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Magnetic recording with acoustic waves

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ABSTRACT

We demonstrate acoustically assisted magnetic recording (AAMR), a new paradigm in magnetic data storage. In this concept, otherwise unwriteable high-coercivity media, requisite for thermally stable high-density data storage, are made amenable to recording by lowering their coercivity via strain induced by surface acoustic waves. The basic principles of AAMR are proven using galfenol, a low-coercivity magnetostrictive material, as the recording medium. It is shown that the writing field needed to record data in the presence of acoustic strain is lower than the coercivity of the unstrained galfenol film. Further, it is demonstrated that interference between acoustic waves can be tailored to selectively address a bit on the recording medium.

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1. Introduction

Over the past few decades, magnetic hard disk drives have been serving as a successful solution for mass data storage. Historically, an average increase in storage density of 40% to 60% per year has been achieved by scaling the grain size in the recording media [1]. Continued scaling is, however, untenable as data stored in increasingly smaller grains becomes vulnerable to loss by thermal perturbations. To retain good thermal stability in high-density recordings with small magnetic grains, materials with high coercivity such as $L1_0$ FePt, FePd and SmCo are being investigated. The difficulty in using these high coercivity media is that the magnetic field needed to record the data exceeds the fields possible with a write head. To continue to increase storage density, the challenge thus lies in meeting the requirement that the coercivity of the recording medium be simultaneously high for thermal stability and low for writeability. Strategies to address this conundrum include heat-assisted magnetic recording (HAMR) [2] and microwave-assisted magnetic recording (MAMR) [3]. In HAMR, a laser is used to locally heat the recording medium above its Curie temperature to lower the coercivity during writing. The heat is then removed to allow the medium to cool to its original coercivity or thermally stable state for storage. Despite significant advances, unreliable operation due to thermal loading and cycling remains a key concern for HAMR technology. In MAMR, a microwave field is applied perpendicular to the conventional write field to activate precessional switching in the medium during writing. Consequently, data can be recorded with a write field lower than the coercivity of the medium. The principles of MAMR have been demonstrated [4]. However, transducer design for generating microwave magnetic fields of sufficient amplitude in the proximity of the recording head remains a challenge.

In our work, we investigate the feasibility of acoustically assisted magnetic recording, a new paradigm for energy-assisted recording whereby strain effected by surface acoustic waves is applied to a continuous magnetostrictive recording medium to temporarily lower its coercivity during writing. In the proof-of-principle experiments presented here, the full recording medium is strained by the acoustic wave. For practical application, we additionally show that an individual bit in the medium can be selectively addressed, by focusing the surface acoustic waves - thus making it possible to conceive of an integrated acoustic transducer on a hard disk drive head that focuses strain at the location of writing.

2. Experiments and results

In a magnetostrictive material, the coercivity can be modulated by strain. This is known as the Villari effect [5–7]. The extent to which the coercivity changes with strain depends on the magnetostriction coefficient of the material as well as its crystalline texture. Since a large magnetostriction coefficient is requisite for a strong Villari effect, we choose galfenol, an alloy of Fe and Ga with a high magnetostriction of up to 400 ppm [8], in our experiments.

A 57 nm thick galfenol thin film was sputtered on a ST, X cut quartz substrate with 200 W dc power and an Ar pressure of 2.4 mTorr. The in-plane magnetic hysteresis loop was measured in a vibrating sample magnetometer under varying strain conditions [9]. The dependence of the coercivity on strain, as determined

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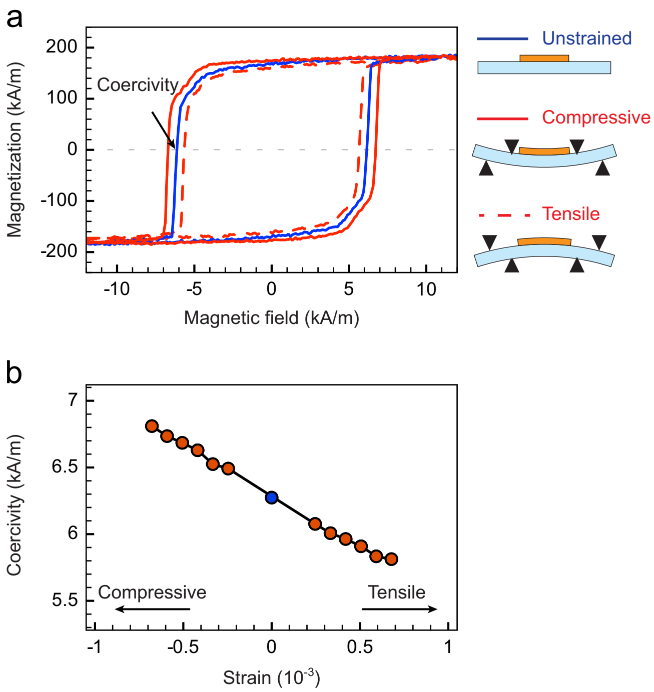

Fig. 1. Strain-modulated coercivity. (a) In plane hysteresis loops for strained and unstrained galfenol films. The strain is perpendicular to the applied field. (b) Dependence of coercivity on the applied strain.

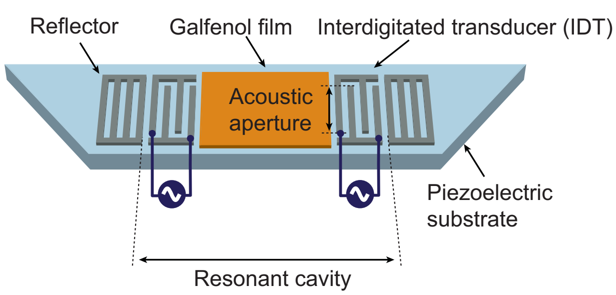

Fig. 2. Schematic of the experimental device. When the IDTs are driven at ~158 MHz, a standing surface acoustic wave with a node-to-node spacing of 10 μm is excited in the resonant cavity, straining the galfenol film. Each interdigitated transducer (IDT) has 574 electrodes and an acoustic aperture of 3 mm.

from these loops, is plotted in Fig. 1b. The coercivity of the unstrained film is 6.3 kA/m. It is seen that the magnetization of the galfenol film under tensile strain can be reversed with a field lower than the coercivity of the unstrained film. This result supports the plausibility of using acoustic strain (i.e., strain induced by surface acoustic waves) to reduce the coercivity for achieving writeability in recording media.

To prove this premise, we demonstrate magnetization reversal in the galfenol film with the assistance of acoustic strain. A schematic of the experimental device is shown in Fig. 2. It consists of interdigitated transducers (IDTs) patterned on a piezoelectric quartz substrate, for generating surface acoustic waves. Reflectors are fabricated adjacent to the IDTs to realize a resonant cavity for the waves. (Complete design details for the transducers and reflectors may be found in Ref. [10].) A 57 nm thick galfenol film is sputtered in the cavity under the same conditions as mentioned above. The coercivity is measured to be 6.7 kA/m. When the transducers are driven synchronously with an ac voltage, a standing acoustic wave, amplified by the quality factor of the cavity, is created in the galfenol film.

Magnetization reversal assisted by the acoustic wave is shown in the Kerr microscope images of Fig. 3. Prior to the experiment, the galfenol film is saturated by a magnetic field to the right. Then a field of 5.8 kA/m, which is lower than the 6.7 kA/m coercivity of the unstrained galfenol film, is applied in the opposite direction. Otherwise unaffected by the reversing field (Fig. 3a), the magnetization is switched when a surface acoustic wave with power density of 1.33 W/mm is applied (Fig. 3b). (Acoustic power density is defined as the power applied to the IDT divided by the width of the acoustic aperture.) As evidenced by the transitions to the right and left, only the magnetization in the path of the acoustic wave is reversed.

Next, acoustically assisted magnetic recording (AAMR) in the galfenol film is demonstrated using a contact recording tester [11]. In a write-wide read-narrow scheme, data tracks are recorded in the galfenol film with a floppy-disk head, which writes in a direction perpendicular to the wave propagation. A magnetoresistive hard disk drive head is used for high-resolution readback. The device is mounted on a two-axis micropositioner to translate the recording medium relative to the write and read heads (see Fig. 4).

Fig. 5 shows six data tracks written with the assistance of acoustic waves in the galfenol film. For each track, the applied acoustic power (or equivalently, the induced acoustic strain) is set

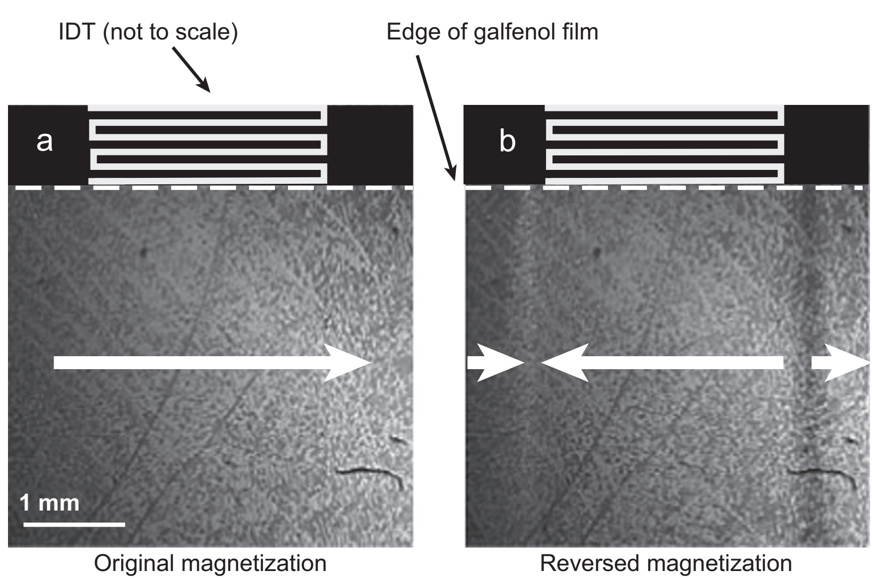

Fig. 3. Acoustically assisted magnetization reversal in a galfenol thin film. Kerr images of (a) saturated magnetization (in the direction of the white arrow), and (b) reversed magnetization in the acoustic path. A yttrium–iron–garnet film is overlaid on the galfenol to enhance the magnetic contrast in the Kerr images.

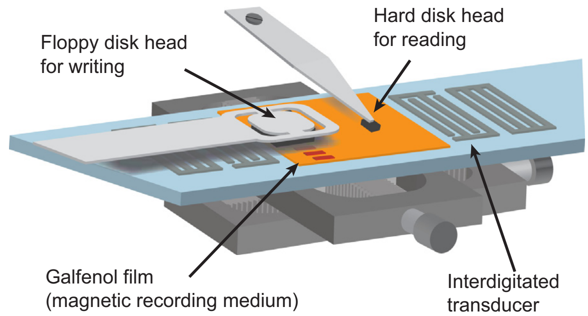

Fig. 4. Schematic of the contact recording tester. A floppy disk head is used to write data on the galfenol film. Data are read back by a magnetoresistive hard disk drive head.

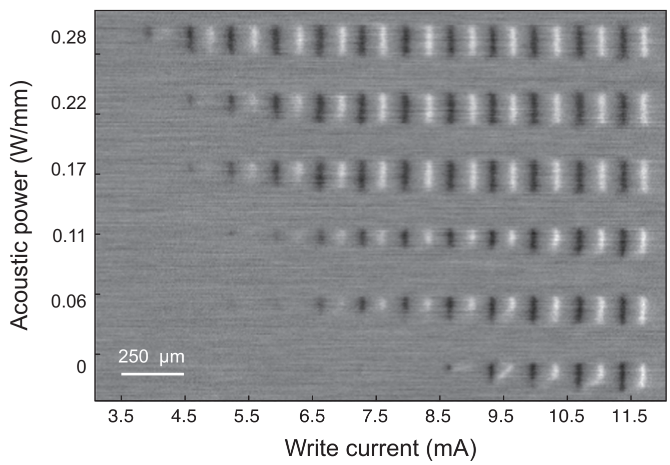

Fig. 5. Data tracks recorded at different acoustic powers. Increasing the acoustic power enables the data to be recorded with a lower write current.

at a different level. The write field varies within each track i.e., as the write head steps from left to right, the amplitude of the alternating write current and thereby the write field is gradually increased. When this field exceeds the coercivity of the film under the given acoustic strain, transitions begin to be recorded. As expected, with higher acoustic power, the film coercivity is lowered further – allowing transitions to be written with progressively smaller write fields.

For practical application of AAMR, strain should be induced only in a selected bit of the recording medium so that data can be recorded locally. This capability may be achieved by using an IDT with curved electrodes, as illustrated in Fig. 6a. Details of the design and fabrication of this transducer can be found in Ref. [10]. Unlike the IDT shown in Fig. 2, which generates a broad beam of acoustic waves, the curved IDT is able to focus the acoustic strain to one spot. The curvature of the electrodes is particularly designed to match the anisotropy in the power flow and wave velocity of the quartz substrate [12] so that the acoustic wave converges tightly at the focal point. Fig. 6b shows the amplitude of the converging acoustic wave measured using laser interferometry [13]. The in-plane strain is calculated from the measured surface vibration using known elastic properties of quartz. As can be seen, the strain produced by the acoustic wave has a distinct maximum at the focal point.

Spatial addressing using the focused waves is shown in Fig. 6c. The curved IDT is driven at a power of 1 W, generating a large acoustic strain at the focus in a previously saturated galfenol film. This strain lowers the local coercivity sufficiently in that its magnetization is switched when a reversing field of only 4.2 kA/m is applied. Note that the unstrained film coercivity is 6.7 kA/m. This reversed magnetization is imaged as an isolated dot under the Kerr microscope. The dot size is about 3 μm.

3. Conclusion

In summary, we have demonstrated acoustically assisted magnetic recording, a novel technique for information storage, which

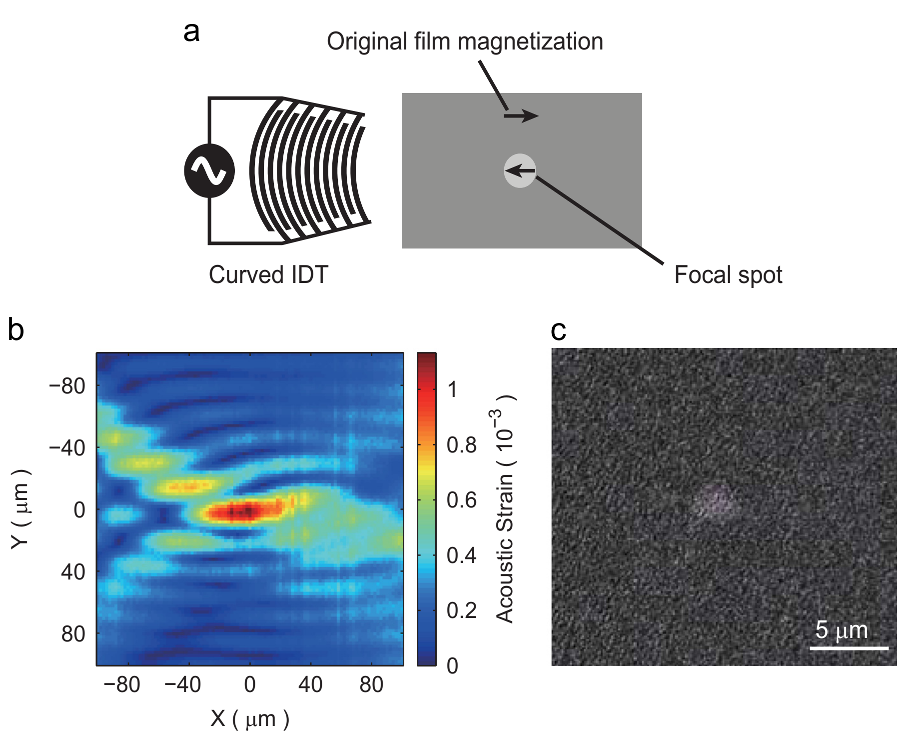

Fig. 6. Spatial addressing for practical application of AAMR. (a) Schematic of a curved transducer for focusing the acoustic waves. (b) Amplitude of the focused acoustic strain measured by laser interferometry. (c) Kerr image of a bit recorded at the focus.

exploits the Villari effect in magnetostrictive materials. We have shown that acoustic waves can temporarily lower the coercivity of a magnetic film to enable writing. Further, the strain can be localized by focusing the waves. For application in a hard disk drive, a focused acoustic wave transducer may be integrated with the recording head to lower the medium coercivity locally at the time of writing. Such a transducer will likely be less complex and simple to integrate with the recording head than transducers being designed for HAMR or MAMR technologies.

In these proof-of-concept demonstrations, highly magnetostrictive galfenol was used as the recording medium for experimental convenience. Due to its low coercivity, galfenol is however unfit for application in hard disk drives. Fortunately, high coercivity materials such as FePd, FePt and SmCo being considered for next-generation recording media also exhibit strong magnetostriction [14,15] and may be suited for AAMR. We presently investigate the potential of these candidate materials for use in AAMR.

Acknowledgments

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