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Influence of stress on nucleation field of CoCrPt perpendicular media

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The influence of stress on the nucleation field was investigated for CoCrPt perpendicular media grown on a Ta/Hf buffer layer. The nucleation field increased to −1.5 kOe (second quadrant) following postdeposition annealing of a sample at 232 °C in air for 1 h. The residual in-plane stress for the annealed film was tensile, and in-plane x-ray diffraction showed that the a_0 lattice parameter increased with increasing annealing time. It is believed that the change in stress was due to surface oxidation of the CoCrPt film. The increased stress anisotropy perpendicular to the plane of the film resulted in the increased nucleation field.
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I. INTRODUCTION

Interest in perpendicular recording technology has been generated over concerns about the thermal stability of longitudinal recording media. The demand for higher areal recording densities requires continual reductions in average grain size in these thin films, making the media more susceptible to thermal decay effects. It is thought that perpendicular media may offer some advantage in terms of increased volume by allowing for taller grains. In any case, sufficient magnetic anisotropy is required to keep written bits stable for extended time periods.

Using high anisotropy media materials is one approach to trying to resolve these issues.[1] Having a material with a squareness ratio (remanent to saturated magnetization) of one and a large nucleation field is desirable.[2,3] The nucleation field is defined as the reversing field (preferably in the second quadrant of a hysteresis loop) at which the magnetization starts to drop from its value at saturation. The more "negative" the nucleation field, the more stable the remanent magnetic state should be since a larger reversing field is required to alter the magnetization. The value of the nucleation field should scale with the component of anisotropy in the direction of the applied magnetic field.

This article demonstrates the use of stress anisotropy to increase the nucleation field of CoCrPt perpendicular media grown on a Ta/Hf buffer. By annealing a thin film sample in air, surface oxidation produced an in-plane tensile stress (compressive stress perpendicular to the plane) which provided a perpendicular magnetoelastic anisotropy component. This effective increase in anisotropy led to the increased nucleation field.

II. EXPERIMENTAL DETAILS

Samples were prepared by dc magnetron sputtering onto thermally oxidized Si (100) wafers heated to approximately 280 °C. The buffer layer consisted of a 5 nm Ta seed layer followed by a 10 nm buffer of Hf. The buffer layers were sputtered in 3 mTorr of Ar. The pressure was increased to 15 mTorr for the deposition of the $CoCr_{19}Pt_{10}$ film.

The sample was annealed on a hotplate at 232 °C in air. After a set period of time, the sample was removed and its magnetic and structural properties were measured. Subsequently, the sample was placed back on the hotplate for further treatment. Magnetic properties were measured with a vibrating sample magnetometer (VSM) or by magneto-optical Kerr effect (MOKE). Lattice parameters (a_0) were measured using in-plane x-ray diffraction (XRD). Changes in film stress were recorded with a KLA Tencor thin film stress analyzer which measures wafer curvature. Samples for plan-view and cross-sectional transmission electron microscopy (TEM) were prepared by mechanical polishing and ion milling of films grown on Si substrates.

III. RESULTS AND DISCUSSION

Figure 1 shows normalized hysteresis loops versus cumulative annealing time as measured by MOKE with the field applied perpendicular to the plane of the film. Films oxidized in air lost approximately 10% of their moment (verified by VSM measurements) due to surface oxidation of the CoCrPt. As the total annealing time increased, both the nucleation field H_n and the slope of the hysteresis loop at coercivity increased. After the first hour of annealing, H_n jumped to about −1.5 kOe and the coercivity increased slightly. Further annealing increased H_n to slightly above −2 kOe, but the coercivity dropped. The slope at coercivity is proportional to a parameter known as "α" which has been proposed as a measure of the exchange coupling and intrinsic noise in perpendicular recording media.[4] The increase in α with annealing time suggested that the exchange coupling was increased in the CoCrPt by the heat treatments. Since grain boundary oxidation within the CoCrPt would be expected to reduce intergranular exchange coupling, it is believed that the oxidation was limited to the surface of the film.

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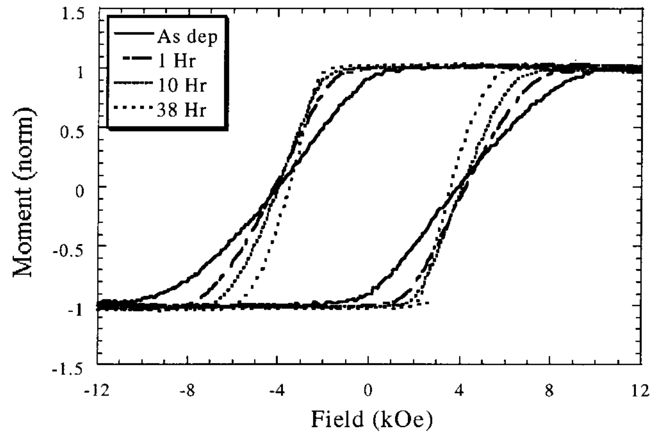

FIG. 1. MOKE loops measured perpendicular to the plane for Ta/Hf/CoCrPt structure during different stages of annealing treatment.

The effects of film oxidation were investigated by annealing a sample in vacuum. Figure 2 compares an as-deposited Ta/Hf/CoCrPt sample with one annealed in vacuum at 232 °C for 1 h. In this case, a slight increase in the magnetic moment was observed for the annealed sample which is typical for CoCrPt alloy films. Annealing in vacuum did not result in a large increase of H_n, but it did produce an increase in α. Therefore, the increase of H_n for the sample annealed in air was related to the oxidation of the film, but surface oxidation was not required to observe an increase in α.

The changes in magnetic properties were linked to structural changes in the CoCrPt induced by annealing in air. X-ray diffraction in-plane scans for the sample at different stages of the annealing process are presented in Fig. 3. This technique provides information about the degree of lattice parameter (a_0) mismatch between the buffer layer and the CoCrPt film. The mismatch between the Hf and the CoCrPt was about 19% for the as-deposited sample. The Hf peak does not change position after annealing, but the CoCrPt (11–20) peak shifted to lower angles due to the expansion of the CoCrPt lattice. The total change in lattice parameter was less than 1% even after extended annealing.

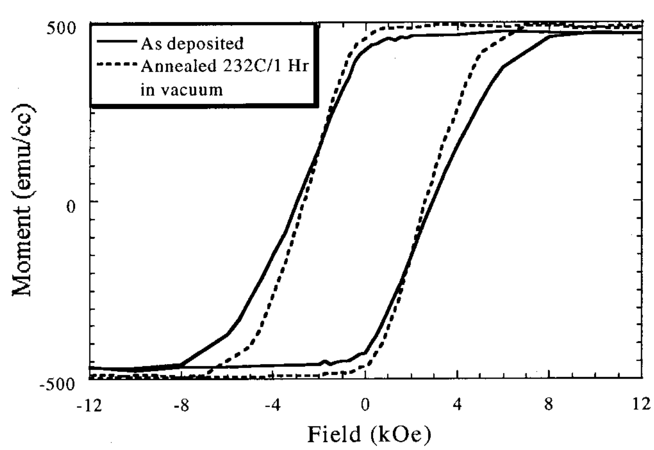

FIG. 2. Comparison of as-deposited vs vacuum annealed Ta/Hf/CoCrPt samples.

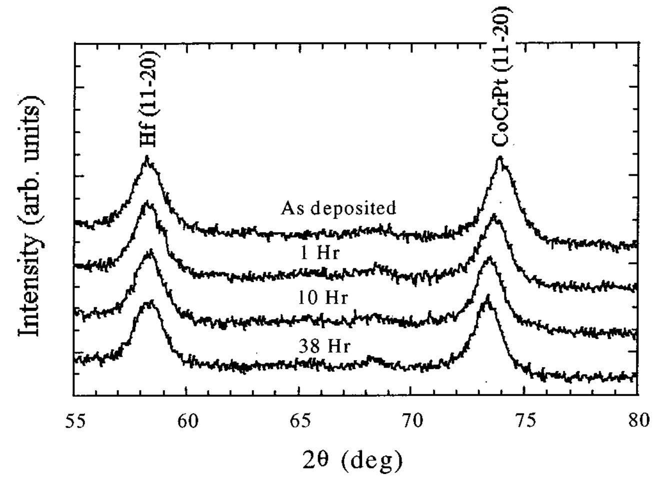

FIG. 3. In-plane XRD scans of Ta/Hf/CoCrPt structure after annealing in air for specified times.

The change in residual film stress was measured as a function of cumulative annealing time to compare with the increases in H_n and a_0. An increasing in-plane tensile stress was expected based on the results from the in-plane XRD. Figures 4(a) and 4(b) plot the dependence of $(-H_n)$ and a_0, respectively, versus annealing time for comparison. Figure 4(c) shows an increasing tensile stress with annealing time, consistent with the increase of a_0.

Cross-sectional TEM was used to compare the microstructures of an as-deposited structure and one that was annealed in air. These images are shown in Fig. 5. Plan-view images (not shown) of the two samples were also taken, but no significant differences were observable in average grain size or grain separation. In Fig. 5, an oxide layer approximately 5 nm thick is seen at the surface of the annealed CoCrPt. The oxidation does not appear to have affected the CoCrPt below the oxidized region, and the grain morphologies of the CoCrPt, Hf, and Ta layers in the two samples are similar.

An interfacial amorphous layer can also be seen in the images between the Hf and CoCrPt layers. This layer has been attributed to interfacial stress due to the large lattice mismatch and the subsequent intermixing of Co and Hf to form an amorphous region.[5] An amorphous interlayer was not observed by Lee *et al.*[6] for thin (<20 nm) CoCrPt films grown on a CoZr/Ti buffer. In that case, a large negative nucleation field and increased perpendicular anisotropy were attributed to high magnetoelastic strain in the CoCrPt film which had expanded its lattice to match the buffer (17% mismatch). The amorphous region appeared, however, in structures with a CoCrPt film thicker than 20 nm. The thick CoCrPt was unable to tolerate the high strain energy and subsequently relaxed to its bulk state after formation of the amorphous transition region. The H_n was small for the thick CoCrPt.

In this study, the as-deposited structure had an amorphous transition region and a small H_n. A large H_n resulted from postdeposition annealing in air and subsequent surface oxidation. For CoCrPt, similarly annealed films that were grown on buffer layers[5] other than Ta/Hf did not show the

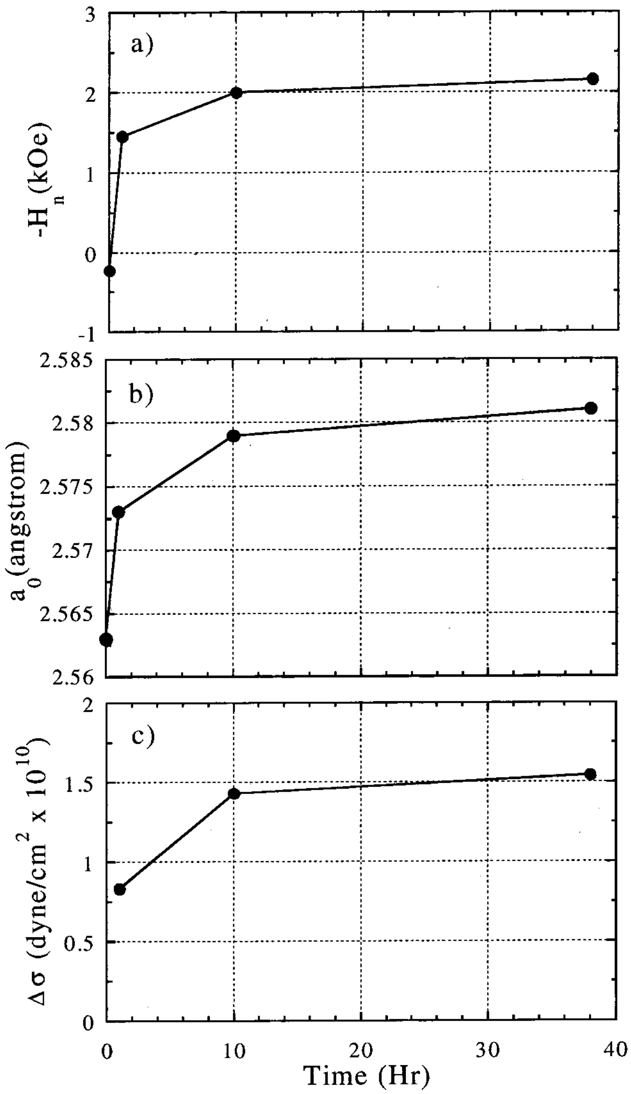

FIG. 4. (a) H_n vs annealing time, (b) lattice parameter vs annealing time, and (c) change in film stress vs annealing time.

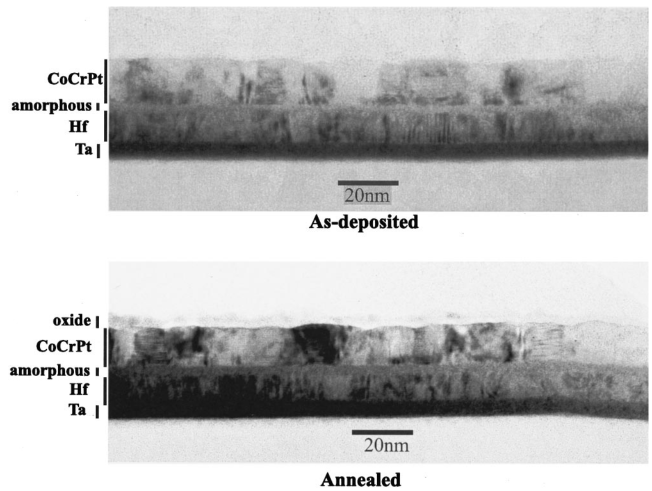

FIG. 5. Cross-sectional TEM images of as-deposited and air-annealed Ta/Hf/CoCrPt structures.

same magnitude of effect on H_n. Clearly, the control of H_n is not as simple as using a surface oxide layer to modify film stress. The resultant perpendicular anisotropy depends on the contributions to the CoCrPt microstructure from all layers in the media. The particular role of the buffer layer is the focus of Ref. 5.

IV. CONCLUSIONS

The annealing in air of a Ta/Hf/CoCrPt thin film structure resulted in a substantial increase in H_n. Tensile stress increased in the plane of the film as a result of the annealing process and surface oxidation. The increase in the hysteresis loop parameter α with annealing time suggested that the exchange coupling among grains in the CoCrPt film was increasing. Therefore, grain boundary oxidation within the film was not likely. The magnetoelastic anisotropy introduced by the tensile stress effectively increased the perpendicular anisotropy and H_n of the CoCrPt film.

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