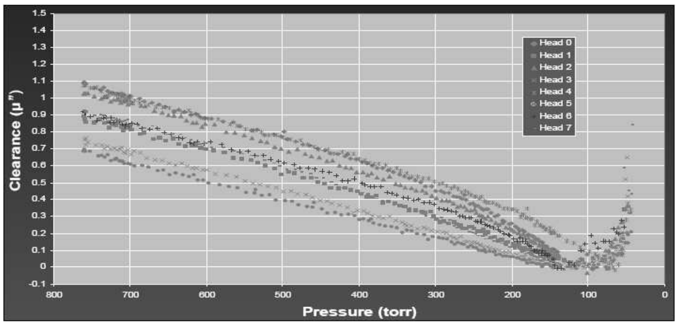
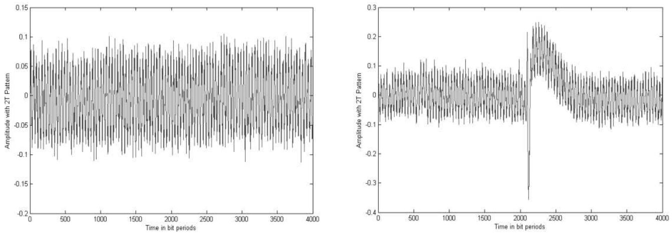


Fig. 4. The flying clearance of different TGMR heads as a function of ambient air pressures.



(a) (b)

Fig. 5. The effect of the head/disk spacing, where (a) the normal readback signal, and (b) the corrupted readback signal caused by the thermal response.

head/disk clearance, we perform an experiment in the laboratory. The ambient air pressure is gradually decreased from 800 to 0 torr, while measuring the clearance of the head/disk. The results of this experiment are shown in Fig. 4. It is clear that head/disk clearance is related to the ambient air pressure. Specifically, a lower ambient air pressure results in a lower head/disk clearance. Furthermore, when the ambient air pressure approximately reaches 100 torr for all the heads tested, a strange head/disk interaction phenomenon is observed.

As a result, we can force the head/disk interaction to occur in a real HDD by decreasing ambient air pressure. Keep in mind that when the head/disk interaction happens, the thermal response will suddenly occur in the readback signal. In the following subsections, we investigate how head/disk spacing, zone position, temperature, and writing polarity affects the behavior of the thermal response resulting from the head/disk interaction.

A. Evaluation of Head/Disk Spacing

In this experiment, the spacing between the read gap of the head and the medium surface is controlled by adjusting the pole-tip protrusion from a computer. We observed the head/disk interaction phenomenon only when the pole-tip protrusion of the TGMR head slaps the disk surface. The result of the slap can be seen by a corruption the readback signal caused by thermal response. This implies that the thermal response causes corruption in the RDx/y signal and is a function of head/disk spacing, as depicted in Fig. 5.

B. Evaluation of Zone Position

To study this, we adjust the read position of the TGMR head from an OD (outer diameter) zone to MD (middle diameter) zone and ID (inner diameter) zone, and look at the readback signal. We observed that although the zone position is changed, the shape of the readback signal corrupted by the thermal response remains the same throughout the OD, MD and ID zone positions. This implies that the corrupted readback signal in terms of its amplitude and its time duration is independent of the zone position as illustrated in Fig. 6.

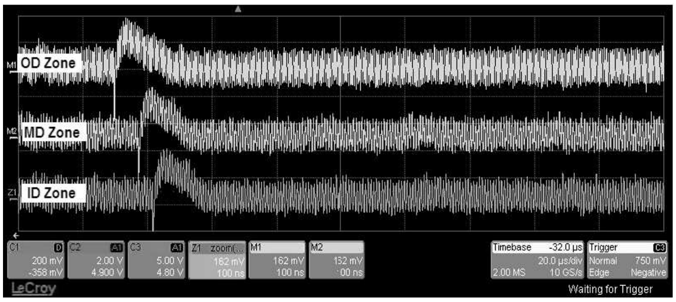
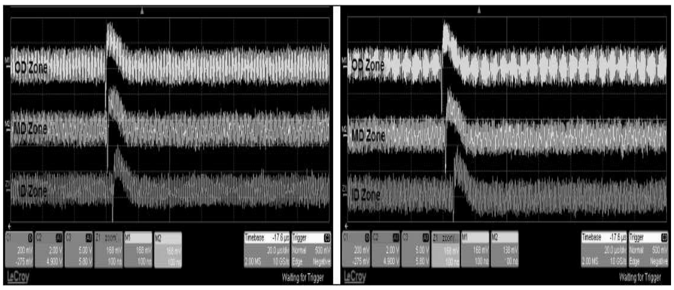


Fig. 6. The effect of zone positions upon the shape of the readback signal.



(a) (b)

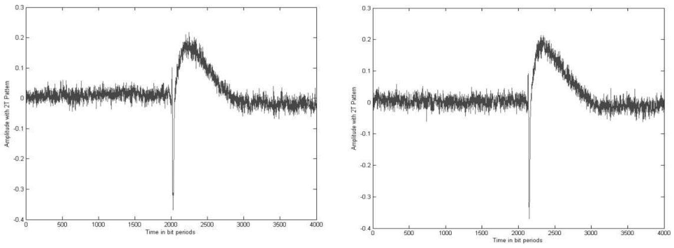
Fig. 7. The effect of the temperature upon the shape of the readback signal, where (a) the readback signal corrupted by the thermal response at cool temperature (e.g., 0 C°), and (b) the readback signal corrupted by the thermal response at hot temperature (e.g., 55 C°).

C. Evaluation of Temperature

This experiment investigates how temperature affects the shape of the readback signal corrupted by a thermal response due to head/disk interaction in terms of its amplitude and its time duration. This can be done by gradually adjusting the ambient temperature from 0°C to 55°C. We found that even though the temperature is varied, the shape of the corrupted readback signal is still the same for all zone positions. This implies that the corrupted readback signal is also independent of temperature as shown in Fig. 7.

D. Evaluation of Writing Polarity

In this experiment, we study how the polarity of signals written on the medium surface affects to the polarity of the readback signal corrupted by the thermal response. To achieve this, we write the positive and the negative DC erase pattern on the medium. We observed although the polarity of signals written on the medium surface is changed to positive or negative, the corrupted readback signal still has the same polarity as depicted in Fig. 8. This implies that the polarity



(a) (b)

Fig. 8. The effect of the writing polarity, where (a) the corrupted readback signal with a positive DC erase pattern, and (b) the corrupted readback signal with a negative DC erase pattern.

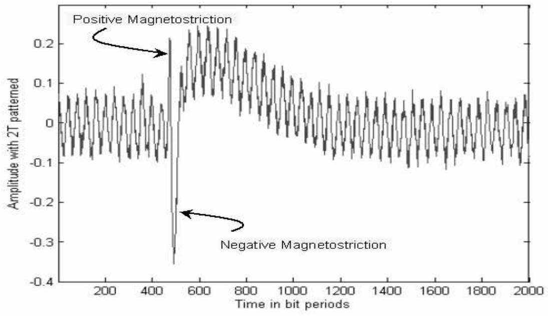


Fig. 9. Thermal response caused by the current TGMR head design with an MgO barrier.

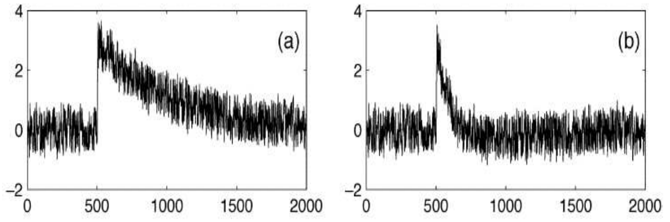


Fig. 10. The readback signal caused by the classical thermal response, where the corrupted readback signal (a) before and (b) after high-pass filtering [4].

of the corrupted readback signal is again independent to the polarity of signals written on the medium surface.

E. Note on Thermal Response Caused by TGMR Heads

The four experiments described above reveal that the thermal response resulting from the current TGMR head design with an MgO barrier can distort the readback signal and causes a baseline shift of approximately 160 – 400 bits. Furthermore, we also observed that the thermal response occurred in all experiments exhibits a bi-polar response on opposing DC (positive and negative) backgrounds. This is primarily driven by magneto-striction [6] as depicted in Fig. 9. The magneto-striction causes the thermal response to look different from the classical thermal response described by Stupp *et al*. [4], as shown in Fig. 10.

Typically, magneto-strictioin is a property of ferromagnetic materials that change physically in response to changing its magnetization. This effect was first identified in 1842 by James Joule [7] when observing a sample of nickel that changed in length when it was magnetized. This effect can cause losses because of frictional heating in susceptible ferromagnetic cores. Because the mechanism of magneto-striction is at an atomic level and is relatively complex, this paper will skip its details. For details about magneto-striction, readers can find in [6].

IV. CONCLUSION

With the increases of areal recording density in hard disk drives, the current TGMR head design is currently the most promising candidate. Specifically, the head physically becomes smaller, and the junction with an MgO barrier exhibits higher TGMR performance with a lower RA value. However, as the actual flying height is reduced, negative head/disk interaction in real disk drive environments frequently occurs and can distort the readback signal to the extent of causing possible sector read failures. The head/disk interaction phenomenon seen on the readback signal is known as a "thermal response."

Practically, the thermal response causes a shift in the baseline of the readback signal and exhibits bi-polar magneto-striction on opposing DC (positive and negative) backgrounds. This magneto-striction causes the thermal response to look different from the classical thermal response introduced by the MR sensors. Based on our experiments, we found that the thermal response caused by the current TGMR head is independent of head/disk spacing, zone position, temperature, and writing polarity. This can, in turn, enable the development of new algorithms for detecting and correcting this thermal response, which will improve the performance of the current hard disk drives.

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