Journal of ELECTRICAL ENGINEERING, VOL 55. NO 10/S, 2004, 35-37

MAGNETIC PROPERTIES AND MAGNETOELASTIC COUPLING MEASUREMENT IN LAYERED Fe-Co-B THIN FILMS

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This paper describes an optical cantilever-based system for the measurement of the magnetoelastic coupling of magnetostrictive thin films. The system is calibrated to evaluate the magnetoelastic coupling with no dependence on the Young modulus of the substrate. It has been applied to the measurement of the magnetoelastic coupling of a $(Fe_{80}Co_{20})_{80}B_{20}$ amorphous alloy which appear to be a good magnetostrictive material for piezoelectric-magnetostrictive sensor applications.

Keywords: magnetic sensor, piezoelectric-magnetostrictive, magnetoelastic, FeCoB

1 INTRODUCTION

One interesting familiy of magnetic sensors are the piezoelectric-magnetostrictive. Their sensitivity depends strongly on the magnetostriction coefficient of the magnetic layer as well as the good mechanical coupling between the magnetic and piezoelectric materials. First prototypes were made using a viscous interface [1,2] between both layers and were later improved growing a magnetostrictive thin film by sputtering on the piezoelectric substrate [3,4]. It is then desirable to have a material with a large magnetostriction coefficient which can be easily grown as a thin film directly on the piezoelectric substrate.

The measurement of the magnetostriction coefficient in thin films can be made by a cantilever system in which the magnetostrictive film is deposited onto a non magnetic substrate. The application of a magnetic field parallel to the long axis of the cantilever causes a small deflection of the free end which can be measured either by an optical [5,6] or a capacitive [6,7] system. Measuring this deflection it is possible to obtain the magnetostriction coefficient as a function of the material dimensions and mechanical properties.

In this work we describe an optical cantilever system developed to measure the magnetoelastic coupling of a magnetostrictive thin film. This system can be calibrated to avoid the dependence of the measurements on the mechanical properties of the substrate. We report results obtained for the measurement of the magnetoelastic coupling in $(Fe_{80}Co_{20})_{80}B_{20}$ thin films.

2 EXPERIMENTAL

Films of $Mo/(Fe_{80}Co_{20})_{80}B_{20}/Mo$ with thickness (15nm/320nm/15nm) have been grown in a magnetron sputtering system on different substrates and with different induced anisotropies. Common cover glasses, corning-glass and mica were used as substrates. The samples were grown covered by two thin Mo layers, the lower to improve the elastic coupling with the substrate and the upper to avoid oxidation. The anisotropy of the samples was induced by an in-plane applied magnetic field of ~80 Oe during the deposition. A substrate rotation mechanism was used to control the orientation of the magnetic field and so the induced anisotropy.

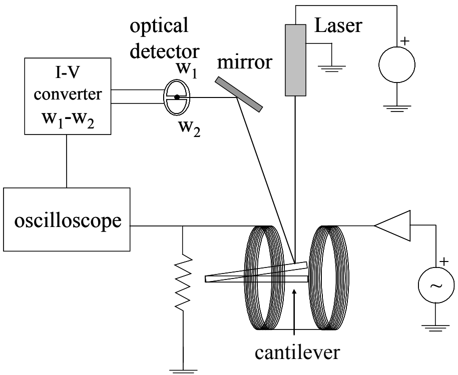

Fig. 1. Magnetoelastic coupling measurement set-up

Samples were magnetically characterized by VSM and MOKE. Magnetoelastic coupling measurements were carried out by using an optical cantilever set-up as shown in figure 1. The cantilever consists in a non-magnetic material used as substrate on which the magnetostrictive thin film is grown. The application of a magnetic field along the long axis of the cantilever causes an elastic magnetostrictive strain in the ferromagnetic film which in turn causes an elastic deformation of the substrate. The cantilever is clipped by one side and a laser beam is reflected on the surface at the opposite free end. The bending of the cantilever is measured by the deflection of the laser beam. Comparing the deflexion produced by the field (D_λ) with that from another measurement made with no field applied but with a well known weight located at the edge of the cantilever (D_p) we can obtain the magnetoelastic coupling of the sample.We will deduce the relationship between these two measurements. The parameters used in the calculation are shown in Fig. 2.

When a magnetic field is applied parallel to the long axis of the cantilever the upper magnetostrictive layer gets elongated while the bottom surface of the cantilever is compressed.

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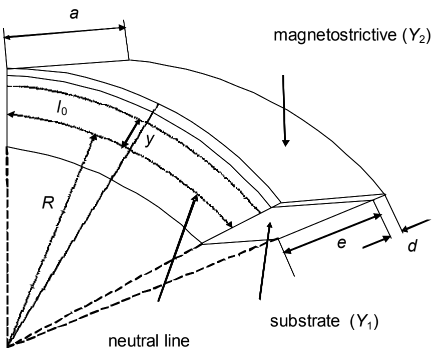

Fig. 2. Cantilever parameters: λ (magnetostriction coefficient), Y_1 (Young modulus of the substrate), Y_2 (Young modulus of the magnetic layer), e (substrate thickness), δ (magnetic layer thickness), l_0 (cantilever length) and a (cantilever width).

Let us call R the radius of the neutral surface, that is, the one with unaltered length. The local elongation in the substrate is y/R being y the distance to the neutral surface. The corresponding elongation in the magnetic layer is $y/R-\lambda$. By applying the equilibrium conditions in a transversal section of the cantilever we obtain y_0 (distance from neutral surface to lower substrate surface) and R.

The equilibrium condition for the forces leads to:

$$\int_{-y_0}^{e-y_0} a\frac{Y_1}{R}y\,dy+\int_{e-y_0}^{\delta+e-y_0} aY_2\left(\frac{y}{R}-\lambda\right)dy=0 \qquad (1)$$

from this expression it is obtained:

$$y_0=\frac{e}{2}+\frac{Y_2\delta}{Y_1}\left(\frac{1}{2}-\frac{\lambda R}{e}\right) \qquad (2)$$

The equilibrium condition for the torques can be written as:

$$\int_{-y_0}^{e-y_0} a\frac{Y_1}{R}y^2dy+\int_{e-y_0}^{\delta+e-y_0} aY_2\left(\frac{y}{R}-\lambda\right)y\,dy=0 \qquad (3)$$

and from this expression it is obtained:

$$R=\frac{1}{6}\frac{e(Y_1\,e+3\,Y_2\,\delta)}{Y_2\lambda\,\delta} \qquad (4)$$

If the length of the sample is l_0 the deflection of the cantilever is:

$$d=R-\sqrt{R^2-l_0{}^2} \qquad (5)$$

and the deflection of the laser beam (see figure 3):

$$d_c=2d\sin(\theta) \qquad (6)$$

Taking into account that the measurement is made with a laser beam reflected in the sample, the angle rotated is

$$\varphi=\frac{l_0}{R} \qquad (7)$$

and the beam deviation is

$$d_b=2\frac{l_0}{R}l \qquad (8)$$

being l the length of the beam. The total displacement is then:

$$D_\lambda=d_c+d_b=2d\sin(\theta)+\frac{2l_0}{R}l \qquad (9)$$

substituting (4),(5) in (9) and simplifying it is obtained:

$$D_\lambda=12\frac{Y_2\;\lambda\;l_0\;l\;\delta}{e\,(Y_1\;e+3\;Y_2\;\delta)} \qquad (10)$$

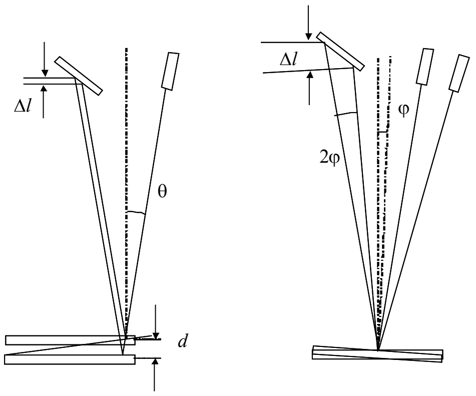

Fig. 3. Laser beam displacement due to cantilever deflection (left) and laser beam deviation (right).

Now let us consider a well known weight $p=mg$ placed on the edge of the cantilever with no magnetic field. Applying the equilibrium equations, as it was done for the magnetic field deflection, the beam deviation is:

$$D_p=12\frac{mg\;l_0^2\;l}{a\;e^2\;(Y_1\;e+3Y_2\;\delta)} \qquad (11)$$

From (10) and (11) it is obtained the ratio between both deviations:

$$\frac{D_p}{D_\lambda}=\frac{mg\;l_0}{Y_2\;\lambda\;\delta\;a\;e} \qquad (12)$$

and finally the magnetoelastic coupling is:

$$Y_2\;\lambda=\frac{mg\;l_0}{\delta\;a\;e}\frac{D_\lambda}{D_p} \qquad (13)$$

The calibration of the system allows us to obtain the magnetoelastic coupling of the magnetostrictive material with no dependence of the Young modulus of the substrate.

3 RESULTS

The magnetic thin films grown exhibit different properties depending on the substrate they have been grown on. Hysteresis loops show coercive fields higher for more rigid substrates (corning glass) than those measured for more flexible substrates (mica). The magnetostrictive elongation produces a tensile strain which follows magnetization orientation. The only magnetic configuration with no strain is that during the growing process. When magnetization changes orientation the strain produced is maximum for rigid substrates while minimum for flexible substrates as these latter can bend and reduce the stress. For the measuring system it is better to have a flexible substrate in order to maximize the deflection of the cantilever. After some tests thin substrates of common cover glasses appeared the best choice.

To maximize the magnetostrictive effect it is interesting to have well defined easy axis. The magnetostrictive effect is maximum when the magnetization rotates from the easy to the hard direction. From the sensors point of view it is desired to have a soft magnetic material, so the optimal material is that with a well defined anisotropy and low saturating and coercive fields. One possible way to decrease these fields and maintain a well defined anisotropy consists in growing several thin layers with perpendicular anisotropies from one to another. The exchange coupling between layers would maintain the magnetization nearly parallel but there would be a small magnetization rotation from one layer to another due to the different anisotropy in contiguous layers. This magnetization configuration would make easier the change of global magnetization to follow the applied field. For testing this effect we have grown several samples with a different number of layers with perpendicular anisotropies. Figure 4 shows the hysteresis loops of a sample of $(Fe_{80}Co_{20})_{80}B_{20}$ with one single layer 320nm with uniaxial anisotropy and a sample with same thickness but with four different layers with perpendicular uniaxial anisotropies from one to another. As it was expected there is a reduction in both saturating and coercive fields. The saturating field observed for the single layer sample is $H_{sat}>100$ Oe while $H_{sat}<50$ Oe for that with 4 layers. Concerning the coercive fields we have Hc>4 Oe for the single layer one while Hc<0.6 Oe for the 4 layers sample. The reduction is remarkable in both cases.

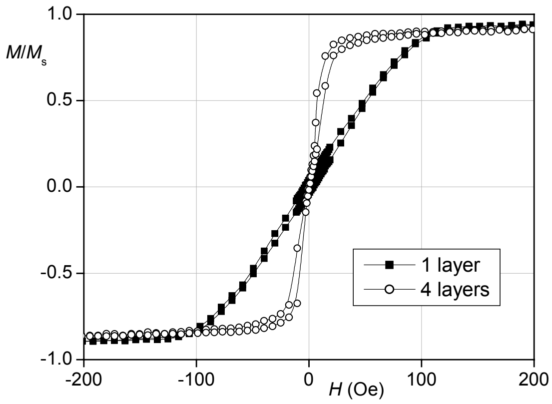

Fig. 4. Hysteresis loops in samples of $Mo/(Fe_{80}Co_{20})_{80}B_{20}/Mo$ (15nm/320nm/15nm) with one single layer uniaxial anisotropy and four layers with perpendicular uniaxial anisotropies

Using the system described before we have measured the magnetostriction of a sample with perpendicular anisotropies. The sample used was grown in a magnetron sputtering system and was later cut in the form of a cantilever of 5mm x 19mm (a = 5mm and l_0=19mm). The thickness of the substrate was e = 150μm while the thickness of the magnetic layer was δ=0.32μm. The weight used for calibration was m = 5mg. Two measurements with an applied field were made, one with a saturating magnetic field parallel to the longitudinal axis of the cantilever and another with a saturating magnetic field transversal to it. The difference between them corresponds to the deformation produced by the magnetostrictive effect. Another measurement was made with no field and with the weight located at the free side of the cantilever. Evaluating (13) with these two measurements and the parameters specified above we obtain the magnetoelastic coupling as it is shown in Fig. 4.

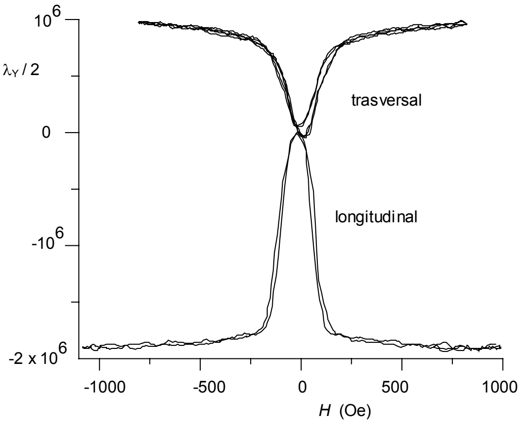

Fig. 5. Magnetoelastic coupling obtained for a $(Fe_{80}Co_{20})_{80}B_{20}$ thin film.

4 CONCLUSIONS

A cantilever system for magnetostriction measurements in thin magnetostrictive films has been developed. A theoretical analysis of the cantilever deflection has been made obtaining an analytical expression for the magnetoelastic coupling without the need to know the Young modulus of the sample substrate. This dependence is avoided by calibrating the system with a known weight. This system has been successfully applied to the measurement of the magnetoelastic coupling of $(Fe_{80}Co_{20})_{80}B_{20}$ samples.

Samples of $(Fe_{80}Co_{20})_{80}B_{20}$ with a single anisotropy and with perpendicular anisotropies have been grown. Hysteresis loops reveal a decrease in the coercive and saturating fields for the samples with perpendicular anisotropies while maintaining a large magnetostriction. These kind of treatments appear promising for their application in magnetic materials used for piezoelectric-magnetostrictive sensors.

Acknowledgements

This work has been partially supported by the SENPIMAG European project E040915069 and by the MCYT Spanish projects MAT-2001-3554-C02 and TIC-2002-04132-C02.

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Received 29 July 2004

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