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Effects of oxide addition on magnetic and structural properties of CoNiPt alloy films

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The effects of oxide addition on magnetic and structural properties of sputtered CoNiPt alloy films for high density longitudinal recording with a random c-axis orientation of hcp Co have been studied. It is found that the addition of SiO_2 up to 4.2 at. % results in a significant increase in the in-plane coercivity from 1700 to 2400 Oe and a signal to media noise ratio with a slight decrease in coercive squareness from 0.90 to 0.87, while the perpendicular magnetic anisotropy is not significantly changed. X-ray diffraction shows that the c-axis orientation normal to the film plane does not change and the hcp lattice is strained due to the addition of SiO_2. A marked decrease in the grain size is observed with the addition of 4.2-at. % SiO_2, which causes the development of grain separation and therefore enhances the coercivity. The origin of the increase in coercivity with 2.1-at. % SiO_2 is also discussed.

I. INTRODUCTION

CoPt-based alloy films have attracted much interest for use in high density longitudinal recording, because a high coercivity (H_c) of around 2000 Oe and low media noise properties can be obtained by optimizing both alloy compositions and sputtering processes.[1,2] Therefore, the relationship between the microstructure and magnetic properties in the CoPt-based alloy films are still the subject of interest.

On the other hand, ferromagnetic metal films with oxide's addition have been studied because of their potential for high H_c.[3] Magnetic anisotropy originating from the interface between the metal and the oxide is discussed.[4] Recently, the addition of oxides such as SiO_2 to CoCrPt magnetic films has been shown to cause an increase in both in-plane H_c and coercive squareness (S^*) due to the reduction of the strong hcp Co c-axis texture perpendicular to the film plane.[5]

In this paper, we report the effects of SiO_2 addition on CoNiPt alloy films which have a random hcp Co c-axis orientation and strong in-plane magnetic anisotropy.

II. EXPERIMENTAL PROCEDURE

A NiP underlayer[2] with a thickness of 420 A and a CoNiPt magnetic layer were successively deposited on NiP-plated and mechanically textured Al substrates by rf sputtering. Ar pressure during the deposition was 20 mTorr. SiO_2 was added to the CoNiPt films by placing pure SiO_2 chips on the $Co_{81}Ni_7Pt_{12}$ alloy target. The composition of the SiO_2 was controlled from 0 to 8 at. % by changing the number of the chips and the overall composition was determined by ICP and Auger electron spectroscopy (AES).

Magnetic hysteresis curves were measured by the vibrating sample magnetometer (VSM) and magnetic anisotropies were evaluated by a torque magnetometer. Media noise was measured by a recording tester using thin film head. Signal frequency was 6 MHz and media noise integrated in the range from 0 to 13 MHz was measured as a ratio to the signal intensity (STMNR). The Si–O bonding state in the sputtered alloy films were analyzed by XPS. Crystal structures, such as lattice constant, crystal orientation, and crystallinity were determined by using x-ray diffraction with Cu-$K\alpha$ radiation. Grain structure was observed by SEM and TEM.

III. RESULTS AND DISCUSSION

Figure 1 shows in-plane magnetic hysteresis properties, such as in-plane H_c, thickness saturation-magnetization product (tM_s) and S^*, measured by VSM as a function of SiO_2 content in the $CoNiPt(SiO_2)_x$ films with a constant film thickness of 525 Å. H_c rapidly increases from 1400 to 2600 Oe with increasing SiO_2 to 3.5 at. %. Saturation magnetization gradually decreases as the amount of SiO_2 increases. S^* decreases slightly from 0.90 to 0.85 in the range from 0 to 3.5-at. % SiO_2.

Magnetic properties of the $CoNiPt(SiO_2)_x$ films with constant tM_s of 4.50 $\pm$0.15 memu/cm^2 are listed in Table I. The addition of SiO_2 results in the significant increase in H_c without a large reduction of squareness. The uniaxial anisotropy energy $K_\perp$ is measured by the field dependence of the torque for the direction at 45° from the film normal.[6] The magnetic anisotropy energy K including shape anisotropy energy is calculated by the equation, as follows:

$$K=K_\perp+2\pi M_s^2.$$

The observed values of $K_\perp$ are positive, which indicates that the in-plane uniaxial anisotropy exists. The SiO_2 addition causes the slight increase in the $K_\perp$. However, this increase in the $K_\perp$, which means the increase in the in-plane anisotropy, is relatively small compared with the shape anisotropy. No systematic dependence of K which represents macroscopic in-plane magnetic anisotropy, with respect to the SiO_2 content, is observed and the increase of H_c with SiO_2 addition cannot be explained by the increase in $K_\perp$. Media noise is also shown as STMNR in Table I. The addition of SiO_2 is very effective for reduction of the media noise.

XPS shows the chemical shift in the binding energy of Si atoms in the sputtered films is close to that of bulk SiO_2, which indicates that the Si atoms in the sputtered film are in the form of SiO_2. The formation of SiO_2 in the sputtered

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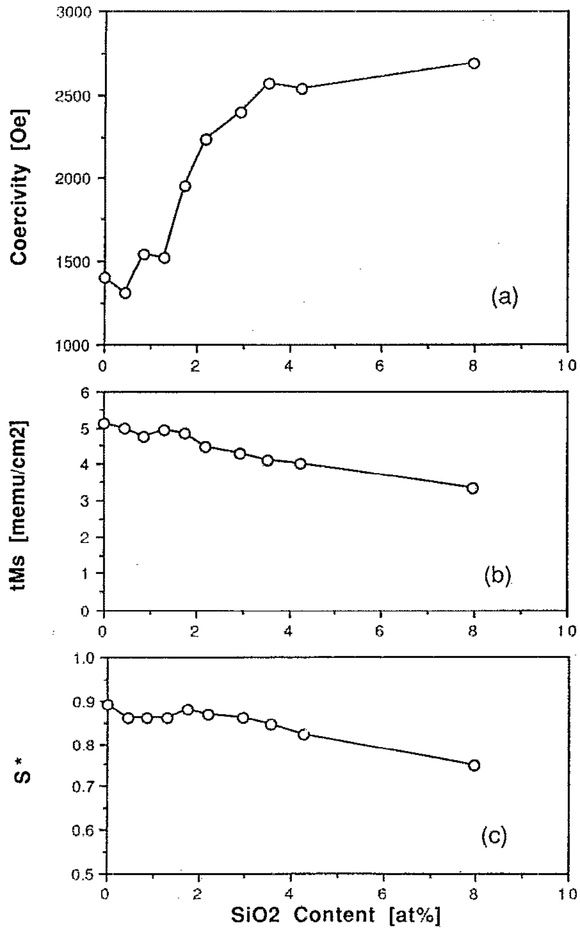

FIG. 1. Magnetic hysteresis properties, such as H_c (a), tM_s (b), and S^* (c) in CoNiPt(SiO_2) films with a constant thickness of 525 A, as a function of SiO_2 content.

films play an important role in the H_c enhancement. This result is also supported by the fact that Si addition is not effective for the H_c increase.

X-ray diffraction patterns from CoNiPt$(SiO_2)_x$ alloy films are shown in Fig. 2. Diffraction angles (2θ) of pure hcp Co as a bulk are $2\theta(100)=41.72°$, $2\theta(002)=44.80°$, and $2\theta(101)=47.61°$, respectively. Diffraction angles of a bulk CoNiPt (target piece) are measured as $2\theta(100)=40.68°$, $2\theta(002)=43.73°$, and $2\theta(101)=46.45°$, respectively. Thus diffraction peaks of the expanded hcp Co lattice due to the alloying are observed in the sputtered CoNiPt film. The ratio of integrated intensity (I) of the diffraction peak from the CoNiPt film is calculated to be $I(100)/I(101)=0.58$ and $I(002)/$

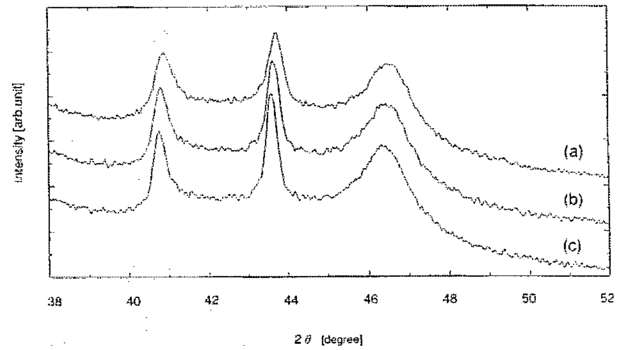

FIG. 2. X-ray diffractions from CoNiPt$(SiO_2)_x$ films, where $x=0$ (a), 2.1 (b), and 4.2 (c).

$I(101)=0.57$. In hcp Co with a perfect random c-axis orientation, the ratio is $I(100)/I(101)=0.20$ and $I(002)/I(101)=0.60$. Hence, the c-axis orientation in the CoNiPt film is random except that the degree of the (100) plane parallel to the film plane is relatively higher, i.e., the film is of slight (100) texture, which is also confirmed by three-dimensional distribution of each planes in pole figure analysis. The diffraction peak from the (101) plane is largely broadened. The addition of SiO_2 enhances the expansion of the hcp lattice, in comparison with that in the CoNiPt film without SiO_2. This result suggests that the hcp lattice is strained by thermal induced stress due to the interface between SiO_2 and CoNiPt. Integrated intensities of each diffraction peak are not influenced by the addition of SiO_2 and the intensity ratio is the same as that in the CoNiPt film with a random c-axis orientation.

Figure 3 shows grain structure of the surface of CoNiPt$(SiO_2)_x$ films, observed by SEM. Grain size is significantly reduced by the addition of 4.2-at. % SiO_2, while that in the film with 2.1-at. % SiO_2 is not strongly influenced. It is suggested that the excess SiO_2 except that present in the grain prevents the coalescence of grains during grain growth and/or enhances the nucleation density at the initial stage of the grain growth. Well separated fine grains with a diameter from 50 to 200 A are clarified in the CoNiPt$(SiO_2)_{4.2}$ film, by TEM analysis as shown in Fig. 4. At present, it cannot be identified whether the excess SiO_2 exists at grain boundaries. By observing the grain structures, the magnetic separation among crystal grains are enhanced in the film with 4.2-at. % SiO_2. This change of grain separation can cause an increase in H_c and a decrease in S^* and media noise without the change of the c-axis orientation of the hcp lattice in those

TABLE I. Magnetic properties in CoNiPt$(SiO_2)_x$ ($x=0$, 2.1, 4.2 at. %) films with a constant tM_s of 4.5 memu/cm^2, measured by VSM and a torque magnetometer.

Alloy	DEKTAK Thickness (A)	VSM H_c (Oe)	tM_s (memu/cm^2)	tM_r (memu/cm^2)	S	S^*	M_s (G)	Torque $K_\perp$ (erg/cc)	K (erg/cc)	Media noise STMNR (dB)
CoNiPt	458	1680	4.35	3.24	0.744	0.903	950	2.29×10^6	7.96×10^6	23.3
CoNiPt$(SiO_2)_{2.1}$	500	2009	4.62	3.36	0.730	0.894	924	2.65×10^6	8.01×10^6	27.3
CoNiPt$(SiO_2)_{4.2}$	550	2414	4.60	3.22	0.698	0.869	836	3.11×10^6	7.50×10^6	29.4

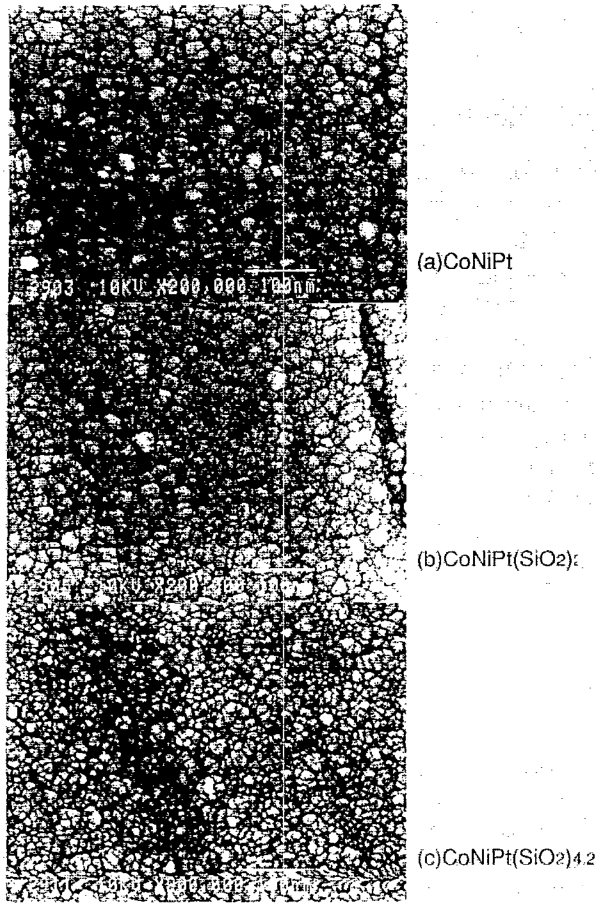

FIG. 3. SEM images of the surface of $CoNiPt(SiO_2)_x$ (x=0, 2.1, 4.2 at. %) films.

systems composed of exchange coupled crystal grains with a random c-axis orientation.[7]

Finally, we consider the origin of the H_c increase with the addition of a small amount of SiO_2. From TEM analysis, in the film with 2.1-at. % SiO_2, the degree of grain separation between crystal grains is observed to be similar to that in CoNiPt film without SiO_2. The shape and outline of the grains are observed to be more clear than those in pure CoNiPt film. It suggests that the addition of a small amount of SiO_2 influence the coalescence of the grain, possibly due to the existence of SiO_2 at the grain boundary. In addition, media noise is significantly reduced even by the addition of 2.1-at. % SiO_2, which suggests that the degree of magnetic isolation between grains is developed. In addition, the hcp lattice is expanded by the SiO_2 addition. In granular metal–

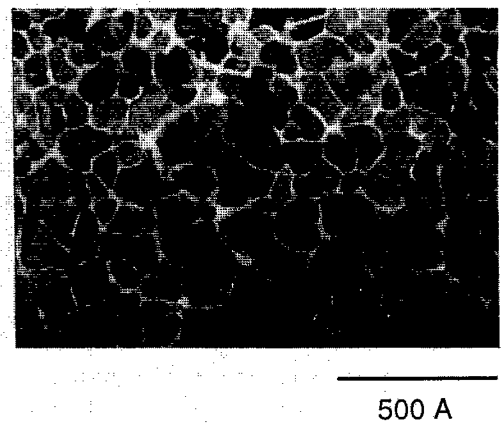

FIG. 4. TEM image of the grain structure in the $CoNiPt(SiO_2)_{4.2}$ film.

oxide films, stress induced magneto-elastic anisotropy due to the lattice misfit and the dislocation at the interface between the metal and the oxide has been discussed.[4,8] Therefore, the increase in crystalline anisotropy of each grain is due to the expansion of the hcp lattice mainly originated from the difference of the thermal expansion coefficient between the CoNiPt and the SiO_2 at the grain boundary is also considered as a possible contribution to enhance H_c, in this alloy system.

IV. CONCLUSIONS

Effects of SiO_2 addition on magnetic and structural properties have been studied in CoNiPt alloy films with a random c-axis orientation. A significant increase in H_c and signal to media noise ratio with a slight decrease in S^* are observed, while the perpendicular magnetic anisotropy decreases, slightly. The hcp lattice is expanded and the orientation of the c axis normal to the film plane is not changed by the addition of the SiO_2. A heavy doping of SiO_2 arises a marked decrease in the grain size and development of intergranular isolation, which result in the increase in H_c and the decrease in S^* and media noise. The origin of the increase in H_c with a small addition of SiO_2 is also discussed.

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