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MAGNETIC FIELD DEPENDENCE OF MAGNETIZATION REVERSAL BEHAVIOR IN Co/Pt MULTILAYERS.

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Abstract

Magnetic field dependence of magnetization reversal in Co/Pt multilayers has been quantitatively investigated. Serial samples of Co/Pt multilayers have been prepared by dc-magnetron sputtering under various Ar pressure. 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 reversing applied field. From the exponential dependencies, the activation volumes of the wall motion and nucleation could be determined based on a thermally activated relaxation model, and the wall-motion activation volume was revealed to be slightly larger than the nucleation activation volume.

I. Introduction

Co/Pt multilayers have been one of the most promising materials for next generation of high density magneto-optical recording media, due to a large perpendicular magnetic anisotropy as well as a large Kerr angle at short wavelengths.[1, 2] To achieve high-density recording, magnetization reversal behavior is very important, since it plays a key role in determining a written domain size, irregularity, and stability.[3,4] Magnetization reversal behavior has been extensively studied in numerous systems and has been reported to be contrastingly changed from wall-motion dominant to nucleation dominant with varying the sample preparation condition, film structure, and composition.[4-7] These reversal behaviors have been analyzed by the thermally activated relaxation model based on the magnetization viscosity curve and also, compared with the theoretical predictions using micromagnetic simulation.[8,9] Recently, we have developed a novel method to quantitatively analyze the magnetization reversal behavior by considering both the nucleation and wall-motion processes based on the time-resolved domain patterns. In this paper, magnetization reversal in Co/Pt multilayers under various strength of an applied field has been examined using a magneto-optical microscope system capable of real-time domain observation. The wall-motion speed V and the nucleation rate R were determined using a domain reversal model based on time-resolved domain reversal patterns. Field dependence of the reversal behavior is discussed based on the wall-motion speed V and the nucleation rate R.

II. Experiments

Serial samples of Co/Pt multilayers have been prepared on glass substrates by dc-magnetron sputtering under various Ar pressure of 2, 5, and 7.5 mTorr. The multilayered structure was achieved by alternatively 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 turned out to be less than 3 %. Various samples of (4- Å Co/11-Å Pt)$_{10}$ were prepared by changing Ar sputtering gas pressure P_{Ar}. All samples have perpendicular magnetic anisotropy and show the Kerr hysteresis loop of large remanance.

Magnetic domain patterns were observed using the magneto-optic microscope system capable of the spatial resolution of 0.4 μm, the Kerr-angle resolution of 0.2°, and ×1000 magnification equipped with an advanced digital video processing. The sample was initially saturated by applying the magnetic field normal to the film plane and then, reversal behavior was observed under a reversed magnetic field near the coercivity. The time-resolved domain images of 128 frames with 10 frames/s were taken under various applied field. The image, composed of 200×160 pixels with the unit size of 200×200 nm, was initially obtained in 256 gray levels and then, intensified by noise filtering and black-and-white image extraction process. The reversed domain area $a(t)$ and the domain boundary length *l(t)* of each image were determined by counting black and white cells with respect to the time *t*. The wall-motion speed *V* and the nucleation rate *R* were obtained by the reversed domain area *a(t)* and the domain boundary length *l(t)* based on the domain reversal model proposed by Choe and Shin :[10]

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

where a' and l' denote the first time derivation of a and l, respectively. The total area s under examination was 40×32 μm^2 and the characteristic length r_0 of nucleation was set to 100 nm, corresponding to unit pixel size of observation.

III. Results and discussion

Fig. 1 shows the domain reversal patterns of (4-Å Co/11-Å $Pt)_{10}$ prepared at 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 under an applied field. Dendritic growth formed by nucleation process were 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 the Ar pressure. It was expected since the sample prepared at low Ar sputtering pressure has a large saturation magnetization M_S, due to its dense film structure and thus, the domain splits into narrow stripes due to its strong demagnetization energy.

Magnetic field dependence of the reversal behavior has examined under various applied field. In Fig. 2, we show the magnetization viscosity curve of (4-Å Co/11-Å $Pt)_{10}$ prepared at Ar sputtering pressure of 7.5 mTorr. The magnetization viscosity curve was obtained by monitoring the reversed domain area *a(t)* in time under a reversing field and the individual curves were obtained under several reversing field. The rate of relaxation was considerably accelerated by increasing reversal field, but basic shape of the curves remained same irrespective of the reversing field. In Fig. 3(a), we show the normalized viscosity curves by normalizing the abscissa axis by the half reversal time τ, where τ was 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 became 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.[11]

Fig. 3(b) shows the variation of the half reversal time τ with respect to the reversing field. It turned out that τ followed the experimental 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 Tables I.

The wall-motion speed V and nucleation rate R were determined from the time-resolved domain patterns during magnetization reversal under various strength of an applied field. In Fig. 4, we plot (a) the wall-motion speed V and (b) the nucleation rate R with respect to reversing field for the (4-Å Co/11-Å Pt)$_{10}$ sample prepared at 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 an 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 exponentially dependence could explain within the context of a thermally activated relaxation process, and the activation coefficient α_W and α_N are represented as follows:

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

where V_W and V_N are the activation volumes for the wall-motion and nucleation processes, respectively. [3]

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 I. It should be noticed that both of the activation volumes of the wall-motion and nucleation processes were decreased with increasing the Ar pressure from 2 to 7.5 mTorr. It could be understood that the defect density is expected to be higher in the coarse film prepared in higher Ar sputtering pressure and thus, the activation volume is split due to the higher defect density at 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. It has been reported that the difference between the activation volumes is closely related with the magnetization reversal behavior; the reversal process having a smaller activation volume is expected to be more dominated since the activation energy is proportional to the activation volume.[12] In this study, we confirm that our Co/Pt multilayer samples have $V_W > V_N$ and thus, they show nucleation dominant process.

IV. 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. Using the field dependence of V and R, the activation volumes of the wall-motion and nucleation processes were determined based on a thermally activation relaxation process. It was found that the wall-motion activation volume was slightly larger than the nucleation one and the unequality of two activation volumes was closely related to reversal behavior.

Acknowledgment

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TABLE I. 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	528	80.5	0.074±0.004	6.6±0.9	6.1±0.9
4.0	5	507	132.7	0.069±0.004	6.3±1.1	5.8±1.1
4.0	7.5	461	212.4	0.040±0.001	3.8±0.5	3.6±0.6

FIGURES

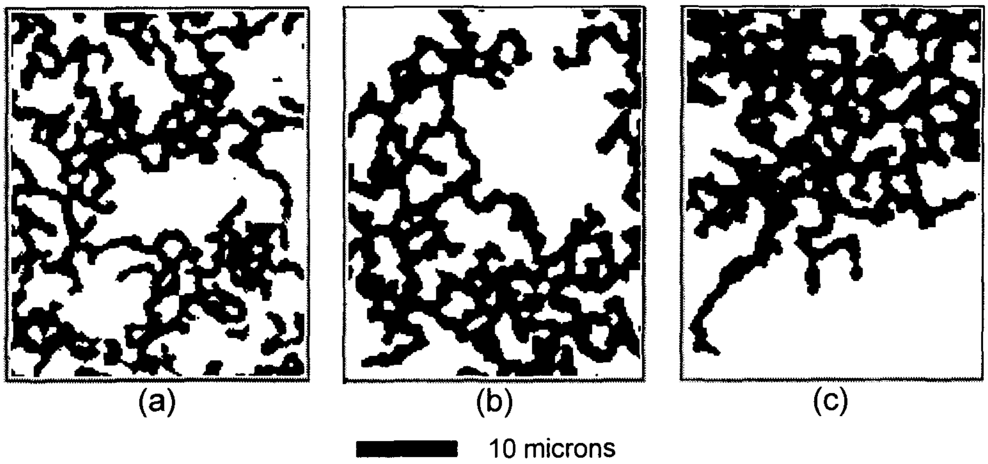

FIG. 1. Domain patterns during magnetization reversal under a reversing applied field for (4-Å Co/11-Å Pt)$_{10}$ samples prepared at Ar sputtering pressure of (a) 2, (b) 5, and (c) 7.5 mTorr, respectively. The domain patterns were taken at 40 % reversal.

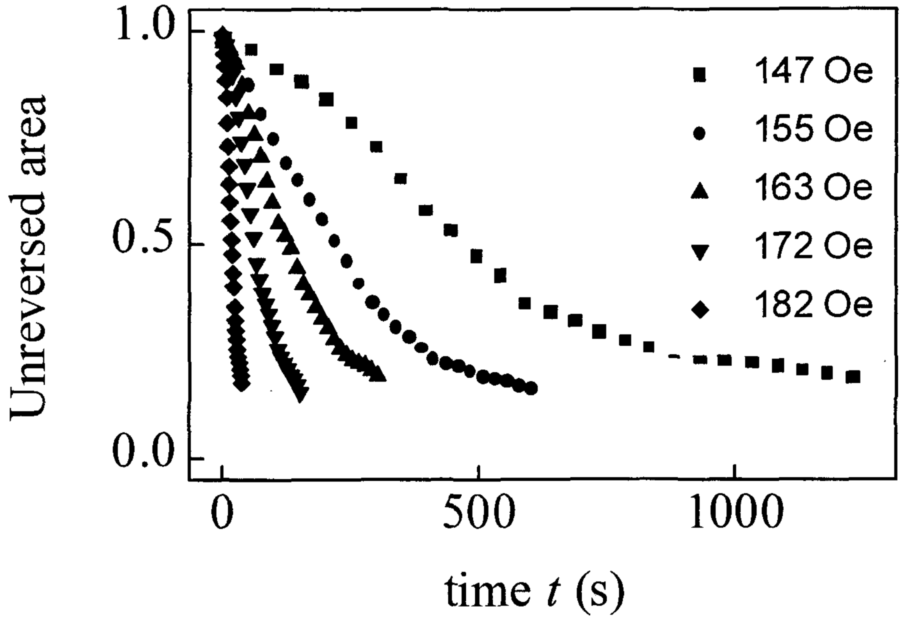

FIG. 2. Magnetization viscosity curves of the (4-Å Co/11-Å Pt)$_{10}$ sample prepared at Ar sputtering pressure of 7.5 mTorr under several reversing field *H* denoted in the figure.

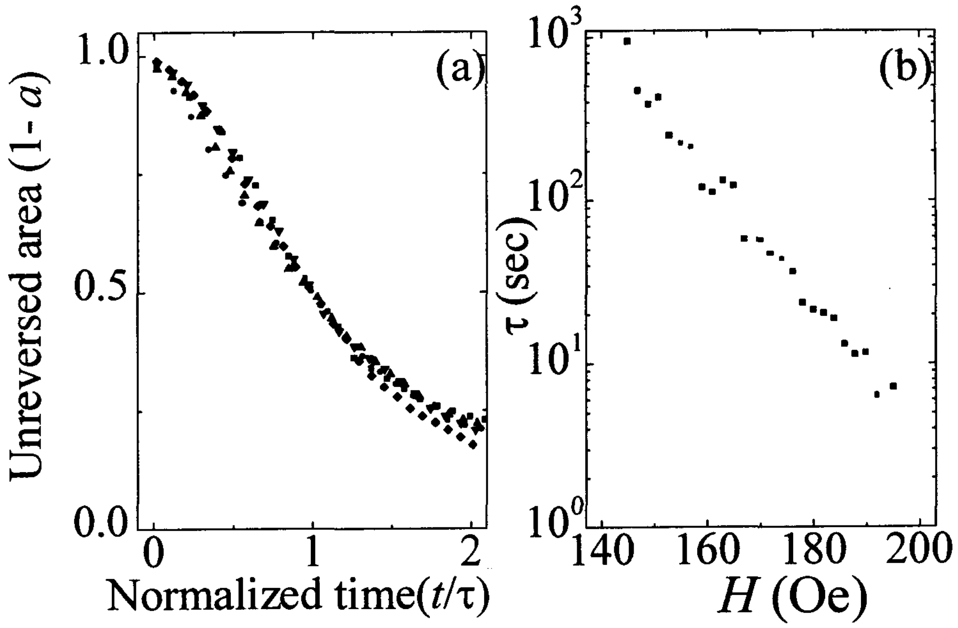

FIG. 3. (a) Normalized magnetization viscosity curves with respect to the time *t* normalized by the half reversal time τ. (b) Variation of the half reversal time τ with respect to the reversing field *H*.

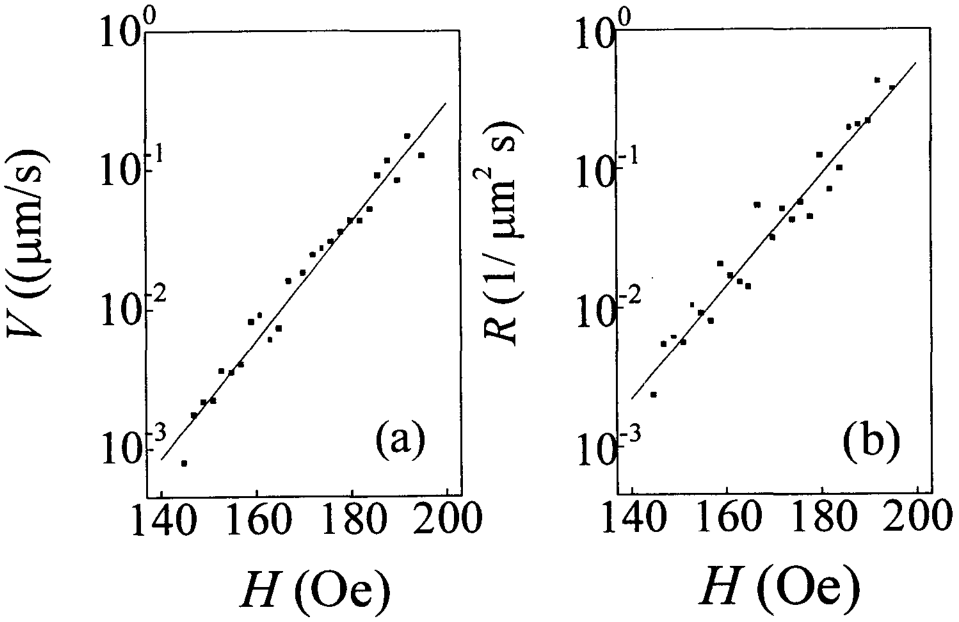

FIG. 4. (a) The wall-motion speed *V* respect to the reversing field *H*. (b) The nucleation rate *R* with respect to the reversing field *H*.