A Two Stages Heating Scheme for Heat Assisted Magnetic Recording

Shaomin Xiong, Jeongmin Kim, Yuan Wang, Xiang Zhang and David Bogy
Department of Mechanical Engineering, UC Berkeley, Berkeley, CA, 94720.USA

Heat Assisted Magnetic Recording (HAMR) has been proposed to extend the areal density beyond 1 Tb/in2 for the next generation magnetic storage. A near field transducer (NFT) is widely used in HAMR systems to locally heat the magnetic disk during the writing process. However, most of the laser power is absorbed in the writing head, which causes overheating of the head and reduces the reliability of the NFT. In this work, a novel method is proposed to reduce the thermal load on the NFT by separating the NFT heating process into two stages. In the first stage, an optical waveguide structure is placed in front of the NFT. This waveguide delivers laser energy directly onto the disk surface over an area of around 300 nanometers to heat it up to a peak temperature somewhat lower than the Curie temperature of the magnetic material. Then, the NFT works as the second heating stage to heat a smaller area (25 nm) inside the waveguide heated area further to reach the Curie point. The energy absorbed by the NFT in the second heating stage is reduced compared with a typical single stage NFT heating system. With this reduced thermal load to the NFT by the two stages heating scheme, the lifetime of the NFT can be extended orders longer.

I. INTRODUCTION

The demand of digital storage keeps growing every year. The magnetic recording based hard disk drive (HDD) plays the most critical role in mass data storage because of its high capacity with lowest cost. The booming data market stimulates the industry to continuously increase the magnetic data storage areal density. While scaling the areal density in magnetic recording, one must maintain the balance in media signal-to-noise (SNR), thermal stability and writability. The magnetic grain is sometimes unable to keep its magnetic orientation because the thermal fluctuation exceeds the energy barrier when the size of it is reduced further in current perpendicular magnetic recording (PMR) technology. Then the written data in the HDD becomes unstable. HAMR [1] was proposed to overcome those challenges and to permit the continued increase in areal density. In HAMR systems, a magnetic material with higher anisotropy is used in the recording layer, which is much more thermally stable than current PMR media. However the current magnetic writer is not able to provide a strong enough magnetic field to write data into the disk. So a laser is used to locally heat the media to the Curie point (~400 °C) allowing the magnetic switching field to be reduced and the writing process can be accomplished .

The size of the magnetic bit needs to be on the order of 25 nm as the areal density keeps increasing further. Therefore the heating spot of the laser should be on the same order in HAMR systems. A small heating area beyond the diffraction limit can be achieved by a near field transducer (NFT). The laser light is emitted from a laser diode and delivered to the NFT structure on the air bearing surface. The light is further focussed by the NFT to about 25 nm or less, depending on the design of the NFT. The NFT structure is usually made from some dielectric material and noble metal, such as gold. Gold has a relatively low melting point at 1300 K and low tensile strength at 120 MPa, which indicates that the NFT could be easily damaged at the media Curie point after applying the thermal load. Furthermore, even with the most efficient light delivery design, only a fraction of the laser power is absorbed by the media. Most of the power is absorbed and dissipated around the NFT in the head and this leads to the overheating of the NFT. The accumulated heat around the NFT raises the temperature of the NFT up to several hundred degrees Celsius and the extreme cyclic thermal load can result in the failure of the NFT after several tens of recording tracks [2], which is far below the 5 years warranty requirement of the commercial magnetic storage application.

To make the NFT more reliable in HAMR systems under millions of cycles, it is necessary to reduce the thermal load to the NFT structure while maintaining the amount of the total transmitted energy to the disk for heating. In this work, we propose a novel method to reduce the thermal load on the NFT by separating the NFT heating process into two stages. In the first stage, a laser waveguide structure is placed in front of the NFT. This waveguide transmits the laser energy to the disk surface and heats the disk to a peak temperature lower than the Curie temperature of the magnetic material. Then, the NFT works as the second stage to heat a smaller area (25 nm) inside the large waveguide heated area further to reach the Curie point. The energy absorbed by the NFT in the second stage is lower than a single NFT heating scheme proposed in other one stage HAMR systems.

In this work, we designed a bow-tie aperture structure as an NFT to focus light to a spot about 25 nm, using a commercial finite-difference time-domain (FDTD) software (CST microwave studio). A 3D finite element method (FEM) thermal model was developed to calculate the temperature increase of the media under the two heating sources, using ANSYS. The magnetic switching field of the magnetic layer was obtained from a Callen-Callen model for HAMR systems [3].

II. Modeling

Figure 1.a shows a schematic diagram of the two stages heating scheme. The waveguide is placed in front of the NFT structure, with a spacing of d. Fig 1.b shows the typical laser intensity distribution on the disk surface from the waveguide, calculated from CST. The dimension of the intensity profile depends on the size of the Ta_2O_5 core of the waveguide. The profile can be simplified to be a 2D Gaussian distribution function. The radius ($1/e^2$) of the laser intensity profile

measured at the surface of the disk is Ra. Fig 1.c shows the absorbed power distribution on the surface of the disk from the NFT. In this calculation, a bow-tie aperture structure was used. The shape of the calculated intensity profile is close to rectangular. The diameter of the profile ($1/e^2$) along down track direction is close to 25 nm which satisfies the requirement of HAMR systems.

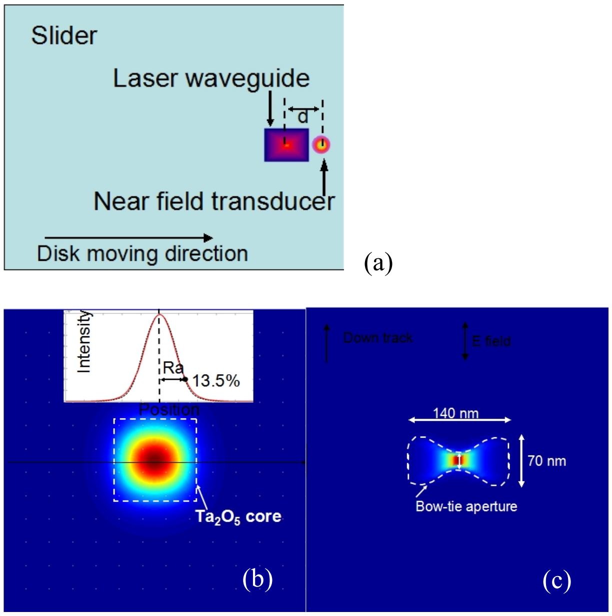

FIG. 1. (a) Schematic diagram of the two stages heating slider; Laser intensity distributions for (b) the first stage heating by the waveguide and (c) the second stage heating by the NFT

The temperature distribution in the medium was calculated by solving the thermal diffusion equation using FEM in ANSYS. The absorbed power distributions described above were used as heat flux sources in the FEM thermal model. The disk has four layers with different thermal properties. Table I [4] shows the material properties used in the FEM thermal model. The mesh size is 25 nm by 50 nm in the x-y plane.

Table. 1 Thermal properties of 4 layers in the HAMR media

Layer	Thickness (nm)	Vertical Thermal Conductivity (W/mK)	Lateral Thermal Conductivity (W/mK)	Specific Heat ($J/m^3 \cdot K$)
Storage	10	50	5	3E6
Inter-layer	15	3	3	2E6
Heat Sink	80	200	200	3E6
Sub-strate	5000	1	1	2E6

A Callen-Callen model [3] was used to calculate the magnetic switching field. The relationship between the saturation magnetization and temperature can be obtained from the mean field theory as shown in the equation below.

$$\begin{aligned} \frac{Ms(T)}{Ms(0)} &= \frac{5T}{6Tc}X \\ \frac{K_1(T)}{K_1(0)} &= \tanh(X)\tanh(\frac{X}{2}) \qquad (1) \\ \frac{5T}{6Tc}X &= \frac{1}{3}\left[2\tanh(X)+\tanh(\tfrac{X}{2})\right] \end{aligned}$$

Here X is the Callen-Callen parameter, Ms is the saturation magnetization and K1 is the first order anisotropy constant. We set Ku to be K1 for simplification. The switching field Hk equals to 2Ku/Ms.

III. Results and discussion

The switching field Hk of the magnetic layer relies on the thermal profile while the thermal distribution depends on the conditions of the heating sources, including the size of the two heating sources and their spacing between them. Fig. 2 shows a typical thermal profile for the two heating stages scheme HAMR. The design goal is to heat a local small area of the magnetic layer to the media Curie point after combining the two heating stages. The waveguide heating can raise the disk background to a temperature lower than the Curie point; for example, it can raise the background to 200 °C. At this temperature, the magnetic bits in the adjacent tracks cannot be thermally erased by the waveguide heating. At the same time, the locations of the two peaks of the temperature profile under the two heating sources should be as close as possible. The distance between these two peaks is labeled Dp as shown in Fig. 2. The background temperature (T*) on the disk surface where the NFT heat is applied is always lower than the peak temperature (Tp1) in the waveguide heating stage. This temperature difference is denoted as ΔT, which can be eliminated when Dp is 0. Dp is determined by the sizes of the two heating sources and their physical spacing between them, which is represented by d in Fig. 1.a. The size of the NFT heating source is constrained to be close to 25 nm because of the requirement of the high recording density. So Dp mainly depends on the size of the waveguide heating source (Ra) in the first stage and on d. Ra is mainly controlled by the dimension of the waveguide and can be calculated using the CST microwave studio.

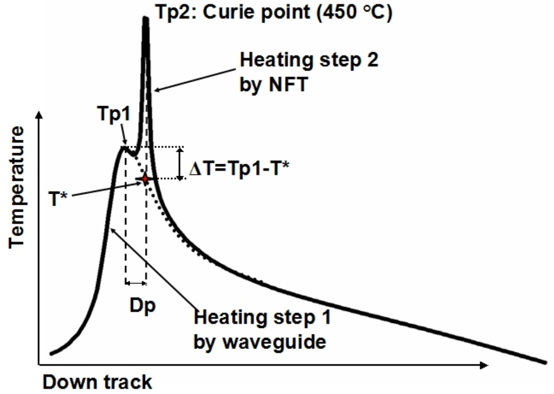

Fig. 2 A typical thermal profile on the media surface under the two heating stages

Figure 3 shows the dependence of Ra on the physical size of the Ta_2O_5 core of the waveguide, calculated from CST. A larger size waveguide can heat a larger area.

The heating sources with different sizes from the waveguide generate different temperature distributions on the disk surface. Fig. 4 shows the full width at half maximum (FWHM) of the temperature profile on the magnetic layer and the power needed to heat the disk close to 200 °C when the disk speed is 20 m/s. More energy is consumed to heat a larger area to 200 °C and the width of the temperature profile is larger. When a larger Ra is used, more adjacent tracks will be heated and affected.

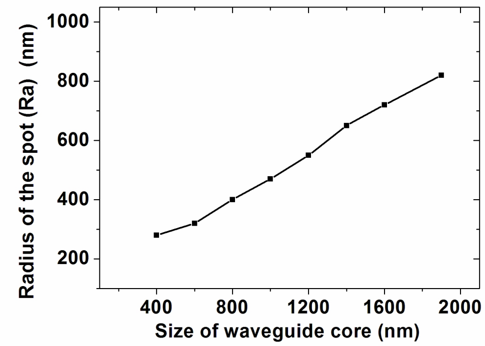

Fig. 3 Dependence of the laser radius (Ra) on the size of waveguide

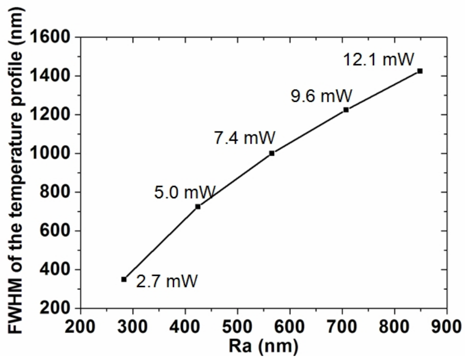

Fig. 4 FWHM of the temperature distribution in the waveguide heating stage by different laser radii (Ra)

There is another trade-off between Ra, ΔT and d. Smaller Ra can provide a sharper thermal gradient which is better for HAMR writing1. However, ΔT changes more when Ra is smaller. It is possible that overheating of the magnetic bits happens at the location of the temperature peak in the waveguide heating if Ra is small and the power input is large. If a larger Ra is used, a larger size waveguide structure should also be used. In this case, the physical spacing between the heating sources should be increased to avoid the interference between the two heating sources. Then Dp is increased and ΔT becomes larger again. Fig. 5 shows the ratio of the background temperature T* and Tp1 in the waveguide heating as Ra changes. It is seen that the ratio decreases as the waveguide heating becomes larger. The size of the heating source from the waveguide is limited by the diffraction limit.

The Callen-Callen model predicts the magnetic switching field distribution of the magnetic layer for this two stages heating scheme, as shown in Fig. 6. The red curve shows the switching field if only the NFT heating source is applied as in the proposed single stage HAMR systems. The gradients of the switching field at the valley of the two curves are at the same order for both HAMR heating schemes. So the two stages heating scheme can have similar writing capability as the single NFT scheme, but have better reliability because the thermal load to the NFT is reduced. In this simulation, the thermal load to the NFT is reduced by 30% in the two stages heating scheme compared with the single stage heating system. However, great care should be taken for the two heating stages scheme because the high temperature background could lead to the adjacent tracks interference in the writing process. Further optimization of the magnetic writer design could help to address this problem.

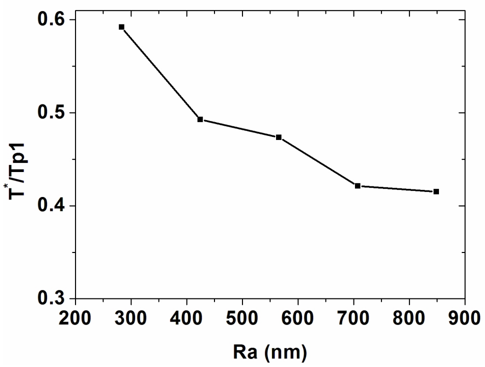

Fig. 5 Ratio of the background temperature T* and peak temperature Tp1 under different Ra in the waveguide heating stage

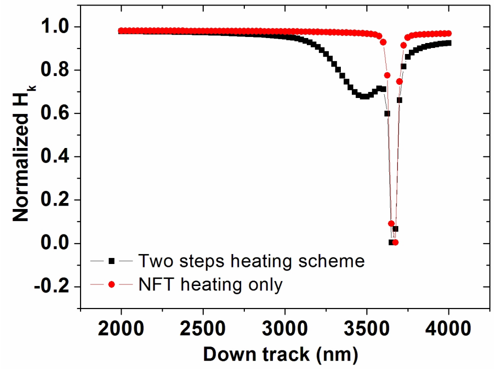

Fig. 6 Hk distribution on the disk surface for the two stages heating scheme and single NFT heating scheme.

IV. Summary

A new heating scheme for the HAMR system is proposed in this work. The conventional single NFT heating scheme was replaced by two heating stages scheme. The first stage provides a background temperature of about 200 °C by use of an optical waveguide, while the NFT heats the media further to the Curie point. Numerical simulation shows that the distance between the two heating sources and the size of the waveguide source affect the performance of the two stages heating scheme. The two stages heating scheme can provide an effective writing performance for HAMR while the thermal load to the NFT is reduced compared to a single stage approach.

REFERENCES

[1] Kryder, M. H., Gage, E. C., McDaniel, T. W., Challener, W. A., Rottmayer, R. E., Ju, G., ... & Erden, M. F. (2008). Heat assisted magnetic recording.Proceedings of the IEEE, 96(11), 1810-1835.

[2] Challener, W. A., Peng, C., Itagi, A. V., Karns, D., Peng, W., Peng, Y., ... & Gage, E. C. (2009). Heat-assisted magnetic recording by a near-field transducer with efficient optical energy transfer. Nature Photonics, 3(4), 220-224.

[3] Lyberatos, A., & Hohlfeld, J. (2004). Model of thermal erasure in neighboring tracks during thermomagnetic writing. Journal of applied physics, 95(4), 1949-1957.

[4] ASTC Technical Documents, “ASTC HAMR reference media stack for NFT modeling”, (The International Disk Drive Equipment and Materials Association, 2011). http://idema-cloud.smartsite.net/?page_id=2269.