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Evolution of microscopic domains in Co/Pt multilayers with perpendicular magnetic anisotropy

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Abstract. We investigated the domain evolutions of (0.3nm Co/0.8nm Pt)$_n$ multilayers (n = 5 and 10) with perpendicular magnetic anisotropy. Our direct observation of magnetic domain structures by means of magneto-optical microscopy reveals that under a negative magnetic field, domain evolution happens via domain wall motion at the domains' boundaries. However, under a reversed field, the domains react differently depending on their domains' substructures. While the domains shrink solely at their boundaries when n = 5, the domain wall motion was observed mostly inside the domains' boundaries when n = 10. This could offer an effective way of using magneto-optical microscopy to investigate domain structures of multilayers with fine substructures without using other high-resolution observation methods.

Keywords: Co/Pt multilayers, Kerr microscopy, domain evolution

1 Introduction

Magnetic multilayers with perpendicular magnetic anisotropy (PMA) have been widely studied because of their interesting properties and potential applications in storage technology [1, 2]. In such multilayers, it is well known that magnetic properties and domain structures vary depending on several factors, such as the thickness of the magnetic layer or the number of magnetic layers [3, 4]. When the magnetic layers are thin and few in number, the domain structures often exhibit circular-like patterns, whereas increasing the thickness or the number of magnetic layers can lead to maze-like or even dendritic-like domain structures [5]. Although these domain structures have been extensively studied, observing domains with fine substructures generally requires high-resolution techniques, with resolutions below a few tens of nanometers [6, 7], with relatively expensive methods such as Transmission Electron Microscopy (TEM) or Scanning Transmission X-ray Microscopy (STXM). These techniques typically require special conditions, such as deep vacuum environments or very thin membranes for transmission observations.

In this work, we report on the domain structure and domain evolution of (0.3nm Co/0.8nm Pt)$_n$ multilayers (where n = 5 and 10) employing direct domain observation using magneto-optical Kerr microscopy. The domain evolution reveals differences in the domain structures of the films under upward and downward external magnetic fields. The multilayers with n being 5 and 10 were chosen for this study because (0.3nm Co/0.8nm Pt)$_5$ displays domains without internal substructures, whereas (0.3nm Co/0.8nm Pt)$_{10}$ shows the presence of fine substructure domains. By reversing the magnetic field, despite the low resolution (~0.5 μm) [8] of the Kerr microscope, we can observe the tiny substructures within some domains. This method is not only relatively inexpensive but also simpler to operate compared with TEM and STXM, as it uses visible light and is carried out under normal atmospheric conditions. To the best of our knowledge, this technique has not previously been used to study the submicron-scale structure of magnetic domains in PMA multilayers.

2 Experimental

The (0.3nm Co/0.8nm Pt)$_n$ multilayers (n = 5 and 10) were deposited on 100-nm SiN membrane substrates with a DC magnetron sputtering system. The base pressure was better than 5.0 × 10^{-9} Torr, and the plasma Ar pressure was kept at 1.0 mTorr. The sputter power was fixed at 30 W for the Co target, 25 W for the Pt target, and 50 W for the Ta target to ensure a very low deposition rate (~0.02 nm·s^{-1}). In fabricating the multilayers, the layer's thickness and the number of layers were confirmed by randomly picking some of the multilayers for TEM measurement. Direct domain observation of domain pattern evolution during a magnetization reversal under an external field normal to the surface of the films was carried out by using magneto-optical Kerr microscopy. The time-dependent magnetization was determined from quantitative analysis of magnetic domain patterns, where magnetization reversal and relaxation curves were determined by summing the Kerr image intensities, then normalized by the saturated image intensity to receive hysteresis loops. The domain images were processed to show domain evolution and domains' substructures.

3 Result and discussion

Fig. 1 presents the dependence of the normalized magnetization (M/M_S) of the films on the external magnetic field with the number of repeat n. The obtained results indicate that perpendicular magnetic anisotropy is established in both samples. Besides, the nucleation field, coercivity, and saturation field of (0.3nm Co/0.8nm Pt)$_{10}$ are significantly larger than those of (0.3nm Co/0.8nm Pt)$_5$.

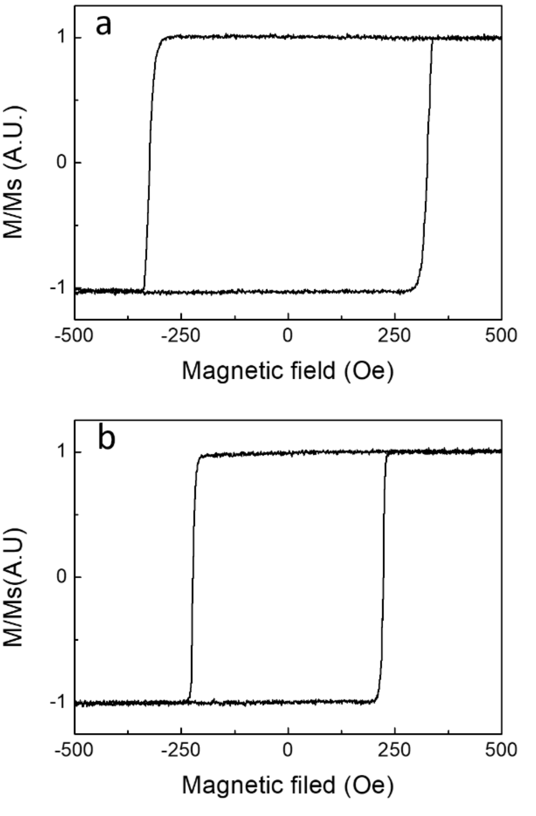

Fig. 1. Hysteresis loop of a) (Co/Pt)$_5$ and b) (Co/Pt)$_{10}$

To capture domain images, each film was saturated positively and then exposed to a negative magnetic field around its coercive value of –310 Oe for (Co/Pt)$_5$ and –190 Oe for (Co/Pt)$_{10}$. As can be seen in Fig. 2, after nucleation with one domain at the centre of the observation field, the domain expands its boundary in all directions to become larger. In both films, the domains show circular-like shapes with smoother boundaries when n = 5; when n = 10, the boundary of the domain is much rougher. These types of domain structures are typical in PMA films [9–11].

The domains' width in Fig. 2 was measured with the time interval of 0.5 s and presented in

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Table 1. The unit is μm. It is clear from the table that the domains grow gradually versus time.

Table 1. Domain size in Fig. 2 (μm)

	1	2	3	4	5
$(Co/Pt)_5$	24.3	50.5	78.6	104.8	128.6
$(Co/Pt)_{10}$	27.6	54.8	84.8	107.1	133.3

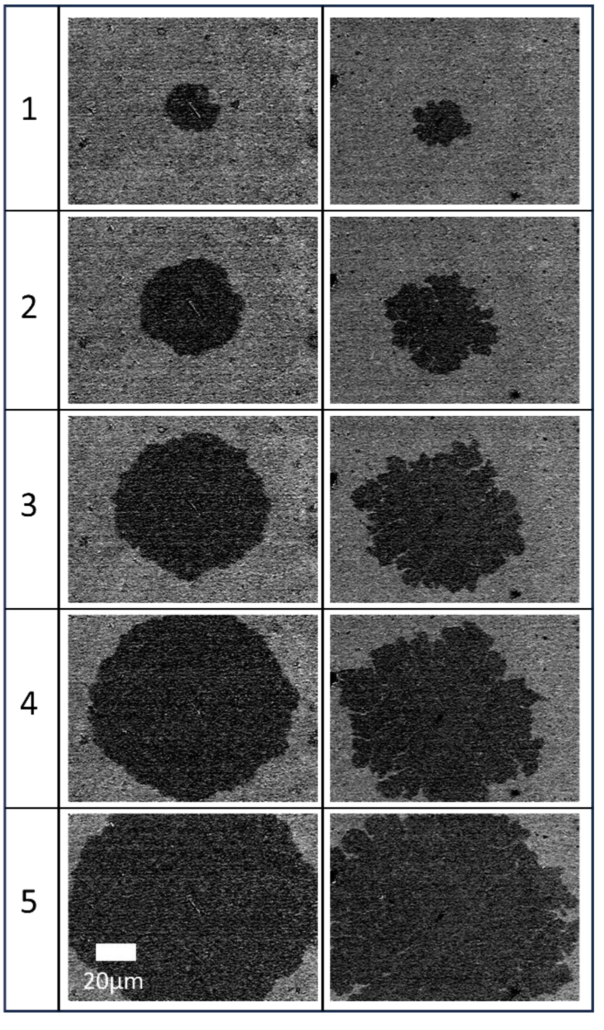

Fig. 2. Domain evolutions of $(Co/Pt)_5$ (left column) and $(Co/Pt)_{10}$ (right column)

The domain images are then compared by cropping the previous image from the next one. The results are presented in Fig. 3. Both films show the expended areas in the shape of rings with gradually increasing diameters.

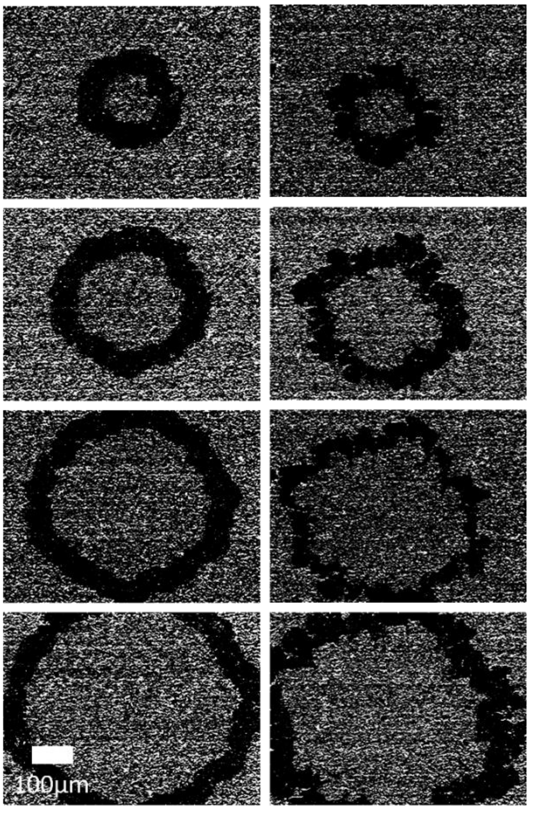

Fig. 3. Domain expansions of $(Co/Pt)_5$ (left column) and $(Co/Pt)_{10}$ (right column)

To further investigate the domain evolution, we captured two series of domain images of the films under a negative field and then a positive field with the magnetic field reversed to the same field strength but opposite in direction.

Fig. 4 shows the results for the $(Co/Pt)_5$ film. Under a negative field, the domain (dark region) expands gradually to the right as seen in Fig. 4a and Fig. 4b, while under the opposite field, it shrinks to the left (Fig. 4c). By overlapping image a from image b and superpositioning image b on image c, the new developing or shrinking areas can be observed in Fig. 4d and Fig. 4e. The grey parts at the domain's boundary represent the developing or shrinking areas. It is obvious that domain evolution happens solely at the edge of the domain.

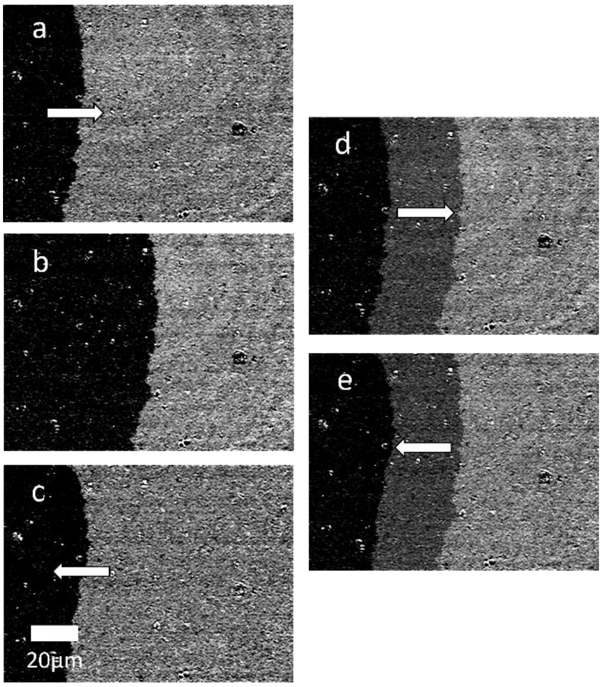

Fig. 4. Domain evolution at the boundary of one domain of $(Co/Pt)_5$ under a negative (a, b) and an opposite applied field (c). The arrows indicate the direction of the boundary movement; (d) comparison between (a) and (b); (e) comparison between (b) and (c)

A similar experiment was carried out for the $(Co/Pt)_{10}$ film, and the obtained domain images are shown in Fig. 5 with one domain (dark area) in the field of view. Here, images a and b were captured under a negative field, and image c is the result of the impact of the opposite field. By subtracting the domain images at the latter time points to the previous ones, the differences between them are obtained and presented in Fig. 5d and Fig. 5e. For this film, under the negative field, the domain develops by shifting its edge to the right, similar to that of $(Co/Pt)_5$. However, under the reversing field, the changes are neglectable at the domain boundary, yet observed mostly inside the domain. It is because, for this film, there are stripe-like microscopic substructure unreversed domains inside the big domain, which are unnoticeable because of noise. This kind of structure has been reported previously for magnetic thin films with PMA [11]. This behaviour cannot be observed in the $(Co/Pt)_5$ film, leading to the conclusion that its domains do not have substructures.

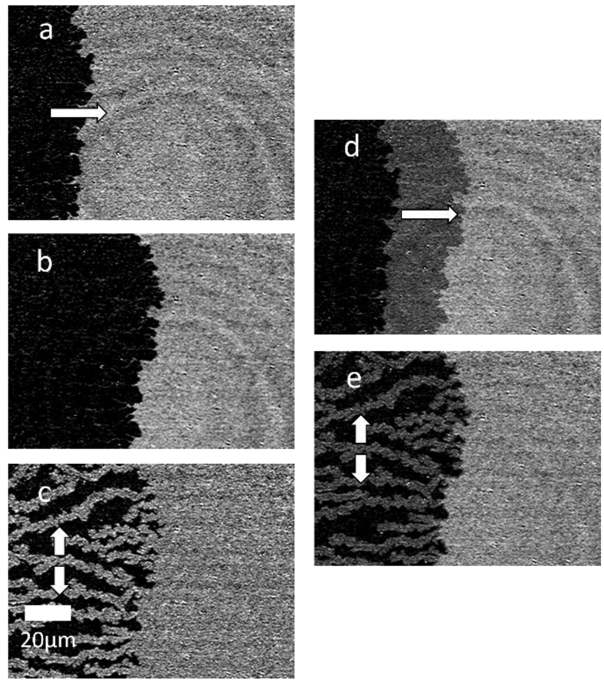

Fig. 5. Domain evolution at the boundary of one domain of $(Co/Pt)_{10}$ under a negative (a, b) and an opposite applied field (c). The arrows indicate the direction of the boundary or substructure domain movement; (d) comparison between (a) and (b); (e) comparison between (b) and (c)

The resolution of the Kerr instrument is usually in microscale [8]. Therefore, this technique cannot be applied to observe magnetic domain structures at submicron scale directly. However, by using the method of reversing the applied field, the substructure domains, if exist, would become visible. This is really useful in investigating domain structure because using an optical microscope is a simple, fast, and much less costly method of domain observation.

4 Conclusion

The domain evolutions of $(Co/Pt)_n$ were examined during its magnetization. The results for the $(Co/Pt)_5$ film show that domains' expanding or

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shrinking occurred at the domains' boundaries. By contrast, in the $(Co/Pt)_{10}$ film, the domains expanded their boundaries but shrunk mostly their substructures inside them. This observation suggests a practical method to study domain structures of PMA films with fine substructure domains.

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