Magnetic Properties and Crystallography of Double-Layer CoCrTa Thin Films with Various Interlayers

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Abstract--In this work, the hysteretic properties and remanence curves of double-layer CoCrTa thin films with various interlayers (Al, Cu, Ag, and Cr) are investigated. It is found that the double-layer CoCrTa films with Cu or Ag interlayers have narrower switching field distributions but similar high coercivities, compared with the films with Cr interlayers. To understand the effects of interlayers on the magnetic properties, the crystallography of epitaxy in these multilayer thin films are also studied. The results from this work show that Ag and Cu are strong candidates as interlayer materials in multilayer magnetic recording media.

I. Introduction

Multilayer magnetic thin film media have recently received considerable attention because of their higher signal to noise ratios compared to single layer magnetic thin films [1]-[3]. It is believed that the reduction in transition noise is due to the combined effect of a larger number of grains per unit area and the reduced magnetic exchange coupling between the magnetic layers and grains in each magnetic layer. Since Cr is widely used as an underlayer, it naturally has been chosen by researchers to be the interlayer in all the published works. Recently, a dependence of crystallographic structure of the upper magnetic layer on the Cr interlayer has been reported [4], [5]. It was found that the upper magnetic layer may not always duplicate the structure of the lower magnetic layer. This is an important issue because the crystallographic decoupling can cause a wider switching field distribution (smaller S*). Thus, it is interesting to compare the films with various interlayers. Herein we report on the effects of different interlayers (Al, Ag, Cu and Cr) on the magnetic properties of double magnetic layer thin film media.

II. Experimental

Fig. 1 shows the configuration of a double-layer CoCrTa thin film. The substrates are Corning 7059 glass. The Cr underlayers were 1000 Å thick. The composition of the CoCrTa target was Co-12 at%-2 at% Ta. Each CoCrTa layer was 200 Å thick. Cr overlayers were used to prevent the second CoCrTa layer from being oxidized and to make the environment of the two CoCrTa layers as similar as possible. These Cr overlayers were 100 Å thick. The interlayers were 50 Å, unless specified otherwise.

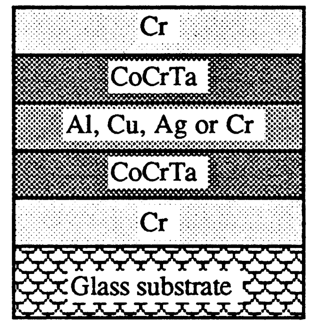

Fig. 1. Configuration of double-layer CoCrTa thin film

All the films were RF sputter deposited in a LH Z-400 sputtering system with a background pressure better than 7.0 x 10^{-7} Torr. The magnetic properties were measured with a vibrating sample magnetometer (VSM). The Cr underlayers were deposited without applying substrate bias, with an Ar pressure of 10 mTorr and a preheating substrate temperature of 260 °C. X-ray diffraction demonstrated that the Cr underlayers had the (002) crystallographic texture.

III. Results and Discussion

A. Magnetic Properties

The hysteretic properties of five films, which have different interlayers, are listed in Table I. Samples A, B, C and D are films with 50 Å interlayers of Al, Cu, Ag and Cr respectively, while sample E has no interlayer. Comparing the films with Cu and Ag interlayers (sample B and sample C) with the film with the Cr interlayer (sample D), it is found that the films with the Cu or Ag interlayer have higher remanant squareness and higher coercivity squareness, while their coercivities are similar to that of the film with the Cr interlayer. Hence, the switching field distributions of the film with Cu or Ag interlayers are narrower than that of the film with a Cr interlayer. Sample A, which has an Al interlayer, has a low coercivity and a very low coercivity squareness. As shown in Fig. 2, the hysteresis loop of this

TABLE I.
HYSTERETIC PROPERTIES OF FILMS WITH VARIOUS INTERLAYERS

Sample	Interlayer	Hc (Oe)	S	S*
A	Al	1385	0.72	0.16
B	Cu	1540	0.75	0.77
C	Ag	1872	0.75	0.78
D	Cr	1858	0.69	0.67
E	--	1892	0.71	0.74

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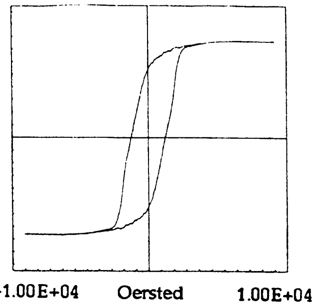

Fig. 2. Hysteresis loop of a film with an Al interlayer.

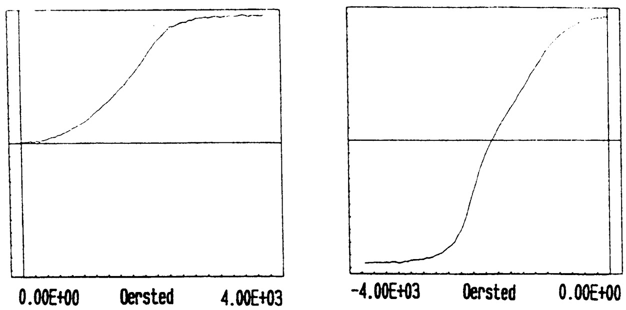

Fig. 3. Remanence curves of the film with an Al interlayer, a) forward, b) reversed.

sample indicates two distinct peaks of the switching field distribution. This is further demonstrated by the reversed remanant curve of this sample as shown in Fig. 3. Hysteresis loops of the other samples do not show this kind of "two phase" characteristic.

The dependence of magnetic properties on the thickness of the Cu, Ag or Cr interlayers has also been studied. As shown in Fig. 4a, the coercivities generally decrease as the interlayer thickness increases. This is most significant for the film with the Cu interlayer. It is also seen that using an Ag or Cu interlayer tends to increase the S* of the film, while using a Cr interlayer tends to decrease the S* of the film (Fig. 4b). Provided the increase of S* is not due to stronger exchange coupling between grains, which increases transition noise, this larger S* (narrower switching field distribution) will benefit the magnetic recording because it promotes a narrow, stable magnetic transition.

B. Crystallography of Epitaxy

To understand the effects of interlayers on the magnetic properties of double magnetic layer thin films, we need to study the role of the interlayer in the formation of the microstructure of these films. In most previous studies, it was assumed that as long as they have the same thickness, each magnetic layer will have the same microstructure, so that the two magnetic layers have the same magnetic properties. The hidden assumption here is that there exists a "perfect" epitaxy between the first magnetic layer and the interlayer as well as between the interlayer and the second magnetic layer. A "perfect" epitaxy means that no new defects

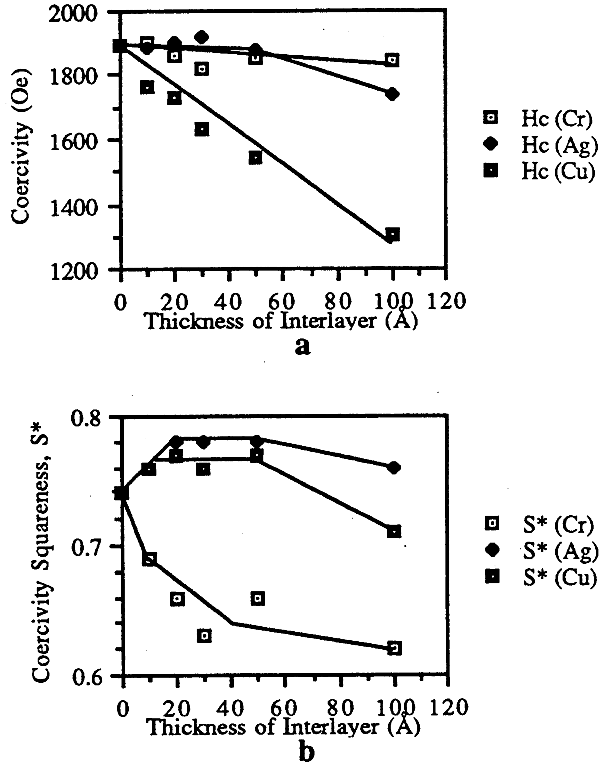

Fig. 4. The dependence of a) coercivity, and b) coercivity squareness on the thickness of interlayers.

(such as new grain boundaries or dislocations) in the second magnetic layer are induced by the epitaxial growth. This can not be the case in the systems studied because perfect epitaxy requires 100% lattice matching. Experimentally, it has been found that several Co grains (or subgrains) can grow on one Cr grain (so that the second Co layer may have a smaller grain size than the first Co layer!) [6]. It has also been reported that the second magnetic layer may not have the same crystallographic texture as the first magnetic layer [4], [5].

Since the Cr underlayer has (002) texture, the first CoCrTa layer should have (11$\bar{2}$0) texture [7]. One of the important requirements for epitaxial growth of the interlayer on the CoCrTa layer is close lattice matching. One way to compare the lattice match is to compare the atomic areal density. Another way to compare the lattice match is to compare the lattice spacing between atoms. Table 2 lists the atomic areal densities of {100}, {110} and {111} planes of Cr, Al, Ag, and Cu. Here, the atomic areal density of the Co (11$\bar{2}$0) plane is set equal to unity. From the table, we can see that Cr, Al, and Ag should have the (002) texture when they grow epitaxially on the Co (11$\bar{2}$0) plane, while Cu should have the (220) texture. In Fig. 5, we can also compare the lattice spacing between atoms for these lattice planes. Here we see that the Cu (220) plane and the Co (11$\bar{2}$0) plane do not provide as good a lattice spacing match as do the Ag or Cr (002) planes to the Co (11$\bar{2}$0) plane. This may explain why the decrease in H_c with increasing the interlayer thickness is more significant for the films with Cu

TABLE 2. AREAL DENSITY OF SOME LATTICE PLANES

	Cr	Al	Ag	Cu
{100}	1.05	1.07	1.05	1.34
{110}	1.48	0.76	0.74	0.95
{111}	0.61	1.24	1.21	1.55

The areal density of Co (11$\bar{2}$0) plane is considered as unit value.

interlayers (see Fig. 4a).

The crystallographic texture of the Cu and Ag interlayers were studied with x-ray diffraction using samples with very thick (500 Å) interlayers. As shown in Fig. 6, the Cu interlayer has the (220) texture and the Ag interlayer has the (002) texture. This is consistent with the lattice matching prediction.

The chemical properties of the interlayer may also play an important role in the magnetic properties. Since Al can form various compounds with Co [8], the system is more complicated and therefore more difficult to control when an Al interlayer is used. The solubility of Cr in Co is quite high. Hence, Cr may diffuse into the Co grains from the Cr interlayer as well as from the underlayer and overlayer [9]. The dilution caused by the diffusion of Cr atoms reduces the saturation magnetization of the Co grains. This may also be related to the decrease of the coercivity squareness of the film. On the other hand, Ag and Cu are almost immiscible with Co [8]. This is an advantage for an interlayer material because it will not change the composition of the magnetic layers. Also, because their melting points are relatively low, the Ag and Cu atoms may diffuse more easily into the boundaries of the magnetic grains, and therefore improve the grain isolation.

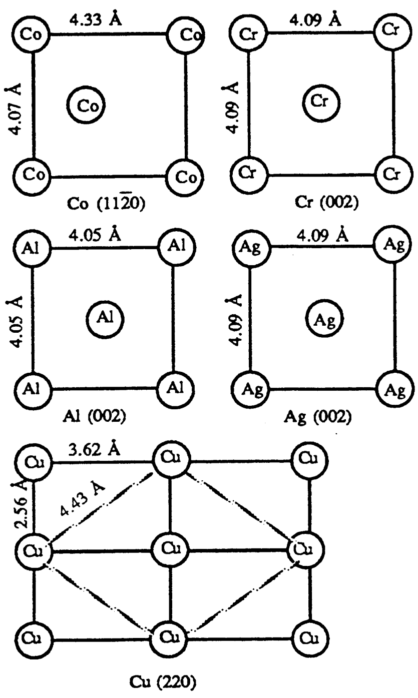

Fig. 5. Arrangement and spacing of atomic lattice planes.

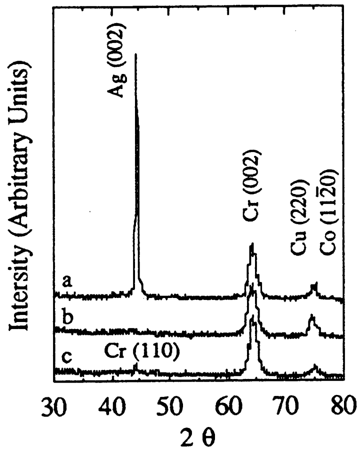

Fig. 6. X-ray diffraction of films with thick interlayers of: a) Ag, b) Cu, and c) Cr.

IV. Summary

The magnetic properties of double CoCrTa layers with various interlayers were studied for the first time. The role of interlayers was discussed in regard to the crystallography and chemistry of the systems studied. It was found that the films with Ag or Cu interlayers have similarly high coercivities as the films with Cr interlayers, and with significant higher coercivity squareness. Hence, Ag and Cu could be added to the list of candidates for use as interlayers. Our future work include studying the recording properties of the films with Ag or Cu interlayers.

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