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The effects of the stabilizing layer thickness and its temperature dependence on the magnetic properties were investigated experimentally. These results were used to analyze the magnetic structure of the thin stabilizing layer and its effect on the coupling strength, which is valuable for improving the design of synthetic antiferromagnetically coupled media. [DOI: 10.1063/1.1555794]

I. INTRODUCTION

Synthetic antiferromagnetically (SAF) coupled media benefit from the stabilizing layer (L_S), which is coupled antiferromagnetically with the magnetic recording layer.[1–3] Therefore, the structural and magnetic properties of the stabilizing layer are essential in controlling the magnetic and recording performance of SAF media. There has been considerable work done to investigate the magnetic and reversal properties of SAF media,[1–11] however, most of it was focused on the top magnetic layer, and the magnetic properties of L_S and its correlation with the coupling strength J have not been investigated intensively. In some of the earlier works, the magnetic properties of L_S were treated as the parameters independent of the stabilizing layer thickness (t_S), however this may not be true for a very thin L_S.

In this article, we have investigated the magnetic properties for the stabilizing layer in a wide thickness range. The experimental results reveal the correlation between the magnetic ordering of L_S and the coupling strength J and the effects of the stabilizing layer thickness (t_S) and temperature (T) on the magnetic properties of L_S. These results are valuable for improving the understanding of the magnetic structure of L_S and the optimal design of SAF media.

II. EXPERIMENTS

Three sets of samples were prepared for this study. The film configuration for set I is underlayer/CoCrTaX/Ru/CoCrPtB/overcoat. Set II is similar to set I except without the top magnetic layer. The thickness of the stabilizing layer (t_S) varies from 20 to 100 Å for set I and from 20 to 210 Å for set II. Samples of set I and II were used to investigate the magnetization (M_S) of L_S in a broad t_S region. The film configuration of set III is similar to set I except the t_S was varied in a small increment from 17 to 60 Å. This set of samples was used for measurements of the effect of t_S on the magnetic properties. The structural properties were investigated by x-ray diffraction, x-ray photoemission spectroscopy (XPS) and the magnetic properties were characterized with an alternating gradient force magnetometer.

III. RESULTS AND DISCUSSION

The film crystallographic texture is of critical importance for the recording media and the Co(110)/Cr(002) texture is desirable. The x-ray diffraction indicates that the Co(110)/Cr(002) grows well expitaxially for all films studied. Figure 1 shows the θ-2θ and rocking scans of Co(110) peak for the stabilizing layer of set II films. Figure 1(a) shows that the Co(110) peak height, which has been normalized to 100 Å for all three films, decreases with decreasing t_S, and that the peak position moves towards lower 2θ value as t_S decreases. These features are attributed mainly to the stress effect in the initial growth of Co(110) planes and the diffusion of the Cr atoms from the underlayer. These two facts expand the lattice constant of the Co alloy in the interface region which causes this peak shift. The interface region with more Cr atoms also reduces the Co(110) diffraction intensity and this has a stronger effect for the thinner L_S. Figure 1(b) shows the rocking scans for these films. The full width at 50% amplitude of the rocking curves increases gradually with decreasing t_S, however, even for the very thin L_S of 20 Å thickness the c axes of the hexagonal-close-packed (hcp) cell of the Co alloy are still oriented preferably on the film plane.

Magnetization (M_S) describes the most fundamental property for a magnetic material. The evolutions of "M_S vs t_S" and "M_S vs 1/t_S" for set I and II samples are shown in Figs. 2(a) and 2(b), respectively. It is seen that M_S depends strongly on t_S, especially for t_S < 50 Å [Fig. 2(a)], which is about the thickness regime of the stabilizing layer for current SAF media. Figure 2(b) indicates that the dead layer thickness is ~15 Å from the linear fitting of M_S vs 1/t_S and the intrinsic magnetization, i.e., the magnetization without the dead layer, is 554 emu/cm^3. These results reveal that the stabilizing layer is not well ordered ferromagnetically for t_S < 50 Å. This ordering can be improved significantly, if t_S increases. However, it is not desirable to have thicker L_S of

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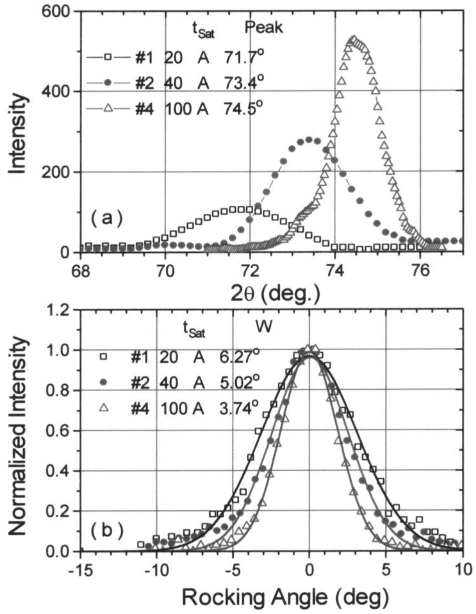

FIG. 1. X-ray diffraction pattern of Co(110) peaks for films with stabilizing layer thickness $t_S = 20$, 40, and 100 Å: (a) x-ray θ-2θ scans. The diffraction intensity corresponds to 100 Å thickness for all films, and (b) x-ray rocking scans.

$t_S > 50$ Å for the current SAF media. This is an important issue to be considered in order to obtain more benefits from the stabilizing layer.

The magnetic properties of the stabilizing layer for a SAF film can be determined by measuring the minor loops at different H field sweep rates.[10] The dependence of stabilizing layer thickness on magnetization (M_S), exchange field (H_{ex}), coupling strength (J), coercivity (H_C), thermal stability factor ($K_u V^*/kT$), and anisotropy (K_u) for set III samples are summarized in Fig. 3. The coupling J is a key feature that enables the SAF film to receive the most benefits in thermal stability from the stabilizing layer. The coupling strength J can be determined by $J = M_S H_{ex} t_S$, i.e., J can be calculated using the M_S and H_{ex} data as shown in Fig. 3(a). It is seen that $J \approx 0$ for $t_S < 17$ Å and J increases linearly with increasing t_S for 17 Å $< t_S <$ 50 Å. This increase in J value is attributed to the increase in M_S rather than the H_{ex}. We notice that both H_{ex} and M_S start at $t_S \approx 17$ Å, the onset of the magnetic ordering for the stabilizing layer, and then the exchange field H_{ex} changes its value slightly while the magnetization M_S increasing significantly as t_S varies from 17 to 60 Å. This behavior has been confirmed repeatedly for several sets of samples in our labs. This result indicates that the minimum thickness of $L_S(t_{Min})$ should be much larger than the dead layer thickness.

The coercivity H_C [Fig. 3(b)] and anisotropy K_u [Fig. 3(c)] of L_S show low values for $t_S < 30$ Å and increase by about an order of magnitude as t_S varies from 30 to 60 Å. This indicates that t_S needs to be greater than 30 Å for a successful stabilizing layer. The thermal stability factor ($K_u V^*/kT$) of L_S has fairly low values of 21–42 as t_S varies from 25 to 60 Å [Fig. 3(c)].

It has been reported that the thin magnetic films show a strong dependence of magnetic properties on temperature

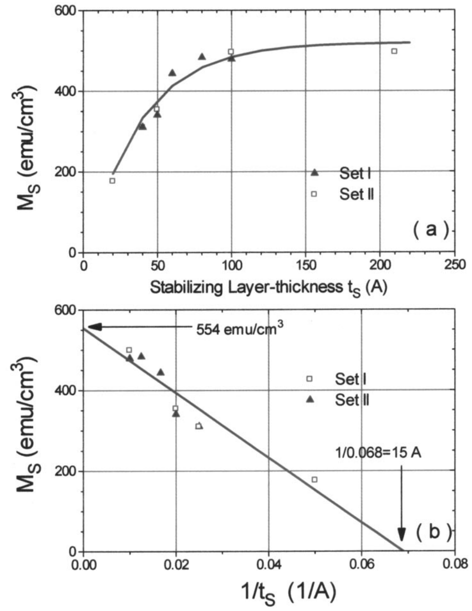

FIG. 2. Stabilizing layer thickness (t_S) effects on magnetization (M_S): (a) M_S as a function of t_S, and (b) M_S as a function of ($1/t_S$).

(T).[12] Since the L_S thickness for the current SAF media is only about 30–50 Å, the temperature dependence of magnetic properties should also be investigated conscientiously. Figure 4 shows the temperature dependent behavior of magnetization $M_S(T)$ [Fig. 4(a)], coercivity [$H_C(T)$] [Fig. 4(b)], and anisotropy field [$H_K(T)$] [Fig. 4(c)] for a sample from set II with $t_S = 50$ Å. The $M_S(T)$ decreases by ~30% as T changes from -80 °C to $+80$ °C and the temperature effects on coercivity $H_C(T)$ and anisotropy $K_u(T)$, which can be

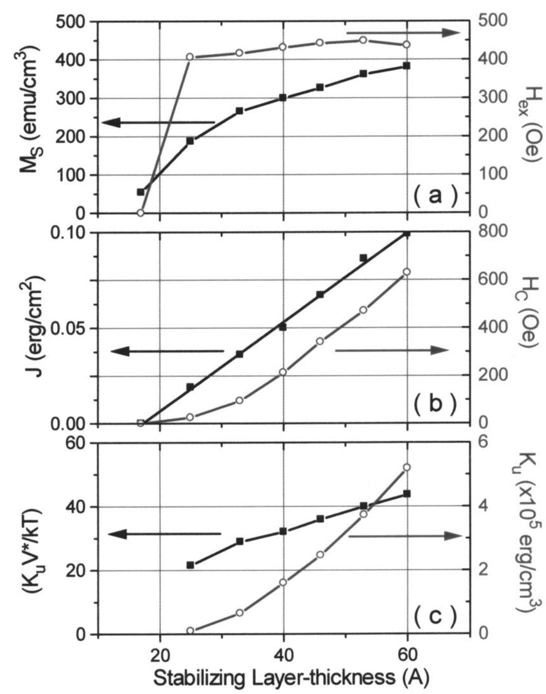

FIG. 3. Stabilizing layer thickness (t_S) effects on magnetic properties: (a) exchange field H_{ex} and magnetization M_S, (b) coupling strength J and coercivity H_C, and (c) thermal stability factor ($K_u V^*/kT$).

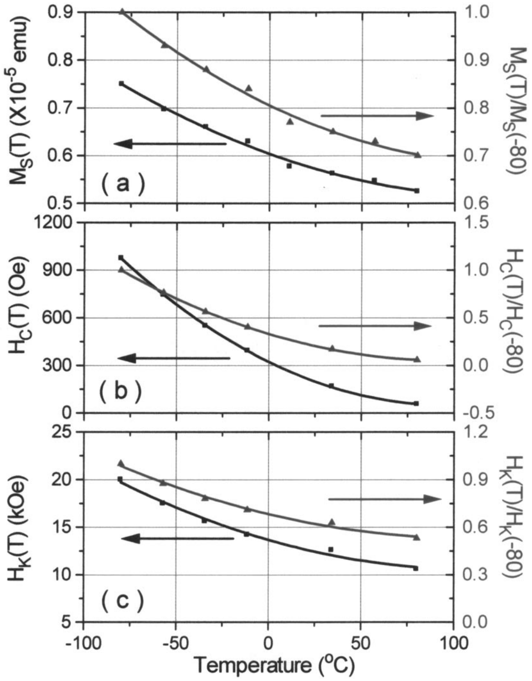

FIG. 4. Temperature effects on the magnetic properties: (a) magnetization $M_S(T)$, (b) coercivity $H_C(T)$, and (c) anisotropy field $H_K(T)$. The normalized values are shown on the right ordinates.

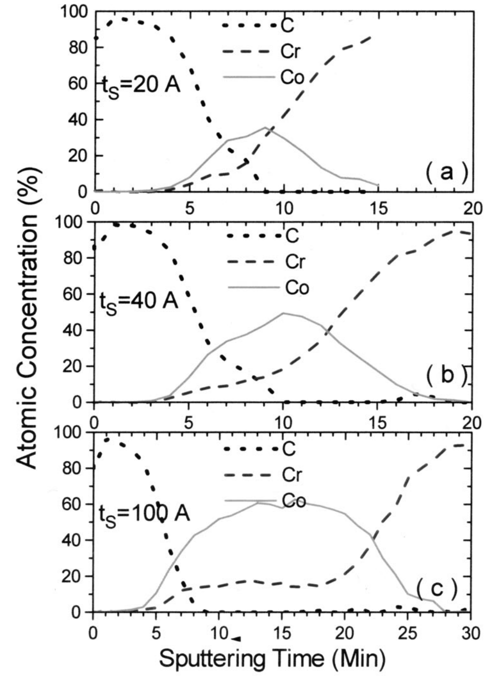

FIG. 5. The composition profiles of stabilizing layers with thickness t_S $=20$, 40, and 100 Å. The profile curves were measured by x-ray photoemission spectroscopy.

estimated by $K_u(T)=M_S(T)H_K(T)/2$, are much more drastic than that of $M_S(T)$. This implies that temperature dependence of magnetization and coercivity, etc., should also be considered for the selection of stabilizing layer.

The appreciable effects of t_S and T on the magnetic properties for the thin stabilizing layer are correlated closely with the interdiffusion of Cr atoms into the stabilizing layer from the underlayer. A set of XPS profiles of Co, Cr, and C are in Fig. 5 showing the profile feature semiquantitatively. It is seen that the Cr atoms from the underlayer diffuse throughout the whole L_S [Fig. 5(a)] for $t_S=20$ Å, and through about half of the L_S [Fig. 5(b)] for $t_S=40$ Å, and the Cr atoms from the underlayer are limited in the interface or boundary region [Fig. 5(c)] for $t_S=100$ Å. Thus, the diffusion of Cr at the interface region has a significant effect on the magnetic properties for the thinner stabilizing layer.

In summary, it has been found that a very thin stabilizing layer is not well ordered magnetically and this ordering can be improved significantly for $t_S>50$ Å, which is about the upper-limit t_S value for the current SAF media. The coupling strength J increases linearly as the stabilizing layer thickness varies from 17 to 60 Å. The rather strong temperature and layer thickness effects on the magnetic properties of the stabilizing layer have to be considered conscientiously in order to improve the properties of SAF media.

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