Magnetisation studies in Co-Tb / Pt multilayers

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We have studied the magnetization in $Co_{86}Tb_{14}$/Pt multilayers under fields up to 1.8 T and as at room temperature. As the do-Tb layer thickness (t_{CoTb}) decreases below 200 Å the saturation magnetization magnetization (M) increases, the rectangularity of the M-H loops and the coercivity (H_c) decrease. The effective anisotropy K_{eff} of the multilayers was determined by a torque magnetometer. The product $K_{eff}\times t_{CoTb}$ shows a linear dependence with t_{CoTb} as normally found for the superlatices yielding the bulk and surface anisotropies of 10^6 erg/cm^3 and –0.2 erg / cm^2, respectively. These results are explained in terms of an interfacial Co-Pt layer. K_{eff} and H_c are related by the equation $H_c = \alpha\ K_{eff}^n / M$ with the fitting parameters α and n.

I. INTRODUCTION

Amorphous films of transition metal-rare earth alloys such as Co-Tb are of interest from both the fundamental and the application points of view. As disordered systems they offer rich possibilities for exploring some fundamental aspects in magnetism such as anisotropy and spin structure. From the practical point of view it is now well established that these alloy films could be used for magneto-optical information storage [1, 2]. The main characteristics of these films, generally obtained by deposition, are the presence of an uniaxial anisotropy (K_u) which makes the film normal the easy axis of magnetization, a rectangular hysteresis loop and coercitivities on the order of a few kilooersteds [1-4]. These layers are chemically very reactive and hence have to be protected either by a dielectric or a metallic layer such as Al or Pt. It is interesting to study the effect of Co-Tb / Pt interfaces. In order to amplify interface effects it is preferable to study Co-Tb / Pt multilayers. Krishnan et al have shown previously in Fe-Tb / Pt multilayers that with a decrease in the Fe-Tb layer thickness, a negative surface anisotropy K_s = -0.73 erg / cm^2 is observed which arise from the surface atoms and which favours the in-plane easy direction [5]. In this work we describe the results of our studies in Co-Tb / Pt multilayers prepared by rf sputtering.

II. EXPERIMENTAL DETAILS

Multilayers of Co-Tb / Pt were prepared by sequential rf sputtering. The system was pumped down using a turbomolecular pump to a pressure of 1-2 $\times10^{-7}$ Torr and baked overnight at a temperature of about 343 K. High purity argon (5N) was used as the sputter gas and its pressure was fixed at 6 × 10^{-3} Torr. The rf power was set at 80 W. Water cooled glass substrates were used. The Co-Tb layer thickness (t_{CoTb}) was varied from 15 to 250 Å and that of Pt was fixed at 20 Å. The number of bi-layers (n) was in the range 4 to 10. The top layer in all cases was 50 Å of Pt, which also served to protect the magnetic layer from oxidation. The thickness of the layers was measured in situ by a quartz oscillator which had been calibrated previously against a «Talystep».

The composition of the magnetic layer was determined by electron probe microanalysis of a single layer of Co-Tb about 1500 Å thick and was found to be $Co_{86}Tb_{14}$. We chose this composition because the compensation temperature for this well below room temperature and therefore will not interfere with the properties (M, H_c) that we are interested

As a routine charaterization a vibration sample magnetometer (VSM) was used to study the M-H loop along the film normal. The effective anisotropy (K_{eff}) and also the saturation magnetization (M) were measured at 300 K, using a torque magnetometer. There was a good agreement with M values obtained from VSM.

III. RESULTS AND DISCUSSION

The magnetic properties of the multilayers were found to be very dependent on t_{CoTb}. The hysteresis loops loose their rectangularity as t_{CoTb} decreases; the magnetization was relatively easily satured in a direction perpendicular to the film plane. In the worst case this required a field of approximately 3.5 kOe. The t_{CoTb} dependence of the coercivity H_c is shown in Fig. 1 It is seen that the coercivity decreases strongly with a decrease in t_{CoTb}. Correspondingly, the saturation magnetization also starts increasing with a decrease in the Co-Tb layer thickness. These results would indicate that the Co sublattice magnetization has increased. So our present results lead us to conclude that some interdiffusion has occured and Pt has alloyed with Co as to be discussed below. Some alloying of Pt with the magneto-optical layer is also possible but it seems to be negligible. However Taylor et al [6] concluded that Tb diffusion in Pt was very much

smaller than that of the transition metals which supports this conclusion.

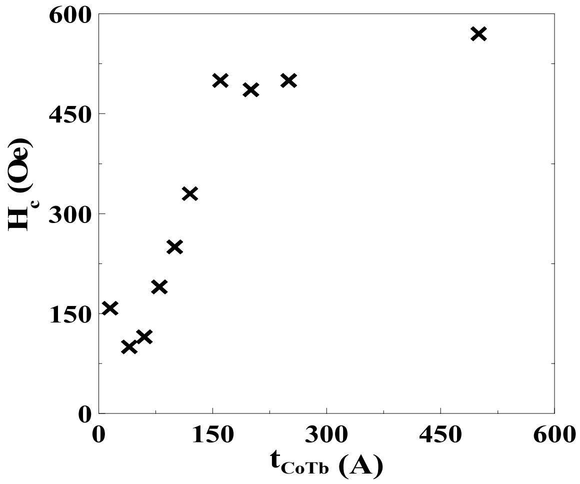

FIG. 1 : The t_{CoTb} dependence of H_C (with n = 8) at 300 K. SL indicates single layer sample.

The saturation magnetization in multilayers can be expressed by the phenomenological model follows:

$$M = M_b + 2\delta \times M_{int} / t_{CoTb} \quad (1)$$

where M, M_b and M_{int} are the magnetizations of the multilayer, the bulk material and interface material, respectively. δ is the interface layer thickness. Plotting $M \times t_{CoTb}$ as a function of t_{CoTb} yields a straight line, whose slope gives M_b and the intercept on the ordinate axis gives the product $2\delta \times M_{int}$. For instance, Fig. 2 shows such a plot at 300 K. By analysing the data, we calculated both M_b and the product 2δ x M_{int}. We find that M_b = 240 emu / cm^3 in agreement with the value obtained on the single-layer thick film. Of course, M_{int} can be determined only if δ is known. By the way it is also known that some transition metals induce a ferromagnetic moment on Pt as has been observed for the Co / Pt multilayers [7]. This also could contribute to the magnetic moment.

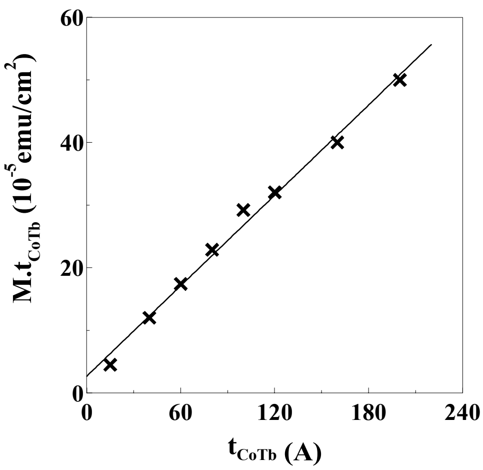

FIG. 2 : The t_{CoTb} dependence of the product $M \times t_{CoTb}$ at 300 K.

Let us now discuss the anisotropy in these multilayers. The measured effective anisotropy K_{eff}, based on the well experimented phenomenological model, can be expressed as

$$K_{eff} = K_v + 2\,K_s / t_{CoTb} \quad (2)$$

where, K_v and K_s are the volume and surface anisotropies. The former can be written (for the case where the film normal is the easy axis of magnetization) under the usual convention as

$$K_v = K_u - 2\,\pi\,M^2 \quad (3)$$

where K_u is the intrinsic uniaxial anisotropy.

In our case eventhough we have an amorphous film, there is a strong uniaxial anisoropy K_u induced by the sputtering process. This involves a strong dependence of the anisotropy on the deposition parameters controlling the structure of the film and of the average anisotropy contribution of the rare earth and transition metal atoms. Different origins have been discussed to account for the observed uniaxial anisotropy such as anisotropic microstructures [8], dipolar interactions [9], stress-induced anisotropies [10, 11], pair ordering [12], anisotropic exchange [13], bond-orientational anisotropies [14] and single-ion anisotropy [15-18]. However, the correlation between deposition parameters and film structure on the hand and the magnetic properties on the other hand is still not yet explained satisfactorily [19].

Figure 3 shows the variation of the product $K_{eff} \times t_{CoTb}$ as a function of t_{CoTb}. A linear decrease with t_{CoTb} is found as predicted by the model. For the thickness below 60Å, the experimental data deviate from the fitted line obtained. Normally in metallic superlattices, for magnetic layers thicker than 15 Å or so, K_{eff} is negative due to a large demagnetization energy. But in some systems [20], for layers thinner than about 10 Å, it could, under the effect of the surface anisotropy change sign become positive. In our present case, thicker Co-Tb layers show a positive K_{eff} and it decreases with the decrease in t_{CoTb}. The extrapolation of the straight line yields a negative (in-plane) surface anisotropy K_s = - 0.2 erg / cm^2. This value is much smaller than what had been observed by Krishnan et al in Fe-Tb / Pt [5]. From the model, the slope of the straight line in Fig 3 gives the volume anisotropy K_v which is found to be 10^6 erg / cm^3. Knowing M_b = 240 emu / cm^3, we calculate the demagnetizing energy to be -0.36×10^6 erg / cm^3. We hence find that the uniaxial anisotropy $K_u = 1.36 \times 10^6$ erg / cm^3. It is interesting to note that this value agrees with the value of 1.6×10^6 erg / cm^3 that we measured on the single thick layer of Co-Tb and the values we had obtained in the case of Tb-Fe films [4].

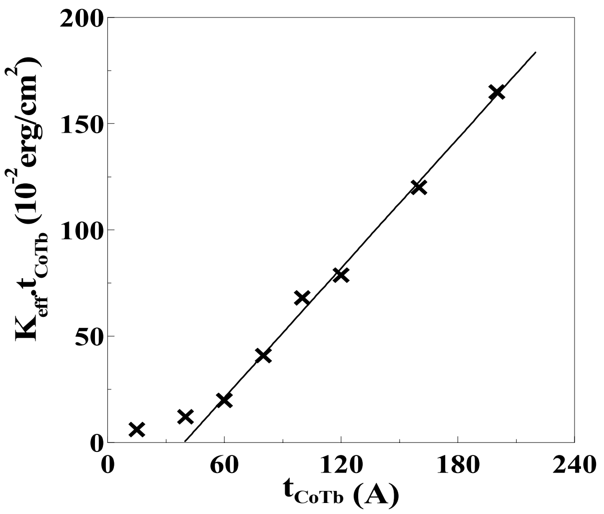

FIG. 3 : The variation of the product of $K_{eff} \times t_{CoTb}$ as a function of t_{CoTb} (with n = 8) at 300K.

In general we assume that the surface anisotropy energy constant K_s could be treated as originating from several effects which alter the surface spins at the interfaces such as misfit strain anisotropy [21], surface roughness [22-23], Néel's anisotropy [24] and from the magnetic polarization of interfacial Pt atoms [25]. When there is some interdiffusion between the magneto-optical layer and the Pt layer, roughness effects may greatly alter the magnetic surface anisotropy.

The coercivity is essentially controlled by the microstructure, the effective anisotropy and the saturation magnetization [26]. Hansen corellated Hc and K_{eff} in a simple relation [27]

$$MH_c=\alpha K_{eff}^{n} \quad (4)$$

According to Eq. (4), the coercivity is expected to increase with K_{eff}^{n} where n is determined by the mechanism controlling Hc. The plot of In(MH_c) vrsus In(K_{eff}) for different t_{CoTb} at a temperature of 300 K (Fig.4) yields n=1.4 and In α = -7.6.

Friedberg and Paul showed that H_c is proportional to $K_{eff}^{3/2}$ at given microstructure if the magnetization reversal process takes place by domain wall motion [28].

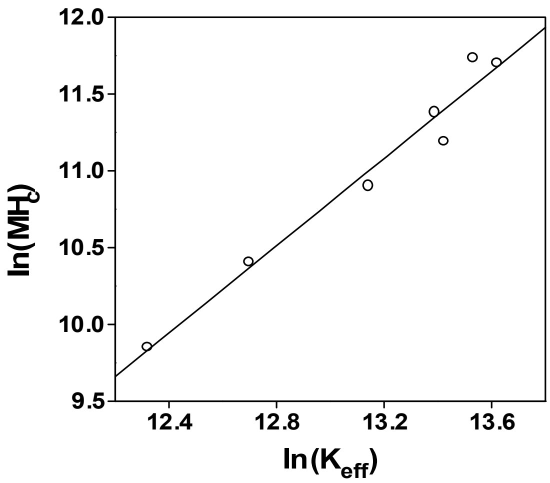

FIG. 4 : The variation of the In(MH_c) as function of In(K_{eff})

In conclusion, we have prepared and studied both single thick layer of Co-Tb and Co-Tb / Pt multilayer films. The coercivity decreases strongly with a decrease in t_{CoTb}. Correspondingly, the saturation magnetization also starts increasing with a decrease in the Co-Tb layer thickness. The product $K_{eff} \times t_{CoTb}$ shows a linear dependence with t_{CoTb} as normally found for the superlattices yielding the bulk and surface anisotropies of 10^6 erg / cm^3 and -0.2 erg / cm^2, respectively.

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