Analysis of Heat Assisted Magnetic Recording to Density of 4 Tb/in^2

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Thermal performance of media is a key factor limiting heat assisted magnetic recording density. In this paper, the effects of near field optical transducer tip size on the thermal profiles of media are studied and results show that even with tip size of 10 nm, the obtained cross track thermal spot size and down track thermal gradient still cannot meet the requirements of 4 Tb/in^2 for continuous wave laser heating. Pulse laser heating can improve the thermal distribution significantly and the requirements for 4 Tb/in^2 can be met at pulse width of 100ps. Dynamic micromagnetic recording simulation with Landau-Lifshitz-Bloch (LLB) equation is conducted for pulse laser heating recording. The results indicate that 4 Tb/in^2 density is realizable for FePt recording media. It is also pointed out that, for short pulse laser heating recording, media with large magnetic damping constant is important.

Index Terms—**Heat-assisted magnetic recording, near field optical transducer, surface plasmon, magnetic recording media, thermal response of media, short pulse laser, micromagnetic simulation.**

I. INTRODUCTION

The main purpose of introducing heat assisted magnetic recording (HAMR) is to pursue a higher recording density [1]. There are many parameters to limit achievable density, such as thermal spot size and gradient of media, media grain size and distribution, Curie temperature distribution of the grains, magnetic switching field distribution, etc. Among them, media's thermal performances are the most critical because the recording track width depends on cross track thermal spot size and a large thermal gradient in down track direction provides a large effective write magnetic field gradient which influences the bit transition length and further bit density. Recording with different bit aspect ratio (BAR, ratio of track pitch to bit length) will require different thermal distribution. For a large BAR recording, a large cross track thermal spot size can meet the requirement in cross track thermal distribution, but large down track thermal gradient and more critical distributions of the media's other parameters are required for achieving smaller bit length. On the other hand, for a small BAR recording, the requirements to thermal gradient and other parameters could be relaxed due to large bit length. Nevertheless, a smaller cross track thermal spot size is needed. Therefore, studying the limitation of thermal spot size and gradient, and exploring realizable solution for HAMR is necessary. We have studied the effects of media structure, its material thermal properties on cross track thermal spot size and down track thermal gradient of recording layer [2, 3]. Due to thermal diffusion/conduction and boundary thermal resistance, thermal spot size is always larger than optical spot size. Reference 4 studied possible recording density with whole system simulation. With transducer tip size of 10 nm, a 36nm thermal spot was achieved. Due to a large thermal spot size, the recording with BAR of 5.5 was used and the achieved density is only 2.9 Tb/in^2. With an assumption of 10 nm ideal Gaussian heat source on upper surface of recording layer, a recording density of 2.8 Tb/in^2 was obtained, which is also because of the large thermal profile [5]. All of these results show that a large thermal profile is the most critical parameter limiting the HAMR potential density. Therefore, exploring methods to reduce the thermal profile is necessary for achieving high density HAMR.

Pulse laser heating is a good approach to improve the thermal performances [6, 7]. The pulse laser heating needs a higher pulse power to heat the media than the required power in CW laser heating. However, the power is within reasonable range[7]. In this paper, the dependences of thermal performances on optical near field transducer (NFT) sizes at continuous wave (CW) laser heating are studied. With reasonable transducer tip size and pulse laser heating, the improvement of thermal performances is discussed and the conditions for 4 Tb/in^2 recording density are obtained. The possibility of 4 Tb/in^2 recording density with pulse laser heating is verified by dynamic micro-magnetic simulations.

II. STRUCTURE AND MODELING

The structures of the used near field optical transducer and media are shown in Fig.1. Lollipop transducer is made of Gold (Au) material with disk diameter of 150 nm and tip length of 10 nm. The transducer with a different tip thickness and tip width will generate different optical intensity distribution within the media. We set tip thickness and width to the same value (It will be specifically indicated if different values are used) and change this value to obtain different optical spot size within the media. The air gap between the transducer and medium surface is assumed to be 4 nm. Less number of interlayers and thinner interlayers will benefit media thermal performance [3]. In this study, the media structure consists of a Carbon doped Iron-Platinum (FePtC) recording layer (10 nm), Magnesium Oxide (MgO) interlayer (4 nm), Copper (Cu) heat sink layer (50 nm) and a glass substrate. The optical constants of Au, FePtC, MgO, Cu and glass at wavelength of 780 nm are 0.15+i4.75, 3.04+i1.87, 1.73, 0.24+i4.84 and 1.45, respectively. The material thermal parameters of the media are listed in Table I. The boundary thermal resistance between

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adjacent layers is assumed to be $2x10^{-9}$ m^2k/W. Environment temperature and heated peak temperature of the media are always set to be 300K and 800K, respectively. In pulse laser heating, a square pulse shape is assumed.

FIG. 1 HERE

TABLE I

In order to verify the possibility of pulse laser heating recording and evaluate its performance, dynamic micro-magnetic simulation with Landau-Lifshitz-Bloch (LLB) equation is carried out [8]. In the modeling, the following parameters are assumed: K_u=2.4x10^7 erg/cm^3 and M_s=800emu/cm^3 with σ of 3% at 0K; grain size is 4 nm (grain pitch of 4.5 nm) with σ of 18%; Curie temperature (T_c) of grain is 660K with σ of 2%; the temperature dependences of the media's magnetic properties are the same with that in Ref. 8. Write magnetic field distribution is generated by a magnetic head simulation and the space between main pole and transducer tip is 20nm. The rise time of magnetic field is assumed to be 20ps.

III. RESULTS AND DISCUSSION

Fig. 2(a) shows dependences of the optical spot sizes, cross track thermal spot sizes and down track thermal gradients on transducer tip sizes at CW laser heating. The generated optical spot size on top surface of media is about 5nm larger than the tip size. The optical spot sizes at the middle position of recording layer are larger than that on the top surface. The difference of both sizes increases as the transducer tip size decreases. This difference change results from smaller surface plasmon element generating surface plasmon radiation with larger divergent angle. Due to thermal diffusion, the thermal spot size is about 20nm larger than the tip size and the difference between thermal spot sizes on top surface and layer center is very small because of the existing boundary thermal resistance [2]. For 4 Tb/in^2 HAMR recording with BAR of 3, a cross track thermal spot size of 27 nm is required to obtain track pitch of 22nm. In down track direction, a thermal gradient of 18 K/nm is desired for a grain pitch of around 4.5nm [9]. The data in the figure shows that the densities of 2.3 Tb/in^2 and 3.0 Tb/in^2 could be obtained for transducer sizes of 15 nm and 10nm respectively. It is very difficult for CW laser heating to meet the requirements of thermal performances for 4 Tb/in^2 recording density.

FIG. 2 HERE

It is actually very difficult to process transducer with tip width of 10nm. However, it is easy to fabricate transducer with different thickness in down track direction (growing desired film thickness). The effects of transducer thickness on thermal distributions at tip width of 15nm are shown in Fig. 2(b). Thinner transducer will generate a smaller thermal spot size and a larger thermal gradient. For thinner transducer, the medium's temperature raises to its peak temperature of 800K at a shorter time. Within this shorter time, the heat energy diffusion is smaller. Therefore, when the peak temperature reaches 800K, the thermal profile is with a smaller cross track thermal spot size and a larger down track thermal gradient. However, the thermal spot size reduction is small. When thickness changes from 15 to 10nm, the cross track thermal spot size reduces from 36nm to 34.5nm, and the down track thermal gradient increases from near 15K/nm to near 16K/nm.

Another factor that affects the thermal profile is disk linear moving speed. Fig. 3 shows the dependences of cross track thermal spot sizes and down track thermal gradients on the speeds at tip size of 15nm. The thermal spot size decreases and gradient increases as the speed increases. However, the spot size decrease and gradient increase are very small when the speed increases from 10m/s to 15m/s.

FIG. 3 HERE

Above results indicate that, for CW laser heating, it is very difficult for a practical transducer to generate required thermal profile for 4 Tb/in^2 density recording at BAR of 3. In order to meet the requirements, another technology has to be used. Short pulse laser heating is one way to achieve a smaller thermal spot size and a larger thermal gradient. Fig. 4 shows the dependences of the cross track thermal spot sizes and down track thermal gradients on the laser pulse widths at transducer tip size of 15nm and disk's linear moving speed of 10 m/s. As the pulse width decreases, the cross track thermal spot size decreases and the down track thermal gradient increases dramatically. The thermal gradient can meet the requirements for 4 Tb/in^2 at the pulse width of around 400ps. However, for the cross track thermal spot size, the pulse width should be less than 100ps. When pulse width is 100ps, the cross track thermal spot size and down track thermal gradient are 28.5 nm and 26 K/nm, respectively. This thermal distribution is slightly below the requirement in cross track direction, but exceeds the requirement in down track direction very much. In this case, a slight increase in BAR may achieve 4 Tb/in^2 recording density.

FIG. 4 HERE

In order to evaluate recording performance with pulse laser heating, the dynamic micro-magnetic recording simulations are carried out. Fig. 5 shows recorded patterns at different pulse widths (Fig. 5(a)) and the relationship between recorded track width and pulse width (Fig. 5(b)) at bit length of 7nm, magnetic write field of 8000 Oe and magnetic damping constant of 0.1. For comparison, the thermal spot size change with pulse width is also plotted in the figure. The recorded track width decreases significantly with short pulse laser heating.

FIG. 5 HERE

Fig. 6 shows the dependences of SNR on pulse widths at damping constants of 0.1 and reader width of 16 nm. When laser pulse width is equal to or larger than 200ps, SNR is larger than 12dB. SNR decreases rapidly with reducing the pulse width when the pulse width is shorter than 200ps.

FIG. 6 HERE

The damping constant effect on SNR at laser pulse width of 100ps is plotted in Fig. 7. The media with a larger damping constant shows larger SNR. SNR starts to decrease when the damping constant is smaller than 0.3. It is 11dB when damping constant is 0.2, and then it decreases rapidly with reducing the damping constant when damping constant is smaller than 0.2.

FIG. 7 HERE

Magnetic domain switching time is associated with damping constant, M_s and applied magnetic field[10]. In our simulation conditions, the switching time is around 100ps. Considering the distributions of the magnetic parameters, when the pulse width is below 200ps, the number of grains that are not switched increases rapidly. Therefore, SNR drops rapidly. Similarly, when damping constant is below 0.2, its switching time increases rapidly which leads to a SNR dropping rapidly. A larger damping constant is desired for pulse laser heating. Fortunately, experimental results has shown that the damping constant of FePt recording layer is larger than 0.26 [11], this makes the recording density of 4 Tb/in^2 to be realizable with 100ps pulse laser heating.

IV. CONCLUSION

In this paper, the thermal performances for a realizable HAMR media are analyzed to study its possibility for 4 Tb/in^2 recording density. The results indicate that it is very difficult to achieve the required thermal profile with reasonable transducer tip sizes for CW laser heating. Pulse laser heating is a good way to improve thermal performances. The simulation results show that with the pulse width decreases, the cross track thermal spot size decreases and down track thermal gradient increases significantly. When the pulse width is 100ps and transducer tip size is 15nm, the down track thermal gradient is 26 k/nm which is much larger than the required 18 k/nm, and the cross track thermal spot size is 28.5nm which is very close to desired 27nm. In this case, 4 Tb/in^2 recording density could be achieved when BAR is slight larger than 3. Dynamic micro-magnetic simulation results have verified its possibility. The results also indicate that media's magnetic damping constant is important for pulse laser heating HAMR and that a large damping constant is desired.

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TABLE I

MATERIAL THERMAL PARAMETERS

Materials	Thermal conductivity (W/m/k)	Density (Kg/m^3)	Specific heat (J/Kg/k)
FePtC	50 (out-of-plane) 5 (in-plane)	14660	340
MgO	3	3580	920
Cu	200	8940	385
Glass	1.38	2203	703

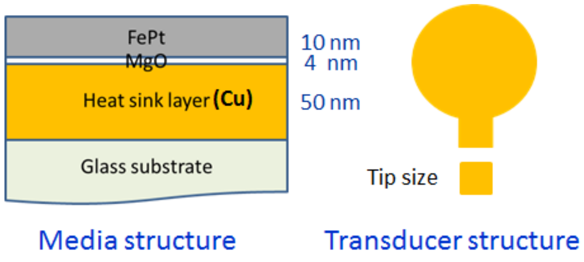
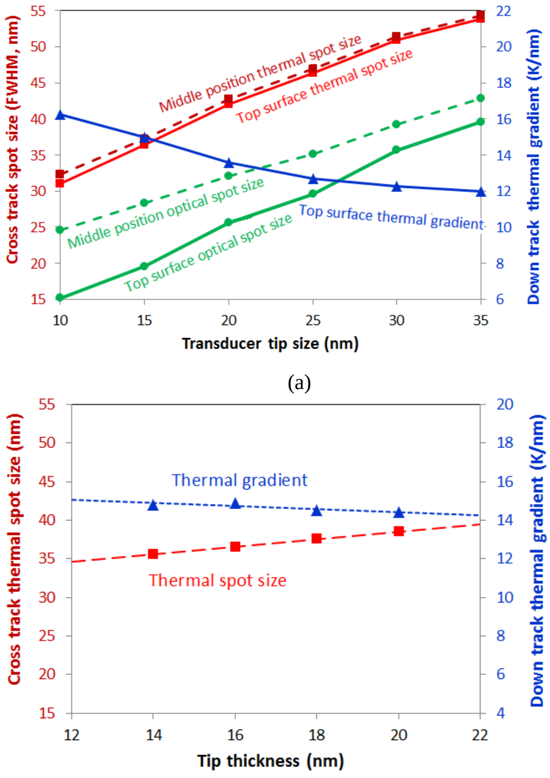


Fig. 1. Schematic structures of media and near field transducer (BTRs between FePt and MgO, MgO and Cu are assumed to be $2x10^{-9}$ m^2k/W).



(a)

(b)

Fig. 2. Dependences of optical spot sizes, cross track thermal spot sizes on top surface and middle position of recording layer, and down track thermal gradients on transducer tip sizes (a) and the dependences of the thermal spot size and gradient on tip thickness at tip width of 15 nm (b).

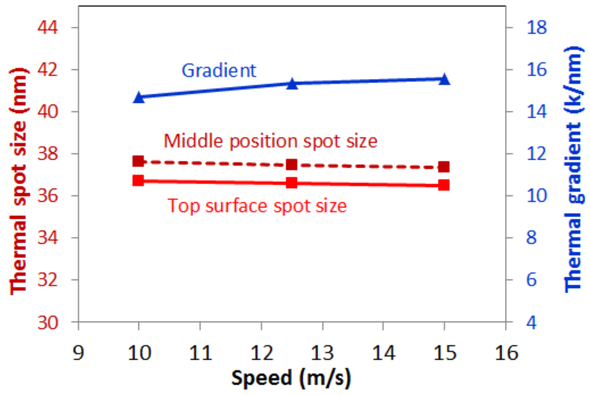


Fig. 3. Dependences of cross track thermal spot sizes and down track thermal gradients on media linear moving speeds.

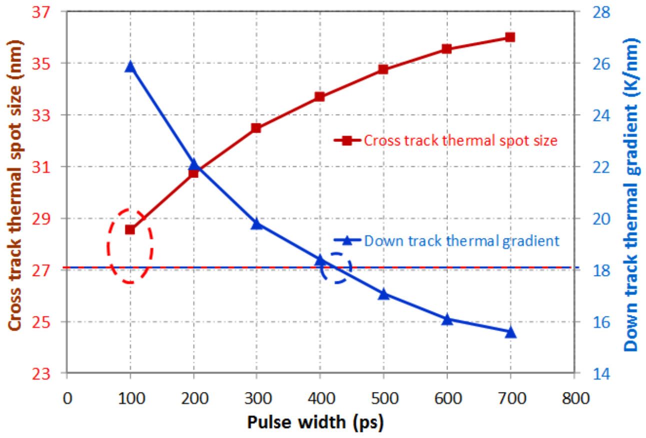
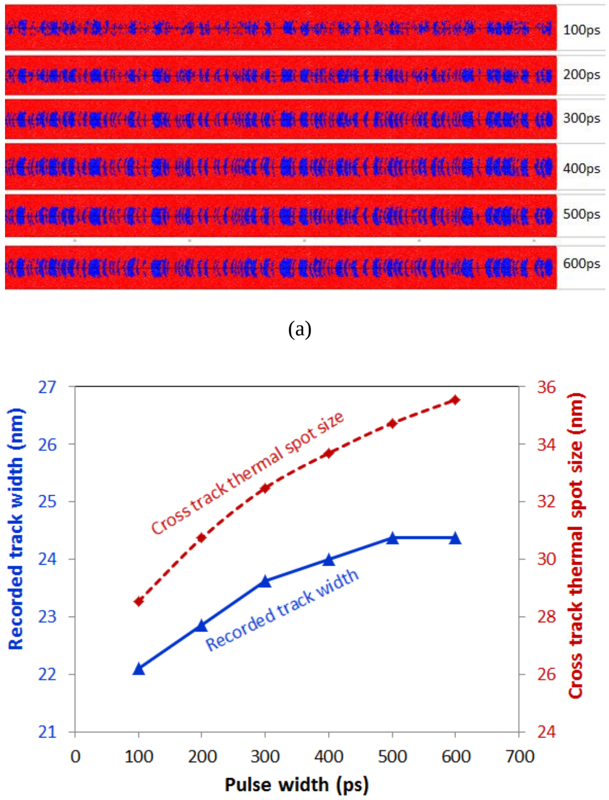


Fig. 4. Pulse width effects on cross track thermal spot sizes and down track thermal gradients at transducer tip size of 15 nm and disk linear moving speed of 10 m/s.



(a)

(b)

Fig. 5. Recorded patterns at different pulse widths (a) and dependences of recorded track width on pulse width (b) at magnetic field of 8000 Oe, damping constant of 0.1 and bit length of 7 nm (For comparison, the thermal spot size change with pulse width is also plotted in the figure).

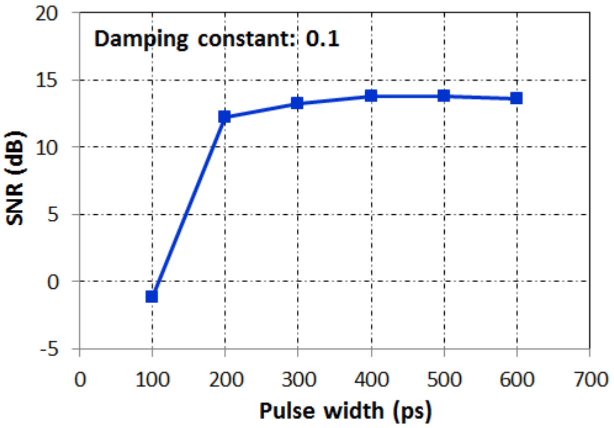


Fig. 6. Pulse width effects on SNR at magnetic field of 8000 Oe, damping constant of 0.1, bit length of 7 nm and reader width of 16 nm.

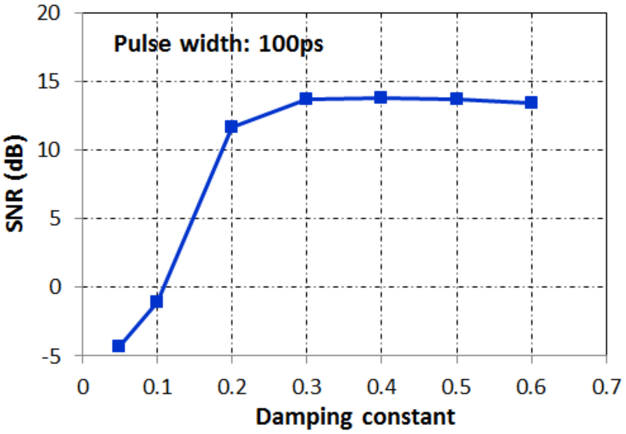


Fig. 7. Damping constant effects on SNR at pulse width of 100ps, magnetic field of 8000 Oe, bit length of 7 nm and reader width of 16 nm.