Challenges in Heat Assisted Magnetic Recording

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To meet the ever-growing demand for digital storage, the recording industry has been maintaining a phenomenal growth in the data storage density. This growth has been maintained by increasing the anisotropy of each of the grains each time their volume was decreased. Heat Assisted Magnetic Recording will allow this scaling to continue by removing the write-ability barrier: Heating the medium during the write process lowers the anisotropy, such that even with a modest magnetic field a bit can be switched, yet remain thermally stable at ambient temperature. In this paper we will address three major challenges that were overcome to successfully put together a Heat Assisted Magnetic Recording system.

1. Introduction

The insatiable demand for digital storage has fueled the phenomenal growth in magnetic data storage densities since the inception of the hard drive, now over fifty years ago. The technological advances to maintain this growth in storage density have been phenomenal. For example, to maintain thermal stability of the data bits, the magnetic recording industry has had to increase the anisotropy ($K_v$) of each of the grains every time their volume ($V$) was decreased. By keeping the value of $K_vV/K_B$ high enough, thermal stability was ensured ($K_B=1.38\times10^{-23} \text{J/K}$ is Boltzmann’s constant, and $T=298K$ is the ambient temperature.) However, the point has been reached where not enough magnetic field is available in the writer to overcome the anisotropy of the grains at ambient temperature. Fortunately, it is still possible to switch the magnetization of the grains by heating the medium to near $T_c$, the Curie temperature. At this temperature the anisotropy of the medium reduces to 0 and only the demagnetization field needs to be overcome to write each bit. Heat Assisted Magnetic recording (HAMR) thus enables the writing of high anisotropy media by temporarily heating the medium and thus lowering the anisotropy so it can be written, while maintaining thermal stability when the medium is at ambient temperature. The challenges now lie in (1) heating only the area of the medium that needs to be written, (2) applying sufficient field to this same area to write the bits as the medium cools back to ambient temperature and (3) to make the head-disk interface robust enough to withstand the heating and cooling cycles for the lifetime of the drive.

2. Design of Experiment

Thousands of heads were manufactured using standard thin-film technologies with a magneto-resistive reader, an optical delivery system and a magnetic field delivery system integrated together\(^1\). The magneto-resistive reader is identical to those in standard magnetic recording heads and requires no further attention here. The heat is delivered using laser light, and a planar solid immersion mirror is used to focus it at the desired location\(^2\). The magnetic field is delivered using a design that is similar to that of a typical write head. It consists of a yoke driven by a pancake coil and a pole and return pole at the air-bearing surface. In order to accommodate the light delivery system, the gap in the ring head is much larger than that of a typical write head. The longitudinal field is therefore rather weak, but the perpendicular field near the write pole is sufficient for HAMR recording.

Heads were then selected based on reader performance, magnetic writer performance, how well they couple light from the grating to the ABS, how well the light is focused at the ABS, and the alignment between magnetic and optical components of the head.

Thousands of media disks were fabricated with a heat sink, media layer and overcoat\(^3,4\). The heat sink is required to prevent lateral spreading of the heat in the recording layer, resulting in tracks as narrow as 130 nm.

![Normalized read-back(top) of a 127 bit pseudo-random bit sequence (bottom) written by a fully integrated Heat Assisted Magnetic Recording Head.](image)

Fig. 1. Normalized read-back(top) of a 127 bit pseudo-random bit sequence (bottom) written by a fully integrated Heat Assisted Magnetic Recording Head. 1 T marks are clearly distinguishable.
The media layer was fabricated to have a Curie temperature near \( T = 650 \text{K} \) so that just a modest amount of laser light could heat the media to \( T = 650 \text{K} \).

Media were then selected based on grain size, grain orientation, thermal diffusion properties, fly-ability and Curie temperature.

A spin stand was modified to allow for HAMR recording\(^4\). Specifically, a light delivery system was added that focused laser light through free space onto the backside of the slider, where a grating allowed for coupling of the laser light into the waveguide. Promising head and media combinations were tested and both laser power and coil current were optimized to achieve HAMR recording as shown in Fig. 1.

In the next few sections, the three major challenges overcome in this achievement will be addressed.

### 3. Delivering the light

The first challenge is to deliver the light in a small spot with sufficient power to heat the medium to a peak temperature (greater than \( T = 650 \text{K} \)) to enable HAMR recording. Normal recording media (Co-alloy) have a Curie temperature around 1200 \( K \), which is too hot to prevent damage to the head-disk interface (HDI). A maximum temperature of 650 \( K \) is more agreeable to the HDI.

Therefore, media with high \( K_u \) and a Curie temperature near \( T = 650 \text{K} \) were selected for this work.

Laser light with a wavelength of 488 nm was focused on the grating on the backside of the head, such that the laser light was coupled from free-space into the waveguide by properly matching the mode of the grating with the mode of the waveguide. A planar solid immersion mirror (PSIM) then focuses the light to a diffraction-limited spot at the air-bearing surface (ABS)\(^2,5\). Theoretically, the efficiency of a grating can be as high as 55\%\(^6\). For a Gaussian spot however, light is lost both in the center of the beam and near the edges as illustrated in Fig. 2. The PSIM has the shape of a parabola, with its focus at the ABS. If we define the center of the parabola at \( x \) (cross track)=0, and \( y \) to be positive going into the slider from the ABS, the PSIM can be described by:

\[
y = \frac{1}{4f} x^2 - f
\]

where \( f \) is a free parameter. The PSIM is open at the ABS and the width of the opening is \( 4f \). The light in the center of the Gaussian beam travels straight down through this opening, is never focused and thus lost. The PSIM also has a finite width at the location of the grating. Since our recording head has a finite height \( h \), the maximum width \( w \) of the parabola is:

\[
w = 2\sqrt{4f(h + f)}
\]

The light that falls outside this width is also lost. Additional losses occur in the waveguide depending on its quality, and some light is lost in the metallic sidewalls of the PSIM. Optimizing all parameters for maximum efficiency is indeed quite a bit of work.

### 4. Delivering the field

The second challenge is to deliver the magnetic field on the trailing edge of the optical spot, so that as the medium cools to ambient temperature the correct field is applied to record the data. Conventional perpendicular recording occurs at the trailing edge of the write-pole, but then the pole would block the light. A ring-head is therefore the better solution for HAMR recording. The gap however will have to be much larger to accommodate the optics (see Fig. 3), and thus the deep-gap field will be significantly lower.

A trade-off exists where a smaller gap will cause loss of light, whereas a bigger gap will cause loss of field. The challenge is to find a balance between providing enough magnetic field and enough light. A 25\% to 30\% loss of light, in addition to the losses described in section 3 appears to be acceptable to provide the field and heat required to write sufficiently sharp transitions.
5. Preserving the Head-Disk Interface

The final challenge is the need to preserve the Head-Disk Interface despite the heating of the head and the heating of the media (and the accompanying protrusion). The head-to-media spacing needs to be close enough for the PSIM to focus the light in the near-field to the sub-wavelength spot desired, and for the magnetoresistive reader to read back the written track. For state-of-the-art recording, this spacing is less than 7nm. Even protrusions of less than 1 nm need to be accounted for at these spacings, as any contact will severely affect the longevity of the recording system. Heating the media to 650 K will cause it to protrude less than 1 nm (as predicted from a model of the medium as pure Co, $a = 1.3 \times 10^{-6} / K$ and assuming it is heated 352 K over ambient for a thickness of 130 nm, due to uniform spreading of the heat from the laser spot.) The head however is likely to protrude more. A typical heater as implemented in a state-of-the-art drive will cause a protrusion of 1 nm per 5 to 20 mW of heat applied. Given that we are applying both a write current and laser light, we must take into account that the pole and waveguide will protrude.

Another concern is the desorption and/or decomposition of the lube. Standard lube used in modern drives (for example Zdol 2000) is of fairly low molecular weight and will desorb completely at 570 K. Two new lubes have been developed that will withstand temperatures up to 650 K as shown in Fig. 4.

Finally, not just the lube, but also the storage layer must be able to withstand the thermal cycling as well. Using both femto- and nano-second pulsed laser systems, the defect threshold in sample media has been tested. For a model system, the threshold temperature was found to be $T=810 K$ well above the operating temperature of $T=650 K$.

6. Conclusions

The challenges described herein are indeed significant, but can be overcome as demonstrated on a modified spin-stand. Fig. 1. shows the read-back signal of a pseudo-random bit sequence written by a fully integrated Heat Assisted Magnetic Recording Head. The 1 T marks can clearly be distinguished, indicating that this is a well-written track. The maximum recording density of the system presented when using 488 nm light is competitive with state-of-the-art products. Extending HAMR technology to much larger densities necessitates the use of a near-field transducer to focus the light to dimensions well below the diffraction limit.

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