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Unequal Activation Volumes of Wall-motion and Nucleation Process in Co/Pt Multilayers

Yoon-Chul Cho, Sug-Bong Choe and Sung-Chul Shin

Department of Physics and Center for Nanospinics of Spintronic Materials, Korea Advanced Institute of Science and Technology, Taejon 305-701, Korea

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Magnetic field dependence of magnetization reversal in Co/Pt multilayers was quantitatively investigated. Serial samples of Co/Pt multilayers were prepared by dc-magnetron sputtering under various Ar pressures. Magnetization reversal was monitored by magnetization viscosity measurement and direct domain observation using a magneto-optical microscope system, and the wall-motion speed *V* and the nucleation rate *R* were determined using a domain reversal model based on time-resolved domain reversal patterns. Both *V* and *R* were found to be exponentially dependent on the applied reversing field. From the exponential dependencies, the activation volumes for wall motion and nucleation could be determined, based on a thermally activated relaxation model, and the wall-motion activation volume was found to be slightly larger than the nucleation activation volume.

1. Introduction

Co/Pt multilayers have been one of the most promising materials for next generation high density magneto-optical recording media, due to their large perpendicular magnetic anisotropy as well as their large Kerr angle at short wavelengths [1, 2]. To achieve high-density recording, the understanding of magnetization reversal behavior is very important, since it plays a key role in determining the written domain size, irregularity, and stability [3, 4]. These reversal behaviors were analyzed by a thermally activated process. The key to a thermally activated process is the activation volume, which is the elementary magnetization entity. Much effort has been made to characterize the activation volumes of the wall-motion and nucleation processes in numerous system, and it is reported that the two activation volumes are almost the same, within the measurement accuracy [6, 7]. However, there is no clear physical reason why this should be the case.

The current study has been motivated to clarify the correlation between the two activation volumes during the magnetization reversal process. For this study, magnetization reversal in Co/Pt multilayers under various applied field strengths has been examined using a magneto-optical microscope system capable of real-time domain observation. The values of wall motion speed V and nucleation rate R were determined using a domain reversal model based on time-resolved domain reversal patterns. From the field dependence of V and R, the activation volumes of the wall-motion and nucleation processes were determined based on a thermally activated relaxation process.

2. Experiments

Serial samples of Co/Pt multilayers were prepared on glass substrates by dc-magnetron sputtering under Ar pressures of 2, 5, and 7.5 mTorr. The multilayered structure was achieved by alternately exposing the substrates to Co and Pt targets. The difference between the actual thickness and the nominal thickness determined from low-angle X-ray diffraction was less than 3 %. Various samples of (4-Å Co/11-Å Pt)$_{10}$ were prepared by changing the Ar sputtering gas pressure P_{Ar}. In Fig. 1, we show the Kerr hysteresis loop of (4-Å Co/11-Å Pt)$_{10}$ prepared at an Ar sputtering pressure of 7.5 mTorr. All samples show a square hysteresis loop and have perpendicular magnetic anisotropy.

Magnetic domain patterns were observed using a magneto-optic microscope system capable of a spatial resolution of 0.4 μm, Kerr-angle resolution of 0.2°, and $\times$ 1000 magnification, equipped with an advanced digital video processing system. The sample was initially saturated by applying a magnetic field normal to the film plane, and then reversal behavior was observed under a reverse magnetic field near the coercivity. Time-resolved domain images of 128 frames at 10 frames/s were taken under various applied fields. The image, composed of 200×160 pixels with the unitsize of 200×200 nm, was initially obtained in 256 gray levels and then, intensified by noise filtering and black-and-white image extraction. The reversed domain area $a(t)$ and the domain boundary length $l(t)$ of each image were determined by counting black and white cells. The values of V and R were obtained from the reversed domain area $a(t)$ and the domain boundary length $l(t)$ based on the domain rever-

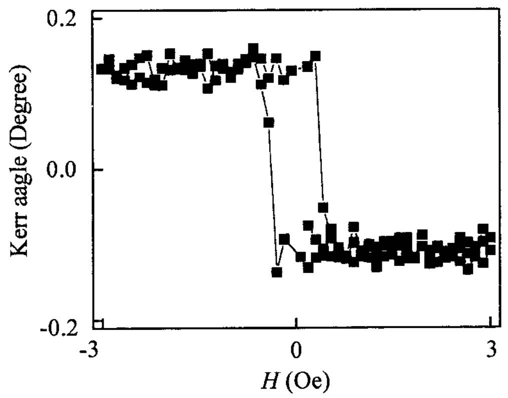

Fig. 1. Polar Kerr hysteresis loop for (4-Å Co.11-Å Pt)$_{10}$ samples prepared at Ar sputtering pressure of 7.5 mTorr.

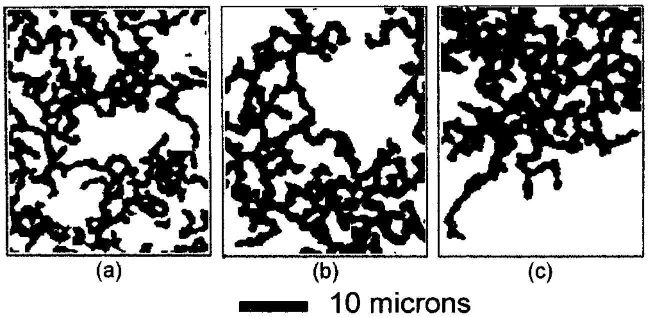

Fig. 2. Domain patterns during magnetization reversal under a reversing applied field for (4-Å Co/11-Å Pt)$_{10}$ samples prepared at Ar sputtering pressure of (a) 2, (b) 5, and (c) 7.5 mTorr, respectively. The domain patterns were recorded at 40% reversal.

sal model proposed by Choe and Shin [8]:

$$\left.\begin{array}{l} V = (a' - r_0 l'/2)/(l - \pi r_0) \\ R = (ll'/2\pi - a')/(1 - \pi r_0) r_0 (s - a) \end{array}\right\}, \qquad (1)$$

where a' and l' denote the first time derivative of a and l, respectively. The total area s under examination was $40 \times 32\ \mu m^2$ and the characteristic length r_0 of nucleation was set to 100 nm, corresponding to the unit pixel size.

3. Results and Discussion

Fig. 2 shows the domain reversal patterns of (4-Å Co/11-Å Pt)$_{10}$ prepared at an Ar sputtering pressure of (a) 2 mTorr , (b) 5 mTorr, and (c) 7.5 mTorr, where the domain patterns were taken at 40% reversal during the magnetization reversal. Dendritic growth formed by the nucleation process was clearly observed in all samples; the domains grew only slightly in size but expanded quickly by dendritic growth throughout the whole area of the sample. The dendritic stripes hardly grew in width, thus the widths of the stripes remained nearly constant during the reversal process [4]. A detailed examination revealed that the stripe width was increased with increasing Ar pressure. This is expected, since the sample prepared at low Ar sputtering pressure has

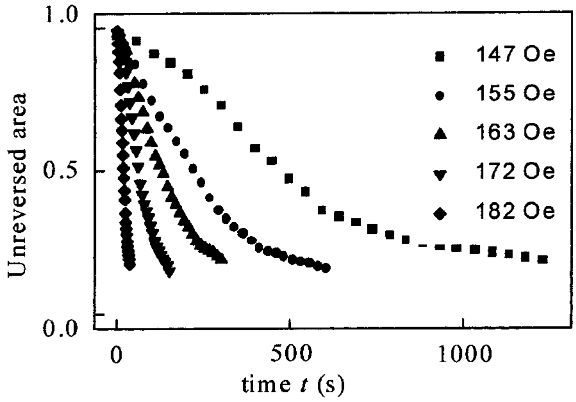

Fig. 3. Magnetization viscosity curves of the (4-Å Co/11-Å Pt)$_{10}$ sample prepared at Ar sputtering pressure of 7.5 mTorr under several reversing fields H, noted in the figure.

a large saturation magnetization M_S, due to its dense film structure and thus, the domain splits into narrow stripes due to the strong demagnetization energy.

Magnetic field dependence of the reversal behavior was examined under various applied fields. In Fig. 3, we show the magnetization viscosity curve of (4-Å Co/11-Å Pt)$_{10}$ prepared at an Ar sputtering pressure of 7.5 mTorr. The magnetization viscosity curve was obtained by monitoring the reversed domain area $a(t)$ vs. time under a reversing field and the individual curves were obtained at different reversing fields. The rate of relaxation was considerably accelerated by increasing the reversal field, but the basic shape of the curves remained identical irrespective of the reversing field. In Fig. 4(a), we show normalized viscosity curves where the time axis is normalized by the half reversal time τ, the time needed to reverse half of the area of the sample under a given reversing field. It is clearly seen that all the curves become a unique curve irrespective of the strength of the reversing field. Thus, the normalized curve could be regarded as the characteristic universal curve representing the magnetization reversal of the sample [9].

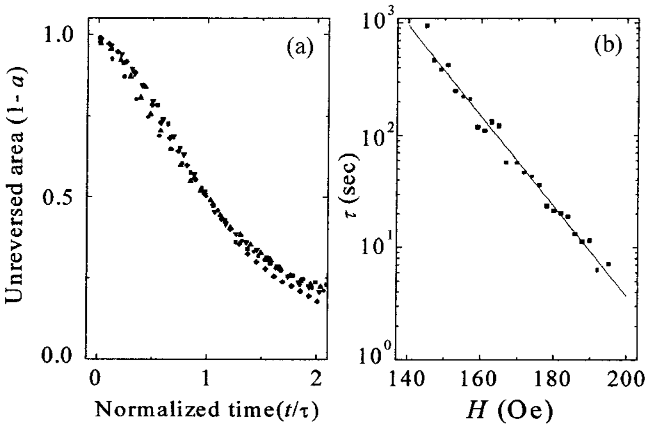

Fig. 4. (a) Normalized magnetization viscosity curves with time t normalized by the half reversal time τ. (b) Variation of the half reversal time τ with reversing field H.

Table 1. Measured magenetic properties: activation coefficients, activation volumes, and reversal ratio of Co/Pt multilayers

t_{Co} (Å)	P_{Ar} (mTorr)	M_S (emu/cc)	H_0 (Oe)	α_τ (Oe^{-1})	V_W ($\times 10^{-18}$ cm^3)	V_N ($\times 10^{-18}$ cm^3)
4.0	2	693	80.5	0.074 ± 0.004	12.9 ± 0.6	10.8 ± 0.5
4.0	5	664	132.7	0.069 ± 0.004	11.9 ± 0.7	10.7 ± 0.7
4.0	7.5	655	212.4	0.040 ± 0.001	6.2 ± 0.2	6.0 ± 0.3

Fig. 4(b) shows the variation of the half reversal time τ with respect to the reversing field. It turns out that τ followes an exponential law:

$$\tau = \exp[\alpha_\tau(H_0 - H)], \tag{2}$$

where α_τ is the activation coefficient and H_0 is defined as the field needed to reverse half of the volume of the sample in 1 s. The values of H_0 and α_τ of the samples are listed in Table 1.

The values of V and R were determined from the time-resolved domain patterns during magnetization reversal under various applied fields. In Fig. 5, we plot (a) the wall-motion speed V and (b) the nucleation rate R with respect to the reversing field for the (4-Å Co/11-Å Pt)$_{10}$ sample prepared at an Ar sputtering pressure of 7.5 mTorr. It is clearly seen in the figure that the wall-motion speed V and the nucleation rate R are also exponentially dependent on the applied field;

$$\left.\begin{aligned} V &= V_0\exp(\alpha_W(H - H_W)) \\ R &= R_0\exp(\alpha_N(H - H_N)) \end{aligned}\right\}, \tag{3}$$

where V_0 is the characteristic wall-motion speed under the wall-motion coercivity H_W and R_0 is the characteristic nucleation rate under the nucleation coercivity H_N. The exponential dependence can be explained within the context of a thermally activated relaxation process, and the activation coefficients α_W and α_N are represented as follows:

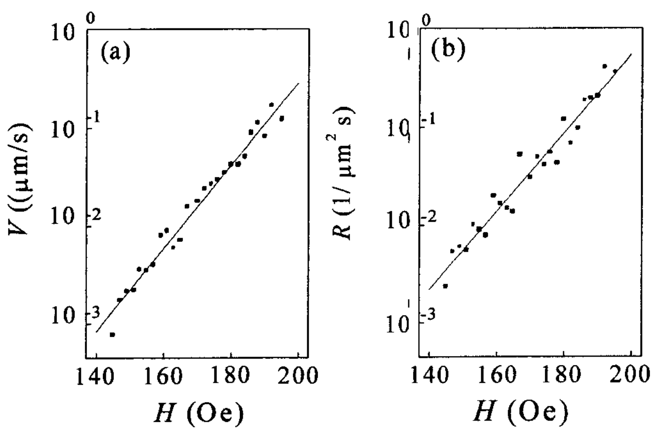

Fig. 5. (a) The wall-motion speed V vs the reversing field H. (b) The nucleation rate R vs the reversing field H.

$$\left.\begin{aligned} \alpha_W &= V_W M_S / k_B T \\ \alpha_N &= V_R M_S / k_B T \end{aligned}\right\}, \tag{4}$$

where V_W and V_N are the activation volumes for the wall-motion and nucleation processes, respectively [3, 5]. The activation volumes of the wall-motion and nucleation process have been determined from the activation coefficients, using the measured value of saturation magnetization M_S of each sample. The values of V_W and V_N of the samples are summarized in Table 1. The activation volume is the volume acting as single-domain particle or the volume swept by a domain wall jump. It is determined by structure, especially defects in a thin film. Hence, we consider that the activation volume is expected to be smaller due to a larger defect density at a higher Ar sputtering pressure, since the defect density is expected to be larger in the coarse film prepared at a higher Ar sputtering pressure. Most interestingly, a detailed examination revealed that the activation volume V_W was slightly larger than the nucleation activation volume V_N for all the samples. Since the activation energy is proportional to the activation volume the reversal process having the smaller activation volume is expected to be dominant. Hence, it can be understood that the nucleation-dominant reversal process in Co/Pt multilayers is due to a smaller activation volume for the nucleation process than for the wall-motion process. Unequal activation volumes for the wall-motion process and the nucleation process have been reported in the Co/Pd system [10].

4. Conclusion

Magnetization reversal in Co/Pt multilayers under a reversing applied field has been quantitatively examined. The wall-motion speed V and the nucleation rate R were determined using a domain reversal model based on time-resolved domain reversal patterns. From the field dependence of V and R, the activation volumes of the wall-motion and nucleation processes were determined based on a thermally activated relaxation process. We found that the wall-motion activation volume was slightly larger than the nucleation volume and the unequality of two activation volumes was closely related to reversal behavior.

Acknowledgment

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