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Microscopic magnetic relaxation processes in epitaxial Fe/GaAs(0 0 1) mesostructures

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Abstract

The magnetic relaxation and domain processes in epitaxial Fe/GaAs(0 0 1) thin films and square dots have been investigated using time-resolved scanning Kerr microscopy. For 55 and 250 Å Fe/GaAs(0 0 1) continuous films, it is clearly seen that relaxation proceeds by both discontinuous and single 'jumps'. Magnetic relaxation studies reveal that large and abrupt wall displacements occur for the magnetisation reversal in 300 Å epitaxial Fe/GaAs(0 0 1) square dots, regardless of dot size ($w = 5$–$45\,\mu$m). Domain observations demonstrate that domain wall motion dominates the magnetisation reversal in the dot structures in spite of the presence of the dot edges. © 2001 Published by Elsevier Science B.V.

Keywords: Epitaxial thin films; Magnetisation reversal; Magnetic relaxation; Magnetic domains

The magnetisation reversal and relaxation of thin film elements are important issues in mesoscopic magnetism and for future device applications. A clear understanding of the magnetisation reversal and relaxation process can provide us with new theoretical approaches to magnetic dynamics and an opportunity to develop magnetic technology. From a technological viewpoint, magnetic relaxation is currently a key factor in establishing the stability of recording media [1–4]. In this article, we report the magnetic relaxation and domain processes in epitaxial Fe/GaAs(0 0 1) thin films and square dots using time-resolved scanning Kerr microscopy.

The thin (55–300 Å) epitaxial Fe/GaAs(0 0 1) films [5,6] were prepared in ultrahigh vacuum (UHV) by electron beam evaporation. The base pressure during Fe growth was less than 6×10^{-10} mbar and growth rate was ~ 1 ML/min. Each was capped with 20 Å Au for ex situ measurements so as to prevent oxidation of the Fe layer. The 300 Å epitaxial Fe/GaAs(0 0 1) dots arrays with square shapes of size $w = 5$–$45\,\mu$m and separation $s = 10\,\mu$m were fabricated by optical lithography and ion beam etching. We have measured magnetic relaxation and observed domain structures using time-resolved scanning Kerr microscopy. The magnetisation as a function of time t, $M(t)$ was measured under a constant amplitude reverse field. Magnetic domain images were taken using a scanning Kerr microscope with a resolution of 1.5 μm.

In the phenomenological models [1–4], the relaxation time $t_{1/2}$ at which $M = 0$ follows the relation

$$t_{1/2} \propto \exp\left(-\frac{M_s V_B (H - H_c)}{k_B T} \right), \quad (1)$$

where M_s is the saturation magnetisation, V_B the Barkhausen volume, and $k_B T$ the thermal energy. The relaxation time $t_{1/2}$ is sensitive to the applied field H and increases with the applied field up to the saturation field, H_s. The samples were oriented such that the magnetic field was along the easy direction of the continuous Fe/GaAs(0 0 1) films and dot arrays. Fig. 1 shows (a) magnetic relaxation curves of 55 Å Fe/GaAs(0 0 1) film and (b) 300 Å Fe/GaAs(0 0 1) dots array with $w = 5\,\mu$m, measured with a probing laser beam spot of approximately a few hundred μm diameter under a constant reverse field. For time $t < 0$ and $t > 45$ s the sample was saturated in the positive direction. The averaged

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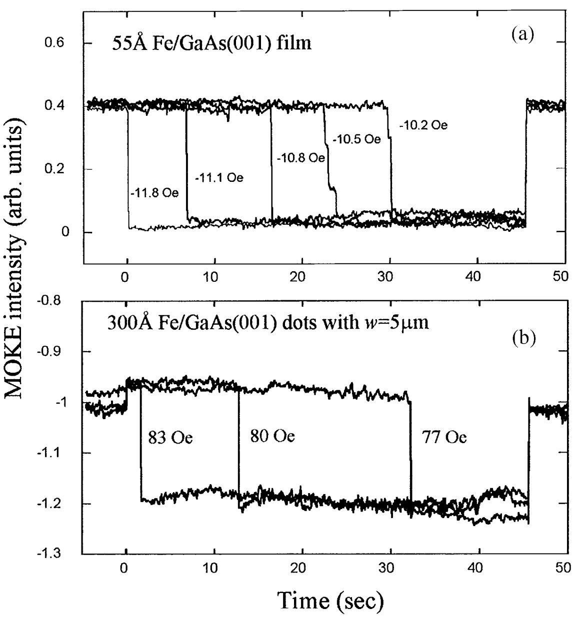

Fig. 1. Magnetic relaxation curves of (a) 55 Å Fe/GaAs(0 0 1) continuous film and (b) 300 Å Fe/GaAs(0 0 1) dots array with $w = 5\,\mu m$ under a constant reverse field.

magnetisation within the area of the laser beam spot changes over time in a constant reverse field. It is clearly seen that relaxation proceeds by both discontinuous and single '*jumps*'. The relaxation curves differs from the results of previous work on Au/Co/Au films [1], GdTbFe films [2], Cu/Ni/Cu/Si(0 0 1) films [3], and Fe/Ag(0 0 1) films [4]. In the Au/Co/Au films [1] and Cu/Ni/Cu/Si(0 0 1) films [3] with perpendicular magnetic anisotropy relaxation occurred by a smooth decay, whereas relaxation occurred by a series of discrete jumps in Fe/Ag(0 0 1) films [4]. On the other hand, González et al. [7] found that relaxation in Co/Ni multilayers occurs in a single step that corresponds to complete magnetisation reversal, which is compatible with our present results.

Our results demonstrate that relaxation jumps correspond to a domain wall moving further than 100 μm. We thus infer the existence of domain wall pinning sites, e.g. macropins by extrinsic defects [4], that are spatially distributed on a few hundred μm. On the other hand, micron-scale Barkhausen jumps by micron-pinning sites are clearly visible for $H = -10.2$ and -10.5 Oe in Fig. 1(a). We also found that such a single jump was observed in relaxation curves for the 300 Å Fe/GaAs(0 0 1) square dots arrays with $w = 5$–$45\,\mu m$ [see Fig. 1(b)], indicating that domain wall motion is still predominant after patterning dots. This behaviour is in contrast with the relaxation curves of Au/Co/Au dot arrays [8] that show a smooth decay. It should be noted that patterning

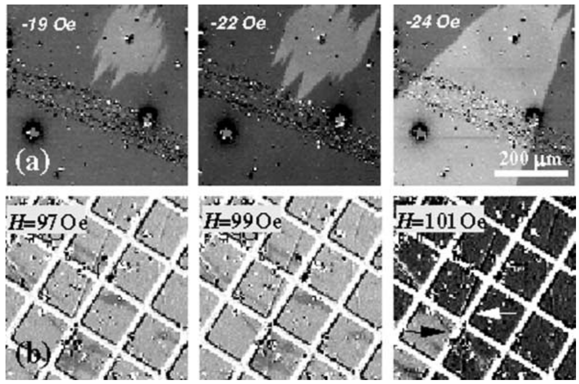

Fig. 2. Field-dependent evolution of domain structures at various fields (a) in the 250 Å Fe/GaAs(0 0 1) film and (b) the 300 Å Fe/GaAs(0 0 1) dots with $w = 45\,\mu m$ during the magnetisation reversal.

arrays of dots in the Au/Co/Au film alters the reversal mechanism as domain wall motion is blocked at the edge of the dot [8].

Magnetic relaxation studies in the continuous films and dot structures show that the magnetisation develops through successive wall jumps at a constant field by thermal activation and that the domain walls expand rapidly through the sample. For the continuous films, the hysteresis loop area A does not depend much upon the field sweep rate $\dot{H}\,(dH/dt)$ in the power-law function, $A \propto \dot{H}^{\alpha}$ [9]. The magnetic relaxation results thus support the view that rapid domain wall motion dominates the magnetisation reversal process in the low dynamic regime, where the values of the exponent α are 10 times smaller than those in the high dynamic regime where slower nucleation processes govern the magnetisation reversal [9].

Fig. 2 presents the field-dependent evolution of domain structures (a) in the continuous 250 Å Fe/GaAs(0 0 1) film and (b) the 300 Å Fe/GaAs(0 0 1) dots with $w = 45\,\mu m$ during the magnetisation reversal process for a field applied along the [0 1 0] axis. It is clearly seen in Fig. 2(a) that a reversed domain nucleates at a defect when the magnetic field of -19 Oe corresponding to the nucleation field (H_n) is applied and that the reversed domain evolves slowly with increasing field until an abrupt propagation occurs at the threshold field ($H = -24$ Oe). It is evident that domain wall motion dominates the magnetisation reversal in the Fe/GaAs(0 0 1) film, i.e. below the coercive field, nucleation is a rare event; it is followed by the subsequent growths. Similarly, the magnetisation in the dots array develops through discontinuous wall jumps as seen in Fig. 2(b), illustrating that domain wall motion dominates the magnetisation reversal in spite of the presence of the dot edges.

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