Method for hybrid recording with single layer CoTbAg medium

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This work presents a hybrid-recording disk with a single layer CoTbAg recording medium. $Co_{69.48-x}Tb_{30.52}Ag_x$ films with $x=0-25.68$ at. % are fabricated on glass and naturally oxidized silicon wafer substrate by dc magnetron sputtering. The effects of Ag content on the magnetic properties and the microstructure of the film are investigated. The transmission electron microscope diffraction pattern indicates that all the films are amorphous. The saturation magnetization of the $Co_{67.23}Tb_{30.52}Ag_{2.25}$ film is about 310 emu/cm^3; perpendicular remanence is about 255 emu/cm^3, and the perpendicular coercivity is about 3100 Oe at room temperature. The saturation magnetization and perpendicular coercivity decrease rapidly as temperature increases from room temperature to 200 °C. The compensation temperature T_{comp} of this film is about 225 °C. This film is a promising candidate for hybrid recording media applications.
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I. INTRODUCTION

The hybrid recording method with perpendicular thermo-magnetic writing and magnetic flux reading was recently proposed to increase the recording density of the magnetic disk.[1,2] This method enables perpendicular magnetic domains to be formed in an amorphous film medium and utilizes a high-sensitivity magnetic flux detector [for example, a giant magnetoresistive (GMR) head or a tunneling magnetoresistive (TMR) head]. The formation of smaller recording domains is the key issue to this method if the recording density wants to increase further.

Using near-field optics, the solid immersion lens (SIL) has been used to shrink the laser spot size to reduce the domain size.[3] However, such near-field recording requires the distance between the SIL and the surface of the disk to be less than the light wavelength λ. Contact between the optical lens and the surface of the disk during recording cannot be avoided. The SIL becomes failed as it contacts with the lubricant on the magnetic disk surface.

Guerra *et al.* proposed a near-field optical data storage disk, the integral near field optics (INFO) disk.[4,5] The SIL cylinder is made circular on the PC substrate of a digital versatile disk (DVD) as the recording track. The track density of this disk can exceed that of a conventional DVD.[4] The numerical aperture (NA) depends on the refractive index of the SIL cylinder.

Figure 1 shows the proposed design called the ''near-field hybrid recording without low-flying optical head,'' which combines the advantages of an INFO disk and hybrid recording: the SIL cylinder is made on the substrate of the recording disk to avoid contact between the optical lens and the magnetic disk surface. And the magnetic recording layer can be closer to the magnetic writer/reader. The SIL cylinder in Fig. 1 is $ZnS:SiO_2$, its effective NA is about 1.1. The recording medium is single layer CoTbAg film.

This design replaces the currently used doubly layered medium[6,7] by a single layer recording medium. A single layered recording medium for hybrid recording must satisfy two requirements: it must provide satisfactory magneto-optical (MO) writing performance and large saturation magnetization M_s that generates sufficient magnetic flux for GMR or TMR head readout. The M_s value of the traditional MO medium is very small near room temperature.[8,9] In a previous study, we have shown that the perpendicular coercivity of the amorphous CoTb film is very high at room temperature but its M_s value is small.[10] This study shows that the single layer $Co_{69.48-x}Tb_{30.52}Ag_x$ film with a little Ag content is suitable for hybrid recording media applications. The effects of Ag content on the structure and magnetic properties of $Co_{69.48-x}Tb_{30.52}Ag_x$ films are also investigated.

II. EXPERIMENT

$Co_{69.48-x}Tb_{30.52}Ag_x$ films (where $x=0-25.68$ at. %) were deposited on glass and natural-oxidized Si(100) wafer substrates by dc magnetron sputtering at room temperature.

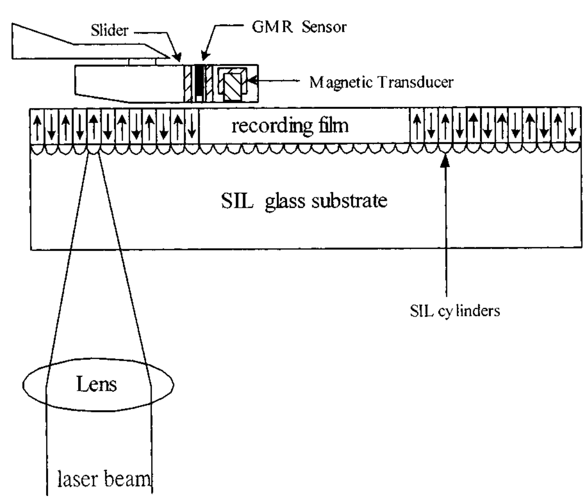

FIG. 1. Configuration of the disk tester.

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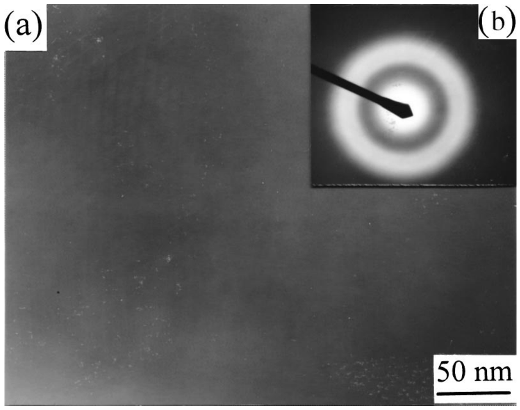

FIG. 2. (a) TEM bright field image and (b) electron diffraction pattern of the $Co_{43.8}Tb_{30.52}Ag_{25.68}$ film.

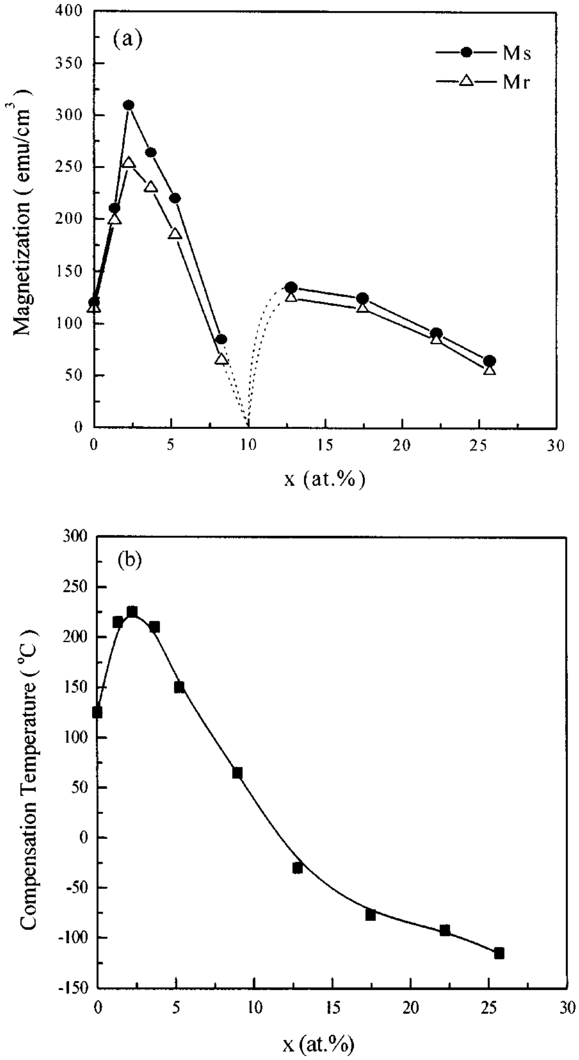

FIG. 4. (a) Variations of M_s and M_r with Ag content of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film and (b) relationship between T_{comp} and Ag content of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film.

The target was a Co disk overlaid with Tb and Ag pieces, to yield the desired film composition. The magnetic film was sandwiched between SiN_x protective layers to prevent oxidation. The SiN_x protective layer was prepared by rf magnetron sputtering of the Si_3N_4 target. The thickness of the magnetic layer and the protective layer was 75 and 30 nm, respectively.

The structure of the film was examined by transmission electron microscope (TEM). The composition of the film was determined by energy disperse spectroscopy. The depth profiles of the elements in the film were analyzed by Auger electron spectroscopy (AES). The film thickness was measured by atomic force microscopy and α-step. The magnetic properties of the films were measured by a vibrating sample magnetometer with a maximum applied field of 13 kOe.

III. RESULTS AND DISCUSSION

The CoTbAg films were examined by TEM to understand the effect of Ag content on the structure of the amorphous CoTb film. It was found that all the $Co_{69.48-x}Tb_{30.52}Ag_x$ films ($x = 0-25.68$ at. %) were amorphous. Figure 2(a) shows a TEM bright field image of the $Co_{43.8}Tb_{30.52}Ag_{25.68}$ film and Fig. 2(b) is the electron selected area diffraction (SAD) pattern of Fig. 2(a). Figure 2(a) shows no crystal grains and the shape of the SAD pattern is a broad halo, implying that the film is amorphous.

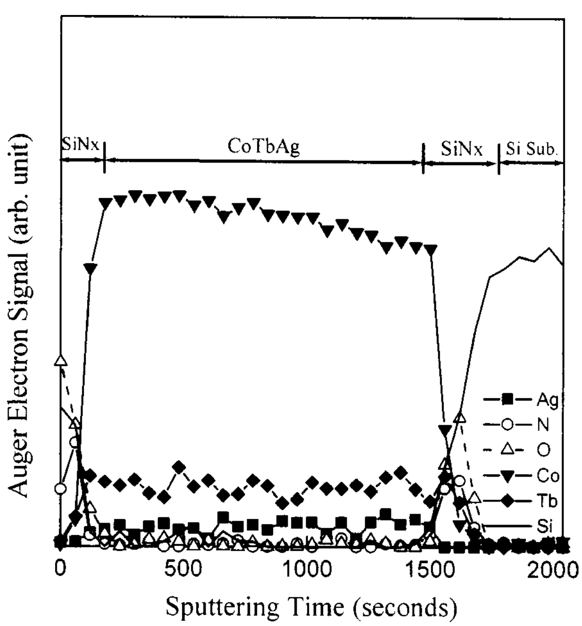

FIG. 3. AES depth profiles of the elements in the $Co_{67.23}Tb_{30.52}Ag_{2.25}$ film.

Figure 3 shows the depth profiles of elements in the $Co_{67.23}Tb_{30.52}Ag_{2.25}$ film. It can be seen that a 30 nm thick SiNx protective layer effectively prevents the oxidization of the magnetic film. Some oxygen is present in the SiNx protective layers and in the surface of the naturally oxidized Si substrate but not in the magnetic layer.

Figure 4(a) shows the variations of saturation magnetization (M_s) and perpendicular remanence (M_r) with Ag content of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film at room temperature. It reveals that the M_s and M_r values of the $Co_{69.48}Tb_{30.52}$ film (x=0 at. %) are about 125 and 115 emu/cm^3, respectively. The variation of the squareness (M_r/M_s) with Ag content is very small and the squareness is higher than 0.8 for all the films. M_s and M_r increase rapidly with Ag content as x

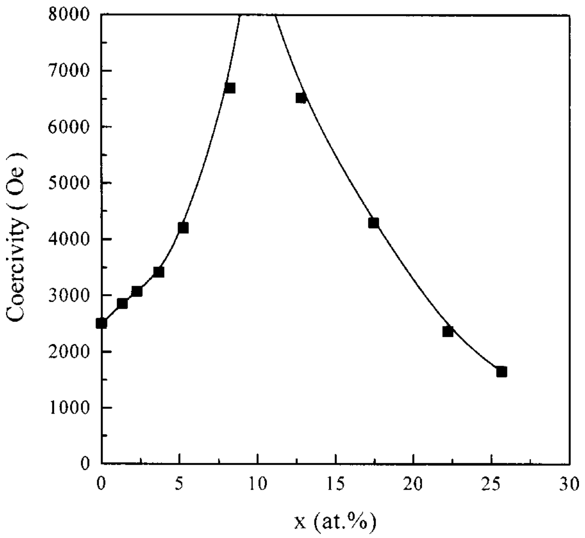

FIG. 5. Variation of H_c with Ag content of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film.

<2.25 at. % and then decrease rapidly with increasing Ag content as $x>2.25$ at. %. The maximum M_s and M_r values occur at $x\sim2.25$ at. %: they are about 310 and 255 emu/cm^3, respectively. In the $Co_{69.48-x}Tb_{30.52}Ag_x$ alloy system, Ag is a nonmagnetic element. The saturation magnetizations of Co/Pd[11,12] and Fe/Ag[13] multilayers have been shown to exceed those of pure Co and Fe films, respectively, because of the spin polarization of nonmagnetic layers. However, the spin polarization of the Ag element is not enough to enhance the M_s value from 125 to 310 emu/cm^3 after addition of 2.25 at. % Ag to CoTb. The variation of M_s value with Ag content follows not only from the spin polarization of Ag atoms but also from the shift of compensation temperature T_{comp}. T_{comp} of the rare earth–transition metal (RE–TM) alloy is very sensitive to the composition of the alloy.[14] Figure 4(b) shows the relationship between T_{comp} and Ag content of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film. The relationship between T_{comp} and Ag content is not linear. T_{comp} increases with Ag content as x increases to 2.25 at. % but decreases as Ag content is increased further. T_{comp} of the $Co_{69.48}Tb_{30.52}$ film ($x=0$ at. %) is about 125 °C, and increases to 225 °C as Ag content is increased to 2.25 at. %. T_{comp} then decreases as Ag content increases, as shown in Fig. 4(b).

Figure 5 shows the variation of perpendicular coercivity Hc with Ag content of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film at room temperature. The H_c value increases from about 2500 to 7200 Oe as Ag content increases from 0 to 8.26 at. %, and H_c decreases rapidly with increasing Ag content when $x>10$ at. %. At room temperature, M_s is zero and H_c is infinite at the compensation composition. Figure 4(b) shows that the compensation composition of the $Co_{69.48-x}Tb_{30.52}Ag_x$ film is $x\sim10$ at. %. Consequently, the $Co_{69.48-x}Tb_{30.52}Ag_x$ alloy is transformed from RE rich to TM rich at $x\sim10$ at. % at room temperature. In the TM-rich region ($x>10$ at. %), H_c decreases as T_{comp} is decreased. In the RE-rich region ($x<10$ at. %), M_s increases, but H_c decreases as T_{comp} is increased. However, in Figs. 4(a) and 5, both M_s and H_c increase with x when Ag content is less than 2.25 at. %. We conjecture the discrepancy between H_c and T_{comp} when

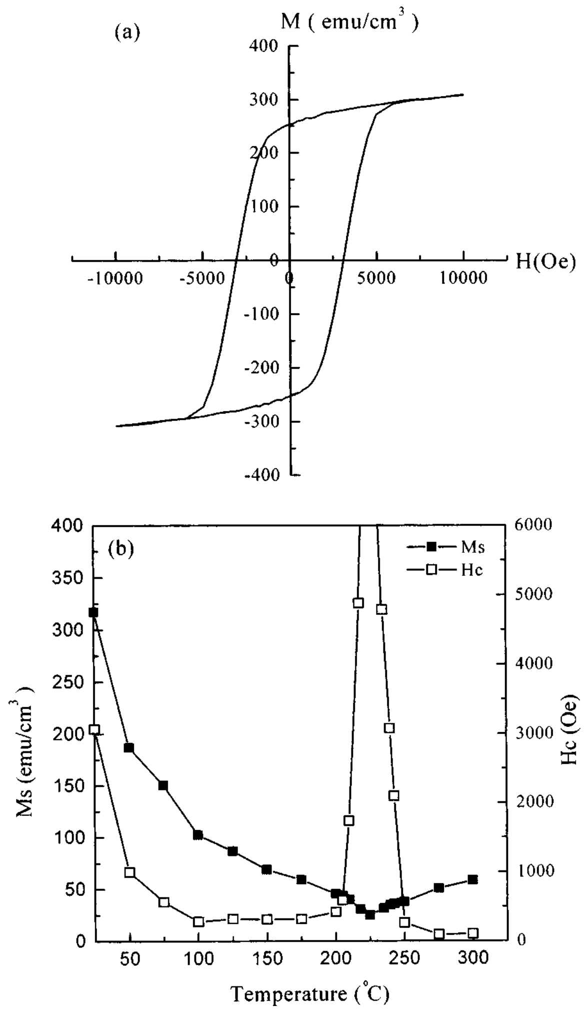

FIG. 6. (a) $M-H$ loop of the $Co_{67.23}Tb_{30.52}Ag_{2.25}$ film and (b) variations of M_s and H_c with temperature of the $Co_{67.23}Tb_{30.52}Ag_{2.25}$ film.

$x<2.25$ at. % is related to some Ag atoms are close forming clusters in the CoTbAg film. (From Fig. 3, it can be seen that the distribution of Ag in the CoTbAg film is not uniform.) These clusters are like defects that impede domain wall motion to reduce the domain wall energy, pinning the domain wall, and increasing the coercivity of the film.[15]

Figure 6(a) is the $M-H$ loop of the $Co_{67.23}Tb_{30.52}Ag_{2.25}$ film at room temperature, where the applied filed is perpendicular to the film plane. The saturation magnetization of this film is about 310 emu/cm^3; M_r is about 255 emu/cm^3, and the perpendicular coercivity is about 3100 Oe. Figure 6(b) shows the variations of M_s and H_c with temperature of this film, with a silicon substrate. M_s of the film decreases from 310 to about 25 emu/cm^3 as the temperature increases from 25 to 225 °C and M_s increases with temperature above 225 °C, indicating that the T_{comp} of this film is about 225 °C. Its H_c decreases from 3100 to about 300 Oe as the temperature increases from 25 to 100 °C, then remains at this low H_c as temperature is further increased to 200 °C. H_c increases rapidly with temperature from 200 to 225 °C and H_c decreases rapidly to about 250 Oe as temperature increases from 225 to 250 °C. This film can be a promising candidate for hybrid recording media.

ACKNOWLEDGMENTS

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[1] J. J. M. Ruigrok, R. Coehoorn, S. R. Cumpson, and H. W. Kesteren, J. Appl. Phys. **87**, 5398 (2000).
[2] H. Saga, H. Nemoto, H. Sukeda, and M. Takahashi, Jpn. J. Appl. Phys., Part 1 **38**, 1839 (1999).
[3] A. Chekanov, M. Birukawa, Y. Itoh, and T. Suzuki, IEEE Trans. Magn. **35**, 3100 (1999).
[4] J. Guerra, D. Vezenov, P. Sullivan, W. Haimberger, and L. Thulin, Jpn. J. Appl. Phys., Part 1 **41**, 1866 (2002).
[5] J. M. Guerra, U.S. Patent No. 5,910,940 (8 June, 1999).
[6] H. Nemoto, H. Saga, H. Sukeda, and M. Takahashi, Jpn. J. Appl. Phys., Part 1 **38**, 1841 (1999).
[7] C.-C. Lin, C.-H. Lai, B. M. Chen, and H.-P. D. Shieh, IEEE Trans. Magn. **37**, 1339 (2001).
[8] S. Takayama, T. Niihara, K. Kaneko, Y. Sugita, and M. Ojima, J. Appl. Phys. **61**, 2610 (1987).
[9] M. Takahashi, T. Niihara, and N. Ohta, J. Appl. Phys. **64**, 262 (1988).
[10] P. C. Kuo and C. M. Kuo, J. Appl. Phys. **84**, 3317 (1998).
[11] F. J. A. den Broeder, H. C. Donkersloot, H. J. G. Draaisma, and W. J. M. de Jonge, J. Appl. Phys. **61**, 4317 (1987).
[12] K. Miura, H. Kimura, S. Imanaga, and Y. Hayafuji, J. Appl. Phys. **72**, 4826 (1992).
[13] Y. B. Xu *et al.*, J. Appl. Phys. **75**, 6190 (1994).
[14] P. Hansen, S. Klahn, C. Clausen, G. Much, and K. Witter, J. Appl. Phys. **69**, 3194 (1991).
[15] *The Physical Principles of Magneto-optical Recording*, edited by M. Mansuripur (Cambridge University Press, Cambridge, 1995), p. 46.