Magnetic properties of pulsed laser deposition-fabricated isotropic Fe–Pt film magnets

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A high-speed pulsed laser deposition method with the deposition rate of several tens of microns per 1 h enabled us to obtain isotropic Fe–Pt thick film magnets. Increase in the laser power enabled us to obtain as-deposited films with $L1_0$ ordered phase due to the heat radiation from a target, which means that a substrate heating system and a post-annealing process are not required to achieve hard magnetic properties in the process. Use of an Fe-rich target enhanced the magnetic properties, and as a result $(BH)_{max}$ value exceeded 100 kJ/m^3 in an isotropic Fe–Pt film fabricated at the power of 3 W, which was comparable to those of isotropic Fe–Pt thick film magnets prepared by a sputtering method. © *2011 American Institute of Physics*. [doi:10.1063/1.3561785]

I. INTRODUCTION

It is generally known that Fe–Pt magnet is one of the promising materials to use in the medical field due to its outstanding biocompatibility.[1] In addition, the miniaturization of Fe–Pt magnets is also required to advance medical micro-electro-mechanical systems.[2] For example, isotropic Fe–Pt film magnets thicker than several microns were synthesized by Aoyama and Honkura[3] and Liu *et al.*,[4] respectively, by using a sputtering method. We also reported isotropic Fe–Pt thick films prepared by using a high-speed pulsed laser deposition (PLD) method with a deposition rate of several tens of microns per 1 h;[5,6] however, the magnetic properties were inferior to those of the above-mentioned sputtering-made films. Watanabe and Masumoto reported that the increase in Fe content in an isotropic Fe–Pt bulk magnet enabled us to enhance the values of remanence and $(BH)_{max}$ because of the increase in the saturation magnetization.[7]

This contribution reports that use of an Fe-rich target is effective to improve the magnetic properties for the PLD-made isotropic Fe–Pt thick film magnets. We also confirmed the existence of soft magnetic phase in the sample through investigations on a good recoil rate and thermomagnetic property.

II. EXPERIMENTAL PROCEDURE

An $Fe_{70}Pt_{30}$ target was ablated with a Nd-YAG pulse laser (wavelength: 355 nm) at the repetition rate of 30 Hz in a vacuum atmosphere. A laser power was measured with a power meter in front of the entrance lens of a chamber. Before the ablation, the chamber was evacuated down to approximately 4×10^{-7} Torr with a rotary pump together with a molecular turbopump. The distance between a target and a Ta substrate was fixed at 10 mm, and the area of all the obtained films were 5×5 mm^2. The thickness increased up to approximately 50 μm in proportion to the laser power up to 7 W. The compositions of Fe–Pt films tended to reduce the amount of Fe by 6–15 at. % compared with that of an $Fe_{70}Pt_{30}$ target. As shown in Fig. 1, the Fe concentration in an as-deposited film increased with increase in the power. The substrate temperature during the deposition was measured with a temperature-detecting-tape commercially called "THERMO LABEL," which showed a comparable value with that evaluated by using an infrared thermometer.

After a sample was magnetized up to 7 T with a pulse magnetizer, *M–H* loops were measured with a vibrating sample magnetometer (VSM) that could apply a magnetic field up to approximately 1800 kA/m reversibly. Thermomagnetic property of *M* (Magnetization)–*T* (Temperature) curve was also evaluated by using a VSM. In the experiment, in-plane magnetic properties were only shown because all the films had isotropic magnetic properties in the power range between 1 and 7 W. Crystalline structure was observed with an x-ray diffractometer and an average thickness was measured with a micrometer.

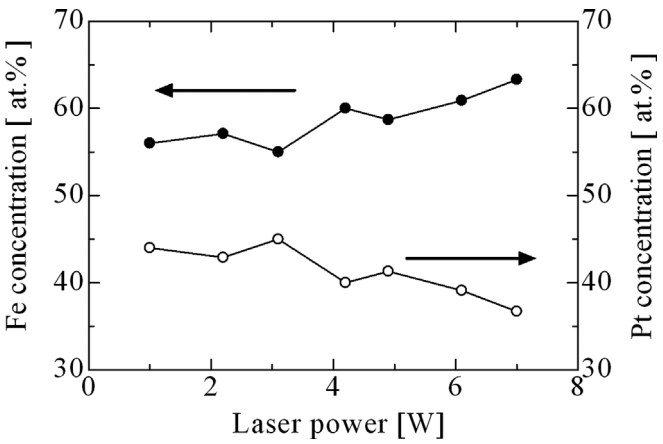

FIG. 1. Fe and Pt concentrations of Fe–Pt film magnets as a function of laser power. The composition of a target was $Fe_{70}Pt_{30}$.

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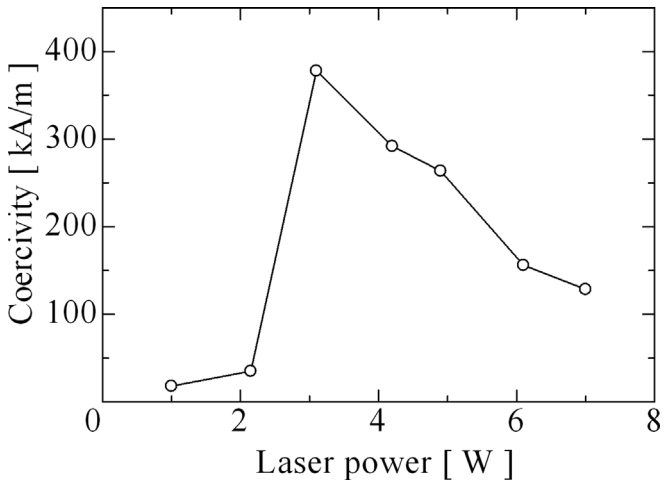

FIG. 2. In-plane coercivity values for as-deposited Fe–Pt film magnets prepared from $Fe_{70}Pt_{30}$ target as a function of laser power.

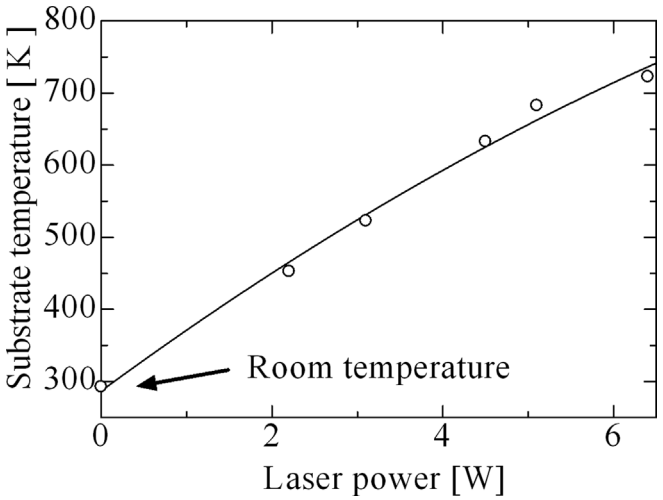

FIG. 4. Substrate temperature during deposition as a function of laser power. The temperature was evaluated by using a temperature-detecting-tape.

III. RESULTS AND DISCUSSION

Figure 2 shows coercivity values of the as-deposited films as a function of laser power. The values drastically increased at the power of 3 W and then gradually decreased with increase in the power. As shown in Fig. 3(a), x-ray diffraction patterns of the samples fabricated at 2, 3, and 7 W, respectively, indicated that an increase in the power up to 3 W led to an order–disorder transformation. In the sample prepared at 7 W, a diffraction peak corresponding to Fe_3Pt phase could be observed [see Fig. 3(b)]. The existence of the Fe_3Pt phase is considered to be attributed to the increase in the Fe content at the laser power of 7 W (see Fig. 1). As shown in Fig. 4, a substrate temperature was proportional to the laser power due to the rise of radiation heat from a target. We considered that the increase in the substrate temperature enabled us to achieve the rapid rise in coercivity by taking advantage of the order–disorder transformation and that the gradual reduction was attributed to the formation of Fe_3Pt as a soft magnetic phase.[8] We succeeded in obtaining $L1_0$ ordered phase and relatively high coercivity by using a suitable laser power without using a substrate heating system and a post-annealing process.

Figure 5 shows in-plane and perpendicular *M–H* loops of an Fe–Pt film fabricated at a power of 3 W. The correction of demagnetization effect was carried out. The values of coercivity, remanence, and $(BH)_{max}$ were 378 kA/m, 0.94 T, and 104 kJ/m^3, respectively. We confirmed that remanence enhancement occurred in the sample because of the saturation magnetization of 1.43 T for $Fe_{50}Pt_{50}$ ordered phase.[8] As shown in Fig. 6, the recoil rate of the Fe–Pt thick film shown in Fig. 5 was superior to that of a sputtering-made Fe–Pt film, which was almost composed of order phase.[9] A thermomagnetic property was also evaluated for the sample. (see Fig. 7) Although it was difficult to observe the Curie temperatures corresponding to disorder FePt and Fe_3Pt phases in the *M–T* curve, a differential curve of *dM/dT* indicated the existence of soft magnetic phases of disorder FePt and/or Fe_3Pt. Tanaka and Hisatsune reported that an Fe–Pt

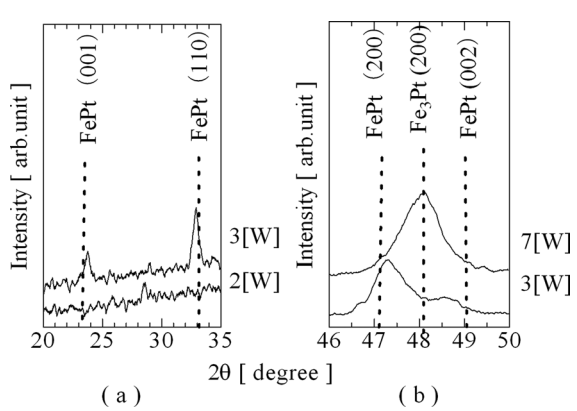

FIG. 3. X-ray diffraction patterns for as-deposited Fe–Pt film magnets prepared at the laser power of 2, 3, and 7 W, respectively.

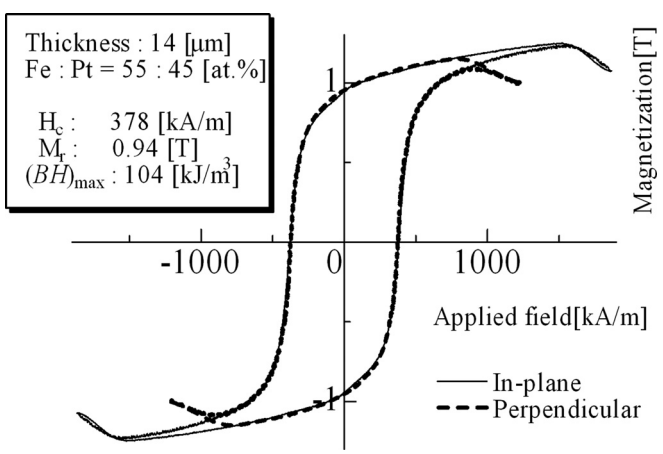

FIG. 5. In-plane and perpendicular *M–H* loops of an as-deposited Fe–Pt film magnet prepared from a $Fe_{70}Pt_{30}$ target. The correction of demagnetization effect was carried out. The values of coercivity, remanence, and $(BH)_{max}$ were 378 kA/m, 0.94 T, and 104 kJ/m^3, respectively.

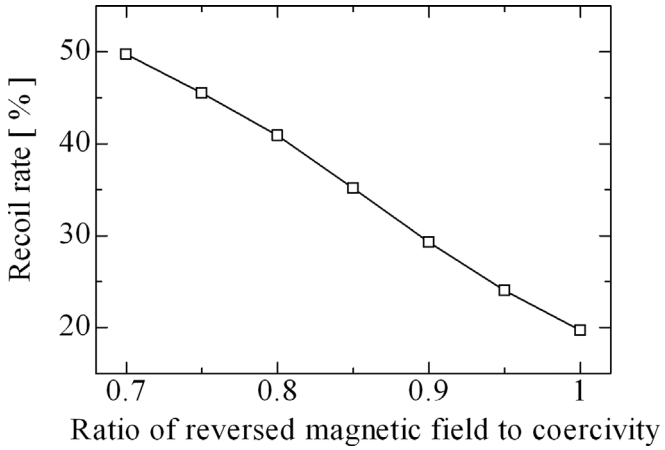

FIG. 6. Recoil rates for an Fe–Pt film magnets seen in Fig. 5. The horizontal axis shows the ratio of reversed magnetic field to coercivity.

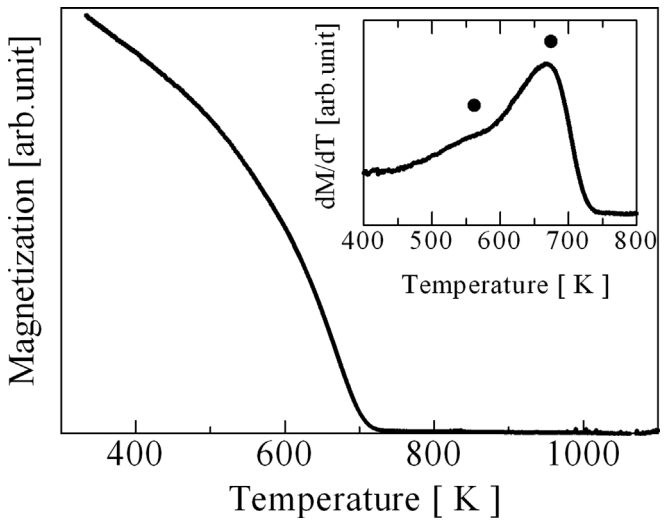

FIG. 7. Thermomagnetic property of M (Magnetization)–T(temperature) curve for an Fe–Pt film magnet seen in Fig. 5. The insert shows a differential curve of dM/dT.

bulk magnet with FePt order phase showed only remanence enhancement without a good recoil rate, which indicated that we had difficulty in obtaining superior recoil rate by taking advantage of only hard magnetic phase.[10] Namely, the recoil rate displayed in Fig. 6 is considered to be attributed to the mixture of hard and soft magnetic phases. In addition, it is known that in some cases not a complete ordering into the $L1_0$ phase is responsible for the high remanence.[9] Consequently, it is considered that the increase of the remanence is attributed to the both exchange couplings of "ordered and ordered phases" and "ordered and disordered phases."

IV. CONCLUSION

In the study, an Fe-rich target was used in order to improve the magnetic properties of a PLD-fabricated isotropic Fe–Pt thick film magnet. As a result, the values of coercivity, remanence and $(BH)_{max}$ for an as-deposited film prepared at the power of 3 W showed 378 kA/m, 0.94 T, and 104 kJ/m^3, respectively, which were comparable to those of isotropic Fe–Pt thick film magnets prepared by a sputtering method.

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