Magnetization reversal in Co/Pd multilayers with varying Co sublayer thickness

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We have investigated magnetization reversal in nanostructured Co/Pd multilayers. Interestingly enough, reversal phenomena in this system were found to be very sensitive to the Co-sublayer thickness and very contrasting reversal behaviors were observed between the samples having 2 Å-thick Co and 4 Å-thick Co sublayers. Direct domain observation and time-dependent magnetization viscosity curves revealed the wall-motion dominant reversal in the former samples, and the nucleation dominant reversal in the latter samples. Magnetization reversal in Co/Pd multilayers was theoretically studied by Monte Carlo simulation and experimentally observed reversal behaviors could be well explained. © 1997 American Institute of Physics.

Nanostructured Co/Pd multilayers are one of the most prospective materials for the next generation high density magneto-optical recording media due to their large perpendicular magnetic anisotropy, substantial Kerr rotation angle at short wavelengths, and high corrosion resistivity.1,2 In spite of numerous studies on their magnetic and magneto-optic properties, magnetization reversal of this system has been hardly understood. The magnetization reversal mechanism has a decisive role in the magnetic domain recording process, since the domain-wall velocity, written domain size, and shape are governed by the domain dynamics. Therefore, it is very important to understand the domain dynamics of magnetization reversal for further improvement of recording performance.

Magnetization reversal in amorphous rare-earth transition-metal, sandwiched Co, and multilayered Co/Pt systems has been reported to occur by nucleation and wall-motion dominant processes.3–6 Recently, we have investigated magnetization reversal mechanisms of Co/Pd multilayers with various Co-sublayer thicknesses. In this article, we report the experimental and theoretical results on two distinct magnetization reversal mechanisms in Co/Pd multilayers.

Samples of \( (t_{Co} - \AA) Co/(11 - \AA) Pd)_n \), where \( t_{Co} \) is the thickness of the Co-sublayer and \( n \) is the number of repeats, were prepared on glass substrates by e-beam evaporation under the base pressure of \( 1.0 \times 10^{-6} \) Torr in the ambient temperature. Care was taken to maintain the same preparation conditions by an advanced thickness-control technique using real-time thickness measurement\(^2\) and the macroscopic magnetic properties were confirmed to be quite reproducible for the same nominal samples prepared in different runs. All samples in this study had perpendicular magnetic anisotropy and showed unit squareness.

Type I samples of (2 Å Co/(11 Å Pd))\(_{10} \) and type II samples of (4 Å Co/(11 Å Pd))\(_{10} \) were extensively examined. Magnetization reversal behavior was investigated by direct observation of domain structure as well as magnetization viscosity measurement. In both of these experiments, the sample was first saturated by applying a magnetic field of 3 kOe normal to the film plane and then reversal behavior was investigated under reversing applied field smaller than the coercivity. The direct domain observation was carried out using a modified magneto-optic microscope capable of \( \times 1000 \) magnification with an objective of 0.9 NA and equipped with advanced video processing techniques. The contrast of the domain image was enhanced by image intensifying steps of background subtraction, smoothing by Gaussian blurring, and finally, black and white conversion. The image analyses for all samples were carried out under the same automatized process. Forty-five pictures were taken for an applied field with one frame per second. The magnetization viscosity measurement was carried out by monitoring the Kerr rotation angle at every 0.1 s. The measured curves were analyzed by adjustment of the offset and normalization of the Kerr rotation angle.

Interestingly, reversal phenomena in this system were found to be very sensitive to the Co-sublayer thickness and the contrasting reversal patterns were observed between type I and type II samples. In Fig. 1, we show typical domain reversal patterns of type I and type II samples in time sequence after applying the reversing fields smaller than the coercivities of the samples. Wall-motion dominant reversal in the type I sample can be clearly seen from Fig. 1(a). In this sample, the nucleation could hardly occur. But once nucleated, domains were observed to expand gradually in size at all domain wall boundaries by wall motion. The completely reversed state was achieved after a long time. The basic patterns of magnetization reversal were the same irrespective of the magnitude of the applied fields, while the rate of reversal was considerably accelerated by increasing the applied field. The ragged domain boundary was possibly caused by local variations in the magnetic properties due to microstructural irregularity of the film. In the type II sample, magnetization reversal of dendritic growth is vividly observed, as shown in Fig. 1(b). In this system, the nucleation was observed to occur at a number of places, but the nucleated domain grew only marginally in size. The domain expanded quickly by dendritic growth into dendrite-like domains throughout the whole area of the samples. The widths of the stripes remained almost unchanged during reversal and were found to be the same all over the film. The ragged
region between the reversed domains remained unreversed even after a long time and could be reversed only by increasing the applied field near to the coercivity.

Corroborative evidence about contrasting magnetization reversal behaviors was confirmed in the magnetization viscosity measurements. In Fig. 2, we show the time-dependent magnetization viscosity curves measured for the type I and type II samples under various reversed fields as denoted in the figures. We measured the Kerr rotation angle instead of the magnetization for rapid measurement. As mentioned earlier, it can be seen that the rate of relaxation is sensitively dependent on the strength of an applied field; it rapidly increases with the applied field up to the coercivity. However, the shapes of the curves in two different samples are quite contrasting. The type I sample shown in Fig. 2(a) exhibits an initially slow relaxation rate curve, followed by relatively fast relaxation with time. Finally, the curve gradually approaches the completely reversal state. This type of viscosity curve is governed by the thermal relaxation of rare nucleation probability and fast domain-wall motion.\(^8\) The initial relaxation rate is limited by the probability of nucleation, while the successive rate is governed by the domain-wall expansion. It can be observed that this curve completely corresponds to the observed domain patterns of wall-motion dominant reversal with rare nucleation as shown in Fig. 1(a). Contrastively, the type II sample in Fig. 2(b) exhibits an initial fast decay rate and slow approach to the equilibrium state. This is a typical type of a viscosity curve for the thermally activated relaxation with large nucleation probability and slow domain-wall motion as mentioned earlier. It is also well matched with the direct domain observation in the type II sample as shown in Fig. 1(b).

A theoretical study of magnetization reversal has been carried out by a simple uniaxial anisotropy model, originally proposed by Kirby et al.\(^9\) In this model, the multilayer is simplified as homogeneous and flat along the film plane with initially slow relaxation rate curve, followed by relatively fast relaxation with time. Finally, the curve gradually approaches the completely reversal state. This type of viscosity curve is governed by the thermal relaxation of rare nucleation probability and fast domain-wall motion.\(^8\) The initial relaxation rate is limited by the probability of nucleation, while the successive rate is governed by the domain-wall expansion. It can be observed that this curve completely corresponds to the observed domain patterns of wall-motion dominant reversal with rare nucleation as shown in Fig. 1(a). Contrastively, the type II sample in Fig. 2(b) exhibits an initial fast decay rate and slow approach to the equilibrium state. This is a typical type of a viscosity curve for the thermally activated relaxation with large nucleation probability and slow domain-wall motion as mentioned earlier. It is also well matched with the direct domain observation in the type II sample as shown in Fig. 1(b).

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periodic boundary condition and uniform along normal to the film plane with finite thickness of the film in contact with air. The film is composed of nano-sized identical single domain cells on in-planed hexagonal lattices. Each cell interacts with others via magnetostatic and domain-wall interactions and the reversal of each cell is governed by thermally activated jump over the energy barrier. The magnetization reversal is evolved as the reversal of individual cell iteratively determined by Monte Carlo probability calculation. In the simulation, the unit cell volume of 2.92×10⁻¹⁸ cc and the anisotropy constant of 4.5×10⁶ erg/cc were used for both samples. Also, the saturation magnetization of 107 and 150 emu, and the exchange stiffness of 3.55×10⁻⁷ erg/cm and 4.95×10⁻⁷ erg/cm were used for type I and type II sample, respectively.

In Fig. 3, we present simulated domain-reversal patterns for the type I and type II samples, taken at 10% domain reversal. Both patterns of domain in Fig. 3, obtained by using the magnetic parameters of the corresponding samples, are essentially similar to the observed patterns of the corresponding samples: areal wall expansion in the type I sample and jumbled-up stripes in the type II sample, respectively. The well-matched correspondency between the experimental observations and the theoretical predictions demonstrates clearly an essential role of the macroscopic magnetic properties on the relaxation mechanism, because the theoretical prediction was obtained by assuming identical cells of uniform films with macroscopic magnetic parameters without considering detailed microstructure of the film.

In summary, we have investigated magnetization reversal of Co/Pd multilayers by direct observations of domain patterns, time-dependent measurements of the magnetization viscosity curves, and theoretical prediction adopting a nanomagnetic model. Magnetization reversal in the Co/Pd system is dominated by wall motion in the multilayers with 2-Å-thick Co sublayers, but dominated by nucleation in multilayers with 4-Å-thick sublayers. It is believed that the reversal phenomenon in this system is mainly governed by the macroscopic magnetic properties.

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