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MAGNETOSTRICTION OF THE AMORPHOUS $Tb_{0.27}Dy_{0.73}(Fe_{1-x}Co_x)_2$ THIN FILMS

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ABSTRACT. A series of amorphous $Tb_{0.27}Dy_{0.73}(Fe_{1-x}Co_x)_2$. Thin films were prepared. Magnetic and magnetostrictive measurements were performed. The partial substitution of Fe atoms by Co enhance magnetostriction.

INTRODUCTION

Magnetostrictive thin films have been studied since at least 1976 [1]. There is presently a renewed interest in these materials because of their potential use in microsystem applications [2],[3],[4]. The magnetostriction of R-Fe based alloys originates from the coupling between the R (ions that have highly aspherical 4f orbital) and the Fe moments.

The aim of our research was to find materials with high magnetostriction at sufficiently low magnetic fields. In order to obtain this, it is necessary to have low macroscopic anisotropy. That was obtained earlier in the famous cubic compound $Tb_{0.27}Dy_{0.73}Fe_2$, by combining two types of rare-earth, with positive and negative 4th order anisotropies [1]. An other way was to use amorphous materials [5].

In this paper there are presented magnetic and magnetostrictive properties of the $Tb_{0.27}Dy_{0.73}(Fe_{1-x}Co_x)_2$ thin film series. The role of the substitution of the Fe atoms by Co is discussed.

EXPERIMENTAL

A series of amorphous $Tb_{0.27}Dy_{0.73}(Fe_{1-x}Co_x)_2$ thin films were deposited on glass substrate (microscope cover-slips with a nominal thickness of 150μm), by RF magnetron sputtering [6]. The height of the films was measured by π-step with a precision of 5% and the typical film-thickness was 1.2μm. The final composition of the films was determined by Scanning Electron Microscopy (SEM). X-ray diffraction was used to verify that no crystalline phase occurred. The samples were annealed for 1 hour

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under a magnetic field of 2.2T in order to induce an in-plane anisotropy. Heat treatments were made at 150°C and 250°C.

Magnetic and magnetostrictive measurements were performed. The magnetisation was measured using Vibrating Sample Magnetometer (VSM) in fields up to 8T from 4.2K to 300K.

Magnetostriction was determined using an optical deflectometer (cantilever method) [7], [8],[9]. This allows the magnetoelastic coupling energy *b* of the film to be determined [10]:

$$b = \frac{\alpha}{L}\frac{h_s^2}{h_f}\frac{E_s}{6(1+\nu_s)},$$

where α - the angle of the deflection of the sample as a function of the applied field.

L - the length of the sample (in the order of 10 mm)

h_s - the thickness of the substrate

h_f - the thickness of the film

E_s - Young's modulus of the substrate (it was taken to be 72GPa)

ν_s - Poisson's ratio of the substrate (0.21).

For comparison, magnetostriction (λ) values were calculated, using:

$$\lambda = \frac{b\,(1+\nu_f)}{E_f},$$

where E_f and ν_f are the Young's modulus and Poisson's ratio of the film, taken to be 80GPa and 0.31, respectively.

We measured two coefficients at saturation, $b_{//}$ and $b_{\perp}$, which correspond to the applied field direction parallel and perpendicular to the sample length and always in the film plane. In addition, the perpendicular direction corresponds to the easy-axis. The intrinsic properties of the material depend on the parameter $b^{\gamma,2}$ (or $\lambda^{\gamma,2}$) which is just the difference $b_{//} - b_{\perp}$ (or $\lambda_{//}-\lambda_{\perp}$).

RESULTS AND DISCUSSION

Table 1. presents the concentration and the thickness of each prepared $Tb_{0.27}Dy_{0.73}(Fe_{1-x}Co_x)_2$ film.

Sample	x_{Co}	h_f (μm)
1	0.00	1.45
2	0.12	1.25
3	0.31	1.55
4	0.47	1.10
5	0.65	1.55
6	0.83	1.55
7	1.00	1.50

Fig. 1. shows the hysteresis-loops for the sample 4 before (curve a) and after annealing (curve b). One can see that the annealed sample reaches saturation of magnetisation in lower magnetic field, which means that the effect of annealing was to reduce the internal stress of the sample.

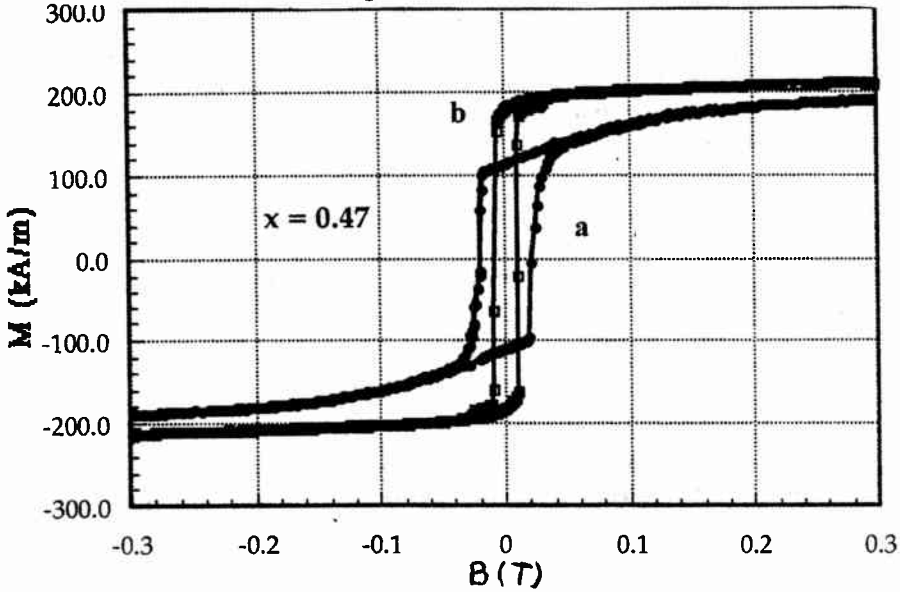

Fig. 1. Hysteresis-loops in case of sample 4

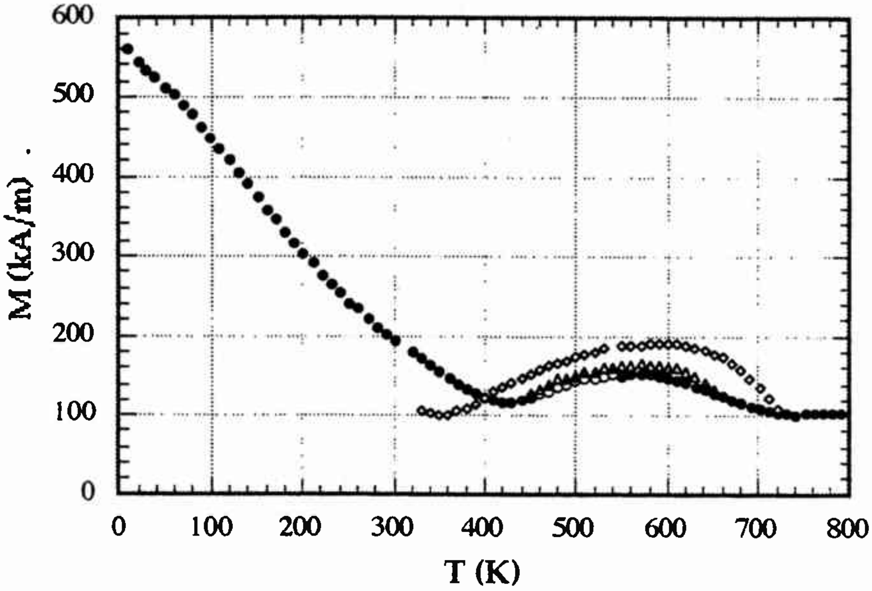

Fig. 2. Magnetisation for several cycles of heating and cooling in case of the oxidation-protected film

In order to verify the conservation of amorphous state, we measured the magnetisation for an oxidation-protected, supplementary sample in several cycles of heating and cooling (Fig. 2.). The protection against the oxidation was insured by a Ta layer (non magnetic) deposited on top of the film. The composition of this film was x_{Co} = 0.55. The following thermal cycles were performed: 340-450K, 340-560K, 340-660K, 340-720K. Above 560K, the magnetisation process is no longer reversible, so at greater temperatures than this, the crystallisation process appears. In case of this sample we found the compensation temperature to be at 420K. The Curie-point could not determined because of the crystallisation of the sample. This is in agreement with values measured by K.Lee and N.Heiman [11].

In Fig. 3. and Fig. 4. we show the variation of the magnetostriction as a function of the applied magnetic field, for the two extreme compositions of the series. Before annealing, $Tb_{0.27}Dy_{0.73}Co_2$ presented a typical easy-plane anisotropy, characterised by $\lambda_{//} = -\lambda_{\perp}$[5]. After annealing an enhancement from 1 to 10 of the $|\lambda_{//} / \lambda_{\perp}|$ratio was observed. One can see that the effect of annealing was in this case also the creation of an easy-axis of magnetisation. In case of the sample $Tb_{0.27}Dy_{0.73}Fe_2$ the measurement indicate that the sample's own internal stresses (due to the deposition) before annealing were relaxed after. The installation of an easy-axis didn't appear.

We present in Fig. 5. the curves of magnetostriction for all the annealed samples that were measured. As it is shown, the presence of both Fe and Co atoms can give rise to greater magnetostriction values than those obtained in case of $Tb_{0.27}Dy_{0.73}Co_2$ or $Tb_{0.27}Dy_{0.73}Fe_2$ films. The very best performances are obtained in case of the $Tb_{0.27}Dy_{0.73}(Fe_{0.53}Co_{0.47})_2$. That is to say that this sample presents the greatest magnetostriction value at saturation and also in very low magnetic fields. For this property the x_{Co}= 0.47 compound could be useful in microactuator-applications. The phenomena of enhancement of the magnetostriction by partly substituting Fe atoms by Co, could be explained, based on [12]. The amorphous Co sublattice is a well ordered ferromagnet whereas for an amorphous Fe sublattice, the opposing Fe-Fe exchange interactions lead to a sperimagnetic structure with a low Curie temperature. However, the Fe moment being larger than the Co one, the R-Fe exchange energy is larger that the R-Co one. The substitution of Fe for Co thus increases the overall R-T exchange energy. However, when more Fe is added, a sperimagnetic sublattice starts to form thus reducing it effectiveness.

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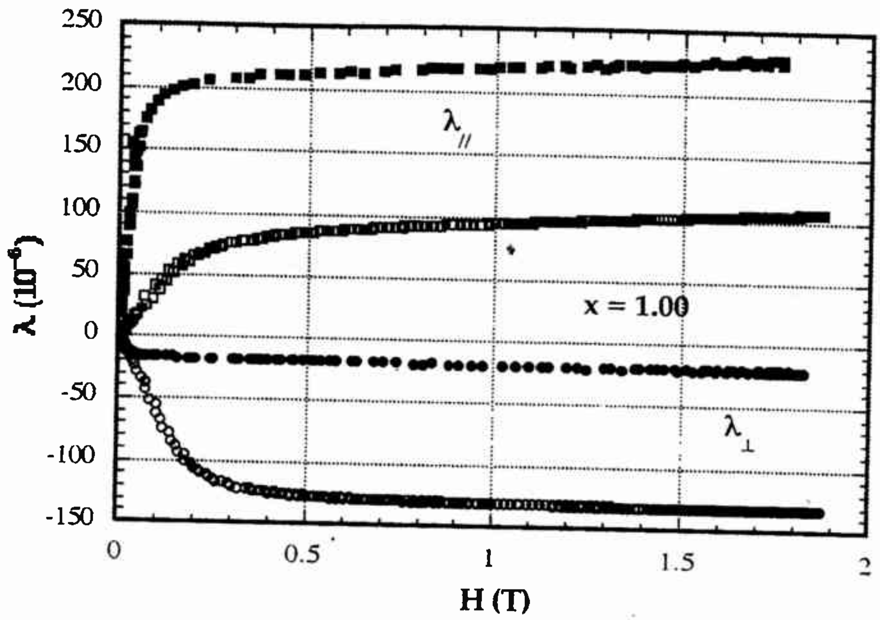

Fig. 3. Magnetostriction before (the empty character) and after the thermal treatment in case of sample 7

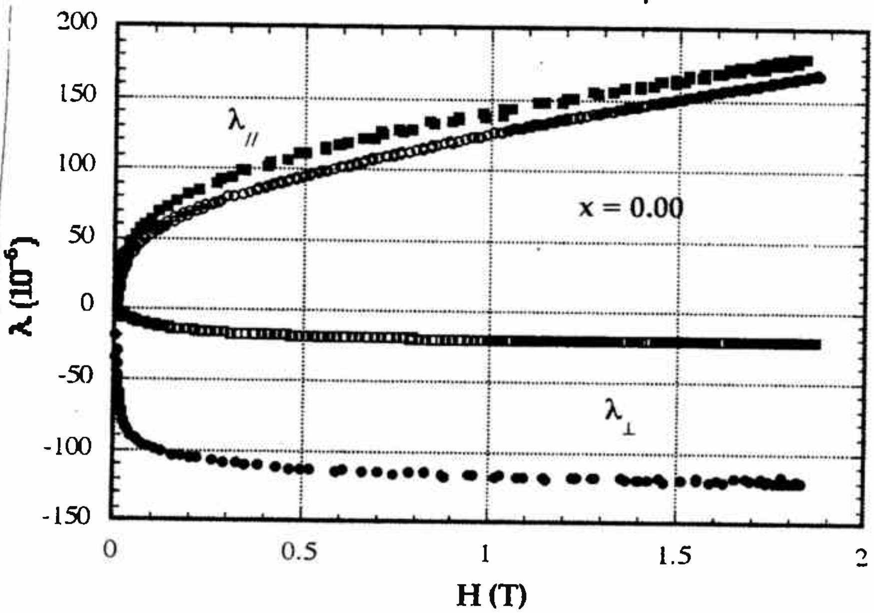

Fig. 4. Magnetostriction before (the empty characters) and after the thermal treatment in case of sample 1

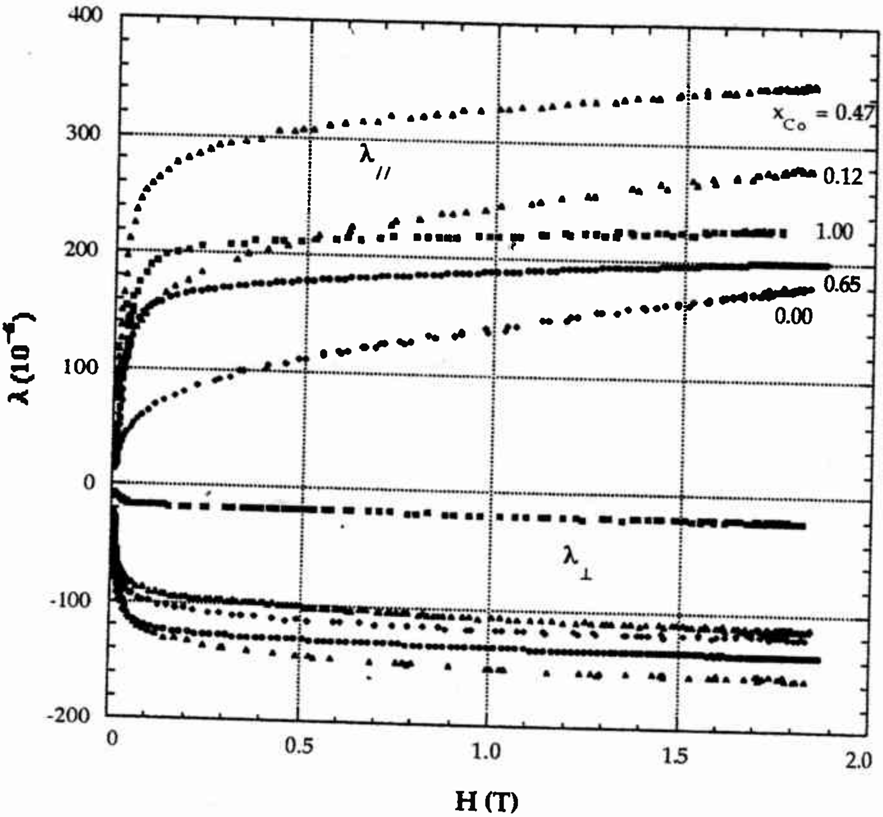

Fig. 5. Magnetostriction curves

CONCLUSIONS

We would like to point out that the creation of a well defined uniaxial anisotropy is advantageous for the enhancement of magnetostriction. The role of the partial substitution of Fe atoms by Co was to enhance magnetostriction, probably by strengthening the exchange interaction energy leading to better oriented rare-earth moments.

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