JOURNAL OF APPLIED PHYSICS **115**, 17B726 (2014)

A multi-functional testing instrument for heat assisted magnetic recording media[a)]

H. Z. Yang,[1,b)] Y. J. Chen,[1] S. H. Leong,[1] C. W. An,[1] K. D. Ye,[1] M. J. Yin,[2] and J. F. Hu[1]
[1]*Data Storage Institute, Agency for Science, Technology and Research (A-STAR), 117608 Singapore*
[2]*Industrial & Systems Engineering, National University of Singapore, 117576 Singapore*

(Presented 6 November 2013; received 23 September 2013; accepted 12 November 2013; published online 20 February 2014)

With recent developments in heat assisted magnetic recording (HAMR), characterization of HAMR media is becoming very important. We present a multi-functional instrument for testing HAMR media, which integrates HAMR writing, reading, and a micro-magneto-optic Kerr effect (μ-MOKE) testing function. A potential application of the present instrument is to make temperature dependent magnetic property measurement using a pump-probe configuration. In the measurement, the media is heated up by a heating (intense) beam while a testing (weak) beam is overlapped with the heating beam for MOKE measurement. By heating the media with different heating beam power, magnetic measurements by MOKE at different temperatures can be performed. Compared to traditional existing tools such as the vibrating sample magnetometer, the present instrument provides localized and efficient heating at the measurement spot. The integration of HAMR writing and μ-MOKE system can also facilitate a localized full investigation of the magnetic media by potential correlation of HAMR head independent write/read performance to localized magnetic properties.
[http://dx.doi.org/10.1063/1.4865969]

I. INTRODUCTION

With the recent development in hard disk drive, heat assisted magnetic recording (HAMR) is a promising technique to increase the recording density by using smaller thermal stable grains with higher magnetic anisotropy. In HAMR, the magnetic grains in the recording area are temporarily heated by a localized heat source. The coercivity of the heated magnetic grains is reduced below the available magnetic recording field. The heated grains are then rapidly cooled in the presence of the recording field. As the rapid developments of HAMR in recent years, the testing of the magnetic properties and recording performances of HAMR media has been widely studied.[1–3] The testing methods include spin-stand[4] for recording performance tests and vibrating sample magnetometer[5] (VSM) as well as magneto-optic Kerr effect[6] (MOKE) for magnetic measurements. Spin-stand is an efficient method to test the overall write-ability and readability of the HAMR recording system. The testing results are affected by both the HAMR head and media.[3] The magnetic properties, such as magnetic moment and coercivity of HAMR media, can be measured by VSM and MOKE. For traditional VSM and MOKE systems, a relatively large sample area/volume is involved, which make the study of the localized magnetic properties difficult. For HAMR media, the temperature dependent magnetic properties are more critical for recording performance and the temperature variable tests are thus highly desired. The traditional heating method, such as oven or electric heating, has the shortcomings of large area/volume heat up, slow heating/cooling speed, and the possibility of the media contamination by the contact heating.

In this paper, we report a HAMR testing instrument, which integrates HAMR write and read capability and μ-MOKE measurement. The main advantage of the present instrument is the localized HAMR write and read testing and temperature dependent magnetic property measurement in the micron range. The correlation between magnetic properties and write/read ability can be readily realized.

II. INSTRUMENT

The instrument includes three parts: MOKE, HAMR writing, and the third part including the electro-magnet for applying magnetic field and the piezo stage for sample movement. A planar schematic of the system is shown in Figure 1. The MOKE part is for magnetic property measurement and to read-back the written signal. Magneto-optic Kerr effect is a phenomenon, which describes the change of the polarization state of the reflected beam by a magnetic surface. The rotation of the polarization direction is called Kerr rotation, which is proportional (in the first order) to the magnetization of the media. As shown in Figure 1, the laser source for MOKE portion is a He-Ne laser at 633 nm. The beam is modulated by an optical chopper, and the signal is recovered with a lock-in amplifier to enhance the MOKE signal. For HAMR writing, the laser source used is a modulated laser-diode (Micron Laserage) at 785 nm. The different laser wavelength of HAMR write and MOKE measurement allows the signal to noise ratio (SNR) of the system to be improved

[a)]Contributed paper, published as part of proceedings of the 58th Conference on Magnetism and Magnetic Materials, Denver, Colorado, USA, November 2013.
[b)]Author to whom correspondence should be addressed. Electronic mail: YANG_Hongzhi@dsi.a-star.edu.sg.

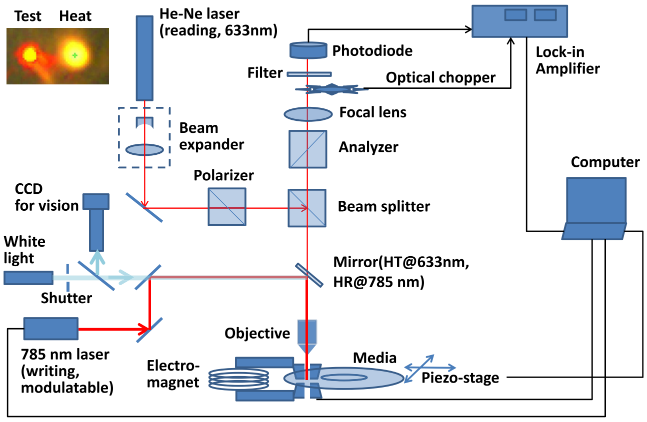

FIG. 1. Schematic of the instrument. The upper left inset is the vision image of the heating and testing beam profile, which can be overlapped.

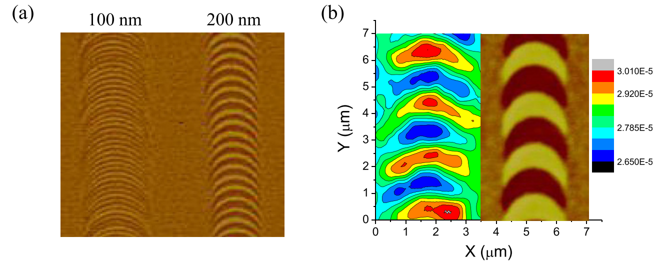

FIG. 2. (a) The MFM image of magnetic field modulation written tracks with bit length of 200 nm and 100 nm on the FePt granular media. (b) The read-back signal by the μ-MOKE function with bit length of 1 μm. On the right side of the read-back 2D imaging is the corresponding MFM image.

through inserting a laser line filter before the photo detector in the MOKE portion. In the HAMR writing part, the writing beam is focused by an objective lens. The focused beam transmits through a hole of the magnetic pole of the electro-magnet and focuses on the testing media. In the temperature dependent magnetic property testing and read-back measurement, the two beams for heating and testing are aligned at the same location on the media with the help of the vision system. The piezo stage (P-527.3CD, PI) in the system provides accurate sample movement in the nm-scale and helps fine laser focusing adjustment. The magnetic field from the electro-magnet can be swept in the range of $\pm$6 kOe.

III. MEASUREMENTS AND RESULTS

A. HAMR write and read

The sample we use in the experiment is a FePt granular media, which is a critical candidate for HAMR.[7] The FePt based granular media were prepared using an Intevac 200 Lean in-line sputter system. FePt granular films were prepared by using the Triatron source, which is a deposition source capable of depositing up to three different materials independently in the same process chamber simultaneously or sequentially. The underlayers for FePt such as NiTa and MgO layers were deposited at room temperature, and the disk was then heated by resistive heater at the heating station just before the Triatron station. The heated disk was transported into the Triatron station for FePt granular film deposition. More details of the sample fabrication process were described in previous publications.[8,9] In the HAMR writing process, an out of plane magnetic field, which is uniform in the central region of a few mm wide in the gap of the magnetic poles, is applied to the area of interest on the media. A tiny spot of the media is then heated to a certain temperature by the pulsed writing laser. When the media cools down below the writing temperature, the heated bit is "freezed" in the presence of the magnetic field, and a bit is recorded on the media. In the HAMR writing and read-back testing, a 50$\times$ super long working distance objective lens (NA = 0.45, Nikon) is used to improve the focusing of the laser on the sample surface. In a typical experiment performed, a modulated magnetic field and single laser pulses of same pulse amplitude and width are used to write a line of magnetic bits by moving the media in nanometer steps with the piezoelectric stage. As shown in Figure 2(a), the bit length of the written signal can be reduced to less than 100 nm, which is determined by the thermal and magnetic properties of the HAMR media. By performing SNR measurements on the profile of the written bits, the write-ability and quality of the HAMR media can be studied.

In the traditional HAMR writing, a near field transducer (NFT) is integrated in the writing head to localize the temperature profile in the media with radius to be much less than 100 nm. The temperature gradient with NFT could be increased to $\sim$10 K/nm.[10] In the present instrument, we use far field optics, which produces a relatively lower temperature gradient with larger bit size. To overcome large bit size, we overlap the written bits by moving the media in nanometer steps with a piezoelectric stage. With this method, the bit length can be reduced to less than 100 nm. This measurement can be performed on different media for comparative study.

When the bits are written on the media, the written pattern can be read-back by the MOKE imaging function. In the experiment, the testing beam (of μm diameter and much smaller power) for MOKE is scanned across the same area for HAMR writing by moving the piezoelectric stage in re-defined steps, the MOKE signal at each position is recorded and 2D imaging can be drawn. In Figure 2(b), we plot the 2D imaging of the read-back signal by μ-MOKE and compare with the magnetic force microscopy (MFM) image. The written bits with bit length of 1 μm can be read-back by μ-MOKE.

B. Heating laser power dependent magnetic properties measurement

The measurement of the magnetic properties of the HAMR media at various temperatures is important towards understanding the writing and reading performance of the media.[11] In this instrument, we use an intense heating beam, which is slightly defocused (with larger spot size), to efficiently and locally heat up the testing area of the media, while a weak testing beam, which is focused (with smaller spot size) and overlapped with the heating beam at the center on the media, tests the magnetic properties at a certain power of the heating beam. In this configuration, the testing area under the testing beam is relatively smaller than the laser heated area (<1:5), and the media temperature reaches

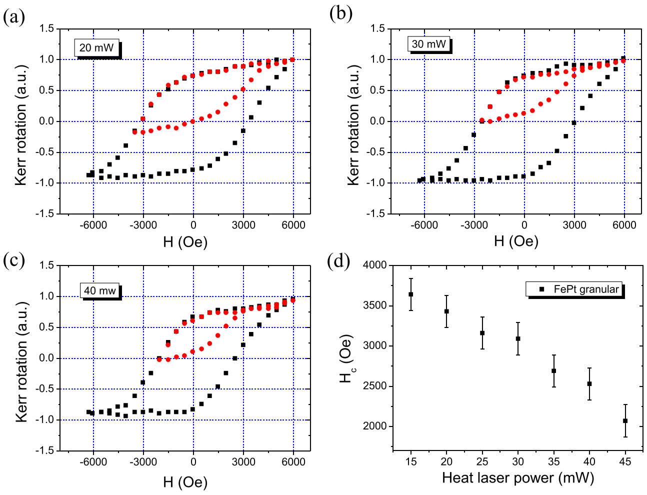

FIG. 3. (a)–(c) The hysteresis major and recoil loops of the FePt granular media at the heating power of 20, 30, 40 mw. (d) Coercivity of the FePt media versus the heating optical power.

a stable state from the continuous heating of the heating beam, as shown in the inset of Figure 1.

The testing results are shown in Figure 3. The sample we used in the testing is a FePt granular media film structure with coercivity of ~10 kOe at room temperature. When the media is not heated, the magnetic loop is a minor loop as the field is swept in the range of ±6 kOe. However, when the heating power increases gradually, we observe a change from a minor loop to a major loop, due to the decrease of the coercivity of the HAMR media as temperature increases. Figures 3(a)–3(c) shows the hysteresis major and recoil loops at heating laser power of 20, 30, 40 mw. Figure 3(d) shows the dependence of coercivity of the media on the heating power. A clear trend is observed and the measurement is consistent with other reports.[1,2] As shown in Figures 3(a)–3(c), the instrument can also be developed to perform recoil loop measurements to obtain detailed magnetic properties, such as temperature dependent switching field distribution of the HAMR media.[12,13] In the measurement, the hysteresis loops can be repeated, which demonstrates that the heating does not degrade the media.

As the temperature of the heated area in the media is dependent on the optical power of the heating beam, the measurement of the heating laser power dependent magnetic properties also reflects the dependence of the magnetic properties on temperature, even though the exact temperature has not been calibrated. The instrument can be further developed to make temperature calibration by introducing a separate probe beam with the pump-probe configuration, as demonstrated by the thermal reflectance measurement.[14]

IV. CONCLUSION

In conclusion, the present instrument integrates HAMR writing and reading, with the μ-MOKE testing function. It will facilitate HAMR head independent correlation of local magnetic properties (such as obtained from magnetic hysteresis loops) with the media write-ability and readability, by allowing *in-situ* measurements at the same exact testing spot, all on the same setup. In addition, the instrument can also be extended to study HAMR transducer thermal imaging,[15] and HAMR media write/read by HAMR transducer through clever insertion of a HAMR transducer between the focusing optics and magnetic media while making use of the existing focused laser already in place.

[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]R. E. Rottmayer, S. Batra, D. Buechel, W. A. Challener, J. Hohlfeld, Y. Kubota, L. Li, L. Bin, C. Mihalcea, K. Mountfield, K. Pelhos, C. B. Peng, T. Rausch, M. A. Seigler, D. Weller, and X. M. Yang, IEEE Trans. Magn. **42**(10), 2417–2421 (2006).
[3]W. A. Challener, C. B. Peng, A. V. Itagi, D. Karns, W. Peng, Y. G. Peng, X. M. Yang, X. B. Zhu, N. J. Gokemeijer, Y. T. Hsia, G. Ju, R. E. Rottmayer, M. A. Seigler, and E. C. Gage, Nature Photon. **3**(4), 220–224 (2009).
[4]N. Guzik, U.S. patent 6,229,303 (8 May 2001).
[5]S. Foner, Rev. Sci. Instrum. **30**(7), 548–557 (1959).
[6]Z. Q. Qiu and S. D. Bader, Rev. Sci. Instrum. **71**(3), 1243–1255 (2000).
[7]D. Weller, O. Mosendz, G. Parker, S. Pisana, and T. S. Santos, Phys. Status Solidi A **210**(7), 1245–1260 (2013).
[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. Cher, and J. Z. Shi, IEEE Trans. Magn. **49**(7), 3737–3740 (2013).
[10]H. J. Richter, C. C. Poon, G. Parker, M. Staffaroni, O. Mosendz, R. Zakai, and B. C. Stipe, IEEE Trans. Magn. **49**(10), 5378–5381 (2013).
[11]X. B. Wang, K. Z. Gao, J. Hohlfeld, and M. Seigler, Appl. Phys. Lett. **97**(10), 102502–102503 (2010).
[12]A. Berger, Y. Xu, B. Lengsfield, Y. Ikeda, and E. E. Fullerton, IEEE Trans. Magn. **41**(10), 3178–3180 (2005).
[13]I. Tagawa and Y. Nakamura, IEEE Trans. Magn. **27**(6), 4975–4977 (1991).
[14]M. Farzaneh, K. Maize, D. Lüerßen, J. A. Summers, P. M. Mayer, P. E. Raad, K. P. Pipe, A. Shakouri, R. J. Ram, and A. H. Janice, J. Phys. D: Appl. Phys. **42**(14), 143001 (2009).
[15]C. B. Peng, W. A. Challener, A. Itagi, M. Seigler, and E. C. Gage, IEEE Trans. Magn. **48**(5), 1801–1806 (2012).