Effects of Pd predeposition layer on magnetic properties in compositionally modulated Co/Pd multilayers

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We have investigated the effects of Pd predeposition layer on magnetic properties in compositionally modulated Co/Pd multilayers. The samples were prepared at the Ar sputtering pressure of 10 mTorr by dc magnetron sputtering. The thickness of the Pd predeposition layer was varied from 0 to 1000 Å with a 100 Å interval. It was observed that the magnetic properties of the saturation magnetization, the perpendicular anisotropy energy, and the coercivity remained relatively constant until the thickness of the predeposition layer was up to 600 Å. However, those were rapidly increased with the predeposition-layer thickness when the thickness was thicker than 600 Å. The results were caused by a change in the microstructure of the multilayers deposited on different predeposition-layer thicknesses.

I. INTRODUCTION

Compositionally modulated (CM) Co-based thin films have been the subject of numerous studies because of their novel properties and potential technological applications. In particular, applications of these materials to magneto-optical (MO) recording are of great interest today due to several advantages compared to the current choice of MO media, rare-earth transition-metal alloy films.

One concern adopting those materials in MO recording is their low coercivities, especially when they are prepared by sputtering. Thus, written domains are unstable against an external magnetic field. It has been reported that the coercivity could be increased by moderating the energetic sputtering atoms using a high-sputtering Ar gas pressure or a heavy sputtering gas such as Kr or Xe. For instance, Shin et al. have observed that the coercivity of a film increased up to about 2 kOe at a 30 mTorr sputtering Ar gas pressure.

This work was motivated to enhance the coercivity and other magnetic properties by introducing a predeposition layer. In this paper, we report the effects of the Pd predeposition layer on the structural and magnetic properties in CM Co/Pd multilayer films.

II. EXPERIMENT

CM Co/Pd multilayers were prepared by dc magnetron sputtering from 2-in.-diam Co and Pd targets on a rotatable table at a sputtering Ar gas pressure of 10 mTorr. Pd was predeposited and its thickness was varied from 0 to 1000 Å with a 100 Å interval. 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-size holes was placed between the targets and the substrate table to prevent the cross contamination of their sputtered fluxes. The base pressure of 5 × 10⁻⁶ Torr was maintained the same in all sample preparations. All samples had the same total thickness of 1100 Å and the same bilayer thickness of 11 Å composed of 2-Å-thick Co and 9-Å-thick Pd sublayers. The CM structure was examined by low- and high-angle x-ray diffractometry. The growth morphology of the Pd predeposition layer was investigated by transmission electron microscopy (TEM). The magnetization was measured by a vibrating sample magnetometer (VSM). The magnetic anisotropy energy was measured using a torque magnetometer at an applied field of 10 kOe and the data were analyzed according to the method of Shin and Kim. The coercivity, Kerr angle, and ellipticity were measured using a polar Kerr hysteresis loop tracer equipped with a 632.8 nm HeNe laser.

III. RESULTS AND DISCUSSION

All samples in this study developed low-angle x-ray diffraction peaks irrespective of the thickness of a predeposition layer, which suggests the existence of the CM structure in those samples. However, the full width at half maximum (FWHM) of the first-order low-angle diffraction peak became narrower with increasing the thickness of the predeposition layer. Therefore, a smoother interface is expected for the sample prepared at a thicker predeposition layer. High-angle x-ray diffraction studies revealed that the samples grew along the [111] cubic orientation with d₁₁₁ = (2.218±0.003 Å) and the degree of texture was enhanced with increasing the thickness of a predeposition layer.

To understand the variation of microstructure in the multilayer, pure Pd films having thicknesses from 100 to 1000 Å were examined using a transmission electron microscope. Figures 1(a) and 1(b) show the surface morphologies of 100-Å-thick and 800-Å-thick Pd films, respectively. A network of void regions surrounding tiny grains less than about 20 Å in diameter is clearly seen in Fig. 1(a). It was observed that the grains were getting larger for a thicker film and thus, the void regions became less and completely disappeared for the film thickness t_{Pd} > 700 Å as shown in Fig. 1(b). One can therefore imagine a smooth and dense-packing multilayer deposited on the Pd predeposition layer having t_{Pd} > 700 Å, compared to a rough and less dense-packing multilayer deposited on a thinner predeposition layer.

In Fig. 2, we plot the saturation magnetization Mₛ as a function of the thickness of a Pd predeposition layer t_{Pd}. As
FIG. 1. TEM images of the surface morphologies for Pd predeposition layer thickness: (a) $t_{pd}=100 \text{ Å}$; (b) $t_{pd}=800 \text{ Å}$.

The anisotropy energy $K_u$ shows a similar behavior to the saturation magnetization as shown in Fig. 3. $K_u$ associated with a multilayer can be described phenomenologically as $K_u = 2K_f/t_{Co} + K_v + 2\pi M_s^2$, where $K_f$ is the interface anisotropy energy and $K_v$ is the volume anisotropy consisting of the demagnetization energy, the magneto-crystalline anisotropy, and the magnetoelastic energy. $K_{eff} = K_u - 2\pi M_s^2$ should be positive to have the perpendicular magnetic anisotropy. Generally, in Co/Pd multilayers $K_r$ is negative due to demagnetization energy and a positive value of $K_v$ is responsible for the perpendicular magnetic anisotropy. Hence, it is desirable to enhance $K_v$ but reduce $K_r$. $K_v$ is known to be strongly dependent on “the state of interfaces” closely related with preparation conditions as well as deposition techniques. A highest $K_v$ of 0.6 erg/cm$^2$ has been reported for molecular beam epitaxy (MBE) sample, which is mainly due to an existence of smoother...
multilayers deposited on the predeposition-layer thickness. In our samples, the value for \( a \) for the reversible rotation of a single-domain sample, while \( a = 0.13 \) for irreversible rotation of a single-domain sample, while \( a = 0.13 \) for irreversible domain wall motion is dominant for other samples.

The domain wall width \( \delta \) is given by \( \pi \sqrt{A/K_u} \) where \( A \) is the exchange stiffness constant. Assuming that \( A \) is the same order as the Curie temperature, \( \delta \) in our sample is estimated to be about 100 Å. Transmission electron micrographs of the samples revealed that the size of the grains increased with \( t_{pd} \) and turned out to be about 100 Å for the sample of \( t_{pd} = 700 \) Å. It is therefore believed that the mechanism of magnetization reversal is changed from wall motion to domain rotation when the size of the grain is larger than the domain wall width in our sample, which might explain a substantial increase of \( H_c \) shown in Fig. 4.

IV. CONCLUSIONS

We have studied the effects of the Pd predeposition layer on magnetic properties in CM Co/Pd multilayers. Magnetic properties such as saturation magnetization, perpendicular anisotropy energy, and coercivity noticeably increased for the predeposition-layer thickness \( t_{pd} > 700 \) Å. The improvement of the magnetic properties with increasing the Pd predeposition-layer thickness was closely related to the change in the microstructure of the films such as the density of the films, the smoothness of the interfaces, and the size of the grains. The mechanism of magnetization reversal changed from wall motion to domain rotation when the size of the grains was larger than the domain wall width and thus, a large coercivity could be obtained for the samples deposited on thick Pd predeposition layers.

This work suggests that the predeposition of Pd of \( > 600 \) Å is very desirable for an application of these materials to magneto-optical recording.

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