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High-density perpendicular recording—advances, issues, and extensibility

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Abstract

Longitudinal recording is approaching its areal density limits, and consequently the compound areal growth rate of areal density on hard disk drives has recently been slowing. A transition to perpendicular recording is expected somewhere above 100 Gbit/in^2. In this paper, the advantages of perpendicular recording over longitudinal recording are briefly summarized and the issues that must be overcome for perpendicular recording to become both successful and extensible are discussed. A key advantage of perpendicular recording is improved writability, which is due to a number of factors, including excellent anisotropy orientation, optimized write field angle, and the use of a soft magnetic underlayer to enhance the write fields. Obtaining an optimized design requires small grain size, large anisotropy field and large effective write fields, just as in longitudinal recording. On the other hand, the use of the soft underlayer brings with it some problems. DC fields from tracks neighboring the one being written or read can affect both the write and read processes. Although areal density is found to be relatively insensitive to bit aspect ratio, it is quite sensitive to the "soft erase" width, the distance that must be allowed between the writer pole edge, and the adjacent track to ensure that repeated writing on a track does not cause thermal demagnetization of previously written bits on an adjacent track. This brings the necessity to confine the write fields in the cross-track direction using shields or some other means. Finally, although at low densities it may be possible to use trapezoidal poles to reduce the effects of head skew on areal density, at high areal densities, other means must be found.

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1. Introduction

The areal density growth rate of magnetic hard disc drives has recently slowed from over 100% per year to less than 40% per year for the most recent product generation. Current products use

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longitudinal recording with areal densities of around 70 Gbpsi and the highest areal density demonstrations with longitudinal recording are only somewhat higher than 100 Gbit/in^2. On the other hand areal densities well beyond 100 Gbit/in^2 have been demonstrated with perpendicular recording, and perpendicular recording areal density demonstrations continue to show progress. Hence, it would appear that perpendicular recording is positioned to soon enter the market place.

This paper first reviews the issues limiting longitudinal recording technology. Then, perpendicular recording is discussed. Perpendicular issues will be reviewed, a sensitivity analysis of key parameters will be discussed, and projections of perpendicular recording areal densities and limits reviewed. Finally, we will look at what the future bears.

2. Background

Limits of longitudinal recording have been discussed in the literature for some time [1]. Traditional scaling has been slowed by physical limits of spacing and also by both practical and theoretical limits on the grain size of the recording medium. The situation was well described as a "Trilemma" [2], because one has to trade off writability of the medium against signal-to-noise ratio and thermal stability. Today, the write field is limited by B_{sat} of the recording head, while the physical grain size is limited by thermal stability requirements, given the maximum writable magnetic anisostropy.

Although theory has provided hope that the saturation magnetization of writer poles might be increased [3], experiment has failed to provide significantly improved materials, and it appears that 2.4–2.5 T represents the maximum attainable. Multi-layer anti-ferromagnetically coupled media provide an avenue to improved thermal stability, but with a cost in spacing loss and switching field and appears to have already been highly optimized with at most very small gains yet possible.

A fundamental architectural issue with longitudinal recording is that the media being recorded is in the fringing field of the writer. Large write gaps are required for high write efficiency; however, the write field fringes laterally about the gap, requiring a significant "dead zone" to protect against adjacent track erasure, thereby limiting the attainable TPI and therefore areal density.

Optimization of write efficiency was one motivator for the development of oriented media. Orientation ratios of 1.8 have been reported, corresponding to an angular distribution, $\Delta\Theta_{50}$, of $\sim 58^\circ$, where $\Delta\Theta_{50}$ is the full-width at half-maximum of the Gaussian anisotropy dispersion, and Θ is the angle between the easy axis of media anisotropy and the write field. This orientation reduces the requirement on write fields to $\sim 0.75 H_k$ as compared to H_k for a non-oriented medium.

3. Perpendicular recording

3.1. Write

As for longitudinal recording, write efficiency is a key parameter for perpendicular recording. A characteristic of good perpendicular media is a tight angular distribution of anisotropy. The angular dependence of the switching field H_{SW} of a uniaxial magnetic material was described by Stoner–Wohlfarth [4].

$$H_{sw}(\theta) = H_k \left(\sin(\theta)^{2/3} + \cos(\theta)^{2/3} \right)^{-3/2}.$$

Since both the write field and the media switching field have significant angular dependence, visualizing the switching threshold is complex. An alternative perspective is to map the media switching field angular dependence into the write field, allowing us to view an "effective" write field while considering the media switching field (or H_c) to have no angular dependence. This perspective will be used throughout this paper.

Following this approach, Fig. 1 illustrates the multiplying factor on the media switching field as a function of write field angle. This figure illustrates that for a field angle of 45°, the effective write field is twice the 0° (inline with the easy axis of anisotropy) case. This effect, coupled with a head/media design for delivering an angled write