HAMR Thermal Modeling Including Media Hot Spot

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All previous thermal modeling on heat exchange between hard disk drive (HDD) head and media treated media as a heat sink with uniform ambient temperature. However in heat-assisted magnetic recording (HAMR) system, the media temperature is no longer uniform and the temperature at the hot spot center can reach as high as 800 to 1000 K depending on recording layer's Curie temperature. In this paper, both media hot spot and the air bearing flow are included in formulating heat transfer across the head-media interface. Numerical results for a waveguide only slider and a slider with a metallic near-field transducer (NFT) are presented to illustrate the effect of HAMR media temperature.

***Index Terms*—Air-bearing surface (ABS), head-disk interface (HDI), heat-assisted magnetic recording (HAMR), media hot-spot.**

I. Introduction

HAMR has become one of the most promising technologies being pursued to push recording area density much higher than 1 Tb/in^2. It used to be a big challenge in HAMR development to deliver enough power to heat the recording material locally above its Curie temperature. Today, it has been routinely demonstrated [1]–[3] that HAMR recording can be realized using reasonably small amount of laser power that many laser suppliers can provide. The progress has been realized through several improvements, such as light delivery system, NFT efficiency, material choices, heat sinking and head fabrication processes. Nevertheless, further advancement in all these areas is still necessary to continuously push head temperature lower while heating the media local temperature high enough.

HDD stores all kinds of information, whether it's important or not, the reliability has always been one of the top requirements. For HAMR HDD, the high temperature that HDD operates at makes reliability more challenging to both head and media. On HAMR media, current focal R&D efforts for smaller anisotropic grain are FePt-based with its coercivity at several Tesla and its Curie temperature ranges from 600 to 750 K depending on the dopants added during the layer growth. Magnetic domain switching occurs only when the magnetic writing field is higher than the material coercivity, however even the most aggressive writer design is not able to deliver field higher than the coercivity. To reduce the FePt coercivity lower enough for writing, temperature within the desired recording spot is at least near or at the Curie temperature, with additional requirements for temperature gradient, recording field amplitude and gradient. Under such a high Curie temperature, the peak temperature on media can easily reach 1000 K by considering the finite track width. At this temperature level, the HAMR HDD presents serious concerns to its head and media reliability. On

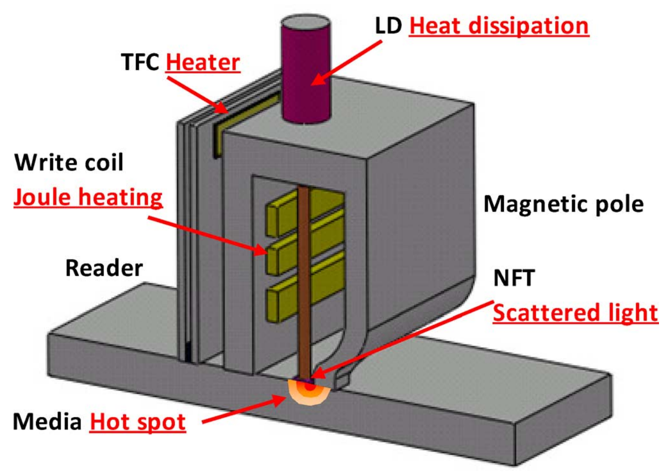

Fig. 1. Key components of a HAMR head relative to HAMR media, heat sources identified in red.

the media side, the efforts are being made to ensure the media protection and lubricant layers can survive the high temperature. While on the head side, lower temperature is a must to protect delicate head elements as well as to maintain its magnetic and optical performances under the elevated temperature.

In this paper, we discuss the effect of head temperature to its long term reliability, and determine the impact of media hot spot. Both air bearing flow and media hot spot are included in the head thermal model. First, heat absorption profile is generated from an electromagnetic model consisting of necessary head elements as well as waveguide, NFT and media stack. The heat absorption profile is then applied to a transient HAMR media model, which determines the power required to heat the recording layer to the desired temperature level and spot size. Media surface temperature profile is extracted and used to construct the hot spot on the disk surface, which is finally applied to a head thermomechanical model along with air bearing code to obtain temperature rise and head protrusion.

II. HAMR Head Reliability and Primary Cause

It has been widely acknowledged that HAMR head high temperature is the root cause of head premature failure and low reliability. However, it is not known the contribution of some of

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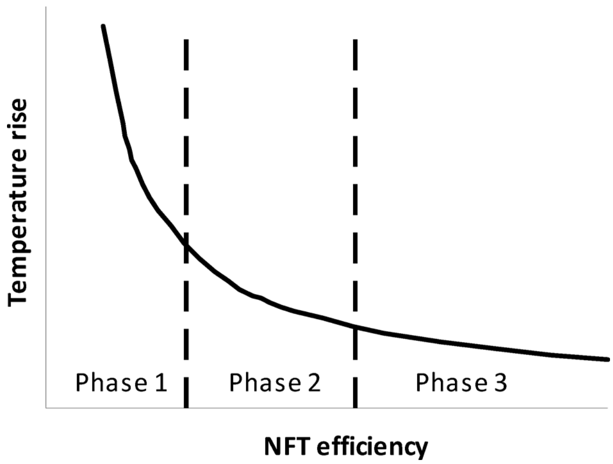

Fig. 2. HAMR head temperature versus NFT efficiency under writing condition with all heating sources considered.

the heat sources to the temperature rise. Prior to HAMR development, conventional heat sources, such as thermal fly-height control (TFC) power, writer current and frictional heating have been well studied. HAMR related heat sources, such as electric heating inside the laser diode (LD), and the scattered light from NFT have also been studied. Although media back heating is considered small effect to slider temperature rise, the exact number is not given. Detailed thermal analyses using each of these heat sources are necessary and would help us understand the contribution to the slider thermal issue. Fig. 1 illustrates some key components of HAMR head and media. Heat sources that contribute to head temperature rise are also identified in red characters.

Except for LD heating and NFT power loss, temperature rise due to other heat sources are defined at writing condition. Since the amount of power to heat media for a defined recording spot on a given media is also determined, the waveguide optical power before hitting NFT can be calculated using the NFT converting efficiency. As temperature is linear to heat source, the head temperature decreases monotonically with the increased NFT efficiency as illustrated in Fig. 2, which includes temperature rise due to other heat sources at writing.

We may divide HAMR head development into three phases as shown in Fig. 2. In Phase 1 development, realizing HAMR recording is the top priority, however head usually burns out very quickly. In Phase 2, head temperature reduces significantly from a number of improvements, such as, better material choices, enhanced heat sinking design, improved NFT efficiency and fabrication processes, however, the temperature is still high and head low reliability prevents it from commercial production. Entering Phase 3, the head temperature is low enough thanks to significant improvement in NFT efficiency. Head temperature will not be the primary cause for head premature failure that leads to low reliability in field operation.

III. Heat Exchange Between Head and Disk Including Media Hot Spot

In characterizing MR reader behavior, Zhang and Bogy [4] and Chen *et al.* [5] developed a 3D thermal model and treated

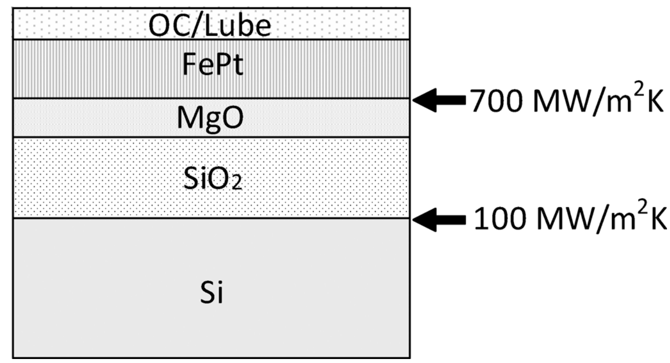

Fig. 3. An example of HAMR media stack used in the analysis.

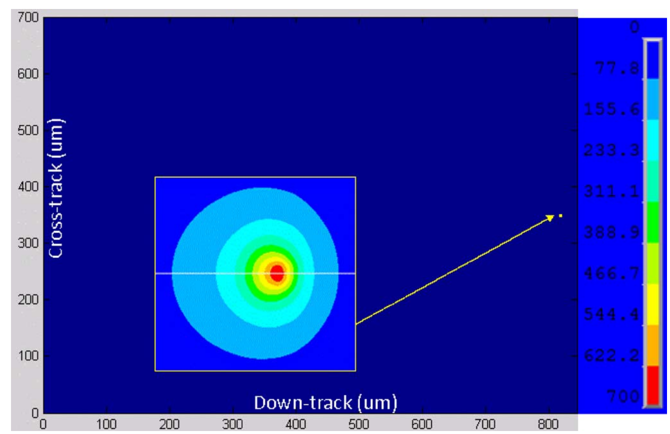

Fig. 4. An example of media temperature profile directly under slider, disk linear speed is 8 m/s.

heat flux between head and disk by applying the slip condition for the velocity and the jump condition for the temperature at the air bearing interface. They concluded the dominant heat transfer was through heat conduction as the other factors are 1–2 orders of magnitude smaller. The heat transfer at the interface can be approximated as follows:

$$\mathrm{q}(x,y) \approx -k\frac{T_s(x,y)-T_d}{h(x,y)+2b\lambda(x,y)} \quad (1)$$

in which, slider temperature T_s, fly-height h, and mean free path λ are functions of position, k is the air thermal conductivity, the parameter $b = 2.037$ which relates to the air thermal properties. Disk temperature T_d is assumed constant at ambient.

Juang and Bogy [6] applied (1) in a 3D thermomechanical model to study heat transfer through the air-bearing surface, as well as head protrusion under an electric heater. Zheng *et al.* [7] studied slider flight height change for a HAMR head.

For HAMR, the disk surface temperature T_d is no longer lower nor uniform. In fact, the local hot spot temperature is much higher than that on slider. Heat flows from disk to slider locally at this hot spot, while it continues sinking from slider to disk away from this spot where temperature is lower. To enable bidirectional heat flow through the air bearing interface, (1) is rewritten as follows:

$$\mathrm{q}(x,y) \approx -k\frac{T_s(x,y)-T_d(x,y)}{h(x,y)+2b\lambda(x,y)} \quad (2)$$

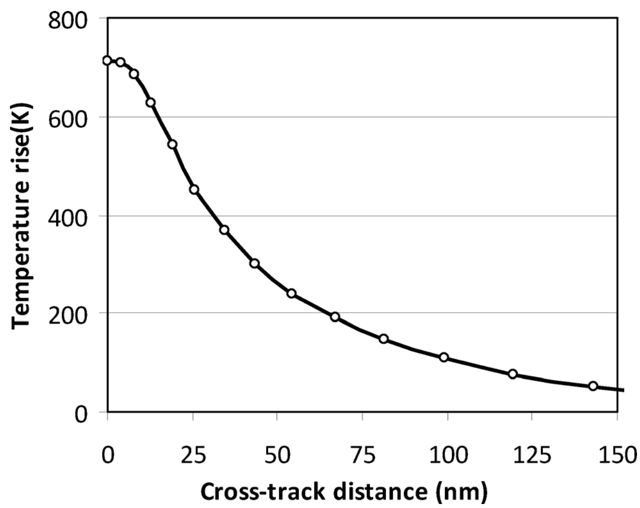

Fig. 5. Disk surface temperature profile in the cross-track direction.

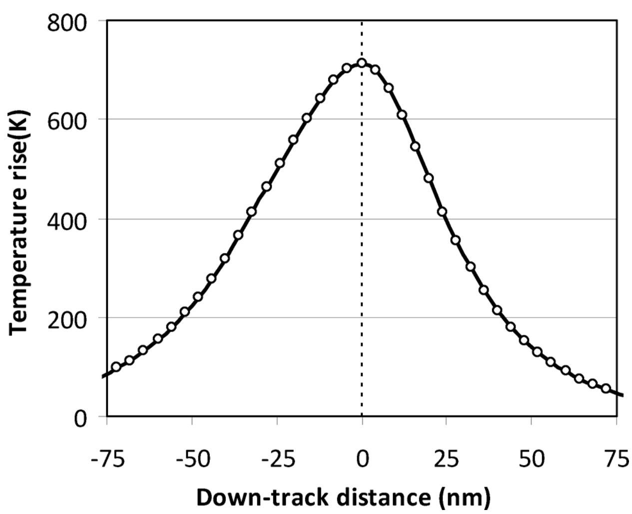

Fig. 6. Disk surface temperature profile in the down-track direction.

in which, T_d is location dependent, other parameters are the same as described in [4] and [5]. For the present near contact recording, fly-height is typically less than 3 nm at the lowest flying region, while term $2b\lambda$ is approximately from 5 to 10 nm depending on air bearing pressure.

An example of HAMR media stack without heat sink layer is shown in Fig. 3, which is used to calculate temperature profile as well as the hot spot on the disk surface. Material interface thermal conductance properties are estimated from Costescu [11].

A mobile disk rotating at 5400 RPM is employed in the FEA model, and a HAMR head is flying near ID delivering heat to disk. Heat absorption profile is obtained from NFT electromagnetic analysis and is applied in the media thermal transient analysis model. HAMR media stack material properties are typical for the thin deposited layers, and material interfacial thermal conductance values are shown in Fig. 3. Carefully grown FePt granular media has good column grains which are isolated by segregant. Such FePt layer is usually orthotropic with its thermal conductivity in the thickness direction about 3 to 10 times the

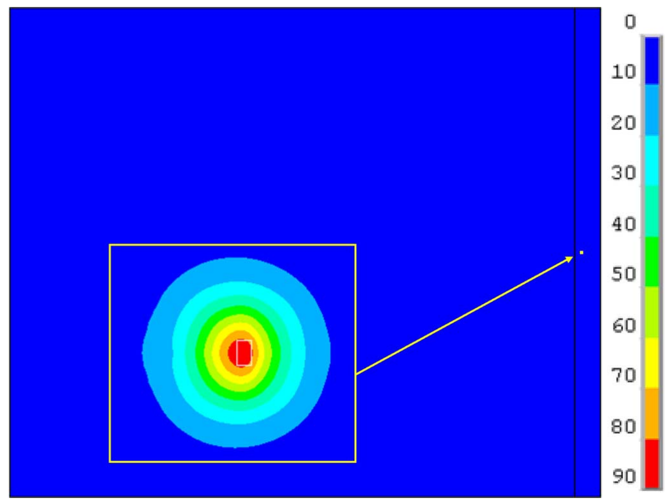

Fig. 7. Slider temperature rise due to media hot spot back heating.

in-plane value. Fig. 4 shows a representative media hot spot directly under the slider when the disk is rotating and is heated by a heating element on a HAMR slider. Majority of the media temperature is low at ambient, only a tiny spot showing significantly high temperature as shown in the inserted picture.

Disk surface temperature along the cross-track direction is plotted in Fig. 5. The recording layer temperature is heated to its Curie temperature at 673 K, or 400 degree about room temperature. It requires 0.21 mW power in the targeted region to heat the media stack to the above specification. Cross track profile is symmetric. Temperature profile along the down-track direction is shown in Fig. 6. As shown, temperature profile is not symmetric due to disk is moving relative to head. Subsequently, disk surface temperature profiles shown in Figs. 5 and 6 are used to construct a media hot spot.

IV. Numerical Results

HAMR thermomechanical model is multiscale both in space and time. In this paper, two HAMR slider FEA models are built, one with waveguide only creating fairly larger thermal spot on media, and the other is a HAMR slider containing all the components shown in the Fig. 1. The Curie temperature of the recording material is assumed at 673 K. For the waveguide only model, the waveguide cross section is 600 nm $\times$ 360 nm. A hot spot with full width at half maximum (FWHM) on media surface is assumed at 500 nm. By employing (2) and air bearing design program [8] in the FEA model, the resultant slider temperature rise on ABS surface is shown in Fig. 7. The peak temperature rise is 86 K with FWHM at 1800 nm.

Fig. 8 shows slider thermal protrusion under media hot spot back heating using the temperature profile showing in Fig. 7. The maximum protrusion is 0.6 nm.

Fig. 9 shows slider temperature rise for a waveguide only slider and a slider having a metallic NFT versus media hot spot FWHM. Temperature rise on a slider with metallic NFT is lower than that on a waveguide only slider, due to better heat conducting metals presented in the region.

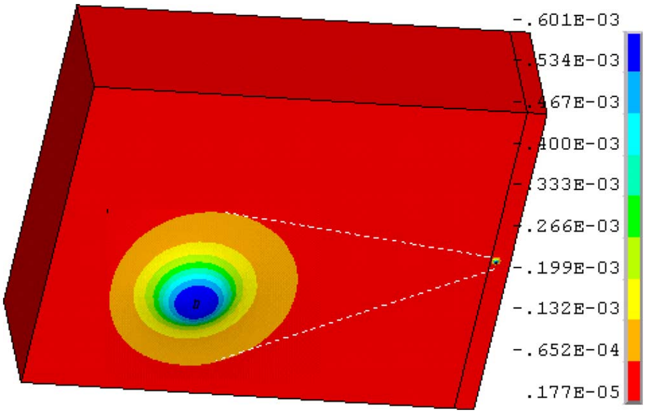

Fig. 8. Slider thermal protrusion due to media back heating.

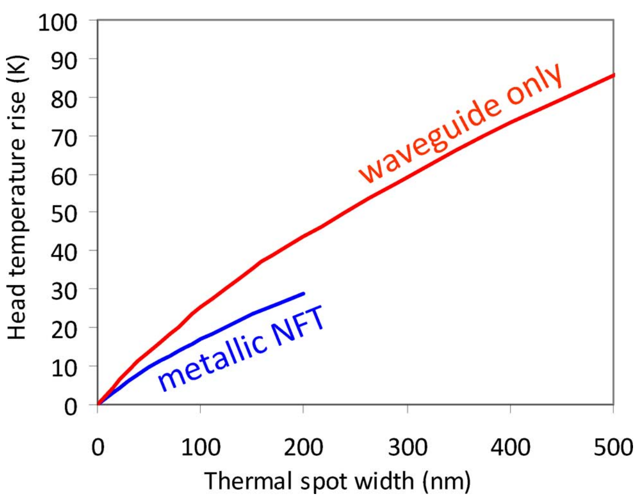

Fig. 9. Slider temperature rise vs thermal spot width (FWHM) for a waveguide only slider and a slider with a metallic NFT.

Fig. 10 shows head temperature varies with media temperature. Head temperature increases linearly with increased media temperature, and it rises faster for larger spot.

V. Summary

Media hot spot is introduced in the heat exchange model between head and disk. Slider temperature rise due to media hot spot back heating is about 3% to 6% of recording layer's Curie temperature for HAMR head containing a metallic NFT. Head temperature rise varies with head structure, especially NFT and its surrounding material composition. Head temperature increases linearly with increased media temperature. NFT scattered light is the major contributor to the head temperature rise, and media back heating is the second major contributor, higher than TFC power and writer current.

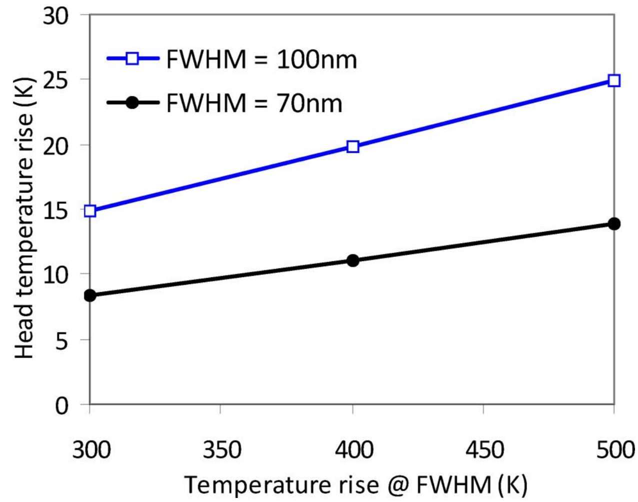

Fig. 10. Temperature rise on a waveguide only slider versus media temperature rise measured at half maximum.

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