General Topics

Method for Measurement of Switching-Field Distribution of Heat-Assisted Magnetic Recording Media

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Abstract—Due to increased emphasis on heat-assisted magnetic recording (HAMR), the characterization of the intrinsic switching-field distribution (iSFD) at elevated media temperatures has become important. In this paper, we introduce an efficient method to measure iSFD based on optical heating and magnetooptic Kerr effect measurement. The major and minor hysteresis loops of perpendicular magnetic recording media and FePt granular media were acquired at different optical heating powers. The optical heating power (or temperature) dependent iSFD of FePt granular media was measured. We observe iSFD broadening of HAMR media at elevated temperatures, which is consistent with theoretical predictions.

Index Terms—General topics, FePt granular media, information storage, heat-assisted magnetic recording, switching field distribution.

I. INTRODUCTION

With the increased emphasis on heat-assisted magnetic recording (HAMR) for next-generation magnetic recording, the characterization of switching field distribution (SFD) of HAMR media at room temperature and elevated temperatures becomes more important [Kryder 2008, Chernyshov 2013]. The intrinsic SFD (iSFD) of the recording media, which is affected by the variations in magnetization, anisotropy, orientation, and texture of the grains, impacts the recording performance. In the hysteresis loop measurement, the actual field applied on the individual grain is the combination of external applied field and the intergranular interaction field such as dipolar and exchange interaction. Intensive studies have been conducted to extract the iSFD of the perpendicular media from the hysteresis loop measurement. Tagawa *et al.* [1991] proposed a simple method of measuring the iSFD of the magnetic media. In this method, the M–H major loop and the minor loop starting at the coercivity field were measured. The field difference between the major and recoil loop when the recoil loop reaches half of the saturation magnetization is believed to be proportional to iSFD of the media. Berger *et al*. developed the $\Delta H(M, \Delta M)$ method, in which the recoil loop is not confined to be starting at the coercivity field [Berger 2005, 2006]. In the $\Delta H(M, \Delta M)$ method, the interaction field $H_i(M)$ is assumed to be an arbitrary function of magnetization and the media particles can be reasonably well described by square hysterons. The intergranular interactions are removed in this method by measuring the field difference (ΔH) of the major and recoil loops at the same magnetization. In recent years, first-order reversal curve (FORC) has been widely used in the measurement of intergranular interaction of magnetic media. The FORC image can give a straightforward illustration of the mean-field factor and interaction field distribution [Pike 1999, Papusoi 2011, Valcu 2011, Grafe 2014]. Other methods that are commonly used include the self-consistent solution of the effective demagnetization factor [Veerdonk 2003], and the method based on the Wohlfarth relation by measuring the dc demagnetization remanence and isothermal remanent magnetization [Huerta 2012].

The main methods for measuring magnetic hysteresis loops are by magnetooptic Kerr effect (MOKE) measurement, vibrating sample magnetometer (VSM) [Foner 1959], and alternating field gradient magnetometer. The MOKE measures Kerr rotation (which is dependent on the sample magnetization) by polarization rotation of the reflected beam. The VSM technique uses the magnetic induction effect. The vibration of the magnetic sample will facilitate the detection of the tiny periodical magnetic signal with the lock-in amplifier. However, in order not to be affected by the spatial distribution of the external magnetic field, the sample is usually limited to small sizes. To allow the measurement of temperature-dependent magnetic properties, heating facilities are usually attached in the VSM instrument. However, the bulk heating of the sample is time consuming and can cause annealing effect at high temperatures. In this paper, we use MOKE to measure the hysteresis loop while another intense beam is used to optically heat up the media at the measurement location. As the optical heating is efficient and localized, and closer to the actual HAMR recording configuration, this approach can be a useful technique to characterize the magnetic properties of the HAMR media at elevated temperatures.

II. METHOD AND DISCUSSION

In the experiment, we combined the MOKE measurement with the pump–probe configuration as shown in Fig. 1. One intense beam locally heats up the media by controlling the optical heating power, while a MOKE testing beam, which is much smaller and less powerful, is overlapped with the heating beam in the center through alignment under a microscope. The MOKE signal is sensitively measured by the lock-in amplifier. The detailed description of the experimental method can be found in Yang [2014].

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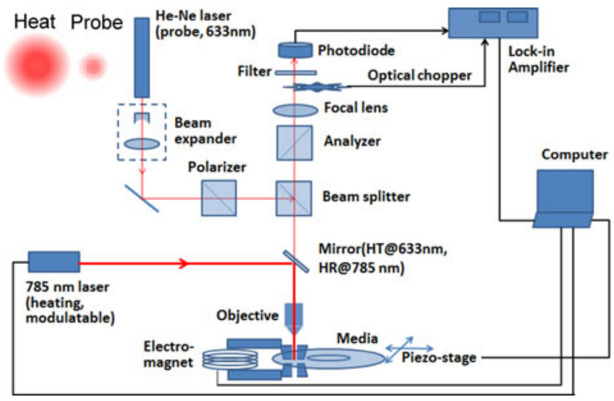


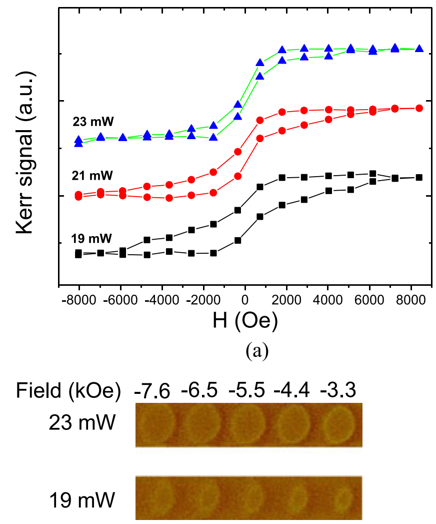
Fig. 1. Schematic of the experimental setup and the two beam profiles on the upper-left corner for illustration.

FePt-based granular media is the most promising candidate for HAMR application. In the synthesis process of the FePt granular media, a NiTa seedlayer and MgO underlayer were first deposited at room temperature, and the disk was then heated at the heating station. The heated disk was transported into the Triatron source, which is capable of depositing up to three materials, for FePt granular film deposition. More details of the sample fabrication process were described in previous publications [Hu 2013a, 2013b].

With the experimental setup in Fig. 1, we measured the magnetic remanence hysteresis loops of FePt granular media at localized regions with different optical heating powers. As the optical heating power increases, the temperature in the localized heating spot in the media also increases. Even through the clear relationship between the media temperature and the optical heating power needs to be clarified, an approximately linear relationship can be assumed for the steady-state measurement with relatively low power intensity. The power of testing beam is less than 1 mW to ensure that the heating effect from the testing beam can be omitted.

The FePt granular media has a coercivity $H_c > 12$ kOe. In order to see the heating effect, we also measured the magnetic force microscopy (MFM) images of the magnetic spots on the media, which were written with the same optical heating power, beam spot size, and pulse duration as in MOKE measurement.

In the MOKE measurement, the testing beam was focused to a spot size of around 1 μm by a super long working distance objective lens (20$\times$, Nikon), while the heating beam, which has a much bigger size, was overlapped with the MOKE testing beam. In the remanence hysteresis loop measurement, a heating laser pulse with pulse duration of 25 ms was incident on the media under a uniform out-of-plane external applied magnetic field and then the magnetization remanence was measured by MOKE beam, which was overlapped at the center of the heated area. As shown in Fig. 2(a), magnetic hysteresis loops of FePt granular media at optical heating power of 19, 21, and 23 mW were measured. As can be seen in Fig. 2(a), for the FePt granular media with room temperature coercivity $H_c > 12$ kOe, a full remanence hysteresis loop can be observed with optical heating power at 19 mW and above with the magnetic field sweeping range of $\pm$8 kOe. As the optical heating power increases, the remanence coercivity of the media decreases dramatically.



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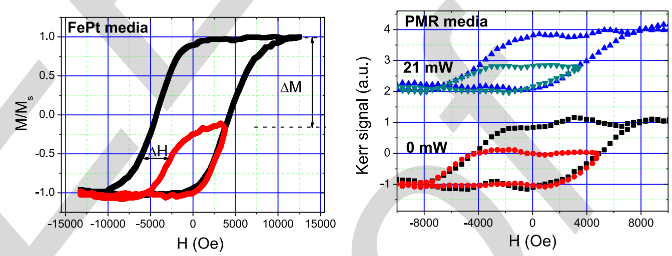

Fig. 3. (a) Approach for measuring ΔH and ΔM. (b) Major and minor hysteresis loops of PMR media at different optical heating power. The hysteresis loops are shifted in the vertical axis for easy observation.

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A perpendicular magnetic recording (PMR) media was used to verify the experiment setup for iSFD measurement of magnetic granular media at different optical heating powers. Fig. 3(a) shows the approach for the measurement of ΔH and ΔM [Berger 2005, Berger 2006]. The major and minor loops of the PMR media with and without optical heating were measured as shown in Fig. 3(b). The turning point of the minor loop started at zero magnetization state. From the methodology introduced by Tagawa *et al.* [1991], the field difference between the major and minor loop at half the saturation magnetization is proportional to the iSFD of the granular media. From the measurement, we can see that the field difference ΔH is not measurable at room temperature (0 mW) and even at elevated temperatures with optical heating (21 mW). This could be due to the narrow iSFD for the commercial PMR media, which are well optimized.

Two FePt granular disk media, fabricated at different deposition temperatures and expected to have different iSFD properties, were tested. In the MOKE measurement, the heating beam was set at continuous wave mode and a focal lens ($f = 75$ mm) was used to focus the heating and probe beams. Due to the different deposition temperatures, the crystalline properties of the FePt media are expected to be very different. For Sample 1, the deposition temperature is lower, the room temperature coercivity was measured to be around 4 kOe, while for sample 2, the deposition temperature is increased and room temperature coercivity is around 6 kOe. Fig. 4(a) shows the major and minor Kerr hysteresis curves for sample 1 and 2 at different optical heating powers. For measurement procedure and data analysis, we used the $\Delta H(M, \Delta M)$ method introduced by Berger *et al.*, as this method is widely used in the iSFD measurement for perpendicular granular media. Fig. 4(b) shows the plot of extracted value of ΔH as a function of M and ΔM. The continuous red curve is the fitting curve with the algorithms of the $\Delta H(M, \Delta M)$ method [Berger 2005, 2006]. For one set of curves for the same sample and optical heating power, the fitting parameters are the same. As shown in Fig. 4(b), the experiment data can be fitted well by the algorithms of the $\Delta H(M, \Delta M)$ method. Fig. 4(c) shows the extracted iSFD curves for the two samples at different optical heating powers. It can be seen that the iSFD curve shows asymmetric shape with a relatively longer tail at high field regime. The measurement is consistent with the previous observation of the log-normal distribution of PMR media at low field sweeping rate [Berger 2006]. As the optical heating power increases from 0 to 17 mW, the distribution maintains an asymmetric shape but shifts to the lower field side as the media temperature increases at higher optical heating power. In Fig. 4(d), the value of σ/H_c versus the optical heating power is plotted, where σ is the standard deviation from H_c and H_c is the coercive field. It is also found that the σ/H_c of sample 1 is higher than that of sample 2. The improvement of iSFD for sample 2 should be due to the higher deposition temperature, which increases the content of the $L1_0$ phase in the FePt film. The improvement of Curie temperature distribution for FePt granular media with higher deposition temperature was also reported recently [Pisana 2014]. For both samples, the broadening of SFD is observed due to the thermal fluctuation and Curie temperature distribution, as predicted by theoretical study [Wang 2010].

III. CONCLUSION

In this paper, we demonstrated a method of measuring the dependence of SFD of HAMR media on temperature with a combination of optical heating and MOKE measurement. This optical-based method is efficient and closer to real HAMR conditions. The broadening of the iSFD is observed as the media temperature increases, which is consistent with the theoretical predictions. We also compared the FePt granular media synthesized at different deposition temperatures. It is found that the SFD improves at higher deposition temperature with the increase of the ordered $L1_0$ fct lattice. The present study will facilitate the magnetic property characterization of HAMR media.

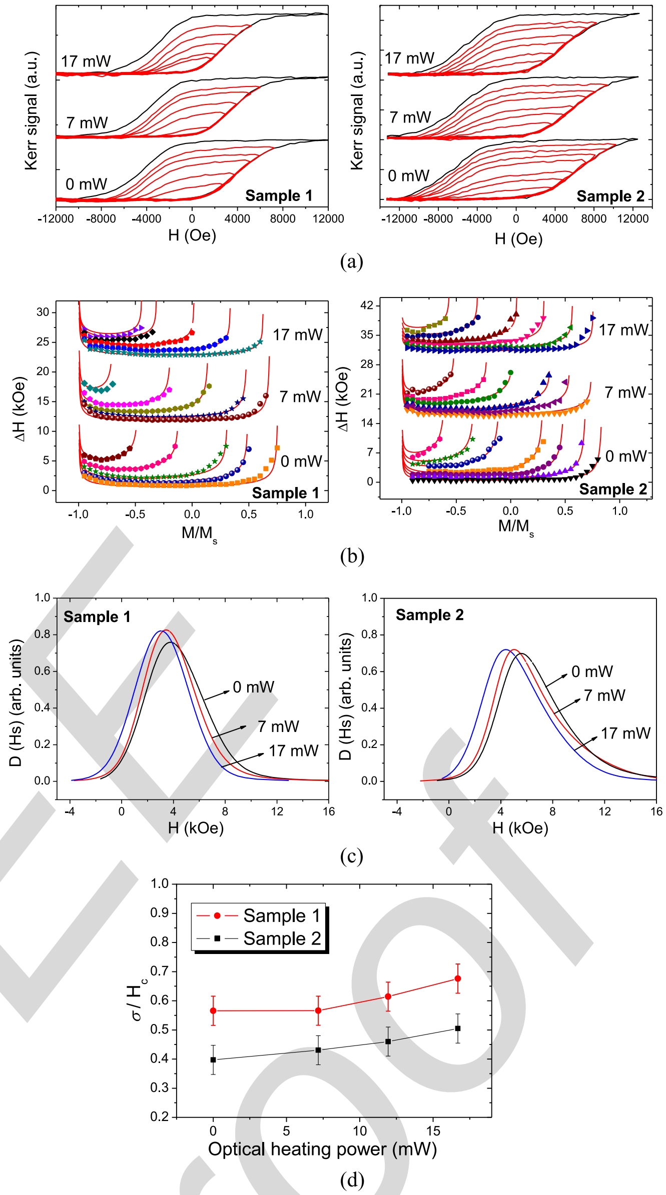

Fig. 4. (a) Major and minor hysterisis loops of FePt granular media at different optical heating powers for samples 1 and 2. The hysterisis loops at different optical heating powers are shifted in the vertical axis for easy observation. (b) Extracted $\Delta H(M, \Delta M)$ experiment data with continuous red curve as the fitting curve. The data at different optical heating powers are shifted in the vertical axis for easy observation. (c) Plot of the extracted iSFD curves for samples 1 and 2 at different optical heating powers. (d) Plot of the value of σ/H_c versus the optical heating power.

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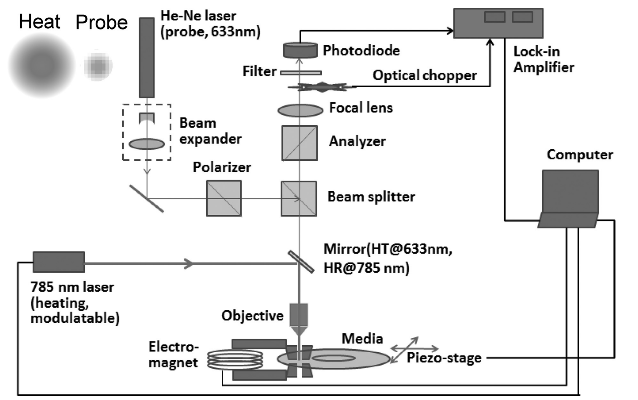

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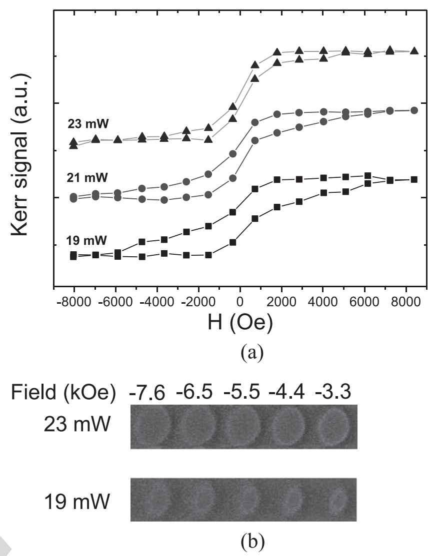

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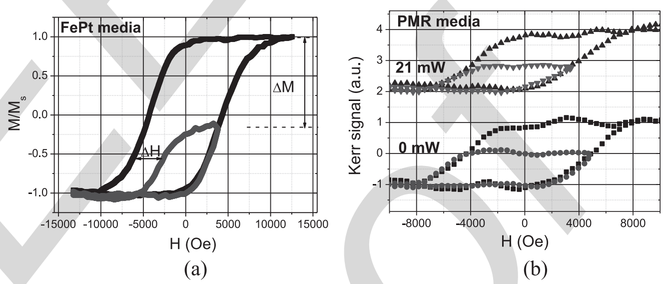

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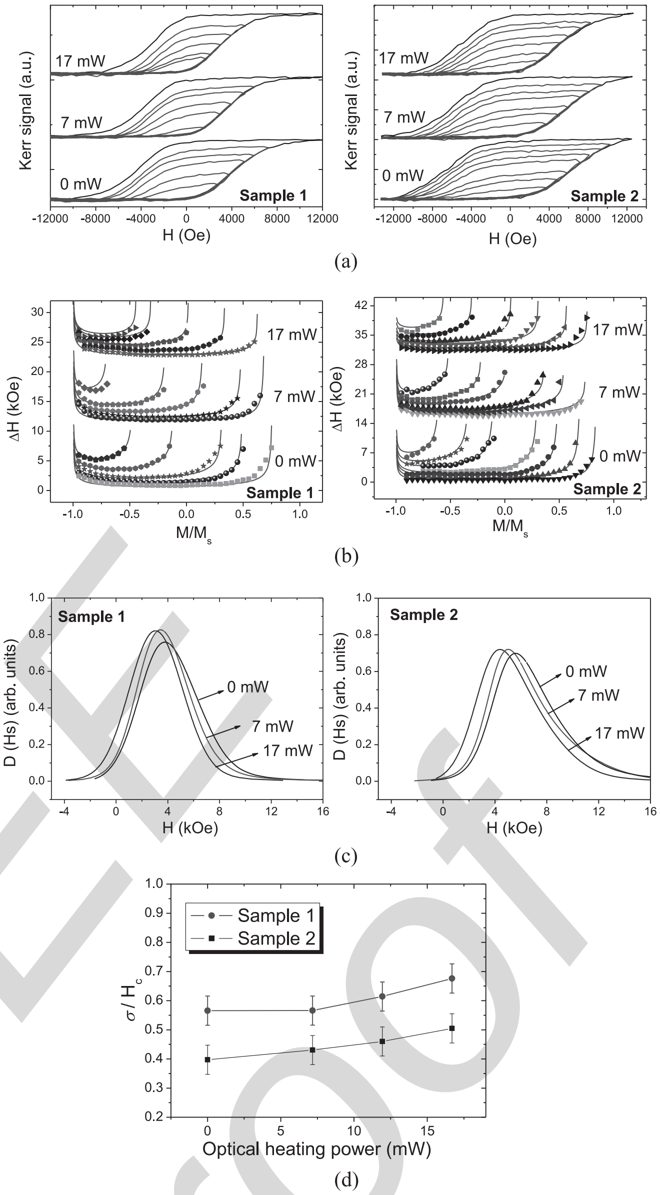

Fig. 4. (a) Major and minor hysteris loops of FePt granular media at different optical heating powers for samples 1 and 2. The hysteris loops at different optical heating powers are shifted in the vertical axis for easy observation. (b) Extracted $\Delta H(M, \Delta M)$ experiment data with continuous red curve as the fitting curve. The data at different optical heating powers are shifted in the vertical axis for easy observation. (c) Plot of the extracted iSFD curves for samples 1 and 2 at different optical heating powers. (d) Plot of the value of σ/H_c versus the optical heating power.

III. CONCLUSION

In this paper, we demonstrated a method of measuring the dependence of SFD of HAMR media on temperature with a combination of optical heating and MOKE measurement. This optical-based method is efficient and closer to real HAMR conditions. The broadening of the iSFD is observed as the media temperature increases, which is consistent with the theoretical predictions. We also compared the FePt granular media synthesized at different deposition temperatures. It is found that the SFD improves at higher deposition temperature with the increase of the ordered $L1_0$ fct lattice. The present study will facilitate the magnetic property characterization of HAMR media.

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