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STRESS-MAGNETIC PROPERTIES OF TbFeCo FILM AND SmFe FILM

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Giant magnetostrictive materials are used in the creation of actuators. These giant magnetostrictive materials are also useful as sensor materials. TbFeCo is a giant magnetostrictive material with a positive magnetostriction coefficient and grows by approximately +1,200ppm in a magnetic field of 80kA/m. On the other hand, SmFe has the negative magnetostrictive coefficient, and is shortened by -800 ppm. This paper describes the following contents. To create micro and high-sensitivity force sensors using these materials, each thin film is made using the DC magnetron sputtering method. Stress is then applied to the thin film by the bending method. While stress is applied to the thin film, the changes in the magnetic characteristics are measured using VSM. Finally, the resulting data are shown and discussed.

Keywords: giant magnetostrictive thin film, TbFeCo film, SmFe film, differential permeability, stress

1 INTRODUCTION

Giant magnetostriction materials (GMMs) have enormous magnetostriction according to the magnetostriction effect (the Joule effect) and the advantage of an initiation stress. Therefore, many effective applications are reported for it as an actuator. These giant magnetostriction materials are also remarkable with the inverse magnetostriction effect (the Villari effect). However, there are fewer examples of applying them to a sensor than to an actuator [1]. The main reason is that the magnetic characteristic is not understood enough. Also, there is the problem of material availability. Therefore, overcoming these obstacles is a goal of this work. So, it is important to make thin films in order to apply the giant magnetostrictive material to the sensor, and to measure its characteristic.

This paper describes TbFeCo thin film and SmFe thin film. TbFeCo is a giant magnetostrictive material with a positive magnetostriction coefficient and grows by approximately +1,200ppm in a magnetic field of 80kA/m, [2]. On the other hand, SmFe has a negative magnetostrictive coefficient, and is shortened by -800 ppm [3]. A method for measuring the characteristics is described while a specified stress is applied to a thin film specimen. Finally, the characteristic measurement results and its fundamental use as a sensor are described.

2 SPECIMEN

The specifications for TbFeCo thin film and SmFe thin film and sputtering condition are shown in Table 1 and 2. The films are deposited by the DC magnetron sputtering method. The preparation of the thin film is spattered in Ar gas, and a film was formed. In the case of a TbFeCo thin film, 22 Tb chips and 6 Co chips 5×5mm^2 in size were used on the Fe target, using 200W of DC electric power for 108 minutes. A thin film 1 μm in thickness was made on the Si substrate of 100 μm thickness. After the film formation, a 60 minute heat treatment was carried out in a vacuum at 300°C.

The SmFe film is deposited on an Si substrate 150 μm thickness, and the thickness of the film is about 0.88 μm. After the film formation, 60 minute heat treatment was carried out in a vacuum at 250°C.

The directions of the axis of easy magnetization are in-plane in both films, and their structure is amorphous. As a result of measuring their magnetostriction by the bending method, a TbFeCo thin film is 1200 ppm at 80 kA/m, and under the same condition a SmFe thin film is -300 ppm.

Table 1. Specifications of thin film

	TbFeCo	SmFe
Size	5.5mm×5.5mm ×Si (100μm), TbFeCo (1μm)	5.5mm×5.5mm ×Si (150μm), SmFe (0.88μm)
Composition	Tb: 56.4% Fe: 32.5% Co: 11.1%	Sm : 17.2 % Fe : 82.8 %

Table 2 Sputtering condition

	TbFeCo	SmFe
Method	DC magnetron sputtering	
Ar pressure	Ar : 0.7 Pa	Ar: 0.5 Pa
DC power	200 W	Fe: 200 W Sm: 75 W
Annealing temp.	300 ℃	250 ℃

TbFeCo film shows positive magnetostriction characteristics, while SmFe film shows negative magnetostrictive properties. Though absolute values of magnetostriction of SmFe film are about 1/4 of TbFeCo, there is sufficient magnetostriction characteristic from the viewpoint of using its inverse magnetostriction value.

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3 MEASUREMENT METHOD

Figure 1 shows the method for applying stress to a thin film. When tensile stress is applied in a thin film and the substrate is bent, it makes a thin film plane on the outside, as is shown in Fig. 1(a). Conversely, when a compressive force is applied, the thin film plane is bent inwards like in Fig. 1(b). The stress added to a thin film is determined from the Stoney equation shown in the following, when the bend radius of the substrate is made to be *R*, [4].

$$\sigma = \frac{E_s d_s^2}{6(1-\nu_s) R d_F}, \qquad (1)$$

where are: σ - internal stress (Pa), E_s - Young's modulus of the substrate (Pa), d_s - thickness of the substrate (m), ν_s - Poisson ratio of the substrate, R - radius of arc (m), d_F - thickness of the thin film (m).

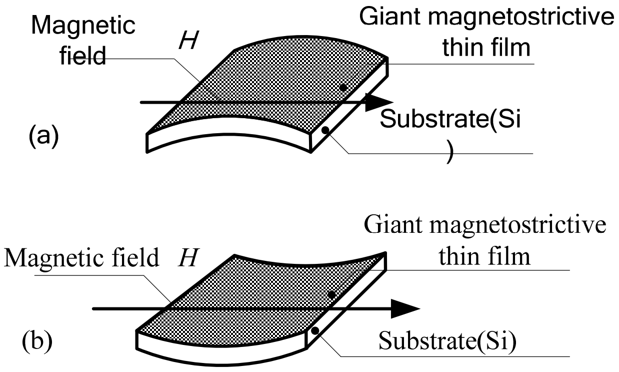

Fig. 1. Stress introduction method by bending: (a) - tension (b) - compression

In the case of an SmFe thin film, the applied stress becomes about 15G Pa when the bend radius is 75mm.

To determine the inverse magnetostriction characteristic, the materials were excited so that the direction of bending stress and magnetic field were in agreement as measured using VSM, [5]. While the films are bent, the *BH* characteristics of films are measured within a ±16 kA/m magnetic field as shown in Fig. 2.

The *BH* characteristic of a TbFeCo thin film is shown in Fig. 3. The maximum magneticflux density was 0.3 T. In the compressive stress case, the *BH* characteristic tilts at TbFeCo film due to its positive magnetostrictive coefficient. Oppositely, the inclination of the *BH* characteristic becomes steep in the tensile stress.

Figure 4 shows the *BH* characteristic of a SmFe thin film. The maximum magneticflux density is over 0.7 T, which is over double that of a TbFeCo thin film. The gradient of the *BH* characteristic becomes steep in compressive stress, since SmFe is a material of negative magnetostriction. Conversely, the inclination of the BH characteristic becomes gentle in the tensile stress.

4 MAGNETIC PROPERTIES

Parameters from the measured *BH* characteristics are extracted and shown in additional figures. Figure 5 and 6 show the aspect in which maximum magnetic flux density and coercive field strength change by the stress. Maximum magnetic flux density and coercive field strength of a TbFeCo thin film show the peculiar property in which sensitively changes with stress.

The differential permeability was obtained from the measured BH characteristic using equation (2). ΔH was calculated as 0.8 kA/m. The case in which the stress is zero is shown in Fig. 7.

$$\mu_d = \frac{\Delta B}{\mu_0 \Delta H}, \qquad (2)$$

where are: μ_d - differential permeability, μ_0 - permeability of vacuum (H/m), ΔB - variation of magnetic flux density (T), ΔH - variation of magnetic field (A/m).

The maximum value of differential permeability is the condition in which the magnetic field is positive, and the change in stress of the largest differential permeability is shown in Fig. 8. The differential permeability of a SmFe thin film is about 900 when the stress is zero, and a TbFeCo thin film is about 100.

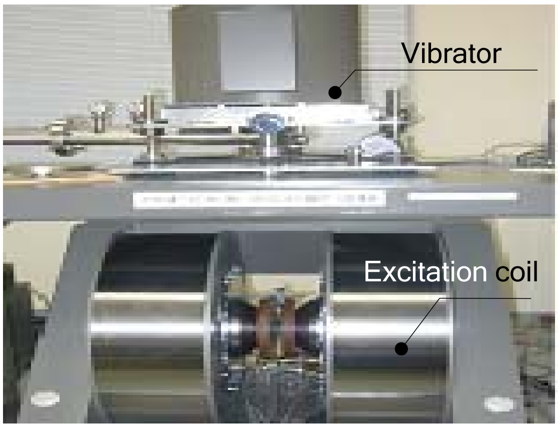

Fig. 2. VSM

For a sensor of the type which converts the inductance change of a coil from the permeability change using the magnetic bias, the characteristic shown in the above is very useful. From this viewpoint, it is proven that SmFe film is more suitable than TbFeCo film as a stress sensor.

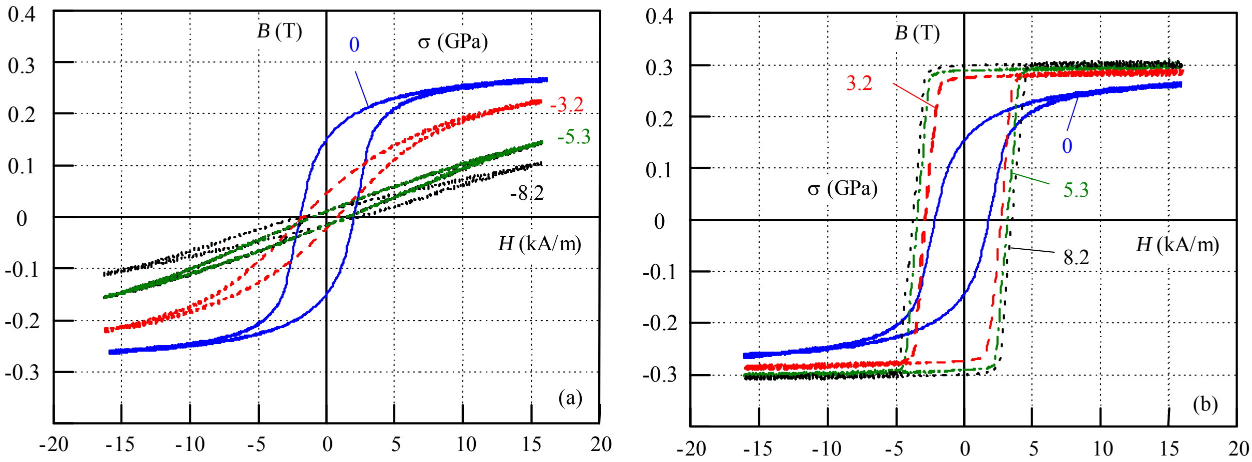

Fig. 3. *BH* Curve versus stress of TbFeCo film: (a) – compression, (b) – tension

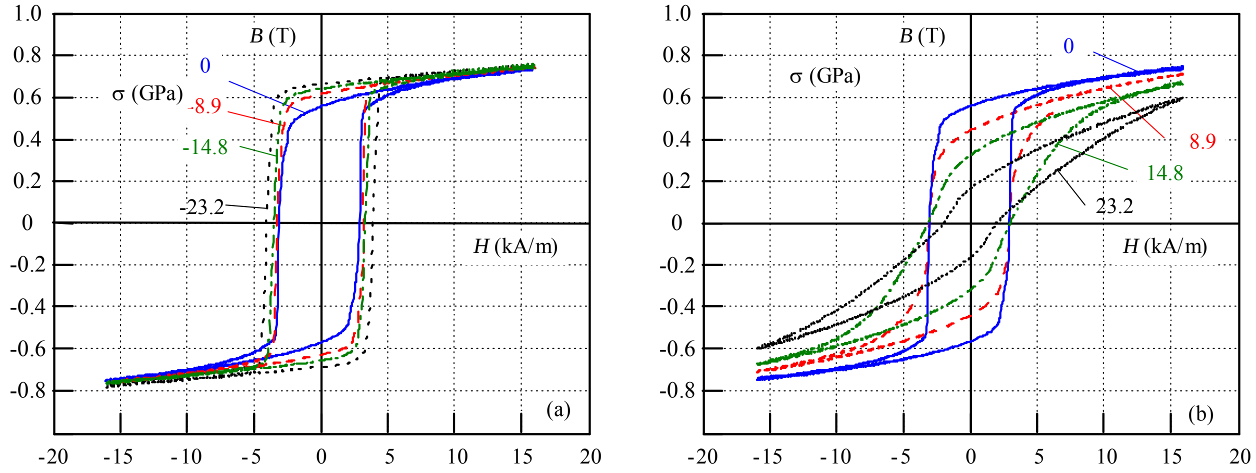

Fig. 4. BH Curve versus stress of SmFe film: (a) – compression, (b) - tension

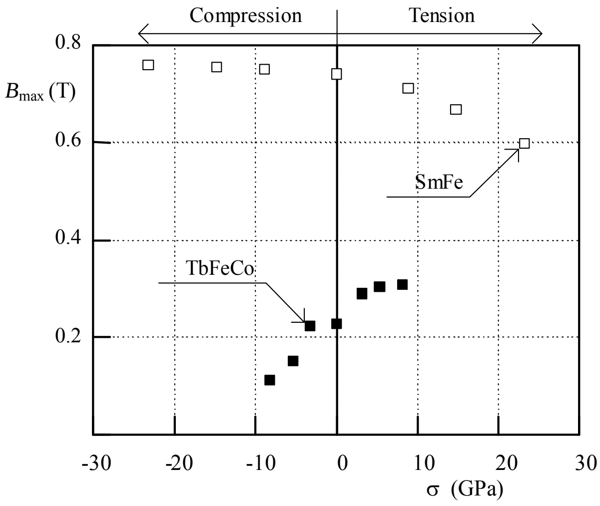

Fig. 5. Change of maximum magnetic flux density due to applied stress

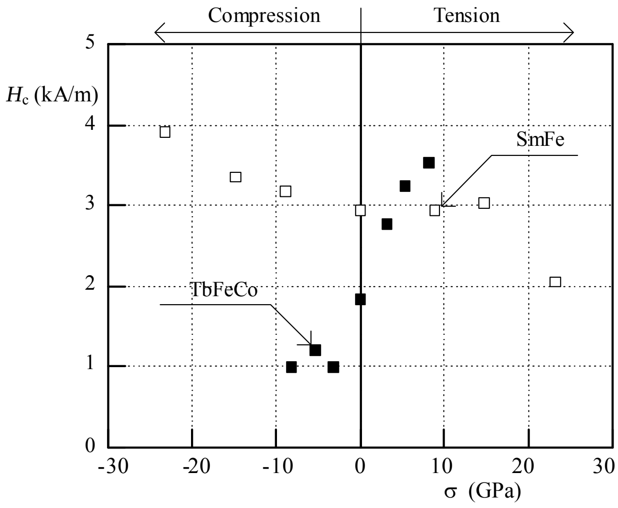

Fig. 6. Change of coercivity due to applied stress

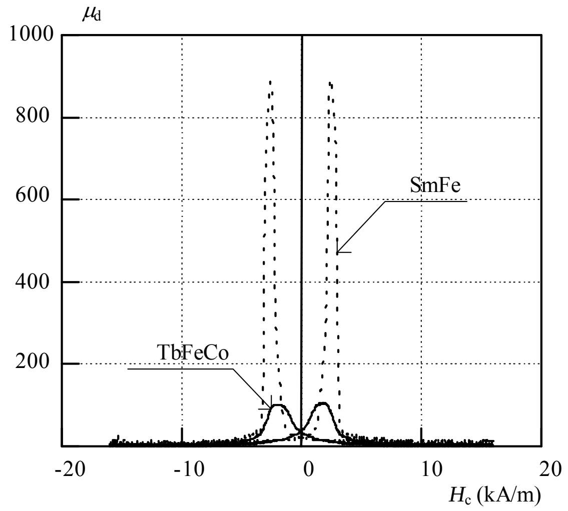

Fig. 7. Differential permeability of thin film

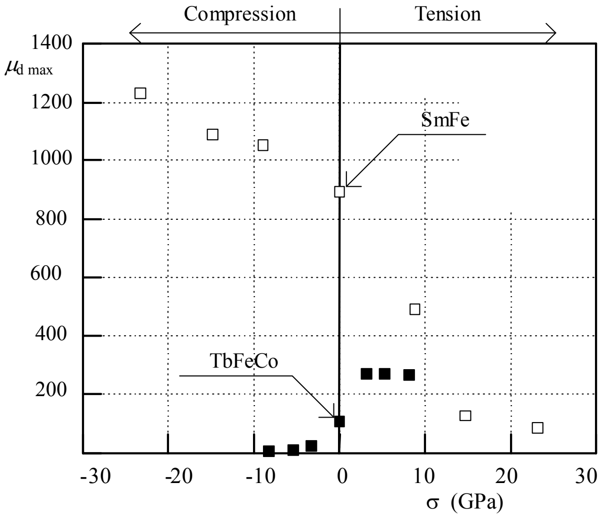

Fig. 8. Change of maximum differential permeability due to applied stress

5 CONCLUSION

In this paper, the following items were clarified.

(1) The maximum magnetic flux density of SmFe film is over double that of TbFeCo film. The maximum magnetic flux density of SmFe film slightly lowers with an increase in tension. At the same time, with an increase in compression force, the maximum magnetic flux density of TbFeCo film rapidly lowers.

(2) Within ±15 GPa, stress does not affect the coercive field strength of SmFe film. On the other hand, stress greatly influences in the coercive field strength of TbFeCo film.

(3) In the ±5 GPa stress range, the permeability of a TbFeCo film greatly changes. Conversely, in the case of a SmFe thin film with a stress of 0-15 GPa, its permeability change is bigger than that of TbFeCo.

By considering the characteristic described in this paper, it is possible to create a high-sensitive force sensor using SmFe film.

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