Coercivity analysis in sputtered Sm–Co thin films

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Hard nanocrystalline Sm–Co thin films having a thickness of 500 nm have been prepared by heat-treating magnetron sputtered amorphous samples deposited over a 300 nm Cr buffer layer onto room temperature water cooled Si substrates. The thermal treatments resulted in the nanocrystallization of the precursor films and in the development of room temperature coercivities covering a range going from a few kOe, measured in the samples treated at low temperature, up to some tens of kOe, observed in the case of the films annealed at high temperatures (the room temperature coercivity of the sample treated at 825 K was 26 kOe). Our analysis of the influence of the thermal treatments on the particularities of the reversal process was based on the measurement of the temperature dependence of the coercive force. It was carried out in the framework of the micromagnetic model, which allowed us to evaluate two parameters accounting for the local anisotropy reduction and the magnitude of the local dipolar fields, respectively. Our results show that the high temperature treatments result in a better degree of crystallization (lower local anisotropy deterioration). That crystallinity improvement is associated to an increase of the local dipolar interactions. © 1999 American Institute of Physics. [S0021-8979(99)68808-9]

INTRODUCTION

Thin films of hard magnetic materials, such as the rare-earth transition metal alloys, have stimulated an active research aiming at their application in different devices and in magnetic recording media. SmCo films with Cr underlayer, prepared under different conditions, exhibiting high magnetic coercivity, small grain size, and high uniaxial anisotropy have shown a good potential for high density recording media.^{1–4} Recently, room temperature giant coercivity values have been reported in nanocrystalline Sm(Co,Cu,Ni)/Cr bilayers, in which the nanocrystalline structure was achieved by postannealing of the initially amorphous as-deposited films.⁵ The possibility of tuning the coercivity through the variation of the heat treatment parameters raises a question about the link between the reversal process and the structural and microstructural modifications induced by the anneals.

The characteristics of the magnetization reversal process of a hard magnetic film and, particularly, the magnitude of its coercive force depend on both the intrinsic and the extrinsic properties of the sample. The intrinsic properties (i.e., magnetocrystalline anisotropy, saturation magnetization, and exchange correlation length) are usually considered requisites for the development of the magnetic hardness and determine the choice of the composition of the main phase present in the film. Nevertheless, the actual coercivity value is ruled by a range of extrinsic features, including from the morphology (e.g., main phase grain shape and size) to the distribution of sites where the local values of the intrinsic properties depart from their bulk values (i.e., magnetic de-

fects). Those extrinsic features should be controlled during the deposition and treatment processes in order to get maximum coercivities. It is then crucial, in order to optimize the hard magnetic behavior, to try to clarify the relationships between the reversal process and all the mentioned extrinsic properties. The basic way of examining those relationships is the analysis of the temperature dependence of the coercive force.⁶ That analysis is based on the link, initially proposed by Brown⁷ and thoroughly developed by Kronmüller,^{6,8} between the coercivity, H_C , the anisotropy field, H_K , and the saturation magnetization, M_S :

$$H_C(T) = \alpha_\varphi \alpha_K H_K(T) - N_{\text{eff}} M_S(T), \quad (1)$$

where α_φ is given by the texture of the hard phase grains and α_K and N_{eff} are fitting parameters depending on the local anisotropy and the stray fields, respectively. Despite its simplicity (it reduces the whole microstructure to only three parameters) this treatment (usually known as the micromagnetic model) has evidenced to be very useful to understand the behavior of permanent magnet samples.⁹

EXPERIMENT

SmCo/Cr bilayers were deposited on Si substrates by means of a direct-current (dc) magnetron sputtering system without substrate heating. The base pressure was better than 10^{-7} Torr and Ar at a pressure of 5 mTorr was used as discharge gas. The Cr underlayers were deposited from a pure (99.9) solid Cr target. A pressed-powder SmCo_5 target was used to grow the SmCo layers. The deposition rates were 1.25 Å/s for Cr and 6 Å/s for SmCo, and were calibrated by low angle x-ray diffractometry (XRD). The thick-

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FIG. 1. Annealing temperature dependence of the average grain size.

ness of the Cr underlayer and the SmCo films were 300 and 500 nm, respectively. A capping layer (15 nm of Cr) was deposited in order to protect the bilayer. Different pieces of the same as-deposited sample were heat treated for 30 min in vacuum (10^{-5} Torr). The annealing temperatures, which ranged from 500 up to 600 °C, were used to designate the heat treatment. The structural properties of the annealed films were determined by XRD. The magnetic properties were measured by means of a superconducting quantum interference device (SQUID) magnetometer with a maximum field of 55 kOe and in the temperature range from 5 up to 350 K. The thermal evolution of the coercivity was determined as follows: (i) the bilayers were magnetized by applying the maximum available magnetic field at the maximum temperature; (ii) the samples were then field cooled down to the measurement temperature; (iii) increasing reversed fields were applied in order to demagnetize the sample.

RESULTS AND DISCUSSION

After the thermal treatments, the as-deposited amorphous films exhibited SmCo₅ XRD reflections as well as a residual amorphous halo whose intensity decreased with the increase of the annealing temperature clearly indicating the

FIG. 2. Temperature dependence of the coercive force of films treated at different temperatures. The inset shows the annealing temperature dependence of the room temperature coercive force.

FIG. 3. Fit to Eq. (1) of the coercivity data.

attainment of a larger fraction of the crystallization process. Figure 1 presents the annealing temperature dependence of the average structural coherence length (grain size) as evaluated, by means of the Scherrer formula, from the measurement of the width of the (111) SmCo₅ reflections. These data show the monotonous increase, from 12 up to 18 nm, of the average grain size with the increase of the treatment temperature.

Our results for the temperature dependence of the saturation coercive force of the annealed films are presented in Fig. 2 (the inset shows the annealing temperature dependence of the room temperature coercivity). As it is apparent from the figure, in all the films the coercive force monotonously increased with the decrease of the temperature. The data in Fig. 2 were analyzed in the framework of the micro-magnetic model by considering the temperature dependencies of the saturation magnetization and the anisotropy field of SmCo₅¹⁰ and $\alpha_\phi = 0.5$ (α_ϕ was evaluated following⁶ and considering nonexchange coupled, isotropically distributed grains). The corresponding fits are presented in Fig. 3 and gives evidence that expression (1) adequately describes the observed coercivity behavior.

Figure 4 presents the annealing temperature dependence of the α_K and N_{eff} parameters. From this figure it is clear that

FIG. 4. Annealing temperature dependence of α_K and N_{eff} .

FIG. 5. N_{eff} dependence on α_K (data corresponding to samples annealed at different temperatures).

the development of high coercivities (samples treated above 525 °C) is linked to the achievement of the highest α_K values, which is understood in the sense that the higher the H_c value, the better the crystallinity of the SmCo grains.⁶ Also, we should point out that the obtained N_{eff} values (in some cases clearly larger than 1) increase with the increase of the annealing temperature which could be ascribed, in close relationship to the annealing temperature evolution of α_K , to the development of polyhedral grains having sharp edges and corners.

It is also interesting to point out that N_{eff} depends, in a close to linear way, on α_K (see Fig. 5) which suggests that the magnetic pole distribution, at the place from where the magnetization reversal proceeds, is strongly influenced by the degree of crystallinity of the hard phase (the better the crystallinity the sharper the grain edges and corners). Finally, we propose that the optimum annealing conditions reflect the compromise between small local anisotropy deterioration (large α_K values) and a relatively small magnitude of the local stray field (linked to small N_{eff} values). That compromise results in our samples in optimum coercivity in the case of the 550 °C annealed sample.

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