Microstructure and Magnetic Properties of Sputtered Co_5Sm Films

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Abstract – Co_5Sm/Cr bilayer films were deposited on Si and glass slides by means of a Direct-Current (DC) magnetron sputtering system with substrate heating. Magnetic properties measurements show that the sample with glass substrate has a comparatively large coercivity (H_c = 2 141.2 Oe) with a relatively low optimal temperature (T_s = 350 ℃). X-ray diffraction patterns indicate that Cr presents a hexagonal-close-packed (hcp) texture on Si, while a body-centered-cubic (bcc) structure on glass substrate, which leads to Co_5Sm films having different lattice constants on Si and glass substrates. At their optimal temperature, the grain size of the sample on glass slide is smaller with its size distribution more uniform. Concurrently, the shape of magnetic domain is more regular and ordered. The value of magnetic switching volume (V^*) for the film on glass is 1.65×10^{-18} cm^3, smaller than that for films on Si. For the film on glass, the magnetization reversal mechanism is mainly influenced by magnetocrystalline anisotropy, the shape of the crystal grain and the stress in the film.

Key words – *magnetic recording media*; *magnetron sputtering*; *Co_5Sm*; *substrate*

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1 Introduction

The magnetic properties of bulk rare-earth transition metals with the $CaCu_5$ structure have been extensively studied since the 1970's. The most outstanding property exhibited by some of their alloy is large magnetocrystalline anisotropy (Ku). The CoSm alloys, especially Co_5Sm with anisotropy larger than 108 erg/cm^3, are expected to be one of the candidates for high-density recording media[1]. In the work of Velu et al.[2], Cr has often been selected as an underlayer for lattice matching of the hexagonal compound Sm-Co_5 on the Cr (110) layer[3]. Zana et al.[4] studied magnetic interactions and thermal stability in very thin films of CoSm fabricated by DC magnetron sputtering on glass substrates.

C. Prados et al. deposited SmCo/Cr films on Si substrates with substrate heating, and investigated the magnetic properties of the resulting films[5]. They found that high temperature treatments yielded better crystallization. Shigeto Takei et al. prepared SmCo/Cr film at substrate temperatures of 250 ℃ on glass, and studied the effects of substrate heating and the dependence of properties on the SmCo thickness[6]. Shan et al. reported systematic studies of the magnetic properties of SmCo/Cr films on glass substrate at room and low temperatures[7].

Here we report the effects of substrate heating and the dependence of the properties of CoSm/Cr films deposited on different(Si, glass) substrates.

2 Experimental details

CoSm/Cr bilayer films were deposited on Si (100) and 7101 glass slides by means of Direct-Current (DC) magnetron sputtering system with substrate heating. The base pressure was below 2×10^{-5} Pa, and Ar at a pressure of 2 Pa was used as the discharge gas. The Cr and alloyed Co_5Sm were obtained commercially. The Cr target was of 99.9% purity. The chemical composition of the CoSm films, determined by Energy Dispersive X-ray spectroscopy (EDX), was Co_5Sm. All of the samples had a structure with Co_5Sm (30 nm) on an underlayer of Cr (90 nm). The power for CoSm was 96 W and that for Cr was 90 W, respectively.

The structural properties were examined by X-ray Diffraction (XRD, D8advance). The magnetic properties were studied at room temperature using Vibrating Sample Magnetometer (VSM, Lake Shore 7310), with a maximum applied field of 2.8 kOe. The microstructure of the films was observed using Scanning Probe Microscope (SPM, Nanoscope IV).

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3 Results and discussion

Shown in Fig. 1(a) are room temperature easy-axis hysteresis loops of the Sm-Co/Cr films with Si substrate deposited at various substrate temperatures (T_s). At low temperature, as the temperature increased, the coercivity of the film increased. When T_s = 500 ℃, the film had a large coercivity (H_c) of 1 350. 3 Oe. If T_s was further increased, magnetic properties degraded. With the Sm-Co/Cr films on a glass substrate (shown in Fig. 1(b)), similar behavior was observed. However, the optimal value of T_s was T_s = 350 ℃ with H_c = 2 141. 2 Oe. From the above results, one can note that the sample with the glass substrate has a relatively low optimal temperature and a comparatively large H_c. The differences between films prepared on two substrates are presumably related to their microstructure.

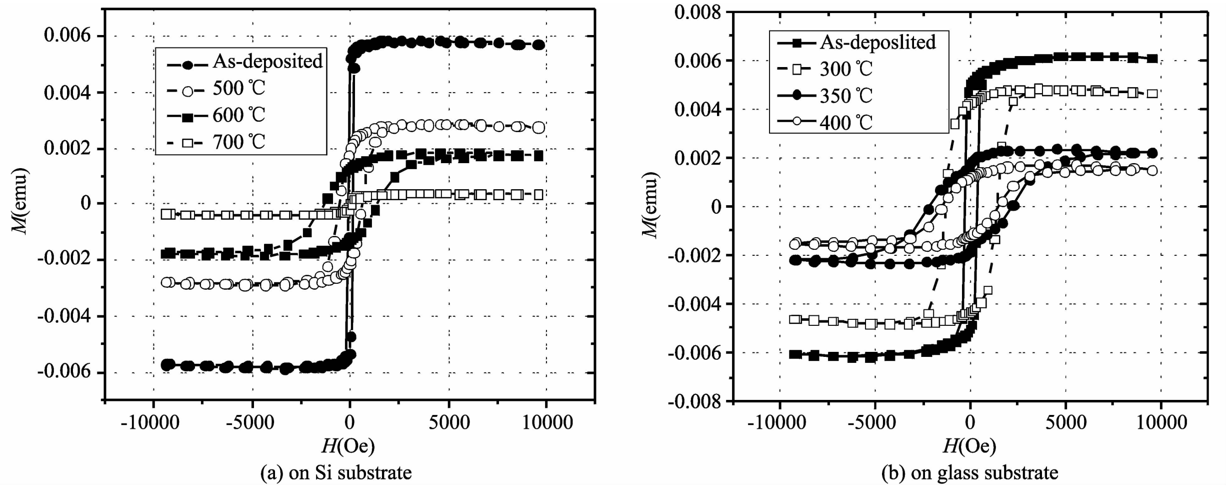


Fig. 1 Room perature easy-axis hysteresis loops of the CoSm/Cr films deposited at various substrate temperatures(T_s)

Fig. 2(a) shows the X-ray diffraction pattern for Co_5Sm/Cr films deposited on Si (100) at a substrate temperature 500 ℃. The texture of Cr layer is hexagonal-close-packed (hcp). The peaks corresponding to the diffraction from Co_5Sm (110), (002) and (201) planes were observed. Co_5Sm is hexagonal with c = 3. 991 Å, a = 4. 966 Å, and c/a = 0. 804. The XRD pattern of Co_5Sm/Cr films deposited on glass at T_s = 350 ℃ is shown in Fig. 2(b). In contrast to the results for the Si substrates, Cr layer has a body-centered-cubic (bcc) structure on glass substrate. Except for the Co_5Sm (201) peak, the other diffraction peaks for Co_5Sm are also different from those of Fig. 2(a). With the glass substrate, the Co_5Sm lattice constant ratio is c/a = 0. 800, very close to that for the sample on the Si substrate. However, the lattice constants for the sample on the glass substrate have increased, with c = 4. 039 Å and a = 5. 046 Å. This may be due to the fact that Cr presents different textures on Si and glass substrates.

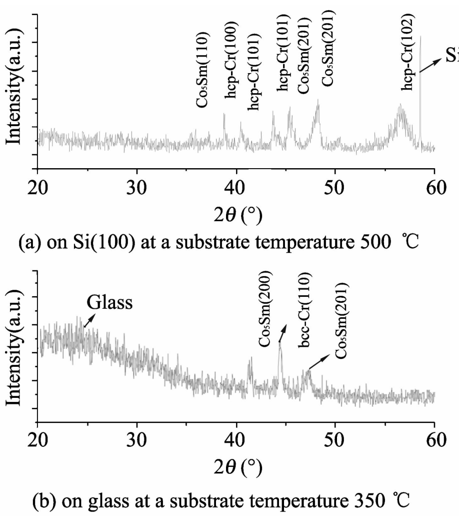


Fig. 2 XRD pattern for Co_5Sm/Cr films deposited

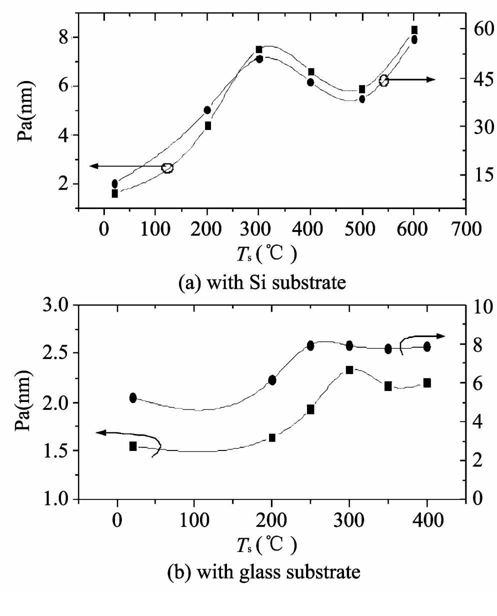
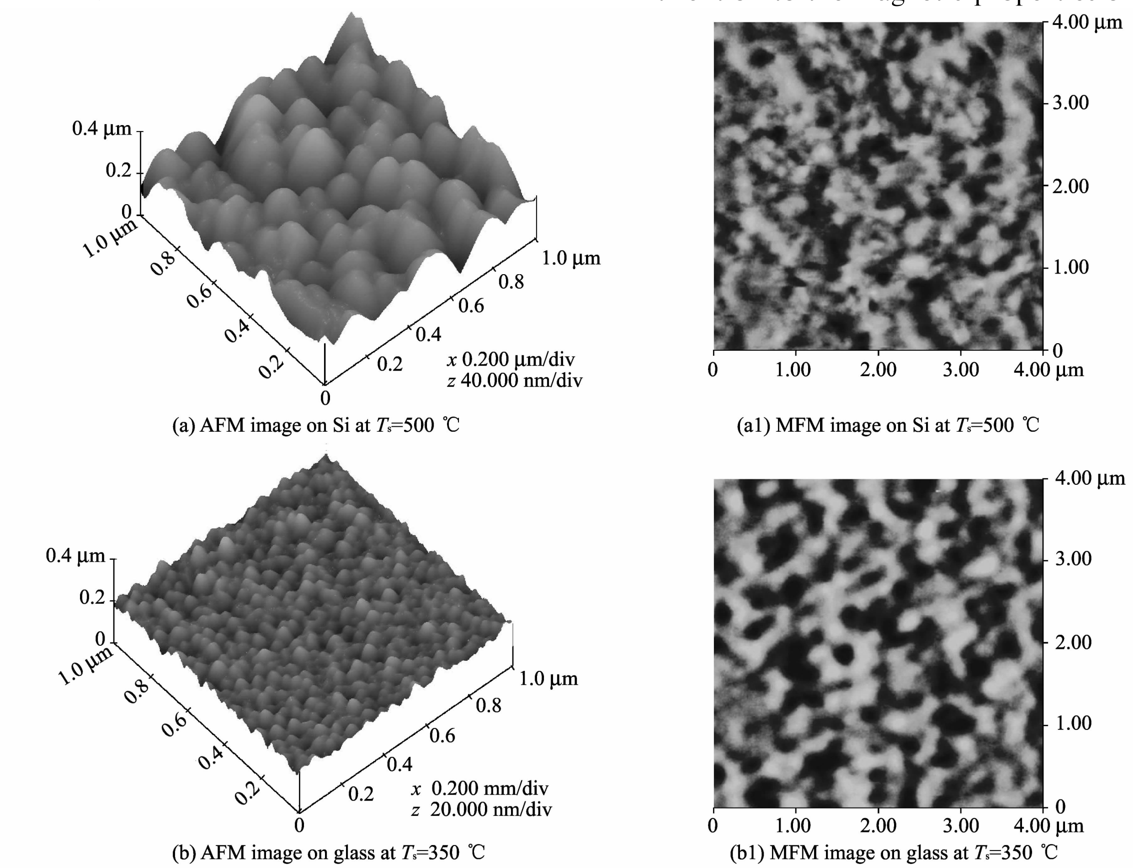


Fig. 3 Grain size (D) and the average roughness (Ra) for Co_5Sm/Cr films deposited on Si and glass substrate at various values of T_s

The surface morphologies of Co_5Sm/Cr films with Si and glass substrates were observed using an atomic force microscope (AFM), and the magnetic domain were obtained by magnetic force microstructure (MFM). From the AFM images, the grain size (D) and the average roughness (Ra) were obtained. Fig. 3 shows Ra and D for Co_5Sm/Cr films deposited on Si and glass substrate at various values of T_s. For both cases, the grain size and average roughness are seen to have the same features, i.e., they first increase with temperature at low temperature, then decrease, and finally increase again. It is well understood that grains grow larger with temperature. Cr also diffuses into the Co_5Sm layer as the temperature increases. At a certain temperature (here for the sample on Si, $T_s = 500$ ℃, and that on glass, $T_s = 350$ ℃), Cr reaches the boundaries of the Co_5Sm grains and isolates them, in this situation, the grain growth of Co_5Sm is inhibited. Further increasing the temperature leads to segregation of the Cr grains, which results in the growth of the Co_5Sm grains. Fig. 4 shows AFM and MFM images of the Co_5Sm/Cr films grown on Si at $T_s = 500$ ℃ (AFM image shown in Fig. 4(a), and MFM image shown in Fig. 4(a1)) and on glass at $T_s = 350$ ℃ (AFM image shown in Fig. 4(b), and MFM image shown in Fig. 4(b1)). Comparing them, we see that the grain size of the sample on the glass slide is smaller and the size distribution is more uniform. Concurrently, the shape of the magnetic domains is more regular and ordered. In addition, for the sample on the glass slide, Co_5Sm grains are seen to have a circular shape with well-isolated Cr. These attribute all contribution to the magnetic properties of the grains.



(a) AFM image on Si at T_s=500 ℃ (a1) MFM image on Si at T_s=500 ℃

(b) AFM image on glass at T_s=350 ℃ (b1) MFM image on glass at T_s=350 ℃

Fig. 4 AFM and MFM images of the Co_5Sm/Cr films grown on Si at $T_s = 500$ ℃ and on glass at $T_s = 350$ ℃

It is of essential importance for films to have both high Ku and low magnetic switching volume (V^*) so as to satisfy the requirements of high values of Hc, highthermal stability factor (KuV^*/KBT) and low noise[8]. Jeong et al.[9] found that magnetic switching volume strongly correlates to the nature and strength of magnetic intergranular interaction. V^* was estimated from the coercivity measured as a function of the sweep rate of the magnetic field[10,11]. As shown in Fig. 5, the value of V^* for the film on glass is $V^* = 1.65 \times 10^{-18}$ cm^3, smaller than that for films on Si. This suggests that the film on glass is more suitable for high-density magnetic recording media. If the diameter of the grains is estimated to be about 10 nm for the film on glass, V^* is almost equal to the volume of the grain. This means that the grain is a nearly single-domain nanocrystallite, and the magnetization reversal mechanism is mainly influenced by magneto crystalline anisotropy, the shape of the crystal grain and the stress in the film.

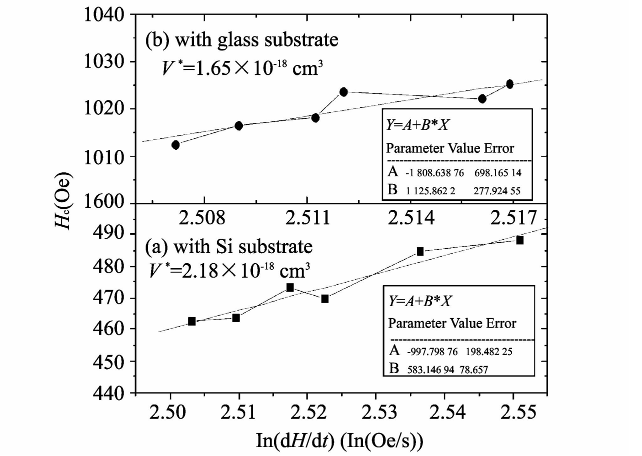


Fig. 5 Magnetic switching volume(V^*)for the Co_5Sm/Cr films on glass and that for films on Si

4 Conclusions

Co_5Sm/Cr bilayer films were fabricated on Si and glass substrates by means of DC magnetron sputtering system with different T_s. Magnetic properties measurements show that the sample with glass substrate has a relatively low optimal temperature with $T_s = 350$ ℃ and a comparatively large coercivity with $H_c = 2\ 141.2$ Oe. XRD measurements indicate Cr presents an hcp texture on Si, while bcc structure on glass substrate. Co_5Sm films have larger lattice constants on glass substrates. At their optimal substrate temperature (for the sample on Si, $T_s = 500$ ℃, and that on glass, $T_s = 350$ ℃), the grain size of the sample on glass slide is smaller, and the size distribution is more uniform. The shape of magnetic domain is more regular and ordered. The value of V^* for the film on glass is smaller than that for films on Si.

This suggests that the film on glass is more suitable for high-density magnetic recording media. For the film on glass, the magnetization reversal mechanism is mainly controlled by magneto crystalline anisotropy, the shape of the crystal grain and the stress in the film.

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