'Dark-Laser-Heating (DLH)' using ultra-fast laser pulsing for mode hop mitigation in Heat assisted magnetic recording (HAMR)

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Laser diode is an integral component in heat assisted magnetic recording (HAMR) technology. Achieving a stable laser power during HAMR operation is extremely challenging and has been a key gating item in achieving high performance and storage from HAMR HDDs. The laser power variation is mostly attributed to the change in opertaing mode of laser diode, namely the mode hop, due to change in temperature. Here, we demonstrate a novel approach of 'Dark Laser Heating (DLH)' based on utilising the turn-on delay of laser diode by applying ultra-fast (few nanoseconds) laser current pulses to pre heat and manage its temperature change during normal forward bias used in HAMR writing process. In sub-nanosecond operation, the laser-diode do not emit optical light but the thermal response is fully efficient to pre-heat the laser diode to match the temperature of the laser diode in HAMR operation and suppress the laser power variations arising from mode hopping.

Hard disk drives (HDDs) have been the workhorse in cloud data centers, where the volume of data doubles every two years, pushing hard drives to achieve high capacity and even higher areal density. Heat assisted magnetic recording (HAMR) is the upcoming magnetic data storage technology used in hard drives which has surpassed areal densities beyond the limits of conventional perpendicular magnetic recording (PMR). HAMR write process requires both the magnetic field and thermal assist from the write head to periodically switch the magnetization on granular magnetic medium with very high magnetic anisotropy. Magnetic medium is locally heated to above its Curie temperature (Tc), around 400-450 C, to reduce coercivity of the magnetic medium. The localized heating of the magnetic medium is accomplished by a laser diode in conjunction with a near field transducer (NFT) embedded in the write head, which produces a hot spot with a size of few tens of nanometers on the recording medium. Individual bits are written in the down-track direction as the magnetic medium disk spins over the HAMR write head.

A laser diode is an integral component of HAMR head. High fidelity HAMR recording system requires laser diode to provide a stable and a reliable optical power during data writing process. Achieving a stable laser power during HAMR operation is extremely challenging and has been a key gating item in achieving high performance and storage from HAMR HDDs. The laser power variation is mostly attributed to the change of its temperature especially at the start of HAMR writing. In the past, we demonstrated a unique approach of Dark Laser Heating (DLH) based on reverse bias to preheat laser diode to manage its temperature change during normal forward bias used in HAMR writing process. The reverse bias increases the laser diode's temperature without any optical response. It was found that matching the laser diode temperature between pre-heat and actual HAMR writing condition suppresses mode hop, leading to a stable HAMR writing condition.

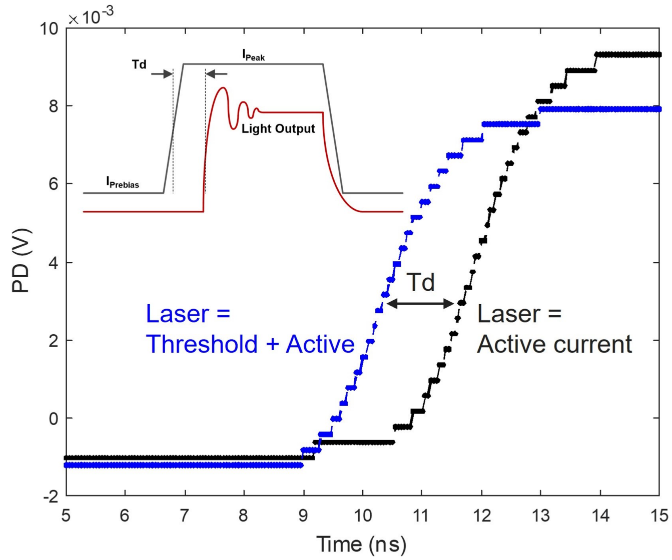

FIG. 1. Main: Photo-diode (PD) response of the laser diode when laser pre-bias is set at 0mA (black) and at laser threshold (blue). Inset shows the schematic of injection current and optical reponse of laser diode.

In this work, we propose and experimentally demonstrate a novel approach of Dark Laser Heating (DLH) in the forward bias, utilizing the turn-on delay of laser diode. By applying ultra-fast (GHz) current pulses, this method preheats the laser diode and manages its temperature changes during normal forward bias applied in HAMR writing process. It is well studied that laser diodes have a "turn-on-delay" which refers to the time for the laser to transition from a non-lasing state to a lasing state after current is applied. Here, we show that during turn-on delay the electrical Joule dissipation inside laser diode is fully efficient and leads to increase in its

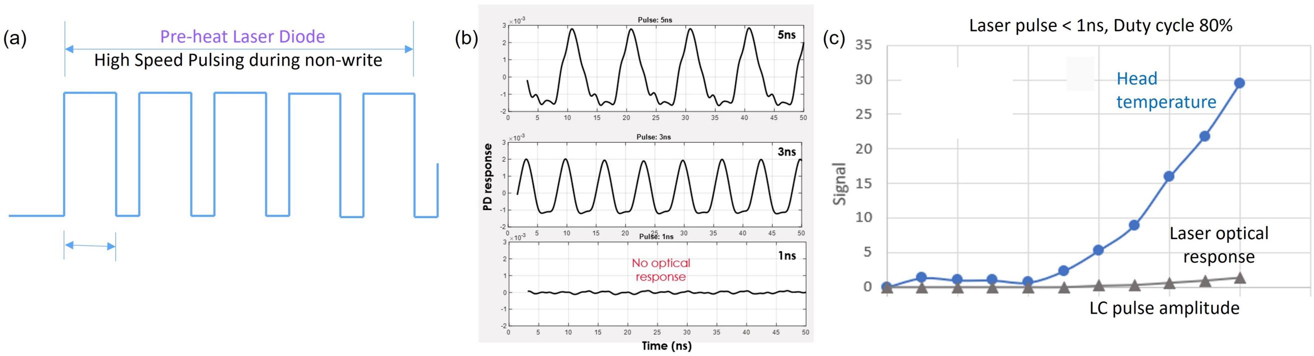

FIG. 2. (a) Current pulse profile to pre-heat the laser diode. (b) Optical response of laser diode (Photo-diode) as a function of time for different turn-on pulse width. (c) Shows the average temperature rise (blue) of the slider and optical response (black) from photo-diode as a function of applied laser current for train of short pulses (<1ns).

temperature. Furthermore, we utilize the accumulated heat from the turn-on delay to pre-heat the laser diode, matching its operational temperature during HAMR operation and suppressing the laser power variations arising from mode hopping.

When the laser current is switched on at t=0, transitioning from I=I_{off} (below the laser threshold) to I=I_{on} (above the threshold) as shown in inset of Figure 1, the carrier density will steadily increase from its below threshold value until the threshold carrier density n_{to} is reached. The turn-on delay, T_d, is primarily governed by carrier lifetime τ_e as follows:

$$T_d = \tau_e ln \frac{I_{on} - I_{off}}{I_{on} - I_{to}} \quad (1)$$

Where I_{to} is the threshold current. Interestingly, both carrier lifetime τ_e and turn-on delay time T_d are on the order of several nanoseconds. For high-fidelity application like HAMR recording, the turn-on delay is avoided by setting laser pre-bias above laser threshold. Figure 1 shows the high-speed photo-diode response for single laser current pulse. Blue line shows the response with pre-bias current set as laser threshold current and Black line shows the response with no pre-bias current. Photo-diode response for laser pulse with no pre-bias current is delayed by about 1 ns. This clearly exemplifies the role of laser pre-bias current in turn-on delay response of the laser diode. Further, we apply the train of high-speed ultra-short laser current pulses to the laser diode (as shown in Figure 2(a)) and simultaneously measure the optical response of laser diode and temperature rise of the head. Figure 2(b) shows the optical response for different pulse width of the laser diode. For laser pulse shorter than 1ns no optical response is measured. Figure 2(c) shows the average temperature rise of the slider and optical response from photo diode as a function of applied laser current. It is to note, for train of short pulses (<1ns) no optical response is observed but laser diode fully dissipate heat in the slider leading to increase laser diode temperature.

In the following, we use the high-speed pulsing of laser diode to pre heat the laser diode to its steady state temperature before doing the HAMR write operation in forward bias (as shown in Figure 3(a)). In absence of preheating the laser diode, the Joule dissipation leads to an increase in laser diode temperature resulting in changes in laser optical power due to laser mode hopping. Preheating the laser diode using the high-speed laser diode pulses brings it closer to HAMR write steady state temperature. We further verified the usefulness of high-speed laser diode pulsing to pre-heat the laser diode in the HAMR operating condition. Figure 3(b) shows the measured phase of written magnetic signal across the single track of HAMR writing with and without preheating the laser diode using the high-speed laser diode pulsing. With no pre-heating (Blue line), the phase varies significantly, which is attributed to the temperature increase leading to the laser power variation from mode hop. For Red line, the laser diode is pre-heated using the high-speed laser pulses before actual HAMR operation. Here, the phase of the written signal remains stable for the full track. This behavior clearly exemplifies the role of preheating to stablize laser diode temperature leading to the stable laser power during HAMR writing.

In conclusion, we have demonstrated a novel approach using the high-speed laser pulsing to preheat the laser diode. The high-speed laser pulses increase the laser diode temperature with no optical response. We have used the train of high-speed laser current pulses to preheat the laser diode to different laser diode temperature. It is found that matching the laser diode temperature between pre-heat and actual HAMR writing condition suppresses mode hop, leading to a stable HAMR writing condition.

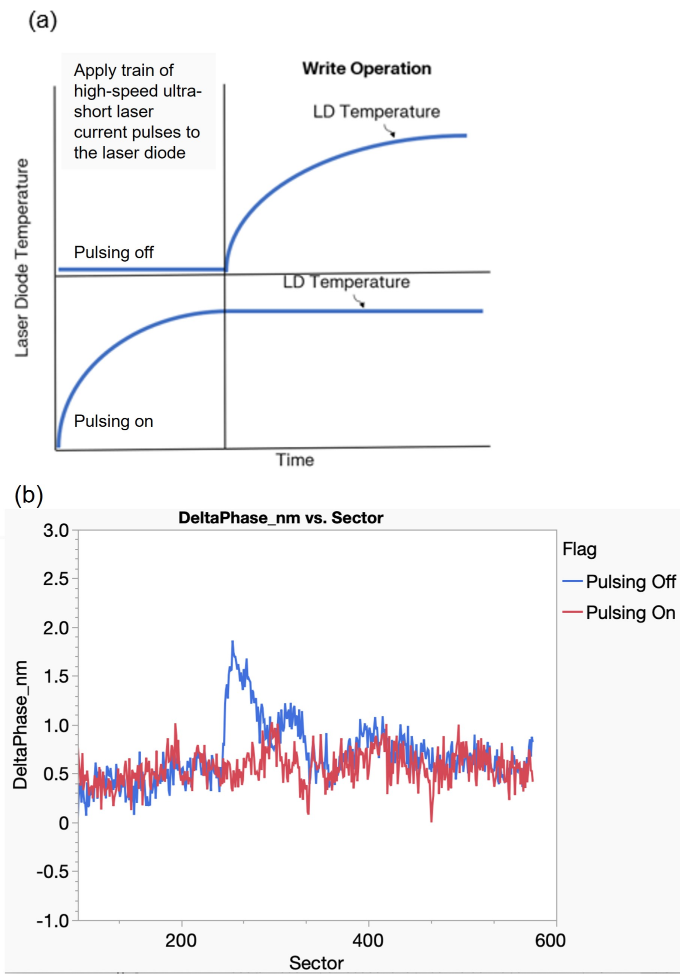

FIG. 3. (a) Cartoon showing the pre-heating the laser diode using the train of high-speed ultra-short laser current pulses to the laser diode before using the laser diode in the usual forward bias operation. (b) Measured phase of written magnetic signal across the single track of HAMR writing with and without preheating the laser diode using the high-speed laser diode pulsing.

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