Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Journal of Magnetism and Magnetic Materials 272–276 (2004) e555–e556
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Domain structures and magnetization processes of ultrathin ordered iron–gold alloys films

J. Jaworowicz[a], A. Maziewski[a,*], V. Zablotskii[b], T. Ślęzak[c], N. Spiridis[d], J. Korecki[c,d]

[a] Institute of Experimental Physics, University of Bialystok, ul. Lipowa 41, 15-950 Bialystok, Poland
[b] Institute of Physics ASCR, Na Slovance 2, CZ-182 21 Prague 8, Czech Republic
[c] Faculty of Physics and Nuclear Techniques, University of Mining and Metallurgy, al. Mickiewicza 30, 30-059 Kraków, Poland
[d] Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences, ul. Niezapominajek 8, 30-239 Kraków, Poland

Abstract

Thickness-dependent changes of the domain period, initial susceptibility and saturation field in ultrathin films was theoretically analyzed considering the equilibrium state of the domain. The experiment was performed on artificially stabilized tetragonal-ordered gold–iron films with thickness varying from 3 up to 50 monolayers. Domain structure and magnetization processes were studied using magneto-optical techniques. Square hysteresis loops were registered for intermediate film thickness.

PACS: 70; 75.70.–i; 78.20.Bh

Keywords: Perpendicular magnetic anisotropy; Magnetic domain structures; Magnetic properties; FeAu superlattice

Ultrathin films of ordered alloys are the subject of growing interest with regard to their unique properties. Perpendicular magnetic anisotropy, a low coercive field, and a very strong GMR promise the possibilities of practical use [1,3], for example, for high-density information storage in magneto-optic recording. Magnetic anisotropy change as the function of film thickness is usually negligible in ordered alloys. The paper is focused on theoretical and experimental studies of domain structures (DS) in such ultrathin systems.

Experiments were performed on $(FeAu)_N$ superlattices (N ranging from 3 to 50 atomic layers, which correspond to thickness d ranging from 1.02 to 17 nm). Samples were grown using MBE by alternating the deposition of Fe(0 0 1) and Au(0 0 1) monolayers on MgO(0 0 1) [4]. These films ($L1_0$ structure) are characterized by strong perpendicular anisotropy described by $Q = K_1/2\pi M_s^2$ (K_1 is the first anisotropy constant, M_s is the saturation magnetization). Magnetization processes and magnetic DS were studied using polar Kerr effect techniques. Significant changes of hysteresis loop shape were observed changing d. In the thickness range $3<N<7$ square hysteresis loops was observed with coercivity $H_c \sim 20 - 120\,\mathrm{Oe}$. The magnetic aftereffect was registered for these thicknesses. This effect was similar to one reported for ultrathin cobalt films [8]. The changes of magnetization reversals with the thickness were observed. The saturation field $H_s(d)$ measured for all d is shown in Fig. 1.

Theoretical description is focused on the thickness dependence of the stripe DS period, initial susceptibility and collapse field in an ultrathin film with the easy axis perpendicular to the film surface. Stripes with infinitely narrow domain walls (DW) can be described by a model [2] in which the characteristic length, $l_c = \sigma_w/(4\pi M_s^2)$, is a key parameter governing the domain period p. In general, the DW energy density, σ_w consists of the exchange, anisotropy and demagnetization energy terms. Neglecting the demagnetizing energy contribution, the zero-field domain period p can be described by a simple

*Corresponding author. Tel.: +48-85-7457229; fax: +48-85-7457223.
E-mail address: magnet@uwb.edu.pl (A. Maziewski).

0304-8853/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2003.11.319

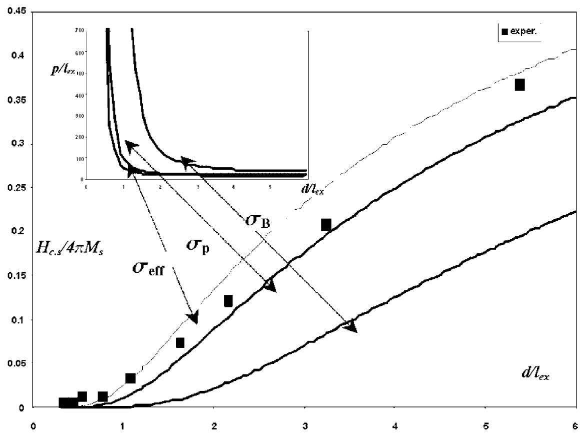

Fig. 1. Thickness dependence of the normalized saturation field, squares are experimental data. The inset shows thickness dependence of normalized domain period. Theoretical curves were drawn for different models of DW.

formula

$$\frac{p}{l_c}\left(\frac{d}{l_c}\right) = c\left(\frac{d}{l_c}\right)^m \mathrm{Exp}\left(b/\left(\frac{d}{l_c}\right)\right), \quad (1)$$

which with accuracy better than 4% fits the numerical solution of the system of equations [2] in the thickness interval $0.25 < d/l_c < 7.5$. Eq. (1) coefficients are $b = 3.0613$, $c = 2.09513$ and $m = 0.85498$. It should be stressed that for ultrathin films with a large M_s the contribution of demagnetization energy to DW energy is quite important [7]. In the following work [7] we take into account the demagnetizing energy as $\sigma_p = \sigma_B f(Q)$, where $f(Q)$ is the function defined in Ref. [7] and $\sigma_B = 4(AK_1)^{1/2}$ is the Bloch (bulk) DW energy. Note, that the corrected DW energy (σ_p) is just between the energies of the "classical" wall and a fully demagnetized one: $\sigma_B > \sigma_p > \sigma_{eff} = 4(A(K_1 - 2\pi M_s^2))^{1/2}$. Thus, we are calling this a partially demagnetized wall. Considering those three expressions for DW energy, the normalized DS period p/l_{ex} was plotted as a function d/l_{ex} assuming that magnetic anisotropy does not depend on d—see inset to Fig. 1 (the exchange length $l_{ex} = (A/2\pi M_s^2)^{1/2} = 3.2$ nm is used, where A is the exchange constant). As it is seen from Fig. 1, the calculated equilibrium DS periods are extremely sensitive to the DW energy involved in calculations.

In the frameworks of the model [2] the initial magnetic susceptibility of a film with a stripe domain structure is

$$\chi_0 = \frac{1}{4\pi}\frac{z/2}{\ln[\mathrm{ch}(z/2)]}, \quad (2)$$

where $z = 2\pi d/p$. Using Eq. (1), from Eq. (2) one could calculate the thickness dependence of the initial susceptibility. The susceptibility drastically increases decreasing d. Calculated $\chi_0(d/l_{ex})$ dependencies qualitatively correspond to results reported in Ref. [5].

Increasing magnetic field stripe DS undergoes a transition into bubble domains which vanish at H_c as described by the well-known formula from physics of bubbles [6]. Thus one could combine the saturation field (H_s) with H_c. $H_c(d/l_{ex})$ dependencies are shown in Fig. 1 for different wall energies. H_c drastically decreases decreasing d.

In summary, in ultrathin films of decreasing thickness the equilibrium domains undergo drastic changes: increase of both domain period and initial susceptibility and decrease of the saturation field; domain properties are strongly affected by the demagnetization effect. Domain size tuning by both d and Q can be done on the basis of the presented calculations. Our experiments made on $(FeAu)_N$ qualitatively agree with the theoretically predicted increase of a saturation field with increasing d. However, the coercivity field "shields" magnetostatic influence on DS.

This work was supported by the Polish State Committee for Scientific Research (Grant No. 4 T11B 006 24), and European Commission program ICA1-CT-2000-70018 (Center of Excellence CELDIS).

References

[1] Y. Samson, A. Marty, R. Hoffmann, V. Gehanno, B. Gilles, J. Appl. Phys. 85 (1999) 8.

[2] C. Kooy, U. Enz, Philos. Res. Rep. 15.7 (1960).

[3] S. Mitani, K. Takanashi, H. Nakajima, K. Sato, R. Schreiber, P. Grünberg, H. Fujimori, J. Magn. Magn. Mater. 156 (1996) 7.

[4] T. Ślezak, W.Karaś, K. Krop, M. Kubik, D. Wilgocka-Ślęzak, N. Spiridis, J. Korecki, J. Magn. Magn. Mater. 240 (2002) 362.

[5] V. Gehanno, Y. Samson, A. Marty, B. Gilles, A. Chamberod, J. Magn. Magn. Mater. 172 (1997) 26.

[6] A. Hubert, R. Schäfer, Magnetic Domains. The Analysis of Microstructures, Springer, Berlin, 1998.

[7] M. Kisielewski, A. Maziewski, V. Zablotskii, T. Polyakova, J.M. Garcia, A. Wawro, L.T. Baczewski, J. Appl. Phys 93 (2003) 10.

[8] J. Ferré, V. Grolier, P. Meyer, A. Maziewski, E. Stefanowicz, S.V. Tarasenko, V.V. Tarasenko, M. Kisielewski, D. Renard, Phys. Rev. B 55 (1997) 15092.