Anisotropic Nd-Fe-B thick film magnets prepared on various substrates

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Abstract. We investigated the effect of substrates for preparing perpendicularly anisotropic Nd-Fe-B thick film magnets prepared by the high-speed PLD (Pulsed Laser Deposition) method with a substrate heating system. Although it was difficult to prepare perpendicularly anisotropic films on W, Zr and Nb substrates, usage of Ta, Mo and Ti substrates enabled us to obtain anisotropic ones. It was found that the preparation of anisotropic PLD-made Nd-Fe-B thick film magnets depends on substrates.

1. Introduction
Size reduction in electronic devices such as milli-size motors and micro-actuators comprising of film magnets thicker than several-ten-microns has been advanced [1]. Up to now, a fabrication of thick film magnets with excellent magnetic properties has been reported [2]-[4]. We also have synthesized anisotropic Nd-Fe-B film magnets deposited on Ta substrates by using a high speed PLD method [5], however the magnetic properties did not attain the values of the above-mentioned anisotropic films. Recently, Itakura et al. reported the existence of an isotropic boundary layer between the Ta substrate and c-axis of columnar grains [6] in the PLD-made films, which suggests that the isotropic region is an important layer in order to obtain a perpendicularly anisotropic film.

In this study, an investigation on the relationship between the anisotropy and various substrates was carried out in the PLD-made Nd-Fe-B films.
2. Experimental
In order to compensate loss of metallic Nd due to oxidation, the nominal composition of targets was set to Nd$_{2.4}$Fe$_{14}$B. The targets include a larger amount of Nd compared with the stoichiometric composition. These targets were ablated with a Nd-YAG pulse laser ($\lambda = 355$ nm) at the repetition rate of 30 Hz, and the distance between a target and a substrate was fixed at 10 mm. In the experiment, we used various substrates of Ta, Mo, Ti, Nb, W, Zr and SiO$_2$. The thickness of all substrates was 50 $\mu$m besides SiO$_2$ (1 mm) and Ta (40 $\mu$m). The substrate temperature was fixed at 873 K with a substrate heating system as shown in Fig. 1 [5]. In the system, a substrate was heated by a Ta sheet-heater around the substrate. Before the ablation, the chamber was evacuated down to approximately $10^{-4}$ Pa with a molecular turbo pump. Duration of the deposition was fixed at 1 h, and a Ti sublimation pump was used as an auxiliary pump during the deposition.

In-plane and perpendicular M-H loops were measured with a vibrating sample magnetometer (VSM). The analyses of crystal structure were carried out with an X-ray diffractometer. In this report, the thickness range of samples was from 10 to 35 $\mu$m.

3. Results and Discussion
A PLD-made Nd-Fe-B film deposited on a SiO$_2$ substrate did not have enough hard magnetic properties because the M-H loop of the film had a knick around coercivity (see Fig. 2). Observation in X-ray diffraction pattern for the film showed the existence of $\alpha$-Fe and Nd$_2$O$_3$ phases, therefore we had difficulty in evaluating the anisotropy of the sample prepared on a SiO$_2$ substrate.

Figure 3 shows M-H loops of samples deposited on various metal substrates. The all perpendicular loops were corrected by using the demagnetization factor of 1.0. Usage of Mo and Ti substrates enabled us to obtain anisotropic Nd-Fe-B film magnets as shown in Figs. 3 (b) and (c). These results have the same tendency compared with that of a film deposited on a Ta substrate (see Fig.3 (a)).
Fig. 3 M-H loops of Nd-Fe-B films deposited on Ta, Mo, Ti, Zr, W and Nb substrates at the heating temperature of 873 K, respectively. The perpendicular loop was corrected by using the demagnetization factor of 1.0.

In the films prepared on a W substrate, although the value of coercivity in the perpendicular direction was higher than that of the in-plane one, the perpendicular magnetization was smaller than that of the in-plane one (see Fig. 3(e)). An observation of X-ray diffraction pattern revealed that the peak intensities corresponding to the c-plane such as (004), (006), (008) and (105) for a film deposited on a W substrate were not strong compared to those of a film prepared on a Ta substrate as displayed in Fig. 4. We also confirmed the same results in the experiments for Zr and Nb substrates. These
results suggest that we have difficulty in obtaining perpendicularly anisotropic Nd-Fe-B film magnets deposited on W, Zr and Nb substrates.

It has already reported that in an anisotropic film magnet deposited on a Ta substrate, at first, isotropic grains are formed, however only the recrystallized grains suitable for the growth direction can keep growing up, and then an aggregate of columnar grains attributed to c-axis are formed [6]. Namely, it is considered that the existence of an isotropic boundary layer between a Ta substrate and c-axis of columnar grains in the film is an important layer in order to obtain a perpendicularly anisotropic film. A future investigation is required on the boundary layer between various metal substrates and each film.

4. Conclusion

In this report, an investigation on the relationship between a magnetic anisotropy and a substrate was carried out in PLD-fabricated Nd-Fe-B film magnets. It was clarified that the anisotropy depends on the substrates and that an investigation on the boundary layer between various metal substrates and each film as a future work.

References

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