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Magnetostrictive Characteristics of Sm-Fe / Sm-Fe-N Multi-layers Thin Films

by

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Abstract

The previous report discussed that magnetostrictive susceptibility of Sm-Fe thin film increased with a small addition of nitrogen into Sm-Fe. However excessive addition of nitrogen amount into Sm-Fe thin film causes decreased magnetostrictive susceptibility and saturated magnetostriction. The magnetostrictive susceptibility and saturated magnetostriction of Sm-Fe thin film decreased with the excessive addition of nitrogen. In this study, we investigated the effects on internal stress in multi-layered giant magnetostrictive materials films by the described nitrogen-added sputtering agent. Sm-Fe/ Sm-Fe-N multi-layers thin films were prepared by the d.c. magnetron sputtering process, and Sm-Fe / Sm-Fe-N multi-layers thin films were prepared by the d.c. magnetron sputtering process. The saturated magnetostriction of Sm-Fe and Sm-Fe / Sm-Fe-N multi-layers thin films was about 1250 ppm. The thin film prepared at 0.2 of Sm-Fe-N/Sm-Fe+Sm-Fe-N thickness ratio showed maximum value of magnetostrictive susceptibility.

Keywords: Nitrogen gas, samarium-iron, giant magneto- striction, thin film, magnetron sputtering, multi-layers

1. Introduction

The giant magnetostrictive materials have exhibit huge magnetostriction over 1000ppm. Comparing to others intelligent materials, the giant magnetostriction materials (GMM) have more merits such as, highly-responsive, large dimensional change with low voltage operation and able to operate this material by applied magnetic field[1, 2]. This material has been investigated for application in actuator and sensor devices of micro machine[3, 4].

Magnetostrictive properties of GMM thin films was systematically investigated using various formation process such as flash evaporation, ion beam sputtering, ion plating, electron beam and magnetron sputtering process[5-9]. As a result magnetostrictive susceptibility is strongly effected by the changing of internal stress due to ion bombardment[10].

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Lim *et al.*, have reported that Sm-Fe-B thin film shows higher magnetostriction susceptibility than Sm-Fe thin film due to lattice expansion with boron addition[11]. Since atomic radius of nitrogen is about similar with boron's atomic radius, nitrogen has been used for Sm-Fe-N compound material instead other elements.

We were prepared Sm-Fe-N thin film in previous study by nitrogen gas addition during film deposition process. As the result, magnetostriction susceptibility of thin films was increased, where saturated magnetostriction was decreased[12]. Therefore, by using d.c. magnetron sputtering as film deposition process, we have prepared Sm-Fe/Sm-Fe-N multi–layers thin films to control decreasing of saturated magnetostriction while increasing magneto- striction susceptibility of GMM thin films. In this experiment, we studied the effect on internal stress in the multi-layered GMM films by the described nitrogen-added sputtering agent.

2. Experiment

2.1 Film Preparation

Sm-Fe/Sm-Fe-N multi-layers thin films were prepared by d.c. magnetron sputtering process shown in Fig. 1. Argon of 99.999% purity and mixed argon and nitrogen gas (nitrogen purity 99.99%) of 5.0 vol % mixed rate were used as sputtering gases.

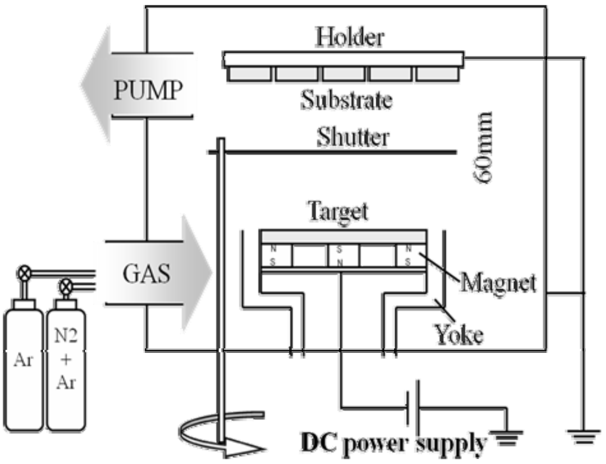

Fig. 1 Schematic diagram of d.c. magnetron sputtering process.

$SmFe_2$ alloy target with diameter of 75 mm was used in this process and distance from target to substrate was 60mm. The single-crystal Si (100) chips size of 25 mm in length, 5 mm in width and 0.28 mm in thickness was used as substrate for prepare Sm-Fe/Sm-Fe-N multi-layers thin films.

The sputtering chamber was evacuated down to 1.0×10^{-4} Pa and partial pressure of sputtering gases pressure was maintained at 1.0×10^{-1} Pa range. Deposition process runs at room temperature of 300K. Target was pre-sputtered about 5 minutes at 100W by argon gas. Then, Sm-Fe/ Sm-Fe-N multi-layers thin films were formed at 100W by argon, and mixed argon and nitrogen gases (N 5.0 vol % mixed rate) have been added during films preparation. Total time for film preparation was an hour. The thickness of this multi-layers thin film was range from 2.5 μm to 3.0 μm.

2.2 Analysis

The structure of the formed films was examined and observed by X-ray diffraction (XRD) using Cu-Kα radiation. Formed GMM thin films composition was determined using energy dispersive X-ray spectroscopy (EDX). Magnetostriction of the films was measured using a sample cantilever method. The following equation has been used to calculate magnetostriction based by measured curvature of the film samples under applied magnetic fields. When l is a distance from clamp to free edge, D is the curvature of the film sample, subscript s and f represent substrate and film, t is thickness, E is Young's modulus and v is Poisson's ratio

$$\lambda = D\, t_s^2\, E_s (1+v_f) / 3 t_f l^2 E_f (1-v_s) \qquad (1)$$

The next equation (Stoney's equation) has been used to estimate internal stress, σ of formed thin films also based on results of curvature measurements[13]. Where curvature radius, R can be estimated by taking $R = l^2 / 2d$.

$$\sigma = E_s\, t_s^2 / 6(1-v_s)\, t_f R$$

Thickness of Sm-Fe/Sm-Fe-N multi-layers thin films has been measured by bench-top surface profiler (DEKTAK 3).

3. Results and Discussion

3.1 Compositions and Crystal Structure

The film sample with $Sm_{27}Fe_{73}$ was obtained by d.c sputtering process. XRD diffraction patterns of Sm-Fe and Sm-Fe-N multi-layers thin films are shown in figure 2. Composition of SmN and α-Fe were observed in multi-layered thin film due to nitrogen addition during deposition process. No distinct diffraction peaks of $SmFe_2$ phase were observed and we were assumed the lattice structures of formed films are amorphous [14)]

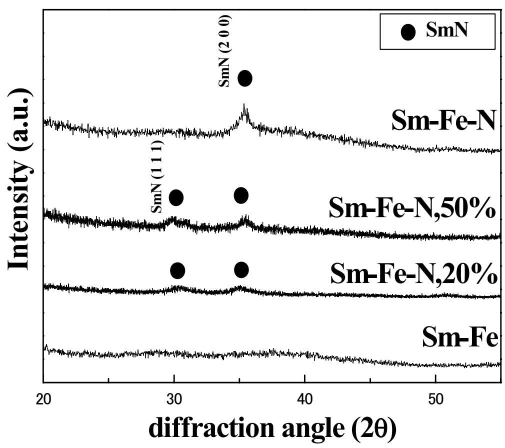

Fig. 2 X-ray diffraction patterns XRD patterns of various Sm-Fe and Sm-Fe-N multi-layers thin film.

3.2 Internal Stress

Figure 3 shows thickness of Sm-Fe-N layer ratio dependence of internal stress of Sm-Fe/Sm-Fe-N multi-layers thin films. By increasing the ratio of Sm-Fe-N layer lead to increased internal stress of Sm-Fe/Sm-Fe-N multi-layers thin films prepared by d.c.

magnetron sputtering deposition process. The figure shows 0.55 GPa of compressive stress was showed at Sm-Fe thin film. The compression stress in thin films was increase to 0.65 GPa at 50% thickness of Sm-Fe-N layer ratio.

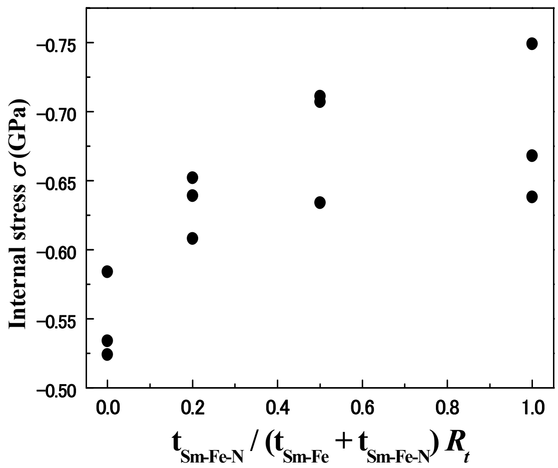

Fig. 3 Internal stress of various Sm-Fe and Sm-Fe-N multi-layers thin film.

3.3 Magnetostrictive Characteristic

Figure 4 shows saturated magnetostriction of Sm-Fe thin film and various Sm-Fe/Sm-Fe-N multi-layers thin films formed by d.c. magnetron sputtering process. It shows saturated magnetostriction of Sm-Fe and each Sm-Fe/ Sm-Fe-N thin films were 1250 ppm, where saturated magnetostriction of Sm-Fe-N thin films was only 800 ppm.

$Sm_{27}Fe_{73}$ was disproportionate during film disposition. Therefore, composition of $Sm_{27}Fe_{73}$ was change to SmN and α-Fe[15,16]. Non-magnetic substance of SmN was formed with nitrogen addition in Sm-Fe thin film lead to the increasing of saturated magnetostriction.

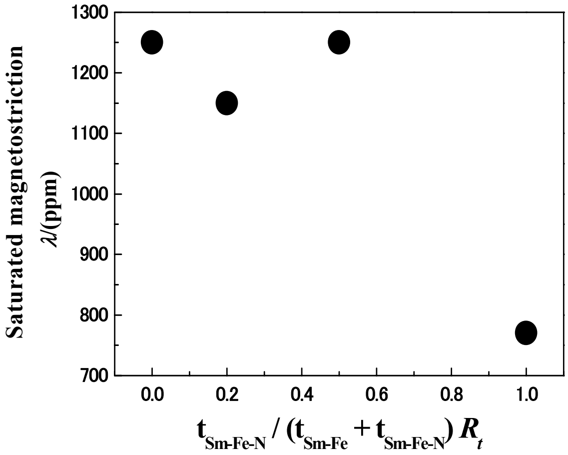

Fig.4 Saturated magnetostriction(λ) of various Sm-Fe and Sm-Fe-N multilayer thin film.

Magnetostrictive susceptibility of Sm-Fe/ Sm-Fe-N multi-layers thin films is shown in figure 5. The highest magnetostrictive susceptibility was 22 ppm/Am^{-1} at 20% of Sm-Fe-N thickness ratio, where it was decreased due to increasing thickness ratio of Sm-Fe-N.

We were assumed the decreased in saturated magnetostriction of formed films lead to the increasing of thin films internal stress.

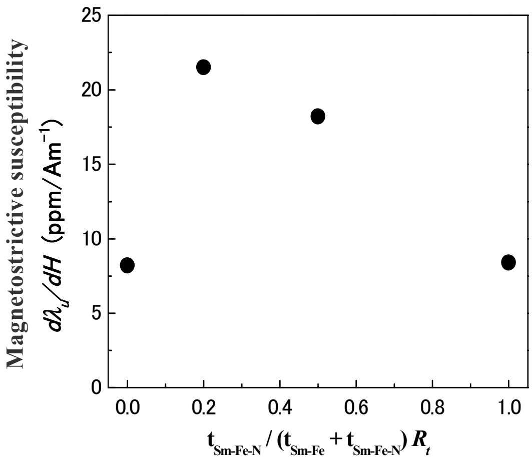

Fig.5 Maximum magnetostrictive susceptibility ($d\lambda_u/dH$) of various Sm-Fe and Sm-Fe-N multi-layers thin film.

4. Conclusions

Formed Sm-Fe thin film with small amount of nitrogen addition in previous study showed higher value of magnetostrictive susceptibility than Sm-Fe thin film whereas saturated magnetostriction was decreased. However, large amount of nitrogen addition in thin film leading to decreased magnetostrictive susceptibility and saturated magnetostriction of multi-layers thin films.

Sm-Fe/Sm-Fe-N multi-layers thin films have higher magnetostrictive susceptibility than Sm-Fe thin film. Moreover, saturated magnetostriction of multi-layered thin film at 50% Sm-Fe-N layer and Sm-Fe thin are similar volume, 1250 ppm. We were observed magnetostrictve susceptibility of GMM thin films increased with increasing of thin films internal stress.

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