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ARTICLE

Effects of Compressive Stress on the Magnetostrictive Characteristics of Sm-Fe-B Films

Zhou Baiyang, Weng Zhangzhao, Li Siwen, Chen Zhijian, Liu Quanzhou, Li Jianxin

Fuzhou University, Fuzhou 350108, China

Abstract: A set of Sm-Fe-B films with different compressive stresses were prepared on substrates with different prestrains by ion beam spurting deposition (IBSD). The influence of compressive stress on the magnetic anisotropy and the magnetostriction in sputter-deposited amorphous Sm-Fe-B films were investigated. Films affected by compressive stress all show in-plane anisotropy and easy axis along the direction of stress is induced in the film with compressive stress increasing. Magnetostriction of Sm-Fe-B films affected by compressive stress is improved in low magnetic field while saturation of magnetostriction decreases slightly. At the same time, the magnetostriction rises rapidly in low field measured in a field parallel to the film plane at room temperature with the growth of compressive stress. It is also found that the magnetic domain component which is perpendicular to the film plane increases on a small scale, though the magnetic domain or the magnetic domain component parallel to film plane still exist dominantly.

Key words: Sm-Fe-B film; compressive stress; magnetostrictive characteristics; magnetic domain

The giant magnetostrictive materials (GMM) have shown enormous magnetostriction with the value over 1000×10^{-6}. With rising of application in micro-electro-mechanical-systems (MEMS), the giant magnetostriction materials exhibit more merits such as, highly-responsive, large dimensional change with low voltage operation and can provide a fast-responding microactuator.

The magnetostrictive susceptibility of GMM is strongly affected by the change of internal stress due to ion bombardment during depositing process [1]. Hiroyuki Wakiwaka et al. described the magnetic characteristic of stress applied Sm-Fe-B film. For amorphous magnetoelastic films, owing to the absence of magnetocrystalline anisotropy, their magnetic anisotropy is influenced greatly by stress induced anisotropy [2]. The previous report discussed that magnetostrictive susceptibility of Sm-Fe thin film increased with the increase of compressive stress, especially in low fields. However, the changing trend of magnetic properties and magnetic anisotropy with different compressive stresses is not clear. In amorphous magnetoelastic film, a controlled amount of stress can be induced by strain growth [3, 4]. Since Sm-Fe-B thin film shows higher magnetostriction susceptibility than Sm-Fe thin film due to lattice expansion with boron addition[5], the different internal stresses of Sm-Fe-B thin film could be expressed by the substrate with different curvature[6, 7] during deposition. Due to all samples being bended toward to film surfaces for the lattice mismatch between glass substrate and film (no matter the film is deposited on concave side or convex side of substrate), the compressive stress in films was produced when the substrate returned to its original state. In the present experiment, we mainly studied the effects of compressive stress on magnetostriction and magnetic anisotropy of Sm-Fe-B GMM films.

1 Experiment

Sm-Fe-B thin films with different compressive stresses

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Corresponding author: Zhou Baiyang, Master, Professor, College of Materials Science and Engineering, Fuzhou University, Fuzhou 350108, P. R. China, E-mail: zby@fzu.edu.cn

(7, 10, 13 and 16 GPa) were prepared on glass substrates by IMS500 type ultra-high vacuum IBSD machine, as shown in Fig.1. During the sputtering, the substrates were kept on a water-cooled holder and high purity argon was used as the sputtering gas. Meanwhile, Sm-Fe-B alloy samples (60 mm × 60 mm × 5 mm) fabricated by vacuum casting was used as the target. Other parameters are listed as follows: base pressure of vacuum furnace $<3.0\times10^{-5}$ Pa, partial pressure of sputtering gases pressure was maintained at 2.0×10^{-2} Pa. Total time for film preparation was 4 h and the thickness of Sm-Fe thin film was 0.5 μm.

The compressive stress of the Sm-Fe-B thin film was calculated by the Stoney formula [8, 9] as follows:

$$\sigma = \frac{E_s t_s^2}{3(1-v_s)Rt_F} \tag{1}$$

where σ-compressive stress, Pa; E_s-Young's modulus of substrate, Pa; t_s-thickness of substrate, m; v_s-Poisson ratio of substrate; R-radius, m; t_F-thickness of thin film, m.

Magnetic measurements were performed using 2900/ 3900-0015 type alternating gradient magnetometer (AGM) of America PMC company, by which hysteresis loops were measured parallel to the film surface along the long axis (*X*), axis direction (*Y*) and the direction (*Z*) that were perpendicular to the film surface. The magnetic domain was determined through USA Agilent 5500LS type magnetic force microscope (MFM) to investigate the influence of the compressive stress on the magnetic anisotropy.

Upon testing magnetostriction, a magnetic field held in cantilever geometry was applied along the longitudinal direction of the film. The deflections of the cantilevers at different magnetic fields were measured by a LK-G150 laser micro-displacement sensor. The magnetostrictive coefficient (λ) for each film is given by the following equation:

$$\lambda = \frac{1 d_s^2 E_s (1+v_f)}{3 l^2 d_f E_f (1-v_s)} \cdot D \tag{2}$$

where D is the deflection of the cantilever, l is the length of the cantilever, E is Young's modulus, d is the thickness, v is the Poisson's ratio, and subscripts of s and f are referred to the substrate and the film, respectively [10].

2 Results and Discussion

To study the magnetic anisotropy, hysteresis loops of the magnetization were measured with the applied field parallel and perpendicular to the film plane. Fig.2 shows the

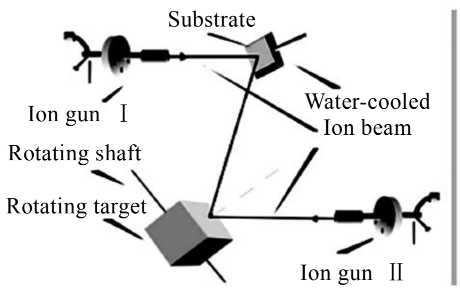

Fig.1 Schematic diagram of the IMS500 type ultra-high vacuum ion beam sputtering instrument

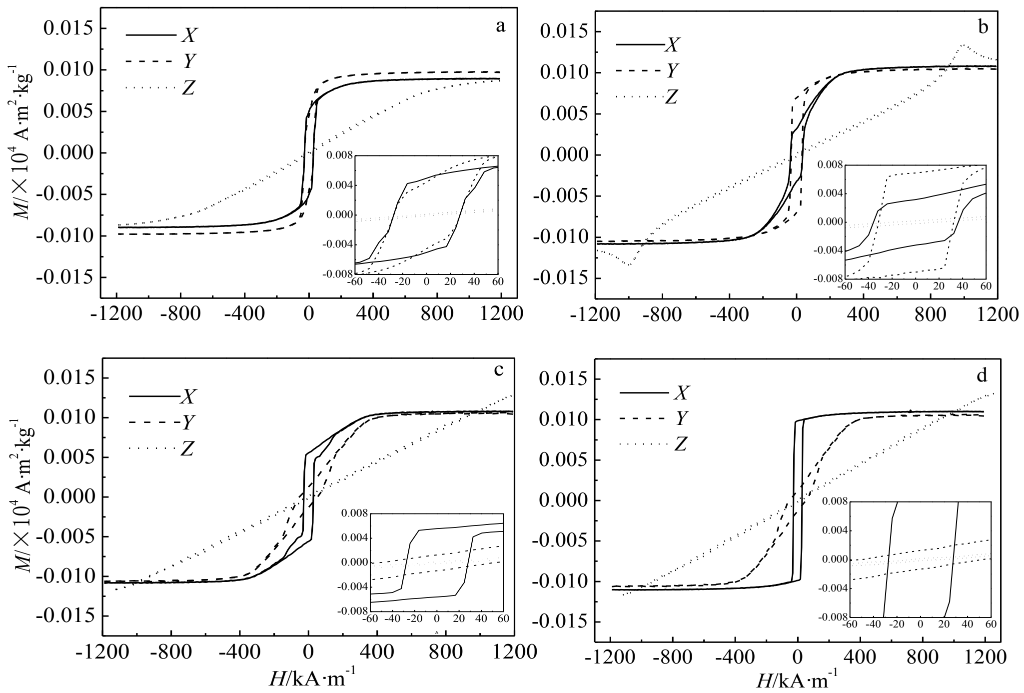

Fig.2 Magnetization characteristics of Sm-Fe-B GMF under different compressive stresses: (a) 7 GPa, (b) 10 GPa, (c) 13 GPa, and (d) 16 GPa