Study of nonlinear dibit interactions

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We investigate isolated dibit interactions by varying the intradibit spacing and observing position fluctuations using a magnetic force microscope. We see that the measured dibit spacing deviates at a recording density that depends on the remanence-thickness product $M_r \delta$ of the medium. The increased dibit separation may be partially due to the demagnetization fields during write; we find that partial erasure annihilates the narrower crosstrack parts of the dibit, effectively inducing an increase in dibit separation. © 1999 American Institute of Physics. [S0021-8979(99)60708-3]

INTRODUCTION

The mechanism and problems of dibit interaction in high density magnetic recording have been frequently addressed (Refs. 1 and 2, for example). Nonlinear recording effects such as partial erasure (PE) and nonlinear transition shift (NLTS) distort the transitions, affecting the recording location and amplitude. Hard disk magnetic media have included reducing exchange interactions and developing media of smaller grain sizes, capable of sustaining higher recording densities. We examine a set of low $M_r \delta$ media through magnetic force microscope (MFM) measurements similar to those in Ref. 2. While head readback data are dominated by linear intersymbol interference (ISI) during read, the MFM data offer a more accurate picture of the recording.

EXPERIMENTAL PROCEDURE

All data presented were recorded on a precision spin stand on CoCrTa (Cr/Ta: 14/4 at. %) disks of the following $M_r \delta, H_k$ values (emu/cm$^2$, Oe): 1.2, 2300; 0.8, 2500; and 0.4, 2600 using a thin film inductive head of track width 3.4 $\mu$m, and gap length 0.18 $\mu$m. Head-medium relative velocity was 14 m/s. MFM images were obtained from a Digital Instruments Dimension 3000 multimode MFM. Intended intradibit spacing varied from 1000 nm (~25 kfc) to 67 nm (~370 kfc) and repeated with a sufficiently low rate so that dibits were isolated. Figure 1 shows 67 and 240 nm dibits on the 0.8 emu/cm$^2$ disk.

RESULTS FROM MEASUREMENTS

Figure 2 plots measured versus intended dibit separation for all three disks. The 1.2 emu/cm$^2$ data start to diverge around the 250 nm separation, while the point of divergence for the 0.8 and 0.4 emu/cm$^2$ data is around 180 nm. Assuming that the demagnetization field is directly proportional to $M_r \delta^2$, we would expect the 0.4 emu/cm$^2$ disk to be capable of sustaining the smallest dibit separation, if the only parameter that varied during disk production was the thickness of the magnetic layer. The performance, in this respect, of the 0.4 emu/cm$^2$ medium was not any better than the 0.8 emu/cm$^2$ medium. We estimated the average magnetic cluster size by the crosstrack fluctuations of isolated transitions scanned with high resolution. The average cluster sizes were 115, 85, and 88 nm for the 1.2, 0.8, and 0.4 emu/cm$^2$ disks, respectively. The fact that the two lower $M_r \delta$ disks have the same cluster size is in accord with the MFM dibit separation plots of the two being almost identical. Dibit separation as a function of trackwidth was also examined. We processed MFM images of various dibit trackwidths, ranging from full trackwidth down to the middle 1.7 $\mu$m of the trackwidth, and found that the dibit separation remained independent of the portion of the trackwidth considered.

All three curves show dibit separations considerably larger than the intended separations at high densities. MFM tip resolution is unlikely to be the reason for this increased dibit separation, since the tip (whose radius of curvature is 40–50 nm) can resolve features of 60 nm in diameter. The diverging shape of the curves is mainly due to the linear ISI between written transitions. Nonzero transition lengths imply that the placement of the two dibit transitions is governed by linear superposition which we will call “linear write ISI” (this is the effect termed “linear PE” in Ref. 4). The shape of the curves in Fig. 2 is due to linear write ISI but is also affected by nonlinear effects, which we will divide into NLTS and nonlinear write ISI.

NLTS results in the second bit being recorded closer to the first, reducing the dibit separation. NLTS measurements were performed using the method of Ref. 5 as described in Ref. 6. Even for high densities, we did not obtain any NLTS larger than 30 nm for any of the disks. Hard transition shift was measured as in Ref. 7, with insignificant shifts found. The MFM data do contain the NLTS and hard shift effects, but these effects are masked by the spatial resolution of the MFM scans (~20 nm per data point).

ANALYSIS AND DISCUSSION

Smaller $M_r \delta$ values lead to smaller transition lengths, which explains why the 0.8 and 0.4 emu/cm$^2$ disks (which had almost identical average cluster sizes) followed the ideal (diagonal) for smaller intended dibit separations than the 1.2 emu/cm$^2$ medium. The presence of magnetic clustering implies that one cannot space two transitions closer than that size. However, considerably before cluster size limitations would impose a plateau for the dibit separation data, we see that magnetostatic interactions (linear and nonlinear write...
FIG. 1. Six 67 nm dibilit and three 240 nm dibilit (3 μm × 3 μm MFM scans of the 0.8 memu/cm² disk).

FIG. 2. Dibit separation plots for 1.2, 0.8, and 0.4 memu/cm² disks.

FIG. 3. Crosstrack processing of a dibit.

FIG. 4. Variance of extremum location in the crosstrack direction for the two dibit transitions as a function of inverse dibit separation.

FIG. 5. (a) Dibit; (b) each horizontal scan line represents a subdibit; (c) each subdibit separation is used to form a histogram of separations.

ISI) affect the shape of the curves in Fig. 2. The various NLTS measurement methods aim to determine the amount of transition shift that is not accounted for by linear ISI. While NLTS affects bit placement through the direct influence of demagnetization fields, we have found that nonlinear write ISI (nonlinear PE) also affects bit placement, but indirectly, through the annihilation of crosstrack parts of the dibit. To demonstrate that effect, we perform crosstrack analysis of the dibilit.

We compute the crosstrack signal power for each dibit [Fig. 3(b)]. A technique similar to that in Ref. 4 is employed to determine PE: the crosstrack sections whose power is below an arbitrary threshold are considered partially erased [Fig. 3(c)], and are disregarded in further processing [Fig. 3(d)]. For the remaining part of the dibit and for each horizontal scan line we determine the locations of the two extrema. This leads to the crosstrack fluctuations in extremum position for the two dibit transitions [Fig. 3(e)].

For each case of dibit separation, data from a number of dibilit were averaged for improved statistics. The variance of crosstrack location of the extremum for the first and second transition in the dibit is computed and plotted as a function of inverse dibit separation in Fig. 4. For all three disks the variance of the second transition becomes considerably larger than that of the first transition at high bit densities. This is experimental verification of theoretical6 and simulation work7 that predicted an increase in the transition parameter caused by the demagnetization fields of the adjacent transition.
To examine nonlinear write ISI effects we consider the dibit to be comprised of subdibits in the crosstrack direction. Figure 5(b) shows how each horizontal MFM scan line produces a separate subdibit output [the wave forms in Fig. 5(b) have been shifted vertically for display]. While the crosstrack average of all the subdibits [gray wave form in Fig. 5(b)] was used to determine the dibit separation, the MFM’s high resolution allows us to inspect each crosstrack part of the dibit separately and determine its subdibit separation. By considering all the subdibits we construct a histogram of subdibit separations [Fig. 5(c)]. We then determine the center of the histogram and form the ratio of subdibit separations smaller than the center (i.e., the sum of the bins to the left of center) over the subdibit separations larger than the center (i.e., the sum of the bins to the right of center). We call this ratio the width distribution skew (WDS). For each case of dibit separation we obtain an average WDS value from all dibit histograms. Figure 6 plots the WDS as a function of inverse dibit separation for the three different disks (the lines are polynomial fits to guide the eye; the data at low inverse dibit separations contain more scatter because of the small number of dibits averaged in producing the statistics). At low densities the WDS hovers about unity. At higher densities though, it starts to decrease and reaches values of 0.6–0.7 for all three disks. A WDS of unity implies a symmetric histogram of subdibit separations; in other words, the number of narrower sections of the dibit is equal to the number of wider ones (Fig. 7). Values of WDS smaller than unity signify that narrower sections of the dibit have been diminished (i.e., have percolated or become wider). This results in an indirect repulsion between the transitions of the dibit: as the narrower parts of the dibit disappear, dibit separation is effectively increased.

The nonlinear aspects of PE have been generally considered as affecting signal amplitude. The results presented herein, however, hint at transition placement effects in addition to amplitude reduction effects. The increase in dibit separation due to erasure of the narrow dibit sections tends to shift the second transition downstream (opposite to NLTS), and the first transition upstream. Obviously, this effect would not be present in an all-ones pattern. Additional work is necessary to determine the magnitude of this effect and what it means for the currently used techniques for measuring nonlinear distortions in order to determine write precompensation.

CONCLUSIONS

We investigated the recording of dibits on media of varying $M$, $\delta$. Measured dibit separation deviated from the intended dibit separation; the lower $M$, $\delta$ media data deviated from the ideal at smaller intended separations and exhibited less deviation. Nonlinear write ISI effects were examined through crosstrack analysis and it was found that nonlinear PE affects transition placement in addition to amplitude. PE starts to annihilate the narrower sections of the dibit first, thus indirectly increasing dibit spacing in a nonlinear manner.

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