SURFACE AND BULK ANISOTROPY OF RE-TM FILMS FOR MAGNETO-OPTIC RECORDING

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Abstract—Magnetic perpendicular anisotropy of RF-sputtered amorphous TbFe/SiN thin films have been investigated. Anisotropy constants were evaluated from both magnetization curves and magneto-optic effects dependences on in-plane magnetic field. Significant difference was observed between the magnetic anisotropy of the whole film and that measured from its surface, and the difference depended on preparation conditions and film thickness. It was proposed that the incoherent magnetization rotation in external field was induced by very thin highly-magnetized surface layer, which was exchange coupled with the film. Therefore the observed value of the anisotropy energy differs from the intrinsic anisotropy value of unoxidized volume.

KEYWORDS: ANISOTROPY CONSTANTS, MAGNETIZATION CURVE, KERR EFFECT, SURFACE LAYER, EXCHANGE COUPLING, SPUTTERING CONDITIONS.

INTRODUCTION

Uniaxial magnetic anisotropy is the vital characteristic of the magneto-optic recording media. Its value determines the minimum size and regularity of written domains. Magnetic anisotropy of amorphous rare-earth transition-metal films was extensively studied for the past years [1]. It was generally believed that the film was magnetically homogeneous and the Stoner-Wolfarth model can be applied to evaluate anisotropy constants from the experimental data.

At the same time it is well known that RE-TM films readily oxidize not only on air but even under UHV conditions [2], therefore the films for practical application are in-situ overdeposited with a dielectric material to protect them from oxidation. The oxide layer was shown to possess high magnetization [3]. Exchange coupling was observed between the layer and the remaining unoxidized film [4].

Therefore the magnetization process in the external field applied along the hard axis may not be described by the Stoner-Wolfarth model. In the case of incoherent magnetization rotation the measured anisotropy constants may differ significantly from the intrinsic anisotropy of the amorphous alloy.

The incoherent magnetization rotation can be observed in experiment by comparing the data on surface and volume spin rotation which in turn can be obtained from magneto-optic measurements [5]. Due to the limited penetration depth of light (30 nm), the Kerr effect reflects the surface characteristics as opposed to the bulk response. Recently it became possible to measure the surface magnetization direction in the surface layer as thin as 1 nm [2].

In this report we present results on measurements of bulk and surface anisotropy constants in amorphous Tb-Fe films for MO recording. Anisotropy constants were measured with

vibrating sample magnetometer (VSM) and with modified magneto-optic (MO) hysteresis loop tracer. The difference between surface and bulk anisotropy constants is discussed in terms of incoherent spin rotation model.

EXPERIMENTAL PROCEDURE

TbFe films and protective SiN under- and overlayers were deposited by RF-sputtering onto glass substrates in a Alcatel SCM-601M system. The chamber was evacuated to a base pressure below 8×10^{-8} mbar by a 8" cryopump and a titanium getter pump. The experiments were undertaken in a class 100 clean room. TbFe target had a composite construction. TbFe composition was varied in the range 18-28 at. % Tb by mounting the appropriate number of terbium chips onto an 8" iron disc. Argon pressure during sputtering was 0.3 - 3 Pa for TbFe and 0.3 Pa for SiN. TbFe layer thickness was measured by precalibrated quartz monitor and was varied in the 5-1000 nm range, SiN layers thicknesses were 85 nm. Deposition rate was varied in the range of 5 - 40 nm/min by the supplied RF power.

The film composition was analysed by Auger and SIMS profiling. The amorphous structure of the films was confirmed by x-ray diffraction.

Sensitive home built VSM equipped with a computer data acquisition system was used to measure the magnetization curves. The accuracy of the instrument was sufficient to measure the magnetization of 2 nm thick TbFe film. The example of the VSM loops is given in Figure 1.

We propose a new characteristic of the quality of the film reversal in the in-plane field. We called this value a planar magnetic moment $M_{||}$. It was calculated from an in-plane loop as a saturation moment of a minor loop superimposed on a non-saturating trend (see Figure 1).

From VSM hysteresis loops spontaneous magnetization I_s and bulk uniaxial anisotropy constants K_1 and K_2 were determined. In accordance with the coherent magnetization rotation model, the free energy density of the magnetic film is:

$$E = K_1 \sin^2 \varphi + K_2 \sin^4 \varphi + 2I_s \cos \varphi - HI_s \sin \varphi \quad (1)$$

where K_1 and K_2 are the anisotropy constants, φ is the angle between the magnetization vector and the film normal, I_s is the spontaneous magnetization, H is the in-plane magnetic field strength. The condition of energy minimum can be written as $Y = AX + B$, where

$$X = \sin^2 \varphi = \left(\frac{I}{I_s} \right)^2, \quad Y = \frac{H}{\sin \varphi} = \frac{H}{(I/I_s)} \quad (2)$$

$$A = \frac{2(K_1 - 2\pi I_s^2)}{I_s}, \quad B = \frac{4K_2}{I_s} \quad (3)$$

Figure 1. Example of the perpendicular and in-plane hysteresis loops of Tb₁₈Fe₈₂ film (80 nm thick).

Figure 2. In-plane magnetization curve of 15 nm-thick Tb₁₈Fe₈₂ film: a) M-H plot; b) the Sucksmith-Thompson plot.

Figure 3. Diagram of magneto-optic experimental setup for perpendicular anisotropy measurements.

If the model describes the magnetization curve $I(H)$ properly, the experimental points (H_i, I_i) re-plotted in the X-Y coordinates must match the straight line. Here I_i is the i -th measured value of the in-plane magnetization. The A and B coefficients of the linear function $Y(X)$ were found by the least mean method. The example of measured dependences (H_i, I_i) and that re-plotted in the X-Y coordinates is given in Figure 2.

The anisotropy constants of the films were measured by magneto-optical method similar to described in [5]. The diagram of the optical part of the experimental setup is shown in Figure 3. The external magnetic field was slightly tilted from the film plane during the anisotropy measurement in order to prevent domains formation in the saturated film. Both Kerr rotation from the film side and the substrate side were measured versus the in-plane magnetic field, as well as the Faraday rotation for films thinner than 80 nm. Figure 4 shows representative example of MO rotation versus in-plane field.

RESULTS AND DISCUSSION

Sputtering gas pressure

Sputtering gas pressure is an important process parameter which affects film microstructure and may give rise to a mechanical stress. The Ar pressure dependences of magnetic properties of the films as measured by VSM are shown in Figure 5. One can see that there is optimum pressure when the anisotropy reaches maximum. At this point the planar magnetic moment $M_{||}$ is minimum and the coherence of the magnetization rotation may be the best.

Figure 6 shows the same dependences of the first anisotropy constant K_1 as measured by the MO technique from top and bottom surfaces of the film. The maximum of the anisotropy value is at the same argon pressure but the amplitude of variation of K with pressure is different. A general trend of K_1 measured with Faraday effect is similar to the VSM results. Anisotropy measured from substrate side is nearly constant with Ar pressure but that for the film side reveals sharp maximum.

Film thickness

Thickness dependence of the spontaneous magnetization for several film compositions is presented in Figure 7. The magnetization is practically constant in films thicker than 50 nm but it varies remarkably in thinner films. The character of this variation is nearly hyperbolic, and the magnetization plotted versus inverse thickness is practically linear (see Figure 7b). Of special note is the slope of the dependences. In iron-rich films the slope is positive, i.e. the magnetization is higher in thinner films. In terbium-rich the slope is negative and the magnetization is lower in thinner films.

Following the authors [6] we propose the existence of very thin boundary oxidation layer in Tb-Fe film. The magnetic moment of the TbFe layer adds (or subtracts for Tb-rich films) from the constant moment of the surface layer due to positive (or negative) exchange interaction [4]. The thickness of the

Figure 4. Dependence of Faraday rotation on the in-plane field for 60-nm thick Tb₂₆Fe₇₄ film. The circles are the experiment, solid line - the coherent magnetization rotation theory.

Figure 5. Dependence of the magnetic properties of $Tb_{18}Fe_{82}$ films on sputtering Ar pressure (measured by VSM).

Figure 6. Dependence of the first anisotropy constant K_1 on sputtering Ar pressure of 80-nm thick $Tb_{18}Fe_{82}$ films (measured by magneto-optic technique).

boundary layer in our samples is less than 5 nm because the dependences in Figure 6b are linear up to this thickness.

Figure 8 shows magnetization curves measured by VSM for films with various thickness and Tb content 18 at.%. One can see that 5 nm thick film easily saturates in the in-plane field about 8 kOe, but the magnetization of thicker films is much harder. The magnetization process seems to be incoherent. It goes easier in thinner films (or near the surface) and harder in the bulk. We believe that it is not correct to apply the Sucksmith-Thompson method formally to these magnetization curves to obtain the anisotropy constants because the reversal is clearly incoherent.

We tried to apply MO technique to measure the thickness dependence of anisotropy. The results of the MO measurements of anisotropy constants seem to be incorrect for the magnetic layers thinner than 50 nm. Strong interference effect was observed in TbFe layer and the Kerr ellipticity was as large as Kerr rotation. The MO method [5,7] was based on the assumption that Kerr rotation angle was proportional to the perpendicular component of magnetization and the

Figure 7. Thickness dependence of spontaneous magnetization of Tb_xFe_{100-x} films: a) I_s versus thickness t , b) I_s versus $1/t$.

Figure 8 In-plane magnetization curves of $Tb_{18}Fe_{82}$ films of various thicknesses. Magnetic moment of every sample is normalized to its saturation moment.

magnetic circular dichroism (MCD) was not taken into account. In fact the measured MO signal depends on both Kerr rotation and ellipticity [7, 8]. The in-plane field dependence of MCD is unknown, hence further improvement of the MO method of anisotropy energy determination is necessary for thinner films.

Micromagnetics of reversal

Angular spin distributions were calculated in the frame of one dimensional micromagnetic model similar to [9] which accounted for the inhomogeneity of a spontaneous magnetization near the film surface. In detail the model will be described elsewhere [10]. Magnetization curves derived for films various thicknesses match well the measured ones. Qualitative distributions of magnetization vectors are shown in Figure 9. In TM-rich films exchange coupling with the surface layer is positive and it is negative in RE-rich ones.

The micromagnetic model predicts that the presence of the boundary surface layer decreases the observed value of the anisotropy in comparison with the intrinsic value for iron-rich films and increases that for terbium-rich films. This fact agreed completely with the experiment.

Figure 9. Micromagnetic magnetization distributions near the film surface a) TM-rich film; b) RE-rich film.

CONCLUSION

- a) Significant difference have been observed between the magnetic anisotropy measured on the film surface and the bulk, and the difference depends on preparation conditions and film thickness.
- b) Highly magnetized surface boundary layer was detected in protected TbFe films sputtered under UHV conditions. The layer thickness was less than 5 nm.
- c) In-plane reversal is incoherent because of the presence of the surface layer. Therefore the macroscopically observable value of anisotropy may differ markedly from the intrinsic anisotropy of the amorphous alloy.

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