Heat Assisted Magnetic Recording (HAMR) Smear Characterization by Using Head-Disk Interface (HDI) Sensor

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HAMR is considered to have the potential for achieving the areal densities beyond 4 Tb/in², although smear issues require greater attention. This work presents an experimental study conducted on a spinstand to characterize the accumulated smear at the head-disk interface (HDI) using a thermal proximity sensor integrated into the head. The smear on the head can be detected by changes in touchdown power (TDP) with the HDI sensor, while the acoustic emission (AE) sensor shows almost no response to the smear. It is confirmed that the accumulated smear height detected by the HDI sensor increases proportionally with increasing writing clearance. This indicates that more smear tends to be generated in HDI with greater spacing. Additionally, the hardness of the smear can also be characterized by observing the changes in smear height during multiple touchdown (TD) measurements.

***Index Terms*—Heat-assisted Magnetic Recording (HAMR), Head-disk Interface (HDI), Thermal Proximity Sensor, Smear**

I. INTRODUCTION

Heat-assisted magnetic recording (HAMR) is a technology with potential for realizing the areal density beyond 4 Tb/in^2 [1]. The HAMR heating process utilizes a laser to momentarily heat the recording grains, thereby lowering their magnetic coercivity and making them easier to write. This process can enable HAMR media to utilize smaller, more thermally stable recording grains [2]. However, the heating process will cause the lubricant to desorb and possibly decompose from the disk, condensing on the head [3]. The high temperature may also cause other contaminants to accumulate on heads. These accumulated matters, also known as smear, causes HDI issues and challenges the reliability of HAMR [4], [5]. Some types of smears can disrupt laser delivery efficiency, resulting in a higher NFT temperature, which may ultimately lead to poorer NFT lifetime [6], [7]. Some smear may cause flyability issues, potentially leading to a head-disk crash [8]. Therefore, the detection and characterization of smear are crucial for HAMR.

In this study, an experimental investigation was conducted on a spinstand. Touchdown (TD) experiments monitored by an HDI sensor, supported by an Acoustic Emission (AE) sensor, were introduced. The HDI sensor is a thermal proximity sensor, and its resistance change during TD can be used to detect the smear. We compared the response of the HDI thermal sensor in TD measurements before and after smear accumulation on the head to understand its effect. Finally, we conducted TD experiments on various media designs, and two of the results are presented, along with discussions on the understanding of smear characteristics.

II. EXPERIMENT SETUP

The schematic diagram of the HAMR HDI setup used in this component test work is shown in Fig. 1. The disk rotates at an angular velocity of 7200 rpm, with the head embedded in the trailing edge of the slider. The components, which include a heater, laser diode, waveguide, near-field transducer (NFT),

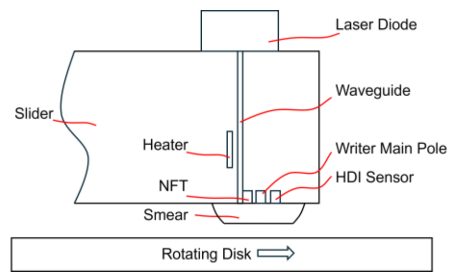

Fig. 1. The schematic diagram of the HAMR HDI (not to scale) with the smear prepared.

writer main pole, and HDI thermal sensor, are illustrated in the diagram. The TD measurement is conducted by increasing the power applied to the heater, which ultimately leads to head-disk contact. The power during this contact is referred to as TD power (TDP), while the power required to withdraw the head from the TD point is known as backoff (BO). The HDI thermal sensor, located near the NFT and writer, can be utilized to monitor the thermal profile during TD. Additionally, an AE sensor was used as an indicator of head-disk contact, and the TD operation was stopped at that power. The AE sensor was positioned near the end of the slider suspension (not depicted in the diagram).

One should note that smear was prepared using continuous laser-on writing, which is called aging, as the laser is guided by an optical waveguide from the laser diode to the NFT. The same measured magnetic write width (MWW) of 51 nm with write clearance of 3 nm was used in the following experiments as the unified test condition. Although in some cases, laser power (LP) was increased to accelerate the aging, while laser-induced protrusion was compensated by the heater as well as the pre-optimized standard LP.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The TD results before and after aging on Media A were monitored by the HDI thermal sensor and plotted in Fig. 2 (a), with the aging condition of LP at 150% for 10 minutes. During aging, the slider was swept over the disk at a target radius of 27.5 mm, resulting in a velocity of ~20 m/s. The TD profile

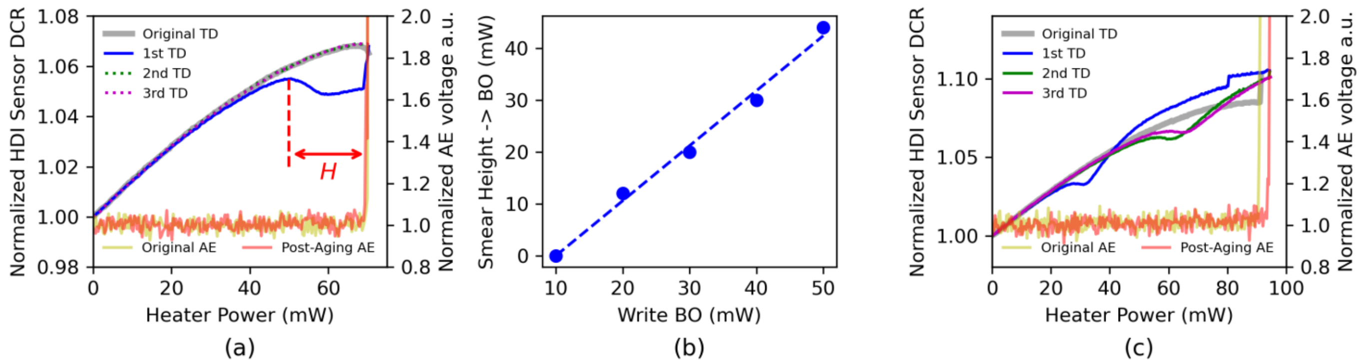

Fig. 2 (a) The normalized resistance of the HDI thermal sensor and the signal from the AE sensor during TD on Media A. (b) The bending BO, understood to correspond to smear height, as a function of the write BO. (c) The normalized resistance of the HDI sensor and the signal from the AE sensor during TD on Media B.

before aging was plotted as the gray curve. By increasing the heater power, the resistance of the HDI thermal sensor increased due to the rise in temperature at the head. The slope of the resistance curve decreased as it approached the disk, and even a negative slope was observed, which is attributed to the cooling effect with the heat transfer towards the media. In general, a further increase in heater power will lead to an abrupt increase in resistance of the HDI sensor, like the gray curve shown in Fig. 2 (c), which is caused by frictional heat with contact. However, since we used the AE signal (yellow curve) as the indicator, some of the friction contact responses from the HDI thermal sensor were not observed. At the point the AE signal reached a specific level, the heater power was referred to as the AE TDP.

When we perform aging first, however, the 1st TD exhibited different behavior: a bending of the resistance curve, understood as a significant cooling effect, was observed at lower heater power than without pre-aging. When the bending starts, the power applied to the heater is denoted as "an HDI thermal sensor TDP". This cooling effect indicates that the smear bridged the head and disk from that moment, leading to additional heat transfer from the head to the disk. By comparing the TDP of the 1st HDI thermal sensor and the post-aging AE, a difference of approximately 20 mW was observed. Since the thermal expansion efficiency of the heater will not be discussed, we regard this differential power as the smear height in the following discussion. Moreover, the bending of the curves was not observed after the 2nd and the 3rd TD, indicating the smear was removed after the 1st TD. In addition, the AE TDP of post-aging TD was nearly identical to the original, suggesting that the AE sensor is insensitive to smear during TD measurement.

We also conducted the TD experiments by adjusting the BO setting during the aging. The increase in BO during aging was anticipated to allow more smear to accumulate and fill the gap in the head disk interface. By employing the previously introduced method, the increase in smear height was confirmed when the write clearance was increased, as shown in Fig. 2(b). Consequently, the HDI thermal sensor is effectively tracking varying amounts of smear.

To gain a deeper understanding of HDI thermal sensor behavior in smear characterization, we conducted additional experiments on various media designs. Across the experiment results, a different behavior was observed in Media B. The TD behavior on Media B is depicted in Fig. 2(c). The early cooling effect of the 1st TD HDI thermal sensor resistance curve indicated the smear accumulated, as expected. However, the HDI thermal sensor curve did not recover during the 2nd and 3rd TDs, indicating that the smear was not fully mitigated by the TDs. The conclusion based on the response of the HDI sensor is that a harder smear is accumulated in the HDI during aging on Media B. Moreover, the post-aging AE TDP also changed, indicating that the solid-solid contact property of the head and disk was changed during aging, which may lead to a head-disk interaction in HDD operation.

IV. Summary

We studied the effect of HAMR smear on the HDI thermal sensor response during the TD experiment. The accumulated smear on the head will lead to an early cooling effect, which can be used to estimate the smear height. In addition, we confirmed the smear height dependence on BO in aging using the HDI sensor. A larger BO will lead to more smear generation. Finally, the HDI sensor-monitored TD process can characterize the smear hardness, which is expected to be utilized to estimate the possibility of head-disk interaction.

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