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Performance benefits from pulsed laser heating in heat assisted magnetic recording

B. X. Xu,[1,a)] Z. H. Cen,[1] J. H. Goh,[2] J. M. Li,[1] Y. T. Toh,[1] J. Zhang,[1] K. D. Ye,[1] and C. G. Quan[2]
[1]*Data Storage Institute, Agency for Science, Technology and Research (A*STAR), 5, Engineering Drive 1, Singapore 117608*
[2]*Department of Mechanical Engineering, National University of Singapore, 117576 Singapore*

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Smaller cross track thermal spot size and larger down track thermal gradient are desired for increasing the density of heat assisted magnetic recording. Both parameters are affected significantly by the thermal energy accumulation and diffusion in the recording media. Pulsed laser heating is one of the ways to reduce the thermal diffusion. In this paper, we describe the benefits from the pulsed laser heating such as the dependences of the cross track thermal width, down track thermal gradient, the required laser pulse/average powers, and the transducer temperature rise on the laser pulse width at different media thermal properties. The results indicate that as the pulse width decreases, the thermal width decreases, the thermal gradient increases, the required pulse power increases and the average power decreases. For shorter pulse heating, the effects of the medium thermal properties on the thermal performances become weaker. This can greatly relax the required thermal properties of the media. The results also show that the pulsed laser heating can effectively reduce the transducer temperature rise and allow the transducer to reach its "dynamically" stable temperature more quickly. [http://dx.doi.org/10.1063/1.4853115]

In heat assisted magnetic recording (HAMR), thermal distribution of the recording media is critical for achieving high recording density. A small thermal spot size in the cross track direction and a large thermal gradient in the down track direction will lead to a high track density and a high bit density, respectively.[1–3] High temperature rise of the near field optical transducer caused by its laser absorption is a big issue for the reliability of a HAMR system.[4] Accumulation and diffusion of the thermal energy are key factors in determining the thermal performances of the media and transducer. Pulsed laser heating is one of the ways to reduce the thermal diffusion.[1] Reference 5 showed, by simulation, that the pulsed laser heating increased signal to noise ratio (SNR) of the recorded patterns at 2 MFCI (million flux changes per inch) (but no SNR increase at 1 MFCI) due to a larger thermal gradient, and also led to a lower temperature rise in the surrounding area of the transducer. However, the transducer kept the same peak temperature rise. In this paper, we report the benefits from the pulsed laser heating such as the dependences of the cross track thermal width, down track thermal gradient, the required laser pulse/average powers, and the transducer temperature rise on the laser pulse width at different thermal properties of the media. The potential density increments are also discussed.

For a good thermal performance, the medium used in this study consists of a FePtC recording layer (10 nm), MgO interlayer (4 nm), Au heat sink layer (50 nm), and a glass substrate.[6,7] The material of the heat sink layer could be Cu, but this will not affect the conclusion made with an Au heat sink layer. The optical constants of FePtC, MgO, Au, and glass in wavelength of 780 nm are 3.04 + i1.87, 1.73, 0.15 + i4.75, and 1.45, respectively.

The transducer structure used in this study is so-called lollipop structure with the material of Au.[8] It has a disk diameter of 150 nm, thickness of 25 nm, peg length of 10 nm, and a peg width of 30 nm. The air gap between the transducer and medium surface is assumed to be 4 nm. The optical spot sizes generated within the recording layer are 35 nm in the cross track direction and 29 nm in the down track direction.

The thermal parameters of the medium materials are listed in Table I. For the recording layer, different process conditions and different doping materials will generate different layer structures (different isolation and columnar structures of the grains). This makes the recording layer have different in-plane and out-of-plane thermal conductivities ($K_{\parallel}$ and $K_{\perp}$). In order to extend our investigations to cover all of these cases, the in-plane thermal conductivities are assumed to be 5 W/m/k and 10 W/m/k; the out-of-plane thermal conductivities are assumed to be 35 W/m/k and 50 W/m/k. Different deposition conditions may also generate different values of boundary thermal resistances (BTR) between adjacent layers. In this investigation, the BTRs between FePtC and MgO, MgO and Au are considered to be at the values of 2×10^{-9} m^{2}k/W, 4×10^{-9} m^{2}k/W, and 6×10^{-9} m^{2}k/W, respectively.[9]

In order to study the transducer temperature rise, a head model similar to that in Ref. 9 is used, but the transducer structure is replaced with a lollipop shape structure. The relative temperature changes compared to that in the CW (continuous wave) laser heating are simulated accordingly.

All investigations in this paper are carried out under the following assumptions: the recording speed is 1 Gb/s; the disk's linear velocity is 10 m/s; peak temperature of the heated medium is 800 K; and the environment temperature is 300 K.

a)Electronic mail: xu_baoxi@dsi.a-star.edu.sg

TABLE I. Medium thermal parameters used in the simulation.

	Thermal conductivity (W/m/K)	Specific heat (J/Kg/K)	Density (Kg/m^3)
FePtC	50, 35(out-of-plane, $K_{\perp}$) 10, 5(in-plane, K_{II})	340	14 660
MgO	3	3580	920
Au	180	128	19 300
Glass	1.38	703	2203

Figure 1 shows the dependences of the thermal width and gradient, as well as the required laser power on the laser pulse width at a BTR of 2×10^{-9} m^2k/W for different recording layer thermal conductivities. As references, the related values in the cases of CW laser heating are also plotted in Fig. 1.

As the pulse width decreases, the thermal width decreases and the thermal gradient increases. Compared to out-of-plane thermal conductivity, the in-plane thermal conductivity has much significant effect on the thermal performance of the media. As the pulse width becomes shorter, the performance variances between different in-plane thermal conductivities become smaller. This shows an important indication: for a shorter pulse width, the effect of the recording layer thermal property on the thermal performance of the medium tends to be weaker. This can greatly relax the stringent thermal property requirements of the media. Moreover, as the pulse width decreases, the required laser pulse power increases in a non-linear manner; but the average power decreases almost linearly.

Generated thermal width and gradient are the integrative result of the heating energy accumulation and thermal diffusion in the media. Short pulse heating has a small thermal diffusion before the media reaches the desired temperature, which leads to a small thermal width and a large thermal gradient. Clearly, in order to heat the media locally up to the desired temperature (800 K in this study), the laser pulse power has to be higher.

In order to understand the effects of BTR, the simulations for BTRs of 2×10^{-9} m^2k/W, 4×10^{-9} m^2k/W, and 6×10^{-9} m^2k/W at $K_{II} = 5$ W/m/k and $K_{\perp} = 50$ W/m/k are performed and the results are plotted in Fig. 2. The medium with a smaller BTR shows better performance in the thermal width and gradient. However, it needs a higher power to heat the medium up to the same temperature. At all the cases of BTR, similar to the cases in the different thermal conductivities, the thermal width decreases and thermal gradient increases with the decrease of pulse width. The value

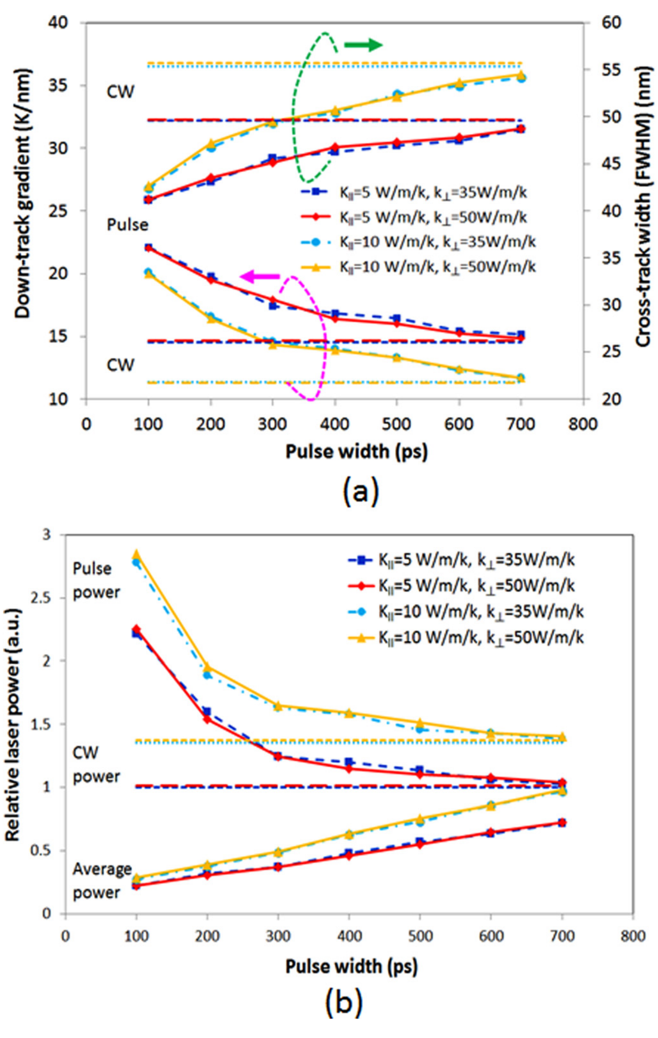

FIG. 1. Dependences of the cross track thermal spot size (FWHM) and down track thermal gradient (a), the required laser pulse and average powers (b) on the laser pulse width at different thermal properties of the recording layer (BTR = 2×10^{-9} m^2k/W; the values in the cases of related CW laser heating are also plotted for comparison).

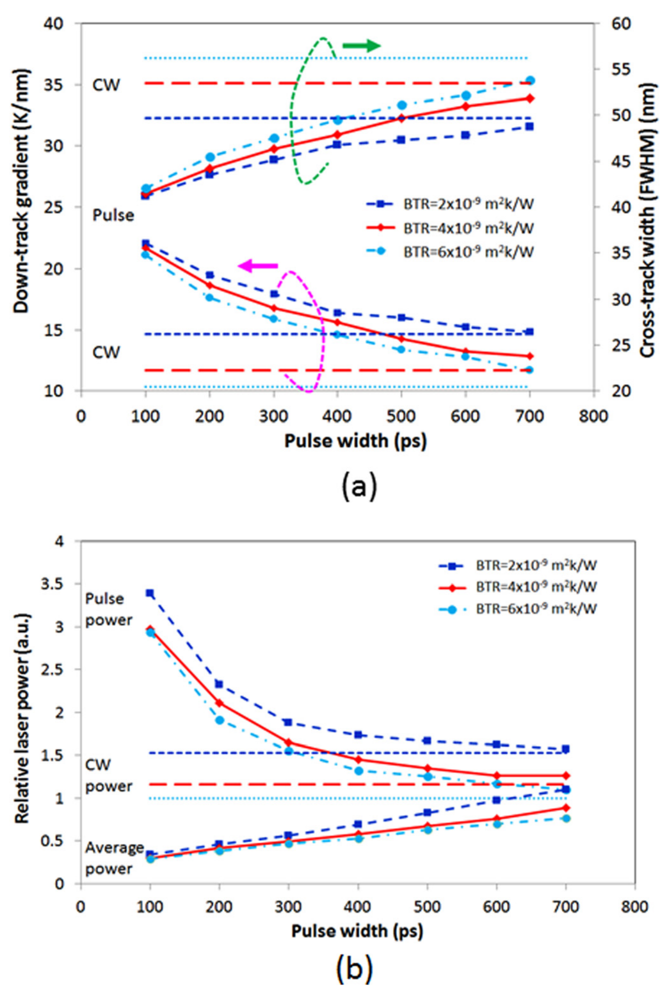

FIG. 2. Dependences of the cross track thermal spot size (FWHM) and down track thermal gradient (a), the required laser pulse and average powers (b) on the laser pulse width at different BTRs ($K_{II} = 5$ W/m/k and $K_{\perp} = 50$ W/m/k; the values in the cases of related CW laser heating are also plotted for comparison).

variances for different BTRs decrease with reducing the pulse width. This indicates again that short pulse laser heating can relax the thermal property of the media. The required laser pulse power and average power show the same trends as that in the cases with different thermal conductivities.

In HAMR writing, the track density mainly depends on the thermal spot size in the cross track direction. A reduction of the cross track thermal spot size will directly lead to an increase in track density. Figure 3 shows the possible track density increases (relative to that in the CW laser heating cases) by reducing the laser pulse width at different medium thermal conditions. As the pulse width decreases, the track density increases. The media with poorer thermal properties (larger $K_{\parallel}$ and BTR) show larger density gain. Within the studied range, the track densities increase 20%–35% at a pulse width of 100 ps.

Bit density has a strong relationship with the down track thermal gradient, and it is also highly affected by other parameters of the recording layer such as the grain size and its distribution, Curie temperature distribution and the switching field distribution of the grain.[2,3] It is therefore difficult to evaluate the percentage of the bit density increase as the pulse width decreases. However, it is certain that a larger down track thermal gradient is beneficial with regards to increasing the bit density.

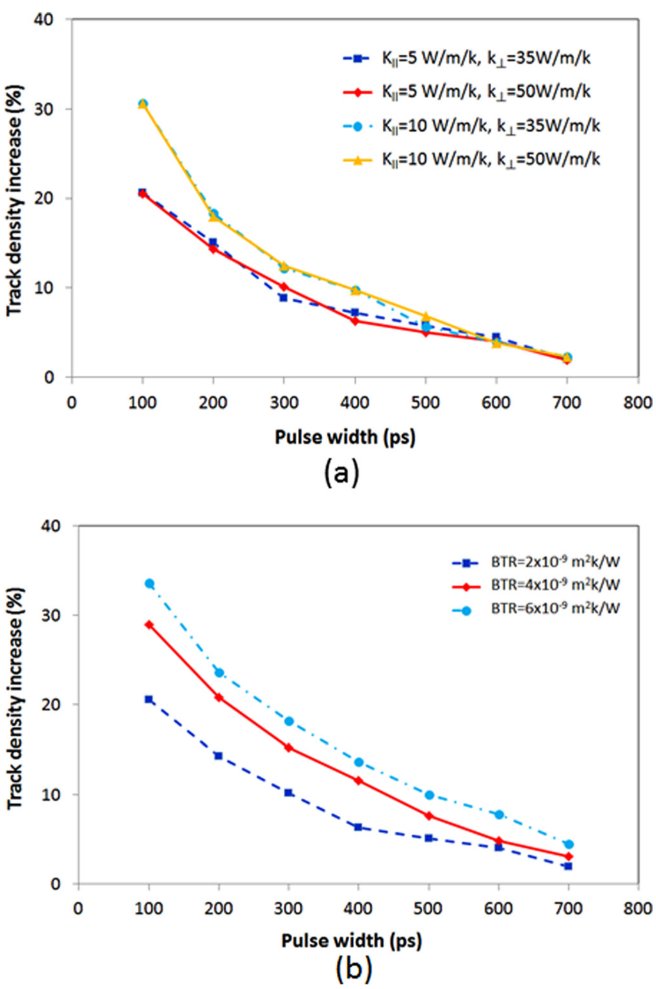

FIG. 3. Track density increases with reducing the pulse width at different thermal properties of the recording layer (BTR = 2×10^{-9} m^2k/W) (a) and at different BTRs ($K_{\parallel} = 5$ W/m/k and $K_{\perp} = 50$ W/m/k) (b).

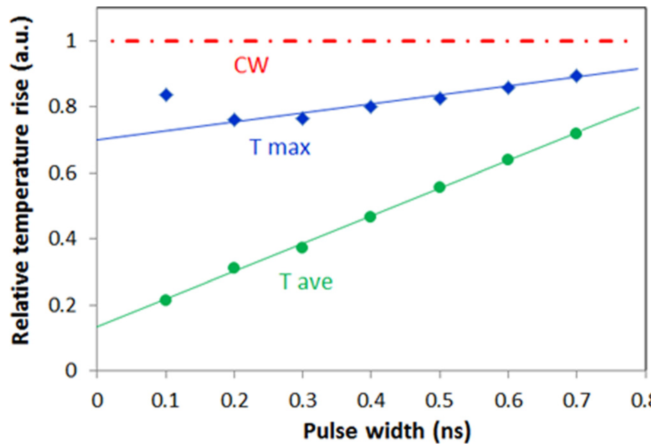

FIG. 4. Dynamic temperature changes (a), maximal and average temperature rises (b) of the transducer at different laser pulse widths ($K_{\parallel} = 5$ W/m/k, $K_{\perp} = 50$ W/m/k, and BTR = 2×10^{-9} m^2k/W; straight lines are for eye guide).

Above results have shown, in pulsed laser heating, that the required laser pulse power increases and average power decreases with the decrease of pulse width. These changes will definitely affect the transducer temperature rise. The transducer temperature rises related to that in the CW laser heating are simulated in the case of $K_{\parallel} = 5$ W/m/k, $K_{\perp} = 50$ W/m/k, and BTR = 2×10^{-9} m^2k/W.

Figure 4 shows the maximal and average temperature rises of the transducer at different laser pulse widths. It is clear that the pulsed laser heating reduces the transducer temperature rise effectively. The shorter the laser pulse width, the lower the transducer temperature rise, and the faster the speed that the transducer takes to reach its "dynamically" stable temperature.

A lower temperature rise of the transducer is desired for realizing a stable HAMR head.

In this paper, the benefits from pulsed laser heating are discussed. Pulsed laser heating can reduce the cross track thermal spot size and increase the down track thermal gradient. These effects will greatly increase the density of HAMR. As the pulse width decreases, the dependences of the thermal spot size and gradient on the medium thermal property become weaker. This will relax the requirements to the thermal properties of the HAMR media. The transducer temperature rise is lowered through reducing the laser pulse width, which will benefit the HAMR head reliability. Fast heating will lead to a rapid temperature change in the transducer. This rapid temperature change may lead to a fast change of the stress between the transducer and its surrounding material. It is essential to further study whether this fast stress change will affect the reliability of the transducer.

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