Magnetic Force Microscopy Observation of Perpendicular Recording Head Remanence

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Abstract. In this work, magnetic force microscopy (MFM) was utilized to observe the magnetic write head remanence, which is the remaining out-of-plane magnetic field on magnetic write heads after a write current is turned off. This remnant field can write unwanted tracks or erase written tracks on a magnetic media. The write head remanence can also occur from device and slider fabrication, either by applying current to the write coil during the inspection or biasing the external magnetic field to magnetic recording heads. This remanence can attract magnetic nanoparticles, which is suspended in cleaning water or surrounding air, and cause device contamination. MFM images were used to examine locations of the remnant field on the surface of magnetic recording heads. Experimental results revealed that the remanence occurred mostly on the shield and is dependent on the initial direction of magnetic moments. In addition, we demonstrated a potential use of MFM imaging to investigate effects of different etching gases on the head remanence.

1. Introduction

In order to reach areal storage density above 1 Tb/in^2 in perpendicular magnetic recording (PMR) technology, one possible solution is by reducing the size of the fringing field generated by magnetic write heads and thus decreasing a magnetic track width. This can be done by surrounding a writer main pole (MP) with magnetic shields [1]. Current PMR write heads have fully wrapped-around shielded (FWAS) design [2] which is composed of a trailing shield (TS), side shields (SS) and a leading shield (LS) as shown in the inset of figure 1. Although, FWAS design offers track density improvement and reduces adjacent track erasure, it brings additional issues [3]. One of those is magnetic remanence that can be found not only from a writer main pole, but also edge corners of the shields. The remanence is the remaining out-of-plane magnetic field on magnetic write heads after a write current is turned off [4] or an external magnetic field is removed [5]. During hard disk drive (HDD) operation, this remnant field can write unwanted tracks or erase written tracks on magnetic storage media [6]. In slider fabrication, the remanence at the main pole and shields can attract magnetic nanoparticles either from surrounding air or cleaning solution, thus causing device contamination. The write head with contamination shows in the inset of figure 1.

In this paper, magnetic force microscopy (MFM) was employed to observe the remnant field on FWAS magnetic write heads. In the next section, we discuss an experimental method as well as the dependence of the head remanence on the direction of the external magnetic field. In addition, we demonstrated the use of MFM observation to analyze the effect of different etching recipes on the head remanence.

2. Experimental setup

A FWAS write head was used as a test sample for this experiment. Its structure seen from air-bearing surface (ABS) view (see the inset of figure 1) is composed of a main pole (MP), a right shield (S_R), a left shield (S_L), a trailing shield (TS), a leading shield (LS) and a write gap (WG). The MP width and surface area are approximately 60 ± 2 nm and 3300 ± 400 nm^2, respectively and the WG is about 122 ± 2 nm.

The MFM system used in this study was similar to conventional MFM systems, excepting that it had a probe connection feeding a current to the write coil of the sample as shown in figure 1. A MFM probe with a soft magnetic coating was employed in the experiment as it has a good response to the AC magnetic field [7].The write head was mounted on a sample table equipped with the xyz piezoelectric scanner. The probe was raster-scanned at 10 nm above the sample surface and a scan speed of 90 μm/s was used. MFM imaging was taken at a scan size of 800 nm × 800 nm and a resolution of 512 pixels × 512 pixels. Measured phase data at each location across the write head was then employed for a construction of the MFM image.

Write head remanence usually results from exposure to strong magnetic fields, either an external field during device/slider fabrication or induced magnetic field from applying current to the write coil. Therefore, for this experiment, test samples were exposed to a 1 T magnetic field to simulate a magnetic field initialization (MFI) process in the slider fabrication [5]. The external field was in the in-plane direction, parallel to the ABS surface of magnetic write heads as illustrated in figure 2(a). Immediately after the sample was exposed to the magnetic field, the remnant field on the sample was observed by MFM imaging. In addition, a 30 mA AC current was applied to a write coil of magnetic write heads to simulate the write process during normal HDD operation in figure 2(b). When the current was turned off, MFM imaging was performed to observe write head remanence and its location.

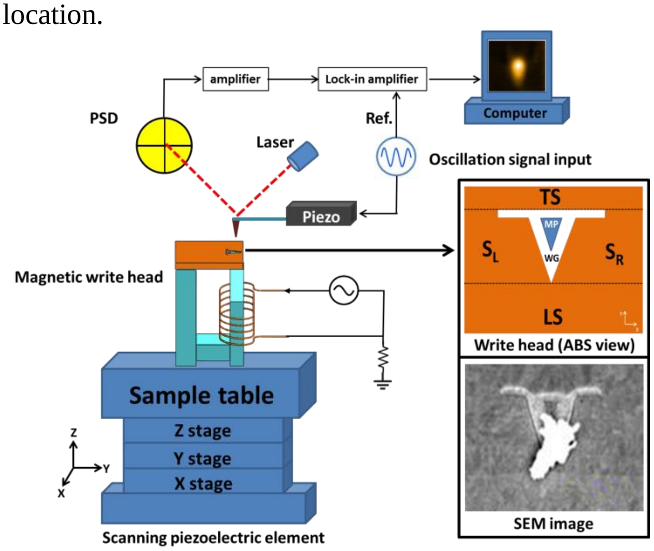


Figure 1. Schematic diagram of the MFM system for the observation of write head remanence.

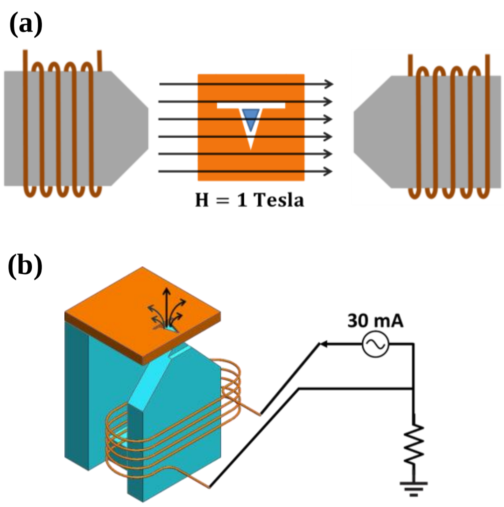


Figure 2. Magnetic write heads exposed to (a) the external magnetic field generated by electromagnets with a constant intensity of 1 Tesla and (b) the induced magnetic field from applying AC current to a write coil.

3. Results and discussions

A. Effect of external/induced magnetic fields on head remanence

In the first part of this section, we compared the remnant field profiles of FWAS magnetic writers induced by two different directions of magnetic field. A constant magnetic field with the intensity of 1 Tesla was applied, in parallel to the ABS surface, along the cross track direction. This experiment was carried out to simulate the effect of a field initialization process [5] during slider fabrication. The process was used to realign the magnetic moments of a tunnelling magnetoresistive (TMR) sensor; however, the field is sufficiently strong to change the direction of the magnetizations of the writer pole and shields. After the initialization process is completed, those magnetizations align themselves to the surface of the main pole and magnetic shields in order to minimize the magnetostatic energy. MFM imaging was then employed to observe the head remanence and its location. Imaging results, measured after applying different directions of the external magnetic field to FWAS write heads, are shown in figures 3(a) and 3(b). The bright colour represents the area having strong out-of-plane magnetic field, while the dark colour representing relatively weak field intensity. As can be seen, the strong remnant field was observed on the side shields and its location was dependent on the direction of the initialization field. Figures 3(c) and 3(d) illustrate the normalized magnetization vectors corresponding to the remnant field in figures 3(a) and 3(b), respectively. We can see some magnetic flux jumping across the write gap from one side shield to the other side; especially the flux density at a narrow spacing gap between the left and right side shields, leading to strong remnant field at the apex of the write gap. These MFM results have a good agreement with inspection results from scanning electron microscopy (SEM), which reveals contaminations adhered to the magnetic shield at the apex of the write gap as shown in the inset of figure 1.

In addition, the effect of the writing process on the head remanence was investigated. This was performed by applying the AC current to a write coil of the magnetic write head. The AC current, as high as 30 mA, was used to ensure that the writer main pole was fully saturated. Figures 4(a) and 4(c) show MFM image and magnetization vectors of the FWAS write head, respectively, when it was biased with 30 mA AC current. After the write current was switched off, the magnetizations of the main pole and FWAS were rearranged and relaxed back to its equilibrium state. MFM image and magnetization vectors of the FWAS write head when switching off the write current are shown in figures 4(b) and 4(d), respectively. As can be seen, the residual flux was found at the edge of the left side shield similar to the case where the external magnetic field was applied to the FWAS write head, from left to right-hand side as shown in figure 3(a). This can be implied that when the write head is energized, magnetic moments in FWAS are arranged themselves from the left to right-hand side and thus causing asymmetrical write field expansion.

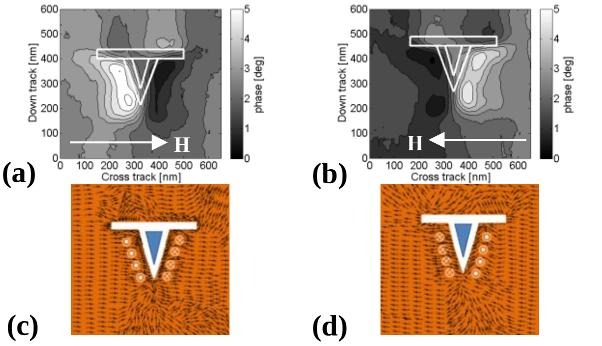


Figure 3. MFM results of the write head after exposed to the external field (a) in the x direction and (b) in the –x direction. (c) and (d) showed the drawing of the possible magnetization for (a) and (b), respectively.

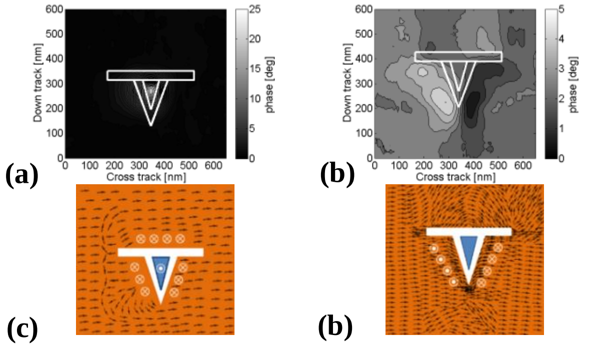


Figure 4. MFM images of the write head (a) when the 30 mA AC current was applied to the write coil and (b) when the applied current was turned off. (c) and (d) showed the drawing of the possible magnetization for (a) and (b), respectively.

B. Effect of gas etching of magnetic heads on head remanence

In this section, we demonstrated the use of MFM observation in order to study the effect of gas etching on the head remanence. Two different etching gases were used in this study; “recipe A” has no Xe in gas composition whereas “recipe B” has Xe-content in etching gases. Magnetic write heads having similar geometry were employed as test samples. Figure 5 reveals MFM images of those write heads after exposed to the external and induced magnetic fields. It was found that the main pole was modified by surface etching with “recipe A” gases as we can notice the remanence on the write main pole after the etched write head was exposed to external magnetic field. The reason behind this phenomenon is under investigation in our group. It was also found that this pole remanence resulted in contamination problem during the slider fabrication. On the other hand, the magnetic write heads etched with Xe content gasses in “recipe B” had no residual flux on the main pole as well as the intensity of the remnant field on side shields was relatively weaker, making “recipe B” a good candidate for being employed in the slider fabrication.

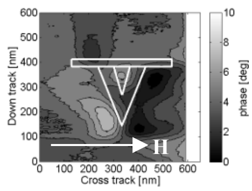
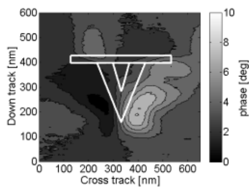
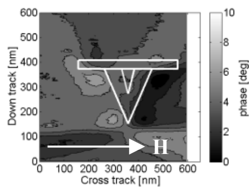
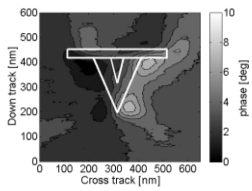
Recipe A		Recipe B	
External field	30mA AC current	External field	30mA AC current
			

Figure 5. MFM images of the remanence on the write heads, which were etched with two different etching recipes, after they were exposed to the external field and biased with 30mA AC current.

4. Conclusion

In this work, a MFM technique for characterizing the magnetic remanence of FWAS writers is presented. The MFM images are used to investigate the location and intensity of the magnetic remanence at the ABS surface of the write heads. For FWAS write heads, the remanence was found at the edge of side shields, which is dependent on the initial direction of shield magnetizations. This agrees well with the failure found in the HDD production due to the contamination of nanoparticles attached on the write main pole. In addition, we demonstrated a use of MFM to investigate the effect of different etching gases on the remanence of FWAS write heads. Two different etching gases were used in this study. It was found that by etching the write heads with the “recipe A”, it resulted in the remaining magnetic on the main pole after those writers were exposed to the external magnetic field. On the other hand, with the “recipe B”, there was no the remnant field observed on the main pole. Therefore, the “recipe B” is more appropriate for being used in the slider fabrication.

5. Acknowledgment

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6. References

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