Magnetic domains and magnetization process of amorphous granular (CoFeB)–SiO_2 thin films

M. Takezawa,[1,a)] A. Shiota,[1] Y. Morimoto,[1] J. Yamasaki,[1] M. Munakata,[2] and M. Yagi[2]
[1]*Department of Applied Science for Integrated System Engineering, Graduate School of Engineering, Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata-ku, Kitakyushu, Fukuoka 804-8550, Japan*
[2]*Energy Electronics Laboratory, Sojo University, 4-22-1 Ikeda, Kumamoto 806-0082, Japan*

(Presented on 6 November 2007; received 13 September 2007; accepted 24 November 2007; published online 8 February 2008)

The domain structure and magnetization process of a granular film were explored using a Kerr microscope. Narrow line-shaped reversal domains were observed in a granular $(Co_{25}Fe_{66}B_9)_{75}-(SiO_2)_{25}$ film, and no increase in the width of the domains was observed during the magnetization reversal process by applying a dc field along the easy axis. In addition, no wall displacement was observed in an ac field along the hard axis because only magnetization rotation occurs due to wall pinning. It was found that wall motion that causes excess eddy current losses at high frequencies is hard to occur by the granular structure. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2838154]

I. INTRODUCTION

Heteroamorphous granular (CoFeB)–SiO_2 thin films have been widely investigated for high-frequency applications because of their high electrical resistivity, large saturation magnetization, and anisotropy field.[1–4] Heteroamorphous granular films consist of ferromagnetic nanosized granules in a dielectric matrix and have been examined for their magnetic properties, e.g., magnetic loss at high frequencies. However, little is known about their domains and magnetization process, which are important properties for application at high frequencies such as rf inductors.[5,6] In this study, the domain structure and magnetization process of a granular film were examined using a Kerr microscope.

II. EXPERIMENT

A granular $(Co_{25}Fe_{66}B_9)_{75}-(SiO_2)_{25}$ film with thickness of 400 nm and an amorphous $Co_{25}Fe_{66}B_9$ film with thickness of 340 nm were fabricated by synchronous triple-rf magnetron sputtering using a rotating cylindrical electrode.[1–4] The magnetic properties were measured using a vibrating sample magnetometer and the electrical resistivity was measured by using the dc four-probe method.

A dc field was applied along the easy axis of the films to explore the domain structure and the magnetization process of the granular (CoFeB)–SiO_2 and amorphous CoFeB films using a Kerr microscope. Domain observation was also performed during the ac magnetization process by applying an ac field of ± 80 Oe at 60 Hz along the hard axis of the film. Figure 1 shows the observation method of the ac magnetization process. A change in the domain image is extracted by subtracting a reference image in the ac applied field using an image processor.[7–9] A domain pattern in the remanent state is used as the reference image, and the subtracted image is integrated 200 times every 1/30 s. Magnetization rotation and wall displacement can, thereby, be identified from their images, as shown schematically in Fig. 1. The wall displacement generates a discontinuous change in the Kerr effect signal, creating an intense bright or dark image depending on the direction of displacement. Thus, the evolution of both magnetization processes can be identified from the intensity of the Kerr effect image.

III. RESULTS AND DISCUSSION

Figure 2 shows the magnetization process of the amorphous CoFeB film exhibiting $4\pi M_s = 16$ kG, $H_k = 300$ Oe, and $\rho = 300$ $\mu\Omega$ cm when a dc field was applied along the easy axis. In the image, the bright and dark domains have magnetizations pointing upward and downward, respectively. Reversal domains in the shape of a triangle along the easy axis can be seen at the edge of the film at the field of −9.4 Oe, as shown in Fig. 2(a). When the dc field was increased, reverse domains grew by continuous wall displacement, and the area of bright domains increased, as shown in Figs. 2(b)–2(f).

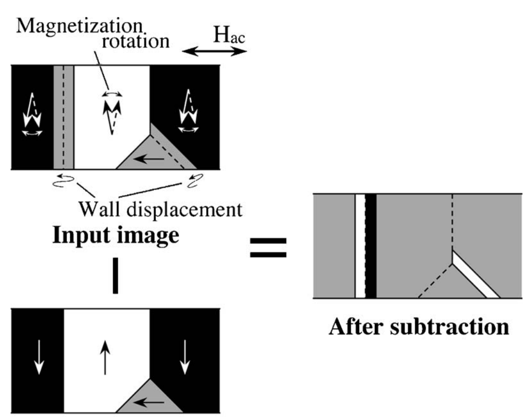

FIG. 1. Principle of domain subtraction using an image processor.

a)Electronic mail: take@ele.kyutech.ac.jp.

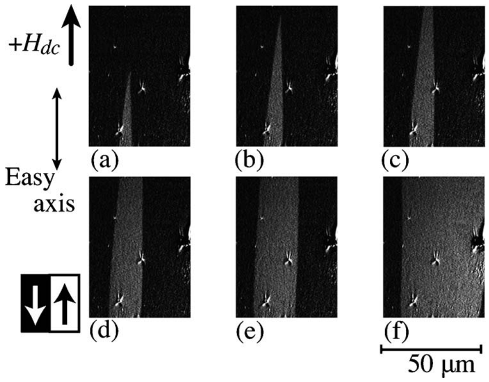

FIG. 2. Magnetization process of amorphous $Co_{25}Fe_{66}B_9$ film: (a) $H=-9.4$, (b) −8.6, (c) 0, (d) +0.5, (e) +1.1, and (f) +2.2 Oe.

Figure 3 shows the magnetization process of the granular $(CoFeB)-SiO_2$ film exhibiting $4\pi M_s=14$ kG, $H_k=300$ Oe, and $\rho=4220$ $\mu\Omega$ cm when a dc field was applied along the easy axis. As shown in Fig. 3(a), many line-shaped reversal domains stretching from the film edge were observed at the field of +42.4 Oe. The width of the reversal domains is a few microns and is narrow compared with the amorphous CoFeB film without SiO_2 phase, as shown in Fig. 2. These narrow domains grew only along the easy axis direction on applying the dc field of +60 Oe or less to the easy axis, as shown in Figs. 3(b)–3(d). However, the increase in the width of the domains was not observed during the magnetization reversal process. This suggests that the granular structure having the SiO_2 phase produces wall pinning in the hard axis direction, which causes a large hysteresis in the magnetization curve along the easy axis. When the dc field is more than 60 Oe, narrow domains were connected together and rapid wall motion along the hard axis direction occurred due to depinning, as shown in Figs. 3(e) and 3(f).

Figure 4 shows wall displacement images of the amorphous and granular films on applying an ac field along the hard axis using an image processor.[7–9] Wall displacement appeared in the amorphous CoFeB film, as shown in Fig. 4(a). In contrast, no wall displacement image can be seen in the granular $(CoFeB)-SiO_2$ film, as shown in Fig. 4(b). The result indicates that the wall displacement is smaller than 400 nm; that is, the image resolution of the Kerr microscope and magnetization rotation is dominant magnetization process due to wall pinning. The results show that wall motion that causes excess eddy current losses at high frequencies hardly occurs in the granular film.

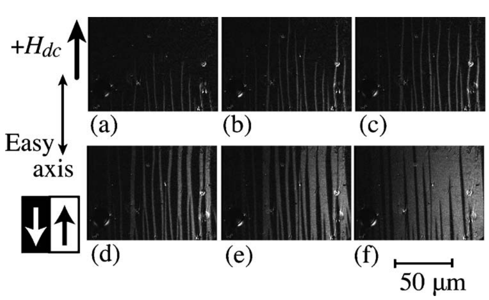

FIG. 3. Magnetization process of granular $(Co_{25}Fe_{66}B_9)_{75}-(SiO_2)_{25}$ film: (a) $H=+42.4$, (b) +44.8, (c) +52.6, (d) +60.2, (e) +61.5, and (f) +68.5 Oe.

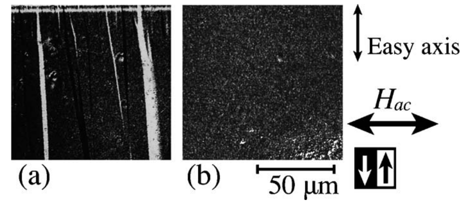

FIG. 4. Image-processed domain changes caused by ac field along the hard axis: (a) CoFeB and (b) $(CoFeB)-SiO_2$.

To investigate the structure of a domain wall in the amorphous and granular films, domain images based on Kerr effect signals were observed in the transverse direction of the magnetization, as shown in Figs. 5 and 6. In these figures, the films are tilted from +20° to −20° to identify the direction of magnetization caused by the longitudinal Kerr effect signals. In Fig. 5(b), bright and dark contrast was seen only along the border between domains. The magnetization component in the amorphous film is shown schematically in Fig. 5(d). The contrast caused by the Néel cap[10] of the domain wall having the magnetization component along the hard axis is seen in Fig. 5(b). In contrast, clear wall image cannot be seen in the granular film, as shown in Fig. 6. The result indicates that the granular film has a very narrow wall compared with the image resolution of the Kerr microscope.

Exchange interaction among magnetic particles along the hard axis is reduced in the granular structures consisting of CoFeB particles separated by the SiO_2 phase,[1–4] and the existence of domain wall is uncertain in the granular film. When a field is applied along the easy axis, magnetization in a wall not only rotates along a field but also aligns neighboring magnetization due to exchange interaction. Both magnetization processes produce the wall motion along the hard axis. Therefore, the small exchange interaction causes the wall pinning along the hard axis direction. It seems that the magnetization rotation along the easy axis direction in CoFeB particles coupling by magnetostatic interaction between their particles is the dominant magnetization process, which produces growth of narrow reversal domains along the only easy axis direction in the granular film.

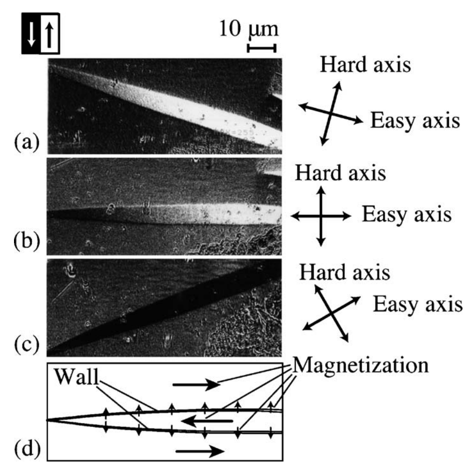

FIG. 5. Domain images of amorphous CoFeB film: (a) tilting angle=+20°, (b) tilting angle=0°, (c) tilting angle=−20°, and (d) model of domain structure.

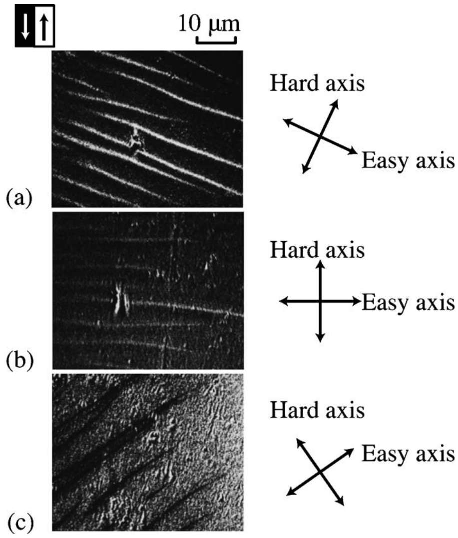

FIG. 6. Domain image of granular $(CoFeB)-SiO_2$ film: (a) tilting angles $=+20°$, (b) 0°, and (c) $-20°$.

IV. CONCLUSION

In this study, the domain structure and magnetization process of a granular film were examined using a Kerr microscope. Narrow line-shaped reversal domains were observed in the granular $(CoFeB)-SiO_2$ film, and no increase in the width of the domains was observed during the magnetization reversal process by applying a dc field along the easy axis. Furthermore, no wall displacement can be seen in an ac field along the hard axis, implying that the granular structure with SiO_2 phase produces the wall pinning. It was also found that the wall motion that causes excess eddy current losses at high frequencies is hard to occur in the granular film. In our future work, it will be necessary to further investigate the relation between the domain structure and the granular structure.

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