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ScienceDirect
Journal of Magnetism and Magnetic Materials 320 (2008) 2571–2575
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

# Magnetic domain wall creep in the presence of an effective interlayer coupling field

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Received 12 December 2007; received in revised form 26 February 2008
Available online 3 April 2008

**Abstract**

We investigate thermally activated domain wall creep in a system consisting of two ultrathin Co layers with perpendicular anisotropy coupled antiferromagnetically through a 4 nm thick Pt spacer layer. The field driven dynamics of domain walls in the softer Co layer have been measured while keeping the harder Co layer negatively saturated. The effect of the interlayer interaction on the soft layer is interpreted in terms of an effective coupling field, $H_J$, which results in an asymmetry between the domain wall speeds measured under positive and negative driving fields. We show that creep theory remains valid to describe the observed wall motion when the effective coupling field is included in the creep velocity law as a component of the total field acting on the wall. Using the resultant modified creep expression, we determine a value for the effective coupling field which is consistent with that measured from the shift of the soft layer's minor hysteresis loop. The net antiferromagnetic coupling is attributed to a combination of RKKY and orange-peel coupling.


*PACS:* 75.60.Ch; 75.70.Cn; 62.20.Hg

*Keywords:* Magnetic ultrathin films; Domain wall motion; Creep; Interlayer coupling; Magneto-optical Kerr microscopy

## 1. Introduction

Magnetic multilayers are currently the subject of intense research, driven in a large part by magnetic memory applications [1]. Since domain wall motion is often the dominant reversal mechanism in these mutlilayer devices [2,3], it is important to understand how it is altered in such systems due, for example, to coupling between the multiple layers. However, while the dynamics of domain walls in continuous [4–8] and patterned [9–12] single layer films are rather well understood, the extent of quantitative measurements of domain wall dynamics in bilayer and multilayer magnetic systems remains quite limited [13–16], especially in systems with perpendicular anisotropy.

The effect of an interlayer coupling of energy, $J$, is generally interpreted in terms of an effective coupling field [17,18]:

$$H_J = \frac{J}{M_S t} \tag{1}$$

where $M_S$ and $t$ are, respectively, the saturation magnetization and thickness of the layer upon which the coupling field is acting. While the coupling field may be measured macroscopically from the shift of the layer's minor hysteresis loop (e.g. Refs. [17–19]), more local measurements which examine the effect of the coupling on the reversal processes that occur during hysteresis can potentially provide a more easily interpreted measurement of $H_J$ and subsequently $J$ [20]. Fukumoto et al. [13] have measured viscous domain wall motion (motion for which pinning is negligible) in an in-plane magnetized NiFe layer in the presence of an effective coupling field resulting from coupling to a saturated Co layer. While the situation may

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doi:10.1016/j.jmmm.2008.03.041

be more complex in patterned structures [16] or when the other layers in the system are non-uniformly magnetized [15], there it was shown that $H_J$ could be considered simply as an additional component of the total effective field acting on the wall.

Rather than viscous dynamics, here we examine thermally activated domain wall creep in the presence of an effective coupling field. We measure this motion in a Pt/Co/Pt/Co/Pt system in which the two antiferromagnetically coupled Co layers both exhibit perpendicular anisotropy. In single layer ultrathin Pt/Co/Pt films [5,6,8,21], it has been shown that the motion of the narrow domain walls in such films is consistent with predictions of general theories for 1D elastic interfaces moving in 2D weakly disordered media [5,22–24]. This is due to these films' strong perpendicular anisotropy, low Co layer thickness and inherent weak disorder (due to structural inhomogeneities [7]) as well as the intrinsic elasticity of the walls (due to their per-unit-length energy) which competes with the pinning and roughening effects of the disorder. Thermally activated domain wall creep occurs at low applied fields when the field alone is insufficient to overcome the pinning [22,23]. Here we shall examine how creep in the softer of the two Co layers is affected by coupling to the uniformly magnetized harder Co layer. This is an initial step toward experiments which examine domain wall dynamics in both of the coupled Co layers.

We begin the paper by demonstrating that the net interlayer coupling in our film is antiferromagnetic and by obtaining an initial macroscopic measurement of $H_J$ from the horizontal shift of the soft layer's minor hysteresis loop. We then show that the domain wall motion in the soft layer is consistent with creep theory when the effective coupling field resulting from the coupling to the hard layer is included in the creep law as a component of the total effective field acting on the wall. From these measurements we are able to obtain a value for $H_J$, and subsequently $J$, based upon the effect the coupling has on the walls during their motion.

## 2. Sample details and hysteresis

The sample was sputter deposited at room temperature onto an etched substrate and has the following structure: Si/$SiO_2$/Pt(4.5 nm)/Co(0.5 nm)/Pt(4 nm)/Co(0.8 nm)/Pt(3.5 nm). Out of plane hysteresis loops obtained using polar magneto-optical Kerr effect (PMOKE) magnetometry at room temperature are shown in Fig. 1. It can be seen from the major loop that the two Co layers, both exhibiting perpendicular anisotropy, switch separately at the rather low field sweep rate used for this measurement (~0.1 kOe/s). The switch at ~50 Oe can be identified with that of the 0.5 nm Co layer which intrinsically yields a smaller magneto-optic signal (attenuated further by the upper 0.8 nm Co layer and the Pt spacer and capping layers). The larger jump corresponds to the 0.8 nm layer

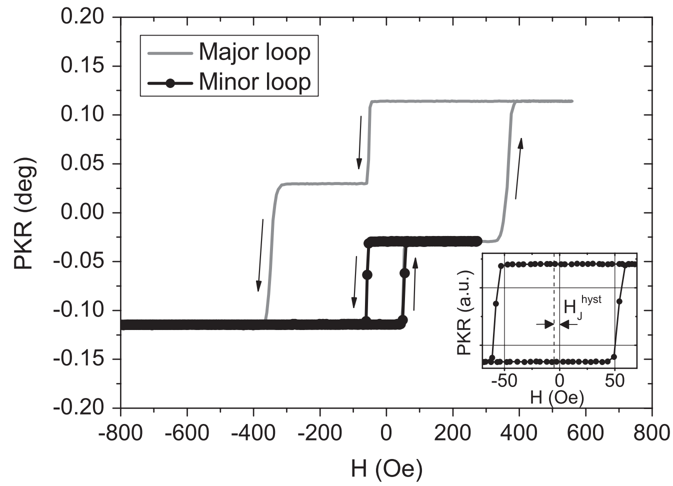


Fig. 1. Major and minor polar Kerr rotation (PKR) hysteresis loops measured at $\lambda = 543$ nm with a field sweep rate of ~0.1 kOe/s. The arrows represent the field cycling direction. The soft layer's minor hysteresis loop is shown in the inset with the leftward horizontal loop shift (resulting from antiferromagnetic coupling to the negatively saturated hard layer) labeled as $H_J^{hyst}$.

which is magnetically harder, consistent with results for single layer Pt/Co/Pt films [8].

In the inset of Fig. 1 we show the minor loop of the soft layer, obtained with the hard layer negatively saturated. The antiferromagnetic coupling to the hard layer results in a positive effective coupling field which acts on the soft layer (the sign of $H_J$ will depend on the orientation of the magnetization of the hard layer). This results in the observed leftward shift of the minor loop along the field axis. The shift gives us an initial macroscopic determination of the effective coupling field which we will denote by $H_J^{hyst} = 3.9 \pm 2.1$ Oe. Note that the shift was measured for 4 different field sweep rates between 0.1 kOe/s and 0.8 kOe/s for which no sweep rate dependence was observable. Averaged, the four measurements yield $H_J^{hyst} = 4 \pm 3$ Oe. The significant percentage error is largely due to the limited field resolution of the magnetometer.

## 3. Domain wall dynamics

Having an initial macroscopic determination of the effective coupling field, we now examine the direct effect of the coupling on domain wall dynamics in the soft layer. The pinning potential experienced by the wall as it moves through the film is characterized by two parameters: $U_C$, related to the height of the pinning barriers and $H_{dep}$, the depinning field. The velocity of domain walls in isolated films in the low field creep regime ($H \ll H_{dep}$) is then predicted to depend on the applied field, $H$, as [22,23]

$$v = v_0 \exp\left[-\frac{U_C}{k_B T}\left(\frac{H_{dep}}{H}\right)^{\mu}\right] \quad (2)$$

where $T$ is the temperature, $v_0$ is a numerical prefactor and $\mu$ is a universal exponent equal to $\frac{1}{4}$ for a 1D interface