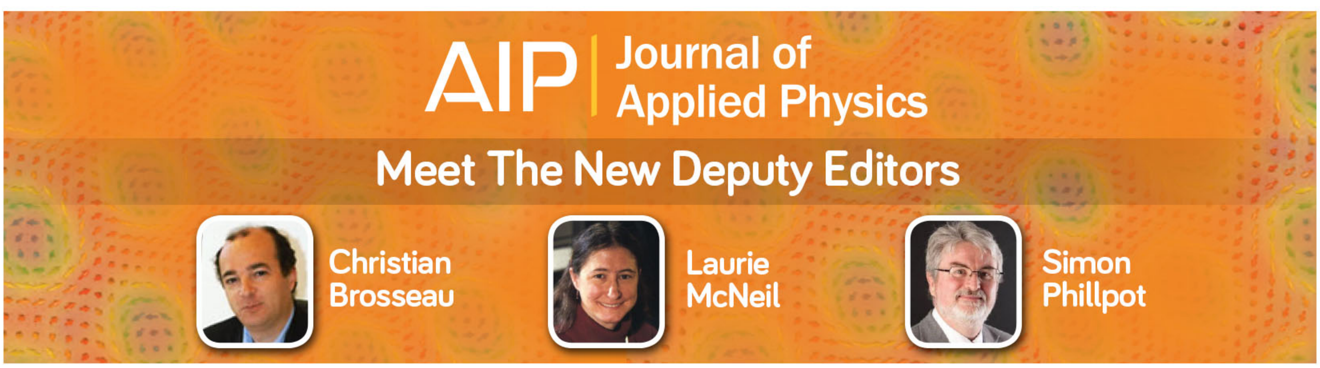
AIP Journal of Applied Physics

Erasure temperature measurements of heat assisted magnetic recording media

Y. J. Chen, H. Z. Yang, S. H. Leong, K. M. Cher, J. F. Hu, P. Sethi, and W. S. Lew

Citation: Journal of Applied Physics **117**, 17D117 (2015); doi: 10.1063/1.4914362
View online: http://dx.doi.org/10.1063/1.4914362
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/117/17?ver=pdfcov
Published by the AIP Publishing



JOURNAL OF APPLIED PHYSICS 117, 17D117 (2015)

Erasure temperature measurements of heat assisted magnetic recording media

Y. J. Chen,[1,a)] H. Z. Yang,[1] S. H. Leong,[1] K. M. Cher,[1] J. F. Hu,[1] P. Sethi,[2] and W. S. Lew[2]
[1]Data Storage Institute, Agency for Science, Technology and Research (A*STAR), 5 Engineering Drive 1, Singapore 117608
[2]School of Physical and Mathematical Sciences, Nanyang Technological University, 21 Nanyang Link, Singapore 637371

(Presented 4 November 2014; received 18 September 2014; accepted 2 November 2014; published online 6 March 2015)

For heat assisted magnetic recording (HAMR) media development, measurement of erasure temperature (Te) is interesting and important for practical HAMR testing and applications. Here, we present an investigation on Te measurements of $L1_0$ ordered FePt granular HAMR media made using a Laser Heating (LH) method on a home-built HAMR write test system versus that from a bulk heating approach. The HAMR write test system provides HAMR writing, micro-MOKE (magneto-optical Kerr effect) signal detection, and MOKE imaging functions at the same testing spot in one single system. Magnetic force microscopy (MFM) and magnetic Kerr microscopy observations of the scanning laser induced degradation/erasure/demagnetization of the pre-recorded magnetic patterns on disk media (over a wide area of a few hundreds of μm^2) show that the magnetic (MFM and Kerr signal) amplitude of the pre-recorded magnetic patterns decreases slowly with increasing laser power (Pw) (/temperature rise) for Pw $\lesssim$ 66 mW and then drops sharply to nearly zero for Pw $\geq \sim$72 mW (the laser power corresponding to complete thermal erasure when the media temperature is ~Te). It was further found that this trend of magnetic amplitude reduction with increased Pw is similar to that from magnetic amplitude decrease of pre-recorded magnetic patterns with increased bulk heating temperature. The temperature for complete erasure at laser power, Pw = 72 mW for the LH method, corresponds therefore to ~650 K ($\approx$Te) for the bulk heating methods. Besides fast measurement, LH (as a comparable and viable approach for erasure measurement) is dynamic, localized, and has time scales closer to practical HAMR situation. © *2015 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4914362]

Heat assisted magnetic recording (HAMR) is considered to be the next major hard disk drive (HDD) technology for areal densities (ADs) beyond ~1.5 Tb/in.^{2} (Ref. 1). In HAMR, a tiny region of high coercivity (Hc) magnetically hard (small grains with high magnetic anisotropy Ku or high anisotropic field Hk) granular media is locally and momentarily heated to around or beyond Curie temperature (Tc), where the values of saturation magnetization (Ms), Hk, and Ku approach zero, so that the magnetization of the heated region can be reversed with a conventional write head field, which is otherwise insufficient to write the media at room temperature. For HAMR media development, measurement of Curie temperature is very important. The typical Tc measurement method is to measure full loop hysteresis curves at each test temperature (T), followed by plotting Ms, Hk, or Ku as a function of T to determine Tc.[2] In practice, it is also interesting and important to measure another Tc related metric of critical temperature for erasure or erasure temperature (Te), where the recorded magnetic transitions are completely erased (remanence Mr approaches zero) by either bulk heating or localized laser heating. One drawback of the bulk heating method is the low measurement speed because of the temperature rise time for bulk heating. In contrast, laser heating (LH) is fast and can be used for Te measurement. The measured Te corresponds to a laser power, which needs to be calibrated.[3] Furthermore, laser heating is a dynamic process, where the time scale is closer to practical HAMR situation. Here, in this paper, we present an investigation on Te measurements of granular FePt based HAMR media using both laser heating based methods and bulk heating methods. Besides fast measurement, LH is dynamic, localized, and has short time scales that can avoid the potential undesired annealing effect from bulk heating.[4]

Strictly speaking, Tc is an intrinsic property of a ferromagnetic materials, except for finite grain size effects,[5] while Te depends on Tc as well as many other extrinsic factors, such as applied field and thermal fluctuations.[6,7] When the time scales associated with Te measurement approach HAMR writing time scales (~ns range), the erasure temperature could approach the Curie temperature.

The 2.5 in. glass disk samples of $L1_0$ ordered FePt granular HAMR media were prepared using an Intevac 200 Lean in-line sputter system.[8,9] Media coercivity as high as >25 kOe (as measured by 9 T high field MOKE (magneto-optical Kerr effect) magnetometer) was achieved by proper film structure design, element doping (such as Ag), and deposition process optimization. The LH Te measurements were

a)Author to whom correspondence should be addressed. Electronic mail: chen_yunjie@dsi.a-star.edu.sg.

performed on a home-built multi-functional HAMR write test system,[10] which integrates HAMR write function, micro-MOKE signal detection, and MOKE imaging functions in one system. The degradation/erasure of the pre-recorded magnetic patterns (arrays of "+" and "−" μm sized dot patterns by HAMR write function[10]) with varying laser power (Pw) was observed through *ex-situ*/*in-situ* magnetic force microscopy (MFM) and magnetic Kerr microscopy imaging, as well as via MOKE signals from another laser (probe) beam aligned and overlapped with the LH (pump) beam. A bulk heating was also carried out to thermal erase the pre-recorded magnetic patterns in a vacuum chamber with uniform disk heating and temperature control function for comparison and temperature calibrations.

Fig. 1(a) shows schematic of film structure for the granular FePt based HAMR media used in this study. Figs. 1(b) and 1(c) show MFM images of thermal degrade/erase of pre-recorded magnetic patterns by point and scanning laser heating with laser power of Pw = 75 mW. The pre-recorded magnetic patterns are arrays of "+" and "−" μm sized dot patterns previously recorded by the same home-built HAMR write test system[10] using the pump laser beam which was focused to smaller beam size of ~1.5 μm in diameter. With the elevated temperature (of ~Tc) due to laser heating, the heated area of the pre-recorded magnetic patterns is thermally demagnetized, leading to magnetization decay and erasure of the pre-recorded magnetic patterns. For faster thermal erasure over larger areas, the laser beam was focused to larger beam spot size (of ~4–5 μm in diameter; laser power density is $\sim 5 \times 10^5$ W/cm^2 for Pw = 75 mW). As shown in Fig. 1(b), the footprint of thermal erasure (~7–11 μm in dimension) is larger than optical beam spot size (~4–5 μm in dimension) due to thermal diffusion in the media film. Note that only single pulse (pulse width is 10 ms) of laser exposure was used in (b) and typical time scale for saturation temperature rise to maximum was ~μs or ~sub-μs range for the HAMR media and laser power density used in this study. Careful investigations also reveal that the thermal erasure of outer region of the thermal spot is less complete than inner area, indicating non-uniform heating and temperature change by Gaussian laser beam and the heat transfer from the hotter center to cooler outer area. To uniformly heat and erase over an even larger area than the laser beam spot size, the sample is also moved by the piezoelectric stage in a step-and-move mode with step size of less than half of the beam spot size (while the pulsed laser beam does not move) so that each thermally erased area is overlapped with the previous. Another way for large area erase is to move the laser beam (in continuous wave (CW) mode) on the stationary sample surface by the motorized optical head stage in scanning mode. Due to the low laser scanning speed (in the range of 0.01 m/s or lower), the heating effects for the scanning mode and sample step-and-move mode are almost the same. Fig. 1(c) shows a MFM image of uniform thermal erasure of the pre-recorded magnetic patterns by scanning laser over an area of ~25 μm × ~30 μm (≈750 μm^2). Note that a total exposure time of ~10 s was used for scanning an area of 50 μm × 50 μm for CW laser in (c). The transition at the boundary from non-erasure to complete erasure is about ~2–3 μm wide. With smaller scanning laser power, the thermal erasure/degradation becomes less significant.

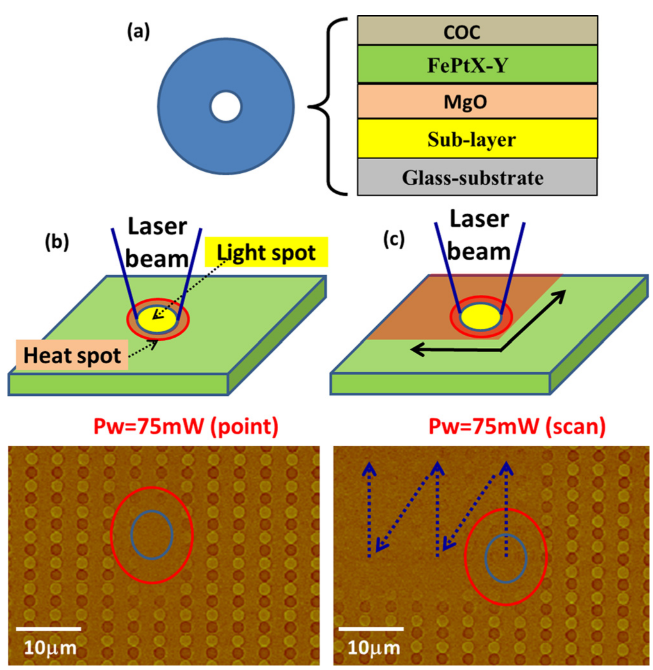


FIG. 1. Schematic of the film layer structure for HAMR disk media used (a), and MFM images (b) and (c) showing thermal erasure of the pre-recorded magnetic patterns by a stationary and scanning laser beam with Pw = 75 mW (for beam spot size of ~4–5 μm in diameter, the laser power density is $\sim 5 \times 10^5$ W/cm^2). Single pulse (pulse width is 10 ms) was used in (b) while a total exposure time of ~10 s was used for scanning an area of 50 μm × 50 μm in (c). Note that the footprint of thermal spot size is larger than the optical beam spot size.

The thermal erasure effects were also observed using CCD (Charge-Coupled Device) camera based Kerr magnetic imaging function which had been integrated into the same home-built HAMR write test system. The advantages of the Kerr imaging include the capability of *in-situ* observations of the thermal decay/degrade of the pre-recorded magnetic pattern with the increasing laser power (heating temperature) in one single system. Figs. 2(a) and 2(b) show magnetic Kerr images of thermal erasure of the pre-recorded magnetic patterns by scanning laser beam with Pw = 45 mW and 70 mW (laser exposure time: ~10 s for scanning an area of 50 μm × 50 μm for CW laser), respectively. It can be seen that the thermal erase effects for Pw = 45 mW are much less significant than the case for Pw = 70 mW. The Kerr imaging observations are consistent with *ex-situ* MFM observations, as shown in Figs. 2(c) and 2(d). However, MFM shows clearer images due to its higher resolution capability. Furthermore, Fig. 2(e) shows MFM line profiles along the indicated dotted lines in Figs. 2(c) and 2(d). The relative MFM contrast amplitude of magnetic patterns for laser heated area vs. that for un-heated area can be used to quantitatively show the trend and degree of thermal decay (media remnant moment (Mr) change), as a function of the temperature from scanning laser power. As shown in Fig. 2(e), the normalized MFM contrast amplitude of heated patterns over non-heated patterns is less than ~15% (near complete thermal erase) for Pw = 70 mW, while ~100% (nearly no thermal erase) for Pw = 45 mW. In

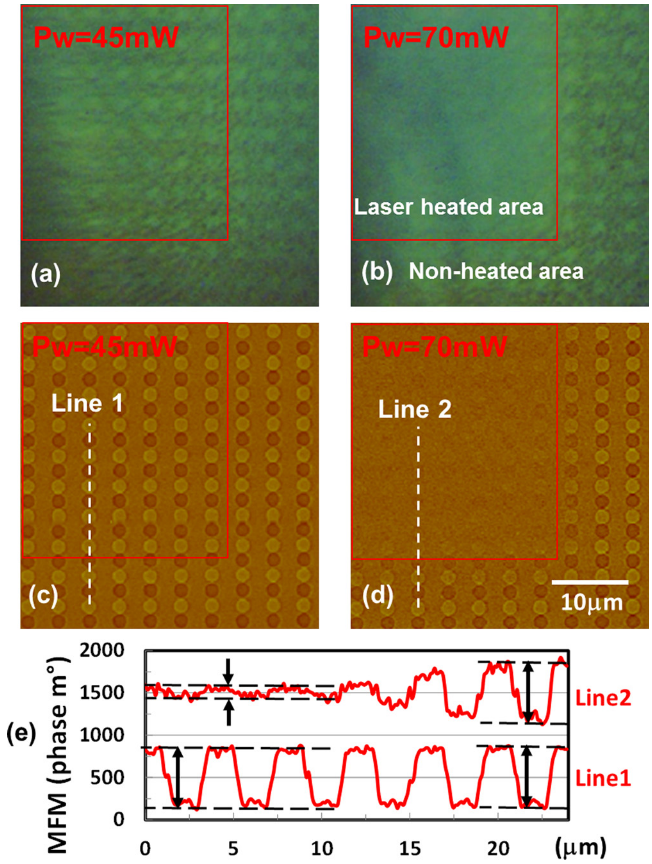


FIG. 2. Kerr magnetic images (a) and (b) and MFM images (c) and (d) for thermal erasure of pre-recorded magnetic patterns by scanning laser beam with Pw = 45 mW and 70 mW. (e) MFM line profiles of line 1 and line 2 in (c) and (d).

addition to magnetic Kerr and MFM observations, the magnetization decay and coercivity decrease as a function of increasing temperature (/laser power) can be detected by MOKE signals at the same testing spot in our home-built test system from another laser (probe) beam aligned and overlapped with the LH (pump) beam.[10]

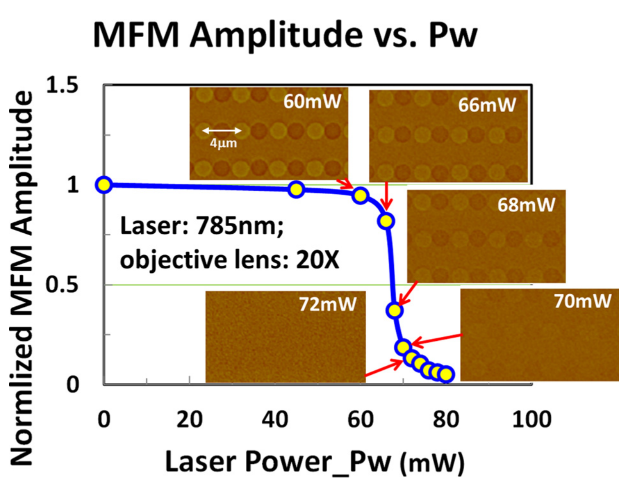


FIG. 3. Plot of MFM amplitude vs. scanning laser power. Insets: MFM images for thermally degraded/erased magnetic patterns for Pw = 60, 66, 68, 70, and 72 mW.

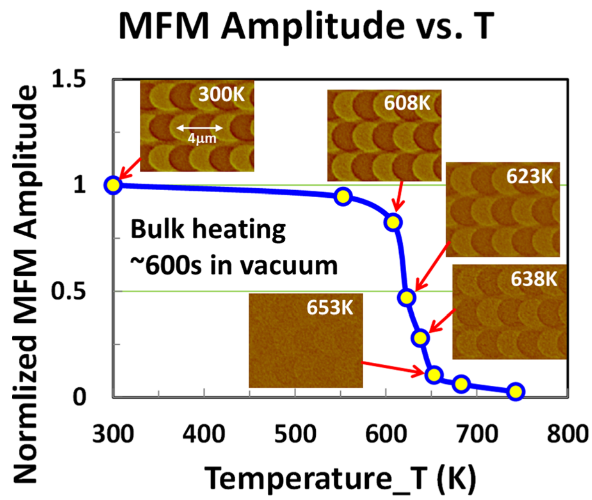


FIG. 4. Plot of MFM amplitude vs. bulk heating temperature. Insets: MFM images for thermally degraded/erased magnetic patterns for T = 300, 608, 623, 638, and 653 K. Note that the crescent shape of the pre-recorded "+" and "−" μm sized magnetic patterns is due to the sequential overlap of the circularly shaped dot patterns over previously recorded dot patterns.

Fig. 3 shows the normalized MFM amplitude of the pre-recorded magnetic patterns vs. scanning laser power. By scanning laser heating, the magnetic patterns degrade slowly for Pw $\lesssim$ 66 mW and then the magnetic amplitude drops sharply with increasing laser power (/heating temperature) to nearly zero for Pw $\geq \sim$72 mW, where the laser power for complete thermal erase is corresponding to ∼Te.

Fig. 4 shows the normalized MFM amplitude of the recorded magnetic patterns vs. disk temperature by bulk heating in vacuum. The heating duration for each temperature is ∼600 s. Note that each disk sample (with the same initial temperature history) was used for each heating temperature. The trend of magnetic amplitude decrease in Fig. 4 is similar to that in Fig. 3 and the temperature for complete erasure is ∼650 K. Due to the much longer time (>1 ms) used for Te measurements in our experiments than that for Tc measurement (<10 ns) in Ref. 11, the measured Te of ∼650 K should be lower than Tc. Comparing LH to bulk heating method, bulk heating approach provides an indicative temperature for the different Pw in LH approach; however, for accurate temperature calibration of Pw (mW) to Temperature (K), thermal stability effects due to different heating time scales for LH and bulk heating need to be considered.

In summary, an investigation on Te measurements of $L1_0$ ordered FePt granular HAMR media using both LH methods and conventional bulk heating methods has been carried out. Besides fast measurement, LH (as a comparable and viable approach for Te measurement) is dynamic, localized, and has time scales closer to practical HAMR situation.

[1]M. H. Kryder, E. C. Gage, T. W. McDaniel, W. A. Challener, R. E. Rottmayer, G. Ju, Y. T. Hsia, and M. F. Erden, Proc. IEEE **96**(11), 1810–1835 (2008).
[2]J.-U. Theile, K. R. Coffey, M. F. Toney, J. A. Hedstrom, and A. J. Kellock, J. Appl. Phys. **91**, 6595 (2002).
[3]A. Chernyshov, D. Treves, T. Le, C. Papusoi, H. Yuan, A. Ajan, and R. Acharya, IEEE Trans. Magn. **49**, 3572 (2013).

[4]J. F. Hu, J. S. Chen, B. C. Lim, and B. Liu, J. Magn. Magn. Mater. **320**, 3068 (2008).
[5]O. Hovorka, S. Devos, Q. Coopman, W. J. Fan, C. J. Aas, R. F. L. Evans, X. Chen, G. Ju, and R. W. Chantrell, Appl. Phys. Lett. **101**, 052406 (2012).
[6]W. T. Coffey and Y. P. Kalmykov, J. Appl. Phys. **112**, 121301 (2012).
[7]Y. J. Chen, H. Z. Yang, S. H. Leong, B. L. Wu, M. Asbahi, H. Y. Y. Ko, J. K. W. Yang, and V. Ng, Appl. Phys. Lett. **105**, 162402 (2014).
[8]J. F. Hu, T. J. Zhou, W. L. Phyoe, K. M. Cher, and J. Z. Shi, IEEE Trans. Magn. **49**(6), 2703–2708 (2013).
[9]J. F. Hu, T. J. Zhou, W. L. Phyoe, K. M. Cher, and J. Z. Shi, IEEE Trans. Magn. **49**(7), 3737–3740 (2013).
[10]H. Z. Yang, Y. J. Chen, S. H. Leong, C. W. An, K. D. Ye, M. J. Yin, and J. F. Hu, J. Appl. Phys. **115**(17), 17B726 (2014).
[11]S. Pisana, S. Jain, J. W. Reiner, G. J. Parker, C. C. Poon, O. Hellwig, and B. C. Stipe, Appl. Phys. Lett. **104**, 162407 (2014).