Available online at www.sciencedirect.com
ScienceDirect
Journal of Magnetism and Magnetic Materials 320 (2008) 2044–2048
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Magnetic field dependence of asymmetry in the magnetization reversal of ultrathin Co films and Co/Pt multilayers with perpendicular anisotropy

Y.L. Iunin[a,*], Y.P. Kabanov[a], V.I. Nikitenko[a,b,c], X.M. Cheng[b], C.L. Chien[b], A.J. Shapiro[c], R.D. Shull[c]

[a]*Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, 142432 Moscow Region, Russian Federation*
[b]*The Johns Hopkins University, Baltimore, MD 21218, USA*
[c]*National Institute of Standards and Technology, Gaithersburg, MD 20899, USA*

Received 28 December 2007; received in revised form 11 February 2008
Available online 6 March 2008

Abstract

We studied the magnetization reversal in ultrathin $[Co/Pt]_n$ films ($n = 1$, 2, and 4) using magneto-optical Kerr microscopy. These materials demonstrate unusual *asymmetries* in the activity of nucleation centers and domain wall motion. It was found that application of very high holding magnetic field prior to magnetization reversal, exceeding some critical value much larger than the apparent saturation field, suppresses the subsequent 'asymmetric' nucleation centers, activity. We revealed that the 'asymmetric' nucleation centers become active again after subsequent reversal cycles coming from a smaller holding field and studied how the asymmetry returns with the decrease of applied holding field. It was found that in low-coercivity ultrathin Co films, the asymmetry in domain wall velocity decreased sharply with the applied field increase and disappeared when the reversal field is greater than $\mu_0 H = 1.5\,\mathrm{mT}$.

PACS: 75.60.Ch; 75.70.Ak; 75.70.−i

Keywords: Ultrathin cobalt film; Co/Pt multilayers; Perpendicular magnetic anisotropy; Asymmetry; Domain wall

1. Introduction

Quasi-two-dimensional magnetic thin films and multilayers have revealed many interesting phenomena, some of which have led to important applications. The lowering of a system dimensionality often leads to new and qualitatively different physical properties. In particular, the ground state of ultrathin magnetic structures can acquire a strong perpendicular magnetic anisotropy (PMA) due to the dominance of the magnetic surface anisotropy. However, most investigations of magnetization reversal of ultrathin ferromagnetic films and multilayers with PMA did not reveal properties that are distinctly different from those of bulk materials. For example, as in the bulk materials, the reversal of ultrathin films occurs by the nucleation and spreading of domain walls [1–4]. The motion of domain walls, depending upon the strength of the magnetic field, may be thermally activated or viscous in nature [2].

Our recent study on ultrathin $Pt/[Co/Pt]_n/Pt$ multilayers ($n = 1$, 2, and 4) revealed some markedly different features in its magnetization reversal behavior [5]. In addition to the usual 'symmetric' nucleation centers, hitherto unknown '*asymmetric*' magnetic domain nucleation centers were also found in ultrathin $[Co/Pt]_n$ structures with $n = 1$, 2, and 4, where the reversal begins for one direction of the field only. The new domains nucleate at *different* positions for magnetization M pointing up or down. A pronounced asymmetry in the mobility of domain walls in single Co films with low coercivity was also observed. These phenomena are in sharp contrast to the expected symmetry of magnetic reversal in general in bulk materials.

*Corresponding author. Tel.: +7 496 524 9498; fax: +7 496 524 9701.
E-mail addresses: iunin@issp.ac.ru, iunin@pisem.net (Y.L. Iunin).

0304-8853/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2008.02.186

To understand the fundamental origin of these salient effects and the potential technological relevance to new devices, one should determine the conditions for the existence of these novel effects. In this work we have studied the dependence of the nucleation centers, activity (both the usual 'symmetric' and the unusual 'asymmetric' centers) in ultrathin Co/Pt films and $[Co/Pt]_n$ multilayers ($n = 1$, 2, and 4) on the magnitude of holding field H_{hold} prior to the magnetization reversal. We have revealed that a very high holding field (much larger than the coercivity) suppresses the activity of the 'asymmetric' nucleation center, preserving only the 'symmetric' nucleation. A reduction in the holding field results in the return of 'asymmetric' nucleation (sometimes with the inversion of the sign of asymmetry). We have also found that the domain wall velocities of the normal and the novel domains have different field dependences. The asymmetry in the velocity of domain walls decreases with the applied field and disappears for the fields comparable to, but smaller than, the macroscopic coercivity of a specimen.

2. Experimental

Ultrathin single Co(0.6 nm) films and [Co(0.4–0.6 nm)/Pt(1 nm)]$_n$ multilayers ($n = 2$ and 4) were grown by DC magnetron sputtering onto a Pt(10 nm) buffer layer on Si(1 1 1) substrates. The domain structure evolution was investigated *in situ* by magneto-optical Kerr effect (MOKE) microscopy at various magnetic fields applied perpendicular to the film plane. The average magnetization as a function of the applied magnetic field H was measured by Hall resistance measurements with H perpendicular to the film plane. Since the extraordinary Hall resistance R_H in multilayers with PMA is proportional to M, the field dependence of $R_H(H)$ yields that of $M(H)$. The $[Co/Pt]_n$ samples with $n = 1$, 2, and 4 show square hysteresis loops (e.g., see inset in Fig. 3), whose coercivity H_c increases with the number of Co layers.

To study the nucleation and the evolution of the magnetic domains, we first applied a holding field H_{hold} before it was reduced to and kept constant at the reversed field H. To observe the backward domain wall motion, magnetic field was inverted again before the domain wall reaches the sample boundaries or other domains in the case of a minor hysteresis loop.

3. Results and discussion

In an earlier work [5] we show an example of evolution of the domain structure in a $[Co/Pt]_2$ multilayer structure. Fig. 1 demonstrates the evolution of domains in the single ultrathin Co(0.6 nm) film when a magnetic field of $\mu_0 H = -7.2$ mT (Fig. 1a) and $\mu_0 H = +7.2$ mT (Fig. 1b) was applied after the gradual decrease from the holding field of $\mu_0 H_{hold} = +9.0$ and -9.0 mT, respectively. Since the field has the same value but only opposite direction, one expects symmetrical events with opposite contrasts when the MOKE images are compared side by side. These 'symmetrical' domains are indeed observed as shown in Fig. 1 by those without an arrow. Reversing the magnetic

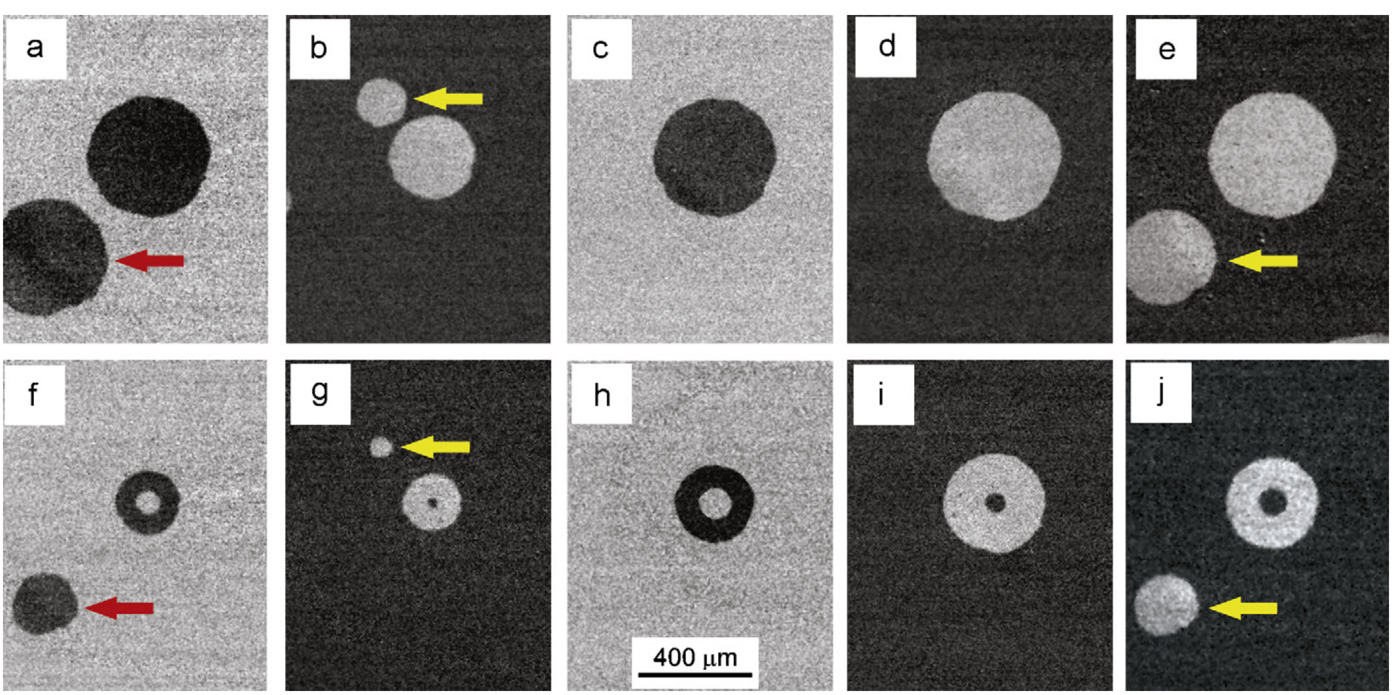

Fig. 1. MOKE images of the domain structure in the ultrathin Co(0.6 nm) film with $\mu_0 H_{crit} = 16$ mT formed under the application of magnetic fields $\mu_0 H =$ (a, c) -7.2 mT and (b, d, e) $+7.2$ mT after the gradual decrease from the holding field $\mu_0 H_{hold} =$ (a) $+9.0$ mT, (b)–9.0 mT, (c) $+47.8$ mT, (d)–47.8 mT, (e)–12.0 mT, and after magnetic field cycling (f–j); yellow and red arrows show the domains produced by 'asymmetric' centers under field upward and downward, respectively.