Vol 18 No 12, December 2009
1674-1056/2009/18(12)/5370-05

Chinese Physics B

© 2009 Chin. Phys. Soc.
and IOP Publishing Ltd

Below-diffraction-limited hybrid recording using silicon thin film super-resolution structure*

Jiao Xin-Bing(焦新兵), Wei Jing-Song(魏劲松)†, and Gan Fu-Xi(干福熹)

Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, *China*

(Received 19 March 2009; revised manuscript received 24 April 2009)

We report on new experimental results for below-diffraction-limited hybrid recording. In our experiments, by means of focused laser assisted magnetic recording, the magnetic domains within TbFeCo thin films are obtained under an external perpendicular direct magnetic field. For a single magnetic medium, the domain size is mainly determined by the focused spot, which is about 620 nm for the laser wavelength $\lambda = 406$ nm, and a numerical aperture of the lens of 0.80. However, when a silicon thin film structure is inserted between the substrate and the magnetic medium, the recording domains can be reduced obviously. By optimizing the experimental condition, even the size can be reduced to about 100 nm, which is below the diffraction limit, i.e. about 1/6 of the spot size. This is very useful for improving the hybrid recording density in practical applications.

Keywords: hybrid recording, super-resolution, magnetic recording

PACC: 4280T, 7550S, 4230H

A continuing increase in area density is pushing the magnetic recording to higher levels. The superparamagnetic limit has been regarded as a potential barrier to further improve the area density. This is because the thermal stability for magnetic recording within a thin medium is exponentially dependent on the quantity K_uV/k_BT (where K_u is the grain anisotropy, V the grain volume, k_B the Boltzmann constant and T the temperature).[1,2] For a constant medium signal-to-noise ratio, i.e. a constant number of grains per magnetic recording bit, the implication is that for smaller bits the volume will decrease for a given bit aspect ratio. The exponential nature of the expression leads the decay time to vary by orders of magnitude for a small change in grain volume.[3,4] The required decrease in volume for very high recording density will be counteracted by difficulties in increasing the anisotropy to prevent the information from becoming thermally unstable and decaying away. Since the grain anisotropy is related to the macroscopically measured coercivity and an increase in coercivity is required, i.e. to adopt a medium with high K_u, the high H_c is an approach to improving the thermal stability of the recording magnetic domains.

However, the need for a coercivity increase is unfortunate as the recording medium must be kept writable, indicating that the coercivity of the medium has an upper limit. This implies that the superparamagnetic limit is actually a writing head problem, i.e. a very strong magnetic field is necessary to write on a high coercive medium. Hybrid recording, also called thermally assisted magnetic recording (or heat assisted magnetic recording (HAMR)) gives a way to avoid the problem.[5] Hybrid recording makes use of the temperature dependences of the K_u and the H_c of a recording medium. In the hybrid recording scheme, writing is carried out at an elevated temperature (usually near the medium's Curie temperature T_c) where the H_c reduces into the range of the head writing field, data are archived at room temperature where H_c is kept high to ensure sufficient thermal stability and a high sensitive magnetic flux detector (such as a giant magnetoresistive head (GMR) or a tunneling magnetoresistive head (TMR)) is utilized for data readout.[6] The local heating of the medium is commonly realized through a focused laser spot.[7] A heated area as small as a data bit produces a coercivity less than the field of the recording magnetic head. To obtain such a small heated area, it is necessary to generate a small spot beyond the diffraction limit. There are several methods to reduce the heating spot, such as a near-field optical head,[8] and the thin film super-resolution

*Project supported by the National Natural Science Foundation of China (Grant Nos 50772120 and 60490290), Funds of the Chinese Academy of Sciences for Key Topics in Innovation Engineering (Grant No KJCXZYW.NANO.06), and the National Basic Research Program of China (Grant No 2007CB935400).

†Corresponding author. E-mail: weijingsong@siom.ac.cn

technique.[9−13] In the present work, we utilize a silicon thin film structure to effectively reduce the heated area for this purpose. Magnetic domains with a size of about 100 nm are recorded on a TbFeCo medium. The detailed experimental results and analyses are as follows.

In our experiments, two kinds of sample structures are prepared; one is the "Glass/TbFeCo(50 nm)/SiN(10 nm)" structure, the other is the silicon thin film super-resolution structure "Glass/SiN(10 nm)/Si(30 nm)/SiN(10 nm)/TbFeCo (50 nm)/SiN(10 nm)" (shown in Fig.1), where the SiN and the TbFeCo with perpendicular anisotropy are used as a protective layer and magnetic recording layer, respectively. Si, called the super-resolution thin film layer, is used to reduce the heating spot. The SiN and TbFeCo films are prepared by radio frequency and direct current (DC) magnetron sputtering, respectively. The Si thin film is also deposited by DC magnetron sputtering. In the process of sputtering, the substrate negative DC bias voltage is kept at about 100 V. The base pressure is below 5×10^{-5} Pa and the sputtering pressure is 0.8 Pa. The magnetic medium target composition is $Tb_{19}Fe_{69}Co_{12}$ in atomic concentration. The distance between the target and glass substrate is 80 mm.

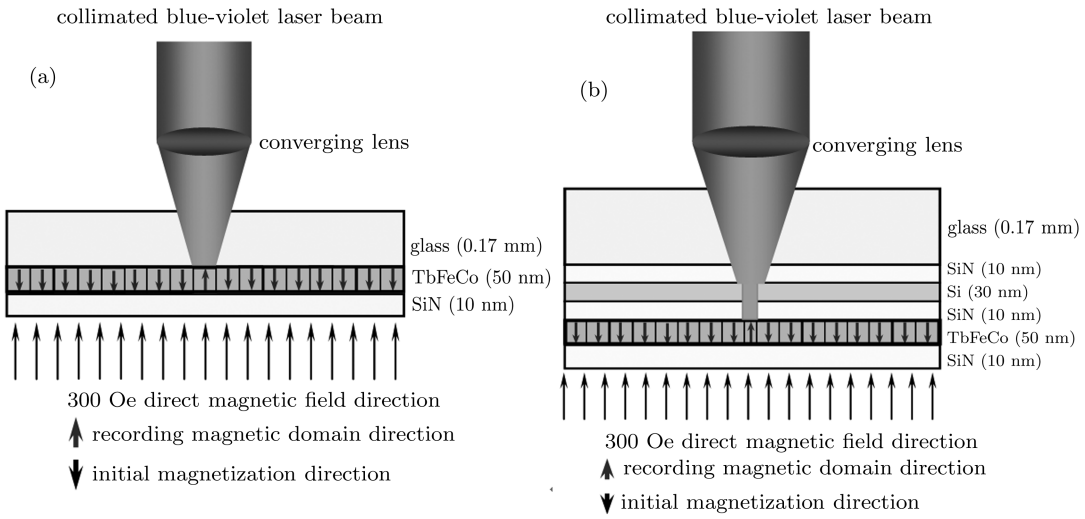


Fig.1. Schematic diagram of the sample structures: (a) Glass/TbFeCo(50 nm)/SiN(10 nm), (b) Glass/SiN(10 nm)/Si(30 nm)/SiN(10 nm)/TbFeCo(50 nm)/SiN(10 nm) (1 Oe = 1 Gb/cm).

Magnetic properties are obtained by vibrating sample magnetometry (VSM) and magneto-optical Kerr rotation measurement. The experimental results are presented in Fig.2. Figure 2(a) gives the VSM results of TbFeCo thin film at room temperature; it can be found that the coercivity in the perpendicular direction is about 5000 Oe and the saturation magnetization is 185 emu/cm^3. The coercivity as a function of temperature can be obtained from magnetic-optical Kerr rotation measurement since TbFeCo is a typical magnetic-optical recording medium. Figure 2(b) presents the magnetic-optical Kerr rotation signal at room temperature; it can be seen that in the perpendicular direction the coercivity is about 5000 Oe, which is basically consistent with the VSM experimental results. Here it should be noted that some large and periodic noise in a frequency range of about 50–60 Hz is observed in the experiment, resulting mainly from the power interference of the measurement setup. Figure 2(c) shows the dependence of coercivity on temperature. One can find that the coercivity decreases with increasing temperature and reduces to zero at about 485 K, i.e. the Curie temperature of TbFeCo film in our experiment is measured to be 485 K, and the coercivity in the perpendicular direction is obtained to be about 300 Oe at 480 K.

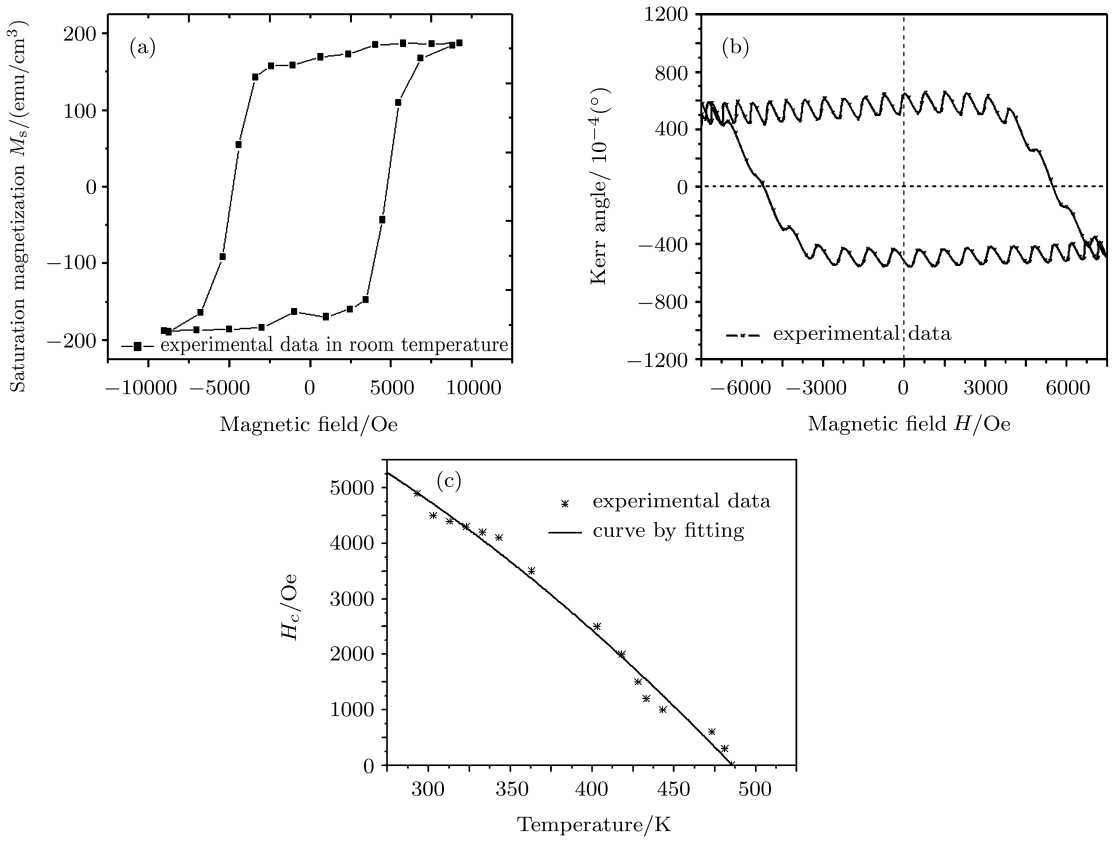


Fig.2. Magnetic properties of the TbFeCo thin films: (a) magnetic properties measured by vibrating sample magnetometry (VSM); (b) the magneto-optical Kerr rotation measurement and (c) the dependence of coercivity on temperature.

The laser assisted magnetic recording is conducted in a home-made static tester, where a Kr^+ laser device with wavelength λ of 406 nm is used as a heating source. In the tester, the laser is firstly modulated into pulsed light by an acousto-optic modulator, and then focused by a lens with a numerical aperture (NA) of 0.80. The final focused spot becomes elliptical due to the acousto-optic modulator. The external direct magnetic field in the perpendicular direction is kept at about 300 Oe (shown in Fig.1). In the process of hybrid recording, the sample is first magnetized under an external strong magnetic field of over 5000 Oe, and then the laser beam is focused on the sample to heat the TbFeCo above 480 K, causing the coercivity of TbFeCo thin film to reduce to below 300 Oe, and then the magnetic domain is reversed quickly under the external direct magnetic field and realizes the information recording. For our experiment, the area of the external magnetic field is far larger than the heating spot, so the recording magnetic domain size is mainly determined by the heating spot. In the recording experimental setup, the heating spot size ($d = 1.22\lambda$/NA) is about 620 nm for laser wavelength $\lambda = 406$ nm and a numerical aperture of the lens of 0.80, that is to say, the recording magnetic domain size should be 620 nm approximately in the single TbFeCo thin film. By using the sample structure shown in Fig.1(a), with laser power $P \approx$2.0 mW, and pulse width $\tau = 60$ ns, the recording domains observed by magnetic force microscopy (MFM) are presented in Fig.3, where figure 3(a) gives the results obtained under the experimental conditions of recording power $P \approx 2.0$ mW and laser pulse width $\tau = 60$ ns. One can find that the domain size is about 630 nm, which is almost the focused spot size. In order to further understand the influence of experimental conditions on the magnetic domains, figure 3(b) presents the domains recorded at laser power $P \approx 1.42$ mW and different laser pulse widths. One can find from area 1 of Fig.3(b) that the domain size is about 800 nm

for $\tau = 100$ ns. The domain size is larger than the spot, which may be due to the thermal diffusion in the process of recording. The domain size can be reduced into about 650 nm for $\tau = 80$ ns (as shown in area 2 of Fig.3(b)), which is almost the domain size in Fig.3(a). A comparison between results of area 2 and area 1 in Fig.3(b) seems to show that the domain size can be reduced by shortening the laser pulse width. In order to verify this point, we continue to reduce the pulse width to $\tau \approx 55$ ns, and the results are shown in area 3 of Fig.3(b). It can be found that the magnetic domain size can be reduced to about 550 nm, but the domain image is very unclear due to the weak magnetic signal, which indicates that the domain size is mainly determined by the spot, and is influenced by the heat diffusion as well.

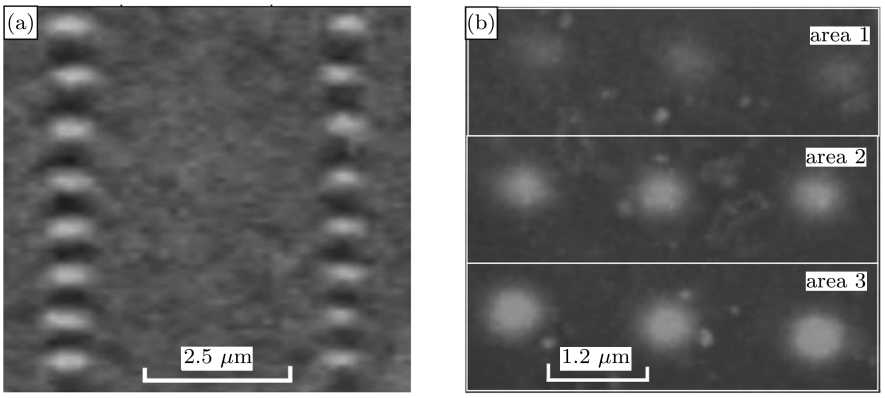


Fig.3. Laser assisted hybrid recording domains in the "Glass/TbFeCo(50 nm)/SiN(10 nm)" sample (laser wavelength $\lambda = 406$ nm, numerical aperture of the converging lens NA = 0.80). (a) $P \approx 2.0$ mW, and $\tau = 60$ ns (b) $P \approx 1.42$ mW. Area 1: $\tau = 100$ ns; area 2: $\tau = 80$ ns; area 3: $\tau \approx 55$ ns.

In order to reduce the heating spot size, the sample structure shown in Fig.1(b) is used, where the Si thin film structure is inserted between the glass substrate and TbFeCo magnetic medium. The detailed experimental conditions and results are shown in Fig.4. Figure 4(a) shows the recording magnetic domains with a size of about 320 nm under the laser power $P \approx 2.2$ mW and laser pulse width $\tau = 60$ ns. In order to reduce the domain size, the laser power reduces to 1.42 mW and the laser pulse width is kept at 60 ns, and the corresponding magnetic domains are shown in Fig.4(b). One can find that the domain size is about 120 nm, which is obviously lower than the focused spot, i.e. below-diffraction-limited hybrid recording domains are realized. In addition,

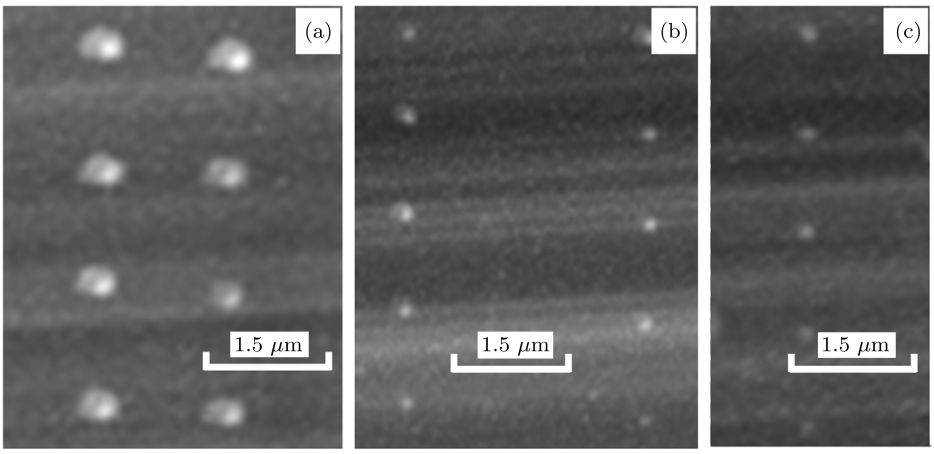


Fig.4. Laser assisted hybrid recording domains in the "Glass/SiN(10 nm)/Si(30 nm)/SiN(10 nm)/TbFeCo(50 nm) /SiN(10 nm)" samples with laser wavelength $\lambda = 406$ nm and the numerical aperture of the converging lens NA = 0.80, (a) $P \approx 2.2$ mW and $\tau = 60$ ns, (b) $P \approx 1.42$ mW and $\tau = 60$ ns, (c) $P \approx 1.42$ mW and $\tau = 55$ ns.

we find that the magnetic domain can be further reduced by shortening the laser pulse width. Figure 4(c) shows the experimental results for the laser power $P \approx 1.42$ mW and pulse width $\tau = 55$ ns; it can be seen that the magnetic domain size is about 100 nm, which may be due to the fact that the shorter pulse width reduces the thermal diffusion effect. It should be noted that the experimental conditions for Fig.4(c) are the same as those for area 3 in Fig.3(b), but the magnetic domain size for the Si thin film super-resolution structure (shown in Fig.4(c)) is only about 1/6 of that in the single magnetic recording medium (as shown in area 3 of Fig.3(b)).

The dependence of mark size on the recording laser power for the Si thin film super-resolution structure is shown in Fig.5 for a fixed pulse width $\tau = 60$ ns. It can be seen that there is no recording mark formation for laser power $P < 1.4$ mW. However, the mark can be produced and the size increases with increasing recording laser power for $P > 1.42$ mW and the minimum mark with a size of about 120 nm is recorded at 1.42 mW. The mark size versus power plot shows a non-monotonic curve as shown in conventional super-resolution experiments for the optical recording media, which may be due to the nonlinear effect of Si thin film under laser beam irradiation. For the experiment, the Gaussian laser beam is focused on the Si thin film and results in the formation of a super-resolution heating spot due to the nonlinear optical effect of Si thin film.[14] The small heating spot leads to small recording magnetic domains and the realization of high density information storage. However, the detailed super-resolution physical mechanism is still unclear so far, and will be further investigated in the future.

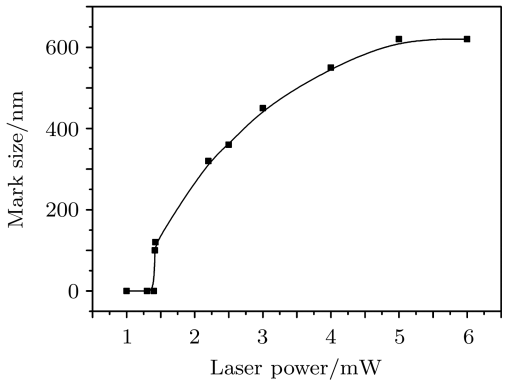


Fig.5. The dependence of mark size on the recording laser power for laser pulse width $\tau = 60$ ns and the sample structure "Glass/SiN(10 nm) /Si(30 nm)/SiN(10 nm)/TbFeCo(50 nm)/SiN(10 nm)".

In summary, laser assisted hybrid recording is realized under an external perpendicular direct magnetic field. The recording domain size can be reduced to the below-diffraction-limited size by using the Si thin film super-resolution structure. In our experiment, the smallest magnetic domains obtained have a size of about 100 nm, which is about 1/6 of the focused spot size.

References

[1] Williams M L and Comstock R L 1972 *A. I. P. Conf. Proc.* **5** 738
[2] Yin J, Takao S and Pan L 2008 *Chin. Phys.* B **17** 3907
[3] Cumpson S R, Hidding P and Coehoorn R 2000 *IEEE Trans. Magn.* **36** 2271
[4] Charap S H, Lu P L and He Y 1997 *IEEE Trans. Magn.* **33** 978
[5] Saga H, Nemoto H, Sukeda H and Takahashi M 1999 *Jpn. J. Appl. Phys.* **38** 1839
[6] Li Z, Cheng X, Jin F, Li Z, Lin G and Yang X 2005 *Proc. SPIE* **5643** 194204
[7] Katayama H, Sawamura S, Ogimoto Y, Nakajima J, Kojima K and Ohta K 1999 *J. Magn. Soc. Jpn.* **23** 233
[8] Nishida T, Matsumoto T, Akagi F, Hieda H, Kikitsu A, Naito K, Koda T, Nishida N, Hatano H and Hirata M 2007 *J. Nanophotonics* **1** 011597
[9] Tominaga J, Nakano T and Atoda N 1998 *Appl. Phys. Lett.* **73** 2078
[10] Tsai D P and Lin W C 2000 *Appl. Phys. Lett.* **77** 1413
[11] Wei J, Xiao M and Zhang F 2006 *Appl. Phys. Lett.* **89** 223126
[12] Wei J and Xiao M 2008 *Appl. Phys.* B **91** 337
[13] Wei J, Ruan H, Shi H and Gan F 2002 *Chin. Phys.* **11** 1073
[14] Choi Y, Park J, Kim M R and Jhe W 2001 *Appl. Phys. Lett.* **78** 856