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The influence of stress and heat treatment on the magnetization of TbDyFe films

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Abstract

Amorphous $(Tb_{0.3}Dy_{0.7})_{43}Fe_{57}$ films were prepared by DC magnetron sputtering. After annealing at 400°C for 1 h, a small amount of $(Tb,Dy)Fe_2$ crystal grain precipitated from the amorphous film. The magnetization in the as-deposited film and the film treated at 200°C is nearly isotropic. After treatment at 300 and 400°C, the films showed anisotropic magnetization with the easy axis parallel to the film surface. For the as-deposited films, stress applied to the films makes it magnetize slightly. Annealed below 200°C, the coercivity of the films did not change. After 300°C heat treatment, the coercivity, H_c, reduced because of the release of stress in the film. For the films with 400°C heat treatment, H_c increased because partial crystallization occurred in the film. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Magnetostriction; Amorphous; Magnetization; Coercivity

1. Introduction

TbDyFe alloys shows giant magnetostriction. The main characteristic of this material — change of length in an applied magnetic field — implies that it may be used for microsensors, microactuators, or tunable surface-acoustic-wave devices [1]. The major requirement for application in microsystem technology is that these materials should be prepared in the form of film and have sufficient magnetostriction at low magnetic fields, and the films have to be magnetically soft. Based on these requirements, the films should be amorphous to reduce the coercivity. According to previous research on the Tb_xDy_{1-x} film, it is amorphous when x is in a special range [2,3]. Even if the film is amorphous, it possesses magnetic anisotropy due to the influence of the composition of the film, preparation condition, stress in the film, and so on. The films with parallel anisotropy (easy magnetization axis is parallel to the surface of the film) are more suitable for use in microsystems because it they have large magnetostriction in low magnetic field which is parallel to the surface of the films [4]. The goal of our research was to prepare the amorphous films with parallel anisotropy. In this paper, the influence of stress and heat treatment on the magnetic anisotropy of the film is discussed.

2. Experimental

The $(Tb_{0.3}Dy_{0.7})_{43}Fe_{57}$ films were prepared by DC magnetron sputtering. The $(Tb_{0.3}Dy_{0.7})_xFe_{1-x}$ alloy was used as target. By adjusting the Fe content in the target, films with the desired composition were prepared. The substrates were glass slides or copper plates with a thickness of 0.05 mm without heating during sputtering. The sputtering parameters were as follows: base pressure, 10^{-3} Pa; P_{Ar}, 0.5, Pa and sputtering power, 120 W. The thickness of the film was 2–5 μm. The sputtering rate was 0.4 nm/s. In order to investigate the influence of stress on the magnetic anisotropy of the films, the copper substrates were elastically arched during sputtering as shown in Fig. 1. The degree of deformation of the substrates were expressed as height (h). After the deposition, the Cu substrates returned to their original flat shape on relaxation from the fixing clamps. So the compressive stress were applied along the arched direction. Three kinds of deformation were applied. The details are shown in Table 1.

The films were given subsequent vacuum heating treatment at 200, 300, 400°C for 1 h.

The magnetic properties of the films were measured at

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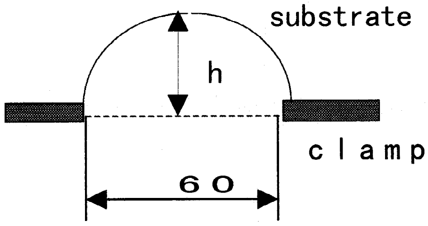

Fig. 1. Schematic drawing of sample fixed during sputtering.

Table 1
Amount of deformation

Sample no.	*h* (mm)
1	0
2	12
3	20

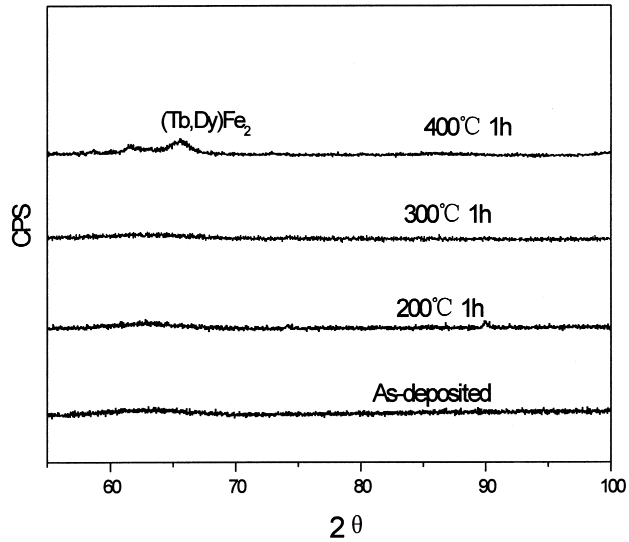

Fig. 2. X-ray diffraction diagram of amorphous sample 1 under different heat treatments.

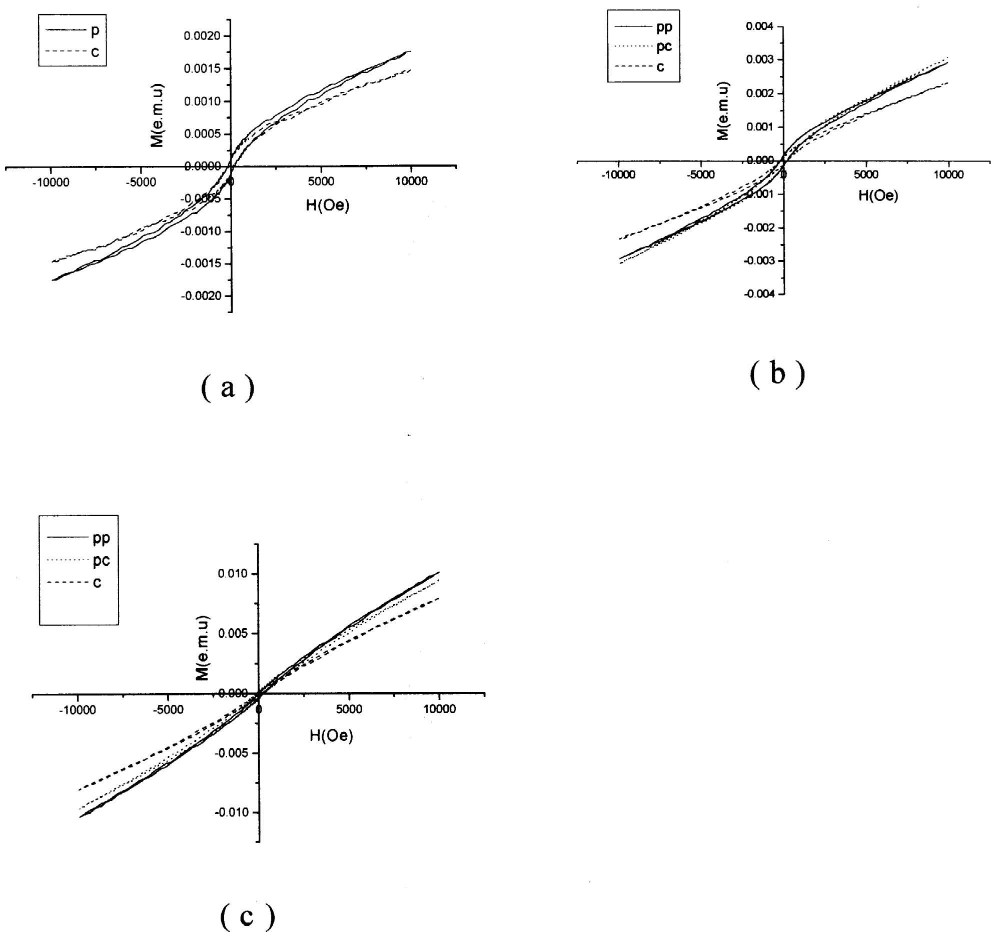

Fig. 3. Magnetization curve of the samples with different h values (a) $h=0$; (b) $h=12$ mm; (c) $h=20$ mm; p, magnetizing direction is parallel to the film surface; c, magnetizing direction is vertical to the film surface; pp, pc, two vertical directions lying in film surface.

room temperature by vibrating the sample magnetometer in a maximum applied field of 10 000 Oe. The composition of the films was measured by energy dispersive X-ray spectroscopy (EDX). The structure of the film was identified by X-ray diffraction (XRD).

3. Results and discussion

3.1. XRD result of films with different heat treatment

The composition of the film was close to

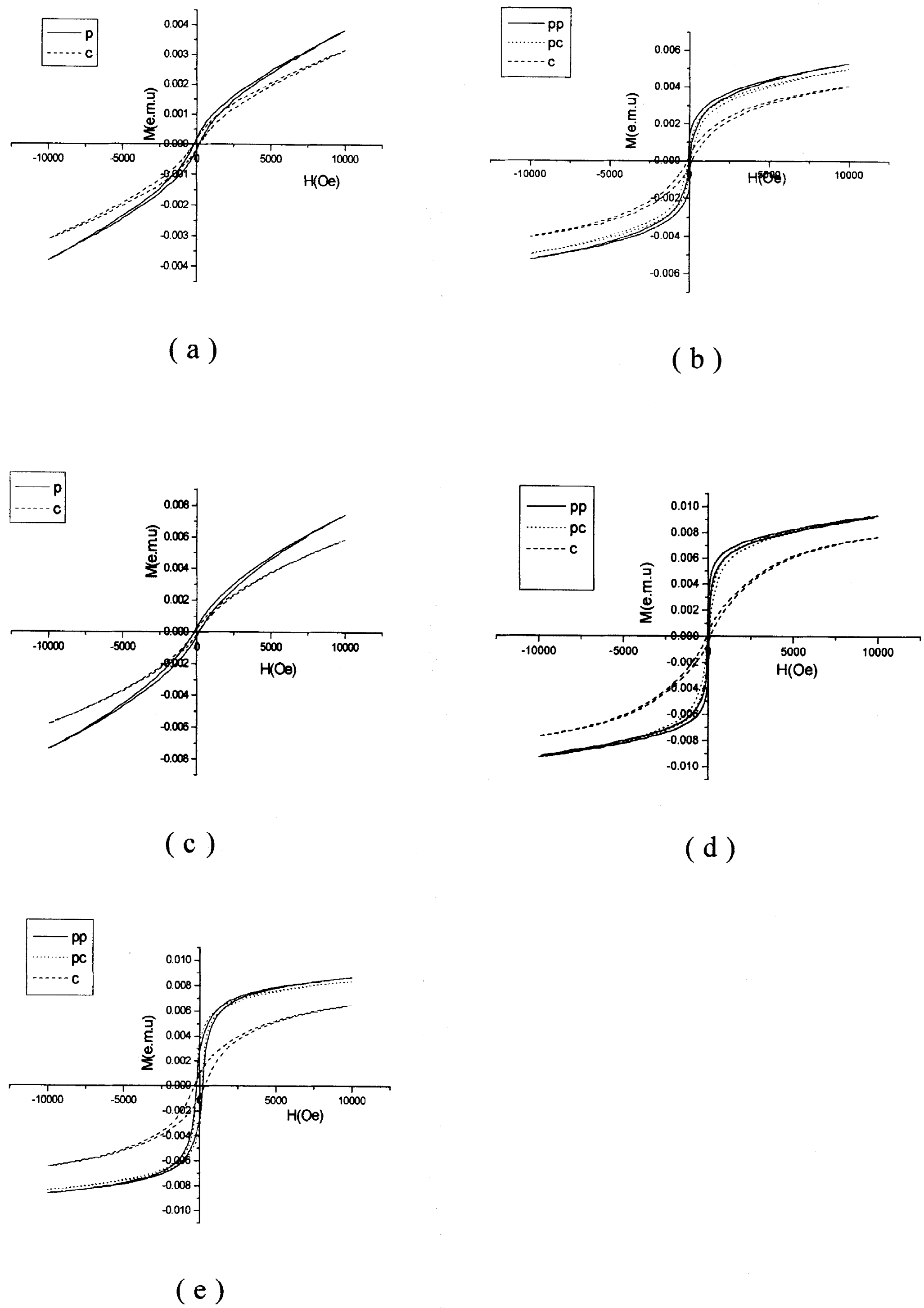

Fig. 4. Magnetization curve with different heat treatment; (a) sample 1, 200°C, 1 h; (b) sample 1, 300°C, 1 h; (c) sample 3, 200°C, 1 h; (d) sample 3, 300°C, 1 h; (e) sample 3, 400°C, 1 h; p, magnetizing direction is parallel to the film surface; c, magnetizing direction is vertical to the film surface; pp, pc, two vertical directions lying in film surface.

$(Tb_{0.3}Dy_{0.7})_{43}Fe_{57}$ from the results of EDX. Fig. 2 shows the X-ray diffraction patterns of sample 1 with different heat treatments.

From the XRD results, it can be seen that the as-deposited films were amorphous, and this state was stable up to 300°C. After 400°C treatment, a weak $(Tb,Dy)Fe_2$ peak appeared indicating that primary crystallization occurred in the film.

3.2. Magnetization, coercivity and anisotropy of the films with different treatment

Fig. 3 shows the magnetization curves of as-deposited films with different degrees of shape change. It shows that three films are of almost equal magnetization. The magnetization curve of samples 1 and 2 are almost similar, but slightly different from sample 3, which seems to be more difficult to magnetize in a low magnetic field. The deformation of sample 3 was the largest among three films, so the applied compressive stress in the films on the restoration of the substrates was higher compared with other two films. It may be the large stress in the film which make it more difficult to magnetize. The coercivity of all the films are $<$200 Oe.

Fig. 4 shows the magnetization curves of samples 1 and 3 under different heat treatments. After being annealed at 200°C for 1 h, no change in the magnetization curve was observed in sample 1 compared with as-deposited films. However, the magnetization curve of sample 3 changed compared with the as-deposited film. The film magnetized more easily at a low magnetic field. This is the result of part of the stress in the film being released. After 300 and 400°C treatments, the parallel anisotropy appeared in all the samples.

Fig. 5 shows the change of coercivity, H_c, with the annealing temperature. For all samples, the H_c value of the film treated at 200°C did not present any obvious changes compared with the as-deposited films. After annealing at 300°C, the H_c value of all the films was reduced, and it increased again with heat treatment at 400°C. According to the XRD result, the film is still amorphous, annealed at 300°C for 1 h. The 400°C heat treated films were partially crystallized. Therefore the change of coercivity with the annealing temperature was caused by the release of stress in the film. The increased of the film coercivity with the 400°C heat treatment is the result of partial crystallization of the films.

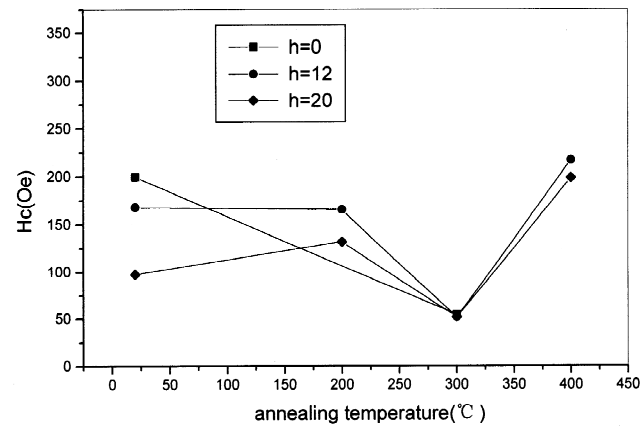

Fig. 5. Coercivity of the film with different heat treatments.

4. Conclusion

Amorphous $(Tb_{0.3}Dy_{0.7})_{43}Fe_{57}$ films were prepared by DC magnetron sputtering. After annealing at 400°C for 1 h, a small amount of $(Tb,Dy)Fe_2$ crystal grain precipitated from the amorphous film. The magnetization in the as-deposited film and the film treated at 200°C is nearly isotropic. After being treated at 300 and 400°C, the films showed anisotropic magnetization with the easy axis parallel to the film surface. For the as-deposited films, stress applied on the films made it magnetize slightly. Annealed below 200°C, the coercivity of the films did not change. After the 300°C heat treatment, the coercivity, H_c, reduced because of the release of stress in the film. For the films undergoing 400°C heat treatment, H_c increased because partial crystallization occurred in the film.

Acknowledgements

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