Methods for characterizing magnetic footprints of perpendicular magnetic recording writer heads

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In this work, the magnetic footprints, along with some of its dynamic features in recording process, of perpendicular magnetic recording writer heads have been characterized by using three different techniques. Those techniques are the spin-stand stationary footprint technique, the spin-stand dynamic footprint technique, and the coherent writing technique combined with magnetic force microscope imaging method. The characteristics of those techniques have been compared to one another. It was found experimentally that the spin-stand stationary method could not precisely catch some peculiar recording dynamics of the write heads in certain conditions. The advantages and disadvantages among all those techniques are also examined and discussed in detail. © 2014 AIP Publishing LLC. [<http://dx.doi.org/10.1063/1.4866518>]

I. INTRODUCTION

As the perpendicular recording technology is being pushed to its limit, HDD industry is facing a number of challenges and issues. Thus, it becomes necessary to gain a better and deep understanding of magnetization dynamics in perpendicular magnetic recording (PMR) writer heads to further improve its write-ability, while minimizing both adjacent track erasure (ATE) and wide area track erasure (WATE) activities.^{1–4} The erasure process and issue caused by writer heads have seriously limited the writer head performance and its actual write-ability. Especially, the issues concerning off-track magnetic fields have been particularly important, as this has been shown to be the cause of ATE and WATE. As a matter of fact, in reality the high data transfer rates could make matters worse, where both ATE and WATE are drastically amplified and can cause severe data corruption.

In order to continually increase both the write-ability and reliability of the writer heads and then data storage densities, it is imperative to characterize the effect of head and shield designs on its erasure processes. This work compares three ATE/WATE characterization techniques experimentally and reveals the effectiveness and strength of each of those methods.

II. EXPERIMENT

All recording measurements were performed on a spin-stand tester with a non-repeatable run out less than 2 nm at 5400 r/min. To pertinently evaluate recording process, the heads with wrap-around shield (WAS) designs were used for this study. In addition, all those heads are equipped with the same tunneling magnetoresistive (TMR) reader sensors. The writer saturation moments range from 2.1 to 2.35 T. The multilayer perpendicular media used in this study have CoCrTaPt recording layers whose H_c ranges from 5100 to

5600 Oe. The magnetic widths of the writer and reader heads are ranging from 60 to 100 nm and 35 to 60 nm, respectively. Two types of heads with different shield compositions and geometries were experimentally examined and characterized in this study.

The typical testing procedure of the spin-stand stationary footprint technique includes media background preparation, stationary footprint writing process, and then a two dimensional (2D) image read-back process. During the spin-stand stationary footprint writing process,¹ the recording head is contacted with the recording media surface without any relative movement between the head and media. This is different from the conventional spin-stand testing process on a spinning disk. In more detail the three steps, media preparation, stationary head record, and a 2D read, involved in the static recording process could be outlined as following. The media is first prepared by either a DC+ or AC band erase. The head is then loaded on a precise location on the disk before the spindle rotation is stopped and locked. The head is then allowed to touch down on the surface prior to performing multiple writes while in this “stationary” mode, e.g., no movement between heads and media. The writes were performed with either DC- or AC. After finishing the footprint writing, a normal reading operation is performed with media disk spinning. The reader is connected to an oscilloscope and the output signals are processed to locate the written footprints and map the 2D footprint images.

The second technique is spin stand dynamic footprint technique or so called the pseudo-magnetic force microscope (MFM) based coherent writing method. In this technique, the media is first prepared by writing a reference track with a single run. This reference track then will be used to enable a more accurate positioning of the head for the subsequent coherent writing processes. The media is also band erased using DC+. Using the reference track, the reader identifies a specific location on the disk and the write head begins to write a track coherently with multiple write cycles at media disk spinning rate of 5400 rpm. After the multiple cycles

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FIG. 1. Writer Pole footprint image of a trailing-shield writer from stationary footprint testing.

writes are completed, the media is then read back by using the 2D spin-stand scan process.

The third technique is the coherent writing technique combined with MFM imaging method, which is also known as the MFM based coherent writing method. This method is also comprised of three main steps: media surface preparation, coherent track writing process during disk spinning, and an MFM scan of the written tracks and their vicinity. Briefly speaking, the media surface is prepared by a DC band erase followed by a coherent write step that involves coherently writing some specific track patterns tens of thousands cycles using write heads in a specific location on the disk. Then this technique uses an MFM to scan the written tracks and their vicinity so as to obtain the data or the written information with very high spatial resolution (~ 20 nm).

III. RESULTS AND DISCUSSIONS

Figure 1 shows the writer pole image from a spin-stand static recording technique. The 2D scan of spin stand read back process on the media surface reveals a clear touchdown mark from the writer head, as shown in Fig. 1. As expected, the point of contact allows for maximum flux through the particular location on the media. However, in Fig. 1, as can be seen, a significant erasure marks located roughly $0.4 \mu\text{m}$ and $0.7 \mu\text{m}$ along the down track location. This corresponds to the locations of the shields where the return field could be leaked out and causing the erasure process. The media were written with a DC+ write field while in a stationary position on a DC+ band erased background.

Fig. 2(a) shows the ABS SEM of a WAS writer. In practice, two side shields of the WAS writer are mainly used to improve the cross track field gradient. However, the side shield could cause the WATE erasure as well. The footprint of a 10 MHz writing process on a DC+ band erased background is shown in Fig. 2(b), with significantly more noise

FIG. 2. (a) ABS SEM writer pole image of a trailing-shield writer and (b) $2 \times 2 \mu\text{m}$ scan image of footprints generated by AC frequency writing process in the static recording process.

than that in Fig. 1. It should be mentioned here that the erasure hot spots observed over a much wider area in Fig. 2(b) are somewhat inconsistent with the observation in Fig. 1. Furthermore, varying the write frequency does not further show significant shape changes of erasure hot spots.

Figs. 3(a) and 3(b) show the footprint of a coherent writing process captured by the pseudo-MFM image processes. Depending on the type of examined head with specific shield structures, the observed WATE footprint patterns vary as was expected, implying that the detailed shield geometry and its composition could affect the WATE performances of recording heads. Furthermore, only the multiple coherent write process (10K writes) during the disk spinning could cause clear WATE signatures and then the hot erasure spots on the heads could be identified correspondingly.

It can be seen that for the head that was used for the experiment, the erasure marks overlap with the written tracks in some situations. This could be due to the fact that the WATE occurred in the vicinity of the write gap of the write head. The drawback of this method is that the coherent writing processes result in sizeable jitter variations compared to the static footprint recording process discussed above. Nonetheless, with this method some dynamic features of the actual writing process are observed, which could not be observed by the previous static footprint recording process.

To make a relevant comparison among all those techniques, the footprints of a coherent writing process were also captured by a MFM imaging process. The MFM scans have quite high spatial resolution (~ 15 – 25 nm) and thus have consistently shown to take the most accurate and precise mapping of the written and erasure patterns. As anticipated, the observed WATE marks on recording media were clearly observed as shown in Fig. 4(a). The read-back process of the MFM scan has no alignment jitter variations in this case and

FIG. 3. (a) The footprint of a coherent writing process (10K writes) captured by pseudo-MFM image process and (b) the footprint of a coherent writing process (10K writes) by using another type head with different shield structures.

FIG. 4. (a) MFM image of the coherent writing patterns (10 K) with relevant WATE marks and (b) 10 K WATE profile and x-axis is the cross track offset.

FIG. 5. MFM scan image of the wide range side-erasure patterns induced by a coherent writing process.

thus gives a clear output signal and un-ambiguously and more reliable results.

To validate the obtained results, the WATE erasure profile was also measured by using bit error rate (BER) losses at 10 K erasure cycles that are plotted in Fig. 4(b). Clearly, the measured WATE profile in Fig. 4(b) indeed has some correlation with the erasure patterns observed in Fig. 4(a). Also, it should be pointed out that obtained WATE profile measured by BER loss is also consistent with the actual erasure patterns observed both the MFM imaging based coherent writing process in Fig. 4(a) and the pseudo-MFM image based coherent writing process in Fig. 3(b).

It should be also mentioned here that both MFM imaging based coherent writing process and pseudo-MFM image based coherent writing process are dynamic writing process. Seemingly, these two techniques could better characterize the WATE erasure processes since the WATE erasure inherently is a dynamic process.

Fig. 5 shows the MFM image mapping of the wide range side-erasure patterns induced by a pulse coherent writing process on a 10 μm wide DC erased background. The erasure bands have a phase shift with respect to the on-track data

pattern, indicating that the erasing spots are located in the trailing shield area. In practice, the erasure locations could be readily identified based upon the phase shift information between the written patterns and erasure patterns. Furthermore, another advantage of based MFM coherent writing method is that its scan area is as much as 100 mm $\times$ 100 mm, which is much larger than the scan areas provided by a 2D spin-stand read-back scan process.

As a final remark, it should be pointed out that our measurement comparison suggests that the measurement accuracy of MFM imaging based coherent writing process is limited by its coherent writing alignment precision. While the method of the pseudo-MFM image based coherent writing process is limited by both writing and read-back alignment precision. On the other hand, the static footprint process is limited by its read-back alignment precision without any coherent writing precision issues.

IV. CONCLUSION

In this work, we have compared the stationary footprint technique with both MFM mapping based coherent writing process and pseudo-MFM imaging based coherent writing process. The MFM based footprint measurement has the largest scan range (100 mm $\times$ 100 mm) and more efficient with the high spatial resolution for 2D field mapping. It is critical for the application of this unique technique in product design development. Experimentally, it was found that dynamic coherent writing process based upon MFM imaging process provides a more authentic avenue for identifying the hot spots of WATE processes.

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