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Discrete track media for 600 Gbits/in^2 recording

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Discrete track perpendicular recording media were simulated to determine the optimum conditions for achieving an areal density of 600 Gbits/in^2. For a 90 nm track pitch the best performance was obtained from a medium with 60 nm land and 80 nm wide write pole. Comparisons with continuous media showed higher on- and off-track signal-to-noise ratio in some discrete track media, mainly due to the absence of erase band noise. Reducing the average grain size narrowed the differences between the two types of media, resulting in almost identical performance for an average grain size of 6 nm. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2170071]

I. INTRODUCTION

The challenge to achieve ever higher areal densities in magnetic recording have been met by moving to other paradigms, such as perpendicular recording. However, in order to further increase the track density patterned media may be required. As a first step, we consider discrete track media (DTM) in which individual tracks are formed either by physically removing part of the recording layer[1,2] or by changing the properties of intertrack regions to make them nonmagnetic, e.g., with ion-beam bombardment.[3]

Patterning the recording layer into land and groove regions has advantages such as the removal of erase bands at the edges of written tracks and a consequent reduction of noise, concentration of flux from the write head in the land regions, and the possibility of reducing transition curvature by allowing the use of write poles which are wider than the land regions.

A finite element model of a single pole write head, recording medium, and soft magnetic underlayer (SUL) was used to calculate the magnetic fields in the recording layer.[4] The write pole was 150 nm long and its width was varied from 50 to 90 nm. Side shields, extending for 1500 nm in the down-track direction, were located on either side of the main pole. The gap between the side shields and the main pole was half of the pole width for the 50-, 60-, and 70-nm-wide poles, 48 nm for the 80-nm-wide pole, and 55 nm for the 90-nm-wide pole. The recording layer was patterned into land and groove regions with permeabilities of 2 and 1, respectively. The SUL was not patterned.

For 600 Gbits/in^2 the target track pitch was 90 nm with a linear density of 2100 kfci. The land and groove widths were varied to determine the optimum combination for the 90 nm track pitch. The magnetic spacing between the write pole and the 9-nm-thick recording layer was 12 nm. A 4 -nm thick, nonmagnetic seed layer was placed between the recording layer and the 200-nm-thick SUL.

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II. RESULTS

Initially, the average grain size was 8 nm with a 12% size distribution. For each head and medium combination, the optimum recording layer anisotropy field H_k was determined by varying the saturation magnetization M_s. The uniaxial anisotropy K_u was fixed at 4.6×10^6 ergs/cm^3 to ensure thermal stability. The optimum recording layer H_k for media with various land widths versus the maximum head field H_z and the effective head field H_{eff} is plotted in Fig. 1. H_{eff} assumes Stoner-Wohlfarth reversal of magnetization and takes account of the angle of the resultant head field from the perpendicular axis.[5] Though the head field was changed by varying the width of the write pole, it also showed a slight dependence on the groove width. In general, H_k was proportional to both H_z and H_{eff} (the lines on the figure are fits to the trends). Closer inspection of the H_k vs H_z data suggests that the relationship between H_k and H_z was also dependent upon the land width. For example, H_k showed less dependence upon H_z for media with 60 nm land than it did for media with 80 nm land.

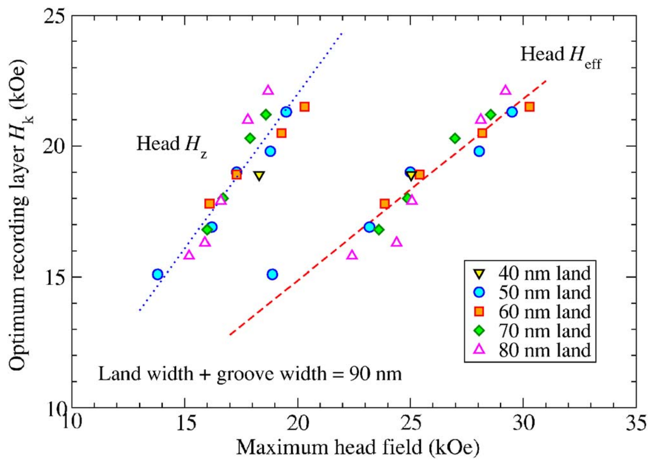

FIG. 1. Optimum recording layer H_k vs maximum vertical head field H_z and maximum effective head field H_{eff}. The optimum H_k is that which maximizes the on-track SNR.

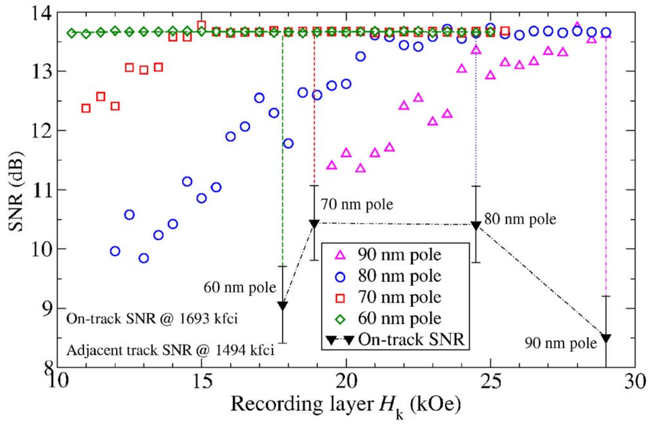

FIG. 2. Adjacent track SNR vs H_k after writing a central track. The solid triangles show on-track SNR at 1693 kfci. Land width=60 nm, groove width=30 nm.

The on-track signal-to-noise ratio (SNR) is not the only consideration in designing a recording media; it is also required that the writing of a track does not result in any adjacent track erasure (ATE). To calculate the amount of ATE, all tracks were initially programmed with a 1494 kfci density bit pattern. Figure 2 shows the average adjacent track SNR in media with 60 nm land after writing central tracks with write pole widths from 60 to 90 nm. The SNR values in the figure were calculated directly from the magnetization as this was more sensitive to small changes than a reciprocity calculation. The 60-nm-wide write pole did not influence the adjacent track SNR over the range of recording layer H_k investigated. For the other write pole widths, there were H_k values below which the adjacent track SNR began to decrease. The wider the write pole, the greater the stray field in adjacent tracks and the larger the minimum H_k needed to avoid ATE. For the 80 and 90 nm write poles, this minimum H_k exceeded the optimum H_k shown in Fig. 1, and it was necessary to sacrifice some on-track SNR to ensure zero ATE. For the 80 nm write pole, H_k had to be at least 24.5 kOe to avoid ATE. However, the on-track SNR was a maximum for H_k of around 20 kOe. In this case, eliminating ATE reduced the on-track SNR by 1 dB.

The vertical lines in Fig. 2 indicate the optimum H_k, or minimum acceptable H_k, for each write pole width and the solid triangles show the corresponding on-track SNR at 1693 kfci. The error bars correspond to one standard deviation of SNR calculated from six simulations. Wider write poles reduce transition curvature and improve the head field gradient. Because of this, the on-track SNR increased when the write pole width increased from 60 to 70 nm. Widening the write pole to 80 nm further increased the head field gradient, but a large increase in the recording layer H_k was needed to prevent ATE and so the on-track SNR was unchanged. When a 90-nm-wide write pole was used, H_k was too large for saturation recording and the on-track SNR decreased. Therefore, for the 60 nm land/30 nm groove media the optimum write pole width was between 70 and 80 nm. However, transition jitter was lower for tracks written with the 80 nm write pole, so this pole width was used in subsequent simulations. The optimum land width was determined

TABLE I. Properties of media with average grain size D. DTM media had H_k of 22.4 kOe.

D (nm)	K_u (ergs/cc)	H_k (kOe)	A (erg/cm)
6	5.67×10^6	21.3	0.563×10^{-7}
7	4.16×10^6	23.0	0.764×10^{-7}
8	3.19×10^6	26.0	1.000×10^{-7}

using the same technique. Land widths from 50 to 90 nm were simulated, and the highest SNR and lowest jitter were obtained for media with 60 nm land.

To reach 600 Gbits/in^2, the linear density should be 2100 kfci, i.e., a bit length of 12 nm. Such linear densities will be difficult to achieve in media with 8 nm grains, so the average grain size was reduced to 6 and 7 nm. To combat thermal instability, the recording layer thickness was increased to 13 nm and K_u was set to keep K_uV/kT equal to 64, where V is the grain volume, k Boltzmann's constant, and T=300 K. The magnetic spacing was reduced to 10 nm and the interlayer thickness to 2 nm, while the air bearing surface SUL spacing remained at 25 nm. Table I shows the magnetic properties for both DTM and conventional, unpatterned (continuous) media. Evaluation of tracks written in the continuous media assumed the same 60 nm track width and 90 nm pitch as the DTM, and the same criterion of zero ATE was applied when determining the optimum H_k. For the discrete track media, H_k of 22.4 kOe was sufficient to avoid ATE.

Figure 3 illustrates a potential advantage of DTM over continuous media. The edges of the written track and the erase band at various densities are shown for a continuous medium with 6 nm grains. On the right is shown part of the sensitivity function for a 60-nm-wide magnetoresistive (MR) head with a 30 nm gap length. The whole of this sensitivity function was used for the SNR calculations in the rest of this paper. A 30 nm gap length was used to increase the MR head output at high densities. Figure 3 shows that adjacent tracks, indicated by region A, make only a small contribution to the signal and noise. Region B depicts the contribution to the signal and noise from continuous media which is absent from

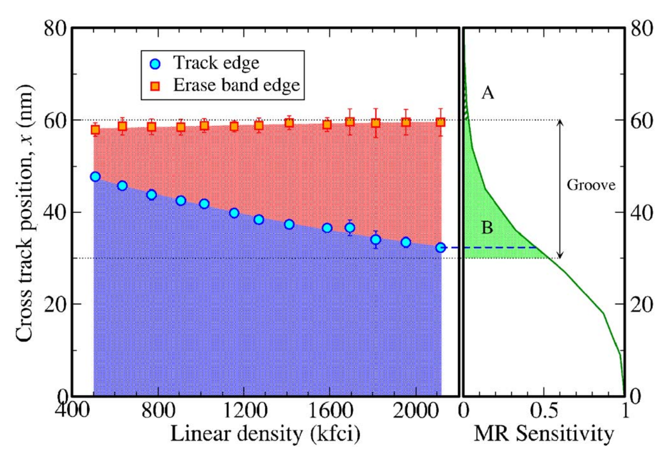

FIG. 3. Written track edge and erase band edge vs linear density for a continuous medium with 6 nm grains. The MR head sensitivity function for M_z is shown on the right.

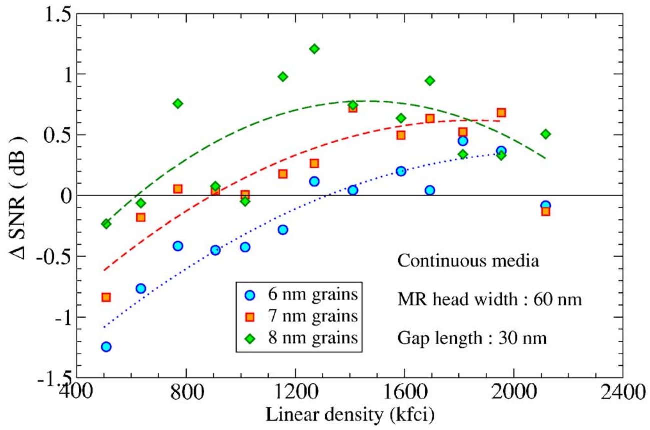

FIG. 4. Change of SNR, ΔSNR, on removing the magnetization of 30-nm-wide bands at the track edges of continuous media with average grain sizes of 6, 7, and 8 nm.

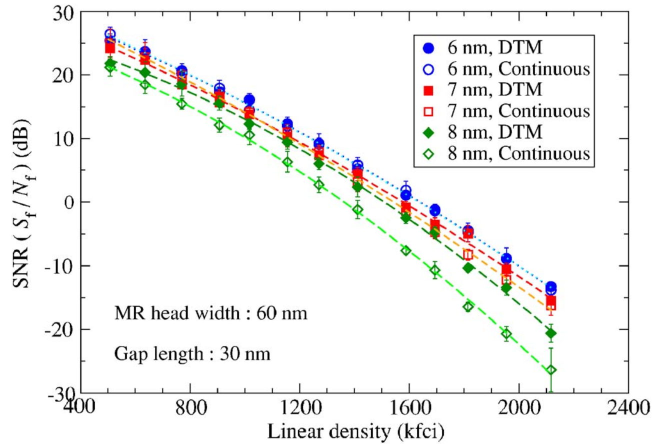

FIG. 5. SNR vs linear density for continuous and discrete track media.

DTM due to patterning. Region B comprises 18.3% of the total area under the sensitivity function. The written track width decreases as the linear density increases, but the erase band widens to compensate. At the target linear density of 2100 kfci, the erase band comprises the larger part of the medium under region B. Erase band noise reduces the SNR of the continuous media relative to the DTM.

To quantify the influence of the erase bands, the continuous media SNR was calculated with and without the contribution from the two bands extending from $x = \pm 30$ nm to $x = \pm 60$ nm in the cross-track direction, i.e., the bands correspond to the grooves in the DTM. The change of SNR on excluding the contribution from these side bands, ΔSNR, is shown in Fig. 4 for media with average grain sizes of 6, 7, and 8 nm. Although the data points in Fig. 4 are subject to large uncertainties, two trends are suggested. Firstly, ΔSNR was greater at higher linear densities; this demonstrates the increasing contribution of the erase bands to the noise at higher densities. Secondly, ΔSNR was greater for media with larger grains, and positive values of ΔSNR were obtained at lower linear densities as the grain size increased.

Discrete track media and continuous media are compared in Fig. 5. For media with 8 nm grains the DTM show higher SNR, particularly at the highest linear densities, e.g., the DTM SNR was 5 dB greater than the continuous media at 1600 kfci, which, at two grains per bit, was the maximum density such a medium could realistically support. For a grain size of 7 nm and a linear density of 1800 kfci the gap between the DTM and continuous media SNR reduced to 1.4 dB, while for the 6 nm media there was no observable difference at all.

Part of the SNR difference can be explained by reference to Fig. 4, and was due to the absence of the erase bands. Also, the H_k for the continuous media with 7 and 8 nm grains had to be higher than the value for maximizing the on-track SNR in order to eliminate ATE. There was evidence that for media with the same H_k, the media with larger grains were more susceptible to adjacent track erasure, possibly because of their lower M_s.

III. CONCLUSIONS

Discrete track media have demonstrable advantages over continuous media, but these advantages disappear as the average grain size is reduced. Both on-track and off-track SNRs were improved in DTM with 8 nm grains as a result of physically removing the erase bands and their associated noise. However, reducing the average grain size led to lower media noise and the benefits of DTM were lost. The media with an average grain size of 6 nm could support areal densities of 600 Gbits/in^2 in the sense that bits written at 2100 kfci were quite distinct. However, obtaining a sufficient readback signal will be a challenge as the SNR was −13 dB at 2100 kfci. Error rate considerations typically require the SNR to be no less than 0 dB, in which case the maximum linear density would be 1640 kfci, or 470 Gbits/in^2.

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