HITPERM soft-magnetic underlayers for perpendicular thin film media

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A class of nanocrystalline alloys, HITPERM (Fe, Co)–M–B–Cu (M= Zr,Hf,Nb, etc.) found to exhibit excellent soft-magnetic properties is being studied for use as a soft-magnetic underlayer for perpendicular recording media. Previously, we reported that HITPERM films of ~100 nm thickness sputtered at room temperature (RT) and at ~2.3 W/cm^2 power density had exhibited an amorphous microstructure, which had turned mixed nanocrystalline when prepared at ~250 °C. However, nanoparticles of FeCo have now been crystallized even at RT without the application of heat, by increasing the sputtering power density to ~4.5 W/cm^2. This dramatically improved the $4\pi M_s$ while still maintaining a low coercivity. There was a further slight increase in the $4\pi M_s$ at ~6.8 W/cm^2. Moreover, these soft-magnetic properties were maintained even when the substrate temperature was subsequently raised to ~250 °C. Transmission electron microscopy studies showed the presence of relatively small nanocrystals of the ferromagnetic α'-FeCo (or α-FeCo) phase alone, for both sets of films. Previously, we had reported that the CoCrPt magnetic layer grew with a strong (00·2) texture on amorphous HITPERM. We have now seen that with a thin Ti intermediate layer (~5 nm) the CoCrPt layer maintained a strong (00·2) texture even on the nanocrystalline HITPERM. Thus, due to their particular nanocrystalline nature, these HITPERM films exhibit much better soft-magnetic properties, while still leading to strong (00·2) texture on the CoCrPt magnetic layer. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1558091]

INTRODUCTION

A double-layer perpendicular anisotropy system, incorporating a soft-magnetic keeper layer under the hard perpendicular magnetic layer is a leading candidate for systems with recording densities higher than 100 Gbits/in.^{2}.[1] The use of a soft-magnetic underlayer (SUL) in the perpendicular mode effectively increases the writing head field and allows for the extension of the superparamagnetic limit to even higher densities due to the possibility of using media with higher anisotropies. Additional advantages are stronger playback signals and effectively lower demagnetization fields in the recording layer.

Previously, we reported on the potential of a class of nanocrystalline alloys (HITPERM) found to exhibit excellent soft-magnetic properties,[2] as possible soft-magnetic underlayers for perpendicular recording media.[3] While HITPERM thin films deposited at ambient temperatures [room temperature (RT)] had exhibited an amorphous microstructure with low coercivity and moderate saturation magnetizations ($4\pi M_s$), sputtering at higher temperatures (~250 °C) had produced a mixed nanocrystalline microstructure, which caused a deterioration of the soft-magnetic properties.[3] However, we have now been able to significantly improve the soft-magnetic properties by crystallizing nanoparticles in HITPERM without heating the substrate. This was achieved by applying higher sputtering power densities. Moreover, these soft-magnetic properties were maintained even when the substrate temperature was subsequently raised to ~250 °C. These and other observations are reported in this article.

EXPERIMENTAL PROCEDURE

Soft-magnetic HITPERM films of ~100 nm thickness were deposited on glass substrates using rf sputtering with an alloy target of composition $(Fe_{0.7}Co_{0.3})_{88}Zr_7B_4Cu_1$. The sputtering powers used corresponded to power densities of 2.3, 4.5, and 6.8 W/cm^2. The pressure of Ar sputtering gas was maintained at 10 mTorr. When the HITPERM thin films were studied by themselves, a thin Ti coating (<3 nm) was used to protect from oxidation on subsequent exposure to the atmosphere. 30-nm-thick CoCrPt magnetic layers were deposited over the HITPERM films with a thin Ti intermediate layer (5 nm) serving to exchange decouple the recording layer from the SUL. CrMn (3 nm) was deposited on top of the magnetic layer with the goal of improving its coercivity by diffusing Cr and Mn to the grain boundaries. Both the CoCrPt and the CrMn were deposited at elevated temperature (~250 °C). Structural analysis was performed using x-ray diffractometry (Cu $K\alpha$). A vibrating sample magnetometer (VSM) was used to investigate the magnetic properties (coercivity, H_c, and saturation magnetization $4\pi M_s$). Transmission electron microscopy (TEM) was employed to study the film's microstructure.

RESULTS AND DISCUSSIONS

HITPERM films deposited at RT (100 nm thickness, 4.5 W/cm^2 sputter power density) showed broad amorphous α'-FeCo (or α-FeCo) (110) humps in XRD scans (Fig. 1).

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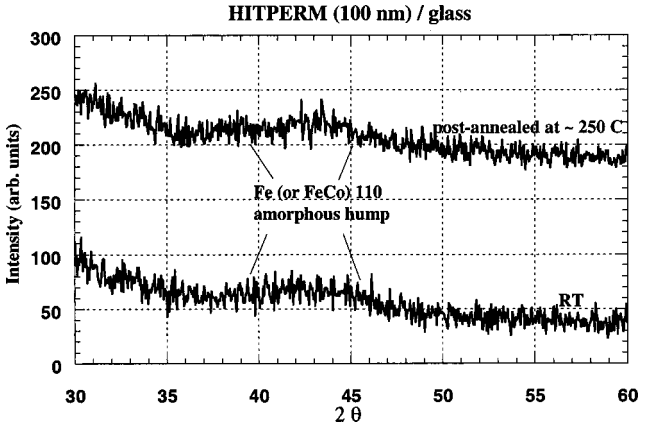

FIG. 1. XRD scans from HITPERM films sputtered onto glass substrates at 4.5 W/cm^2 power density. While both films were prepared at RT, the top one was then annealed at ~250 °C for 30 min.

The amorphous hump remained even when the films were subsequently annealed at ~250 °C for 30 min. (Fig. 1), indicating that the heat treatment had possibly not adversely affected the films either by way of crystallization of secondary phase particles or by way of large grain growth of FeCo crystallites. TEM corroborated this conclusion. Figures 2 and 3 are the bright-field images along with the selected-area electron diffraction (SAED) patterns obtained from HITPERM films, one deposited at RT (Fig. 2) and the other then subsequently annealed at 250 °C (Fig. 3). Both the films exhibit a microstructure consisting of nanocrystalline particles of size <~15 nm in an amorphous phase. The SAED pattern shows the presence of a diffuse α' (or α)-FeCo (110) ring indicating an amorphous phase (the matrix) with the other rings produced by the α' (or α)-FeCo nanoparticles. Since no other rings are present, we can infer that no other crystallites of any nonmagnetic phases are present, especially in the heat-treated film. It should be recalled here that in the HITPERM film (100 nm, 2.3 W/cm^2 power density) that was deposited at 250 °C, besides particles of the ferromagnetic α' (or α)-FeCo, particles of nonmagnetic Fe_2Zr had also been observed.[3] 100-nm-thick HITPERM films were also prepared at 6.8 W/cm^2 sputter power density and at RT, then subsequently annealed at 250 °C for 30 min. As in the case of the preceding set of films, these films too exhibited amorphous x-ray humps that remained even after the heat treatment. For both the films, TEM again showed only nanocrystalline particles of α' (or α)-FeCo to be present.

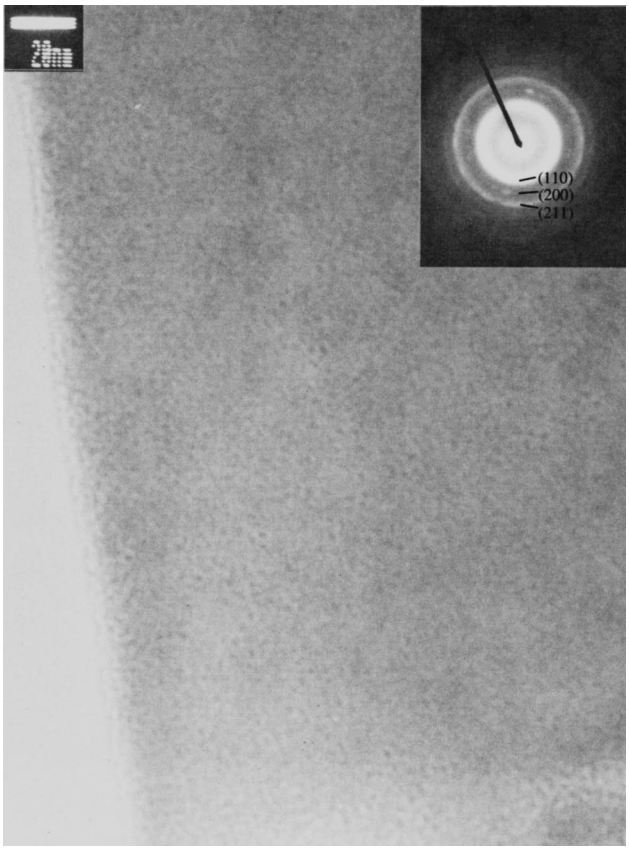

FIG. 2. Bright-field image and SAED pattern of 100 nm HITPERM film prepared at RT and under 4.5 W/cm^2 sputter power density.

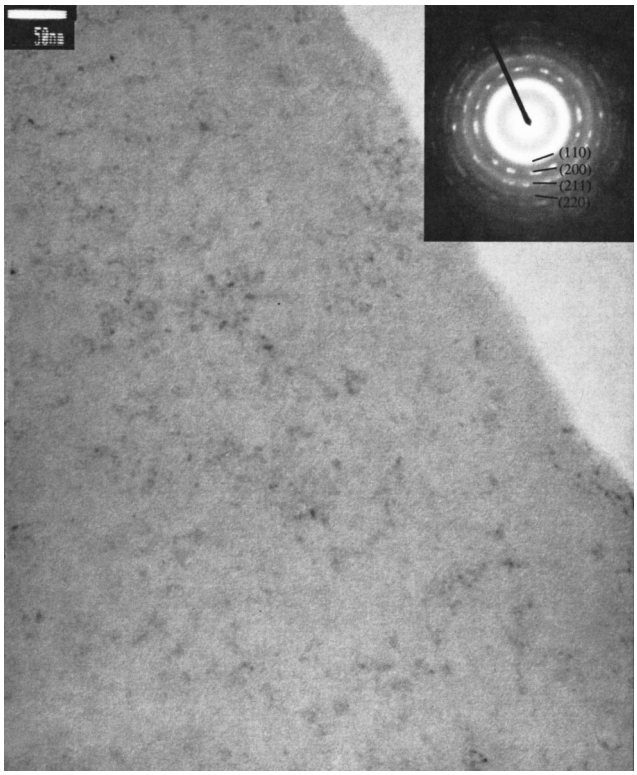

FIG. 3. Bright-field image and SAED pattern of 100 nm HITPERM film prepared at RT and under 4.5 W/cm^2 sputter power density after annealing in-situ at ~250 °C for 30 min.

Figure 4 gives the magnetic properties of these HITPERM films, prepared at the various sputtering power densities. The film produced at the lowest sputtering power density (2.3 W/cm^2) had, when prepared at RT exhibited a low coercivity (~3 Oe) and moderate $4\pi M_s$ (~13.2 kG), but when prepared at 250 °C had displayed a much higher coercivity (~27 Oe) with little change in the magnetization.[3] This had been attributed to the presence of the nonmagnetic Fe_2Zr particles and to the higher average magnetic anisotropy of the nanocrystalline phase compared to the amorphous phase. However, while the HITPERM films sputtered at 4.5 and 6.8 W/cm^2 showed low coercivities (4–5 Oe), they

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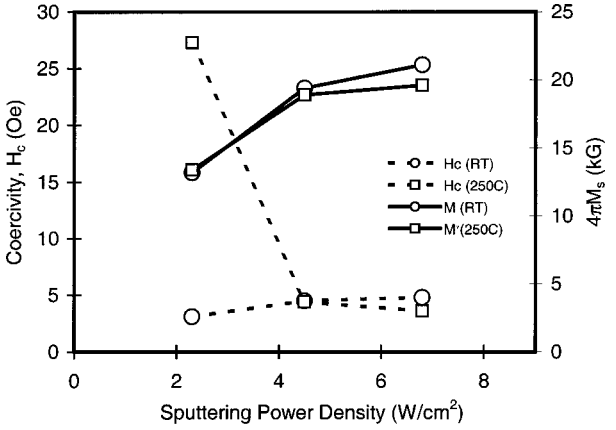

FIG. 4. Magnetic properties of sputtered HITPERM films.

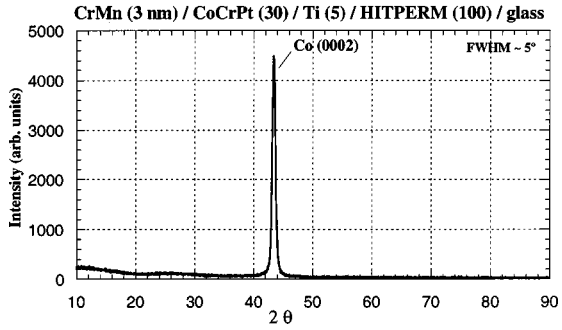

FIG. 5. XRD scan from a CrMn/CoCrPt/Ti/HITPERM film structure where the HITPERM was prepared at 4.5 W/cm^2 sputter power density. The CoCrPt layer shows a strong hcp (0002) orientation with a full width at half maximum distribution of ~5° (determined from rocking curve measurements).

also showed a dramatic improvement in the $4\pi M_s$ (19–20 kG). Moreover, these were maintained even after the subsequent heat-treatment at 250 °C.

The primary and secondary crystallization temperatures in bulk HITPERM, prepared by rapid solidification processing are significantly higher [$T_{x1}=510$ °C for α'-FeCo, $T_{x2}=700$ °C for $(Fe,Co)_3Zr$] than the temperatures used here.[2] While higher surface diffusion rates during sputtering could explain why we see crystallization at much lower temperatures in the HITPERM films sputtered at the lowest power (2.3 W/cm^2),[3] the higher sputtering power (4.5 and 6.8 W/cm^2) is most certainly responsible for causing crystallization at RT itself. The higher the sputtering power, the more energetic are the sputtered atoms and the barrier to the nucleation of crystallites is more easily overcome. Once formed, the crystallites are energetically stable and the subsequent annealing at 250 °C is not sufficient to cause deleterious grain growth. Temperatures higher than 250 °C, however, may cause grain growth and secondary phase crystallization that deteriorate the soft-magnetic properties. The higher sputtering power is also responsible for the improvement in the saturation magnetization, because it probably leads to an increase in the nanocrystalline volume fraction as compared to the amorphous phase.

According to the Herzer model for nanocrystalline ferromagnetic materials,[4] the coercivity H_c is predicted to scale as

$$H_c \sim \frac{K_1^4 D^6}{A^3},$$

where K_1 denotes the first term in the angular expansion of the magnetocrystalline anisotropy energy density, A the exchange stiffness, and D the grain size. For the case of these FeCo-based alloys with the parameters $K_1=8$ kJ/m^3 and $A \sim 1.7\times10^{-11}$ J/m, using an average grain size of roughly 15 nm corresponds to a coercivity of ~0.1 Oe. But the coercivities seen here are at least an order of magnitude higher. Induced anisotropies due to inhomogeneities and strains inherent in thin film preparation are conceivably responsible for the higher coercivities that we see in these alloys.

Figure 5 is the x-ray diffraction (XRD) scan showing a strong (0002) orientation for the CoCrPt magnetic layer. For this case, the HITPERM (4.5 W/cm^2) and Ti layers were prepared at RT. The temperature was raised to 250 °C, and the CoCrPt and CrMn layers were then deposited *in situ*. Thus, it is seen that the CoCrPt grows with a strong (0002) texture even on nanocrystalline HITPERM. Strong CoCrPt textures were also observed over HITPERM films prepared at 6.8 W/cm^2.

This is in contrast to what was seen previously, when CoCrPt displayed a strong texture only when deposited over amorphous HITPERM.[3] The fine nanocrystalline nature of these films, compared to the mixed structure composed of relatively larger grains, is believed to be responsible for this.

CONCLUSIONS

HITPERM thin films with improved soft-magnetic properties have been prepared at RT without the requirement of applying heat, by employing higher sputtering powers. These films maintained their excellent properties even when subsequently annealed at high temperature. The fine nanocrystalline nature of the microstructure and the absence of any deleterious nonmagnetic phases are plausible explanations for these observations. In addition, the fine nanocrystalline nature also imparts a strong (0002) orientation to the CoCrPt magnetic layer.

ACKNOWLEDGMENTS

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