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# SPUTTERING PRESSURE EFFECTS ON MAGNETIC ANISOTROPY IN Co/Pt MULTILAYERS

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*Abstract* - We have investigated the effects of sputtering Ar gas pressure on magnetic anisotropy of Co/Pt multilayers, where sputtering Ar gas pressure was varied from 2 to 20 mTorr. The surface and volume anisotropies were found to be strongly dependent on sputtering Ar gas pressure. In particular, the surface anisotropy exhibited more than fourfold enhancement as Ar pressure was decreased from 20 to 5 mTorr. We have found that the surface anisotropy was closely correlated with the low-angle x-ray diffraction intensity. We believe that these results are mainly ascribed to the variation of microstructure in the Co/Pt multilayer thin films with sputtering Ar gas pressure.

## I. INTRODUCTION

Co-based multilayers have been attracting wide attentions because of their novel properties and potential technical applications [1-2]. Recently, there have been rapidly increasing interests in the magnetic anisotropy of Co-based multilayers. Co/Pt multilayer thin films exhibit a large magnetic anisotropy with the easy axis perpendicular to the film plane [3-4]. This phenomenon mainly originates from Neel's prediction of the surface anisotropy, as a consequence of the reduced symmetry in the surroundings of surface atoms [5]. Besides the surface contribution, volume effects including magnetocrystalline, magnetoelastic, and shape anisotropies are also important origins of the magnetic anisotropy.

Draaisma *et al.*[6] have shown that the effective magnetic anisotropy $K_{eff}$ per unit volume of the magnetic layer with thickness $t$ could be written as the sum of volume and surface terms:

$$K_{eff}t = K_v t + 2K_s \quad (1)$$

where $K_s$ can be interpreted as a Neel-type surface contribution and $K_v$ is a volume term. Equation (1) is commonly used in experimental studies to determine $K_v$ and $K_s$ from a plot of $K_{eff}t$ vs $t$.

In multilayer thin films, their magnetic properties seem to be very sensitive to preparation methods and conditions [4,7] as well as the sublayer and total layer thicknesses [8]. It is well-known that much more energetic atoms are involved in sputtering than vapor deposition. These energetic atoms are expected to smear out the interfaces of constituents and to yield microstructural modification in film structure.

In this paper, we present the effects of sputtering Ar gas pressure on magnetic anisotropy in Co/Pt multilayer thin films.

## II. EXPERIMENT

Co/Pt multilayers were prepared by dc magnetron sputtering from 2-in-diameter Co and Pt targets onto Corning 7059 glass substrates on a rotatable substrate table. The dwelling time, the substrates spent above each target, could be controlled by a programmable timer interfaced to a stepping motor which drove the substrate table. A stainless plate with two target-sized holes were placed between the targets and substrate table to prevent cross contamination of their sputtered fluxes. Sputtering Ar gas pressure was varied from 2 to 20 mTorr. At each Ar gas pressure a series of samples having different Co sublayer thicknesses but a constant Pt sublayer thickness were prepared with maintaining a same total bilayers of 23. The Pt sublayer thickness at each Ar pressure are listed in Table I.

The multilayer structure was examined by low-angle x-ray diffractometry. Magnetization was measured using a vibrating sample magnetometer (VSM). The magnetic anisotropy was measured using a torque magnetometer at an applied field of 15 kOe. The surface morphology was investigated using an atomic force microscope (AFM).

## III. RESULTS AND DISCUSSION

The dependence of $K_{eff}t_{Co}$ on $t_{Co}$ are shown in Fig.1 for the multilayers prepared at 2, 5, 10, and 20 mTorr Ar pressures. As seen in the figure, a behavior at each Ar pressure is well fitted by Eq. (1). Hence, the surface anisotropy energy, $K_s$, could be obtained from the intercept at $t_{Co}$=0 divided by 2 and the volume anisotropy energy, $K_v$, could be obtained from the slope of the line. The obtained values of $K_s$ and $K_v$ at each Ar pressure are listed in Table I. The largest $K_s$ occurs for the multilayers prepared at 5 mTorr Ar pressure, which is more than fourfold enhancement in comparison with the samples prepared at 20 mTorr Ar pressure. The

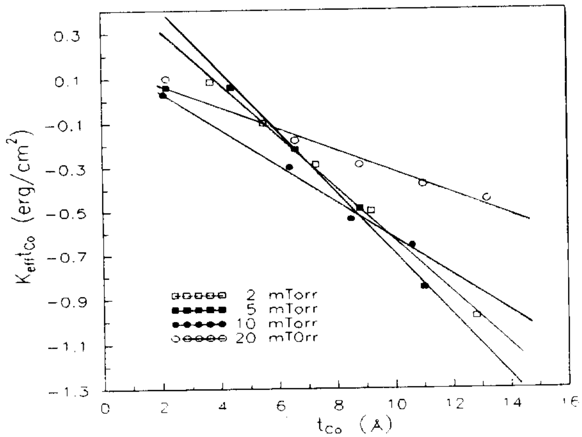



Fig.1. $K_{eff}t_{Co}$ vs $t_{Co}$ for Co/Pt multilayers prepared at different Ar pressure.

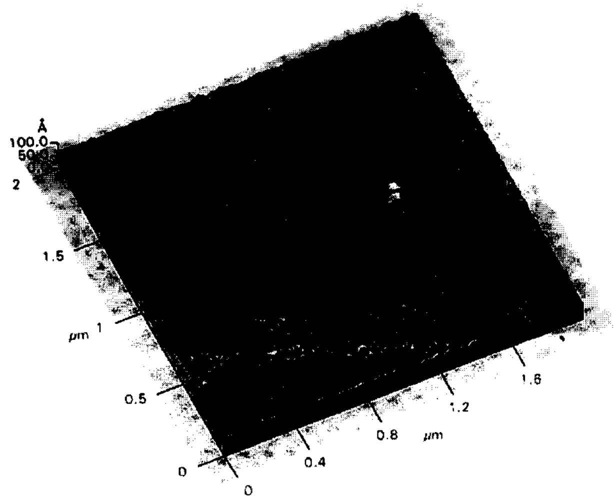
variation of the surface anisotropy is seemed to be ascribed to the change of the interfacial microstructure due to different Ar pressure. It is known that the bombardments of energetic Ar atoms reflected from the target smear out the interfaces of constituents in the low sputtering Ar gas pressure. In order to improve the magnetic properties by enhancing the interfacial sharpness in Co/Pt multilayers, Carcia *et al.* [9] have tried heavy sputtering gas such as Kr or Xe to reduce the damaging effects of energetic bombardments. When Ar gas pressure is 5 mTorr, the moderate bombardments of Ar atoms seem to smooth the surface and enhance the surface anisotropy energy. While, in the high Ar pressure, the surface becomes considerably rough and the surface anisotropy energy gets smaller beacuse of the reduction of the bombardments of Ar atoms and the deposition of exhausted sputtered atoms. Indeed, we have observed a dramatic change of the surface topology of the samples with varying sputtering Ar pressure. Fig.2 shows the AFM images of the surface topologies of 1000-Å-thick Co/Pt multilayers prepared at (a) 2 mTorr and (b) 20 mTorr. A smooth and dense surface can be seen in the sample prepared at 2 mTorr Ar pressure. While, a rough and coarse surface is appeared in the other sample. The interfaces of this sample are speculated not to be well-defined. Later, we will discuss this property with low-angle x-ray diffraction

Table I. Values of Pt sublayer thickness, $K_s$, and $K_v$ for Co/Pt multilayers prepared at different Ar pressure.

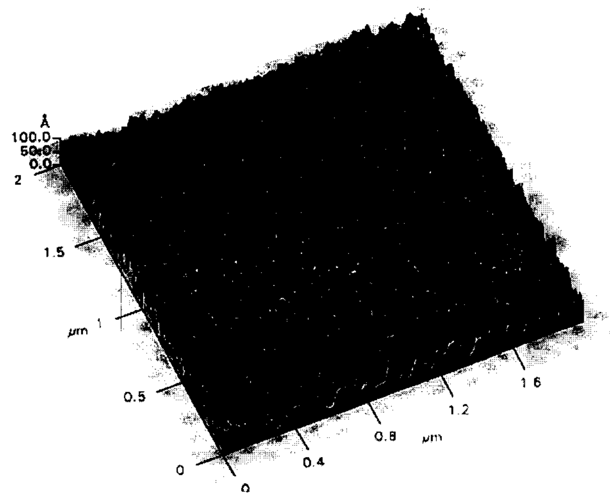
| $P_{Ar}$ (mTorr) | Pt sublayer thickness (Å) | $K_s$ (erg/cm$^2$) | $K_v$ (erg/cm$^3$) |
|---|---|---|---|
| 2 | 11.0 | 0.27 | $-1.3\times10^7$ |
| 5 | 12.2 | 0.34 | $-1.4\times10^7$ |
| 10 | 9.5 | 0.11 | $-8.3\times10^6$ |
| 20 | 11.2 | 0.08 | $-4.6\times10^6$ |

results.

The negative slope in Fig.1 indicates a negative volume anisotropy, $K_v$, favoring in-plane magnetization. $K_v$ values for the multilayers prepared at 2 and 5 mTorr are large in negative, and gradually increases with increasing sputtering Ar gas pressure. A change in the shape anisotropy, due to a variation of the magnetization depending on sputtering Ar gas pressure, seems to be a major cause of the variation in the volume anisotropy as shown in Fig.3.




(a)




(b)

Fig.2. AFM micrographs of (4-Å Co/9-Å Pt)$_{77}$ films prepared at (a) 2 mTorr and (b) 20 mTorr Ar pressures.

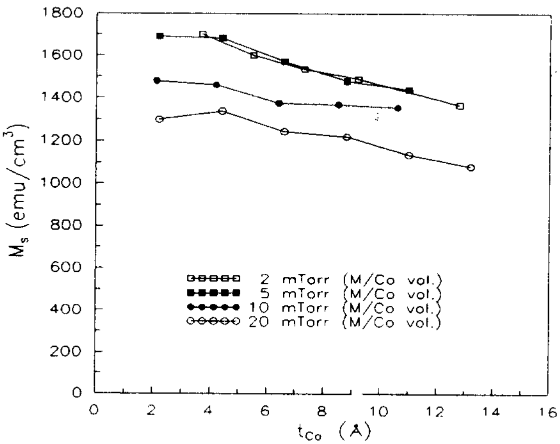



Fig.3. $M_s$ vs $t_{Co}$ for Co/Pt multilayers prepared at different Ar pressure.

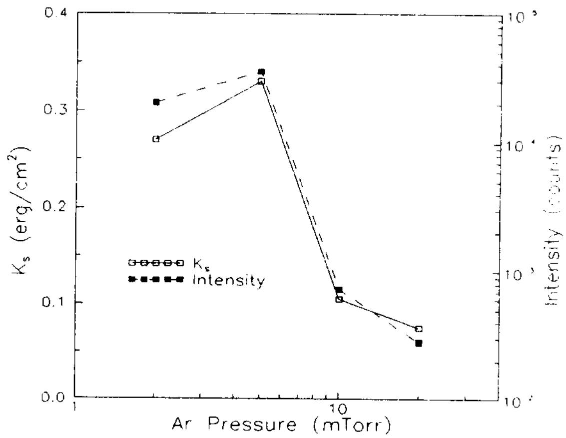



Fig.4. Dependence of $K_s$ and low-angle x-ray peak intensity on sputtering Ar gas pressure.

In Fig.3 the saturation magnetization $M_s$ of Co/Pt multilayers prepared at 2, 5, 10, and 20 mTorr is plotted against the Co sublayer thickness $t_{Co}$. Here, $M_s$ is obtained by dividing the magnetization of the multilayer with only Co volume. It is seen that the saturation magnetization exceeds the bulk value of Co (1422 emu/cm$^3$), except for the film prepared at 20 mTorr. Enhanced magnetization must be due to the polarization of Pt atoms near the Co layer as already reported by several investigations[10,11]. It is worthwhile to mention that $M_s$ decreases monotonously as $t_{Co}$ increases. The dependence of $M_s$ on $t_{Co}$ can be explained by considering the effective number of polarized Pt atoms per unit Co volume. $M_s$ values for the multilayers prepared at 2 and 5 mTorr are similar, and gradually decreases with increasing sputtering Ar pressure. As pointed out by Shin *et al.*[7], the density of the film decreases with increasing Ar pressure, which reflects an increase of porous region due to the fact that less energetic atoms are associated with increasing pressure. Indeed, columnar structure surrounded by network of low density or void regions was observed in the cross section of the films prepared at Ar pressure of more than 10 mTorr. Therefore, it could be concluded that the decrease of film density with Ar pressure mainly accounts for the decrease of $M_s$.

Table II. Total number of bilayers and sublayer thicknesses for the samples measured low-angle x-ray diffractometry.

| $P_{Ar}$ (mTorr) | bilayer no. | Co/Pt |
|---|---|---|
| 2 | 23 | 3.7-Å Co/11.0-Å Pt |
| 5 | 23 | 4.4-Å Co/12.2-Å Pt |
| 10 | 23 | 4.2-Å Co/9.5-Å Pt |
| 20 | 23 | 4.4-Å Co/11.2-Å Pt |

The degree of interfacial 'sharpness' is reflected in the low-angle x-ray diffraction peaks. In Fig.4, the dependences of the low-angle x-ray diffraction peak intensity and the surface anisotropy energy on sputtering Ar gas pressure are plotted. The surface anisotropy energy is obtained from the Fig.1. The sublayer thickness of samples measured by low-angle x-ray diffraction are listed in Table II. It can be seen that the dependences of the surface anisotropy energy and the log-scaled low-angle x-ray diffraction peak on Ar gas pressure are very similar. It is worthwhile to mention that the close correlation between the surface anisotropy energy and the low-angle x-ray diffraction peak intensity is probably caused by the interfacial sharpness of the multilayer. In particular, both of the surface anisotropy energy and the low angle x-ray diffraction peak show maximum at 5 mTorr Ar pressure. It is reasonable to conclude that 5 mTorr is an adequate sputtering Ar gas pressure to obtain high surface anisotropy energy with sharp interfaces for Co/Pt multilayers.

## IV. CONCLUSION

We have studied the effects of sputtering Ar gas pressure on magnetic properties and surface microstructure of Co/Pt multilayers. The surface and volume anisotropies are strongly dependent on sputtering Ar gas pressure, which were mainly ascribed to the variation of microstructure in the multilayer thin films. We have found that the surface anisotropy energy was closely correlated with the low-angle x-ray diffraction peak intensity. 5 mTorr was an adequate sputtering Ar gas pressure to obtain high surface anisotropy energy with sharp interfaces for Co/Pt multilayers.

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