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Shape-dependent anisotropy and damping of picosecond magnetisation dynamics in a micron sized $Ni_{81}Fe_{19}$ element

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Abstract

We have observed a four-fold variation of the anisotropy and damping of the magnetisation precession in a square $Ni_{81}Fe_{19}$ element of 10 μm length by time-resolved scanning Kerr-effect microscopy. The measured frequencies are interpreted with the aid of a coherent rotation model, while micromagnetic modelling is used to understand the dynamic magnetic images and hence the variation of the damping.

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Keywords: Magnetic microscopy; Ultrafast magnetic processes; Magnetic thin film device

Time-resolved scanning Kerr-effect microscopy (TRSKEM) is a powerful probe of ultrafast magnetisation dynamics in small magnetic elements [1–3]. The dipolar interactions within the element depend upon its size and shape, give rise to configurational anisotropy [3–5], and influence the apparent damping [3]. In this article a four-fold dependence of anisotropy and damping is observed in a square element both experimentally and in micromagnetic simulations.

The sample is a square $Ni_{81}Fe_{19}$ element of 150 nm thickness and 10 μm side fabricated on a glass substrate [3]. Hysteresis loops showed saturation fields of up to 110 Oe. A pulsed field $\mathbf{h}(t)$, with 35 ps rise time and 27 Oe peak height, and a static magnetic field $\mathbf{H}$ with strength H and orientation ϕ_H were applied within the plane of the sample. The p-polarised probe beam of 800 nm wavelength and 120 fs pulse-width was focused to a sub-μm spot and the Kerr rotation of the back-reflected beam was recorded.

Fig. 1(a) shows the time-dependent Kerr rotation θ_K measured at the centre of the sample for $H = 410$ Oe and different values of ϕ_H and the right-hand panel shows the fast Fourier transforms (FFT). The time scans show that the damping has a four-fold dependence upon ϕ_H. The FFTs show a prominent peak corresponding to the uniform mode of precession. The dependence of the peak position upon ϕ_H is plotted in Fig. 2(a) and has four-fold symmetry. The uniform mode frequency has been modelled by inserting four-fold and uniaxial anisotropy terms into the solution of the Landau–Lifshitz equation [3,6]. The simulated frequencies, shown by the solid line in Fig. 2(a), agree with the experimental frequencies. Modelling yielded values of 2 and −33 Oe for the uniaxial and four-fold anisotropy fields, and values of 10.8 kOe for $4\pi M_S$ (M_S is the saturation magnetisation) and 2.1 for the g factor. Micromagnetic simulations were performed with the OOMMF software [7]. The element was divided into a 2D grid of 40 nm squares and a value of 0.01 was assumed for the damping coefficient. The time dependence of the out-of plane component of the magnetisation (M_Z), averaged over the entire area of the element, is shown for various ϕ_H values in Fig. 1(b) with corresponding FFT spectra. The simulated curves again show that the damping has a four-fold dependence.

The frequencies obtained from OOMMF are plotted as a function of ϕ_H in Fig. 2(a). The widths of the FFT spectra provide a measure of the damping and are plotted in Fig. 2(b). The finite length of the time scan

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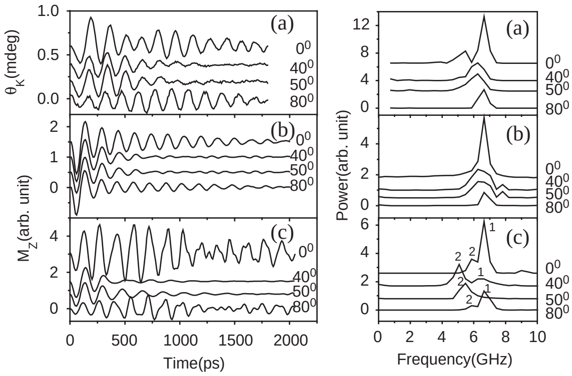

Fig. 1. (a) The measured Kerr rotation (θ_K) is plotted. Simulated M_Z, (b) averaged over the entire area of the sample, and (c) from a 1 μm area at the centre of the sample, are shown. The right-hand panels show the corresponding FFT spectra.

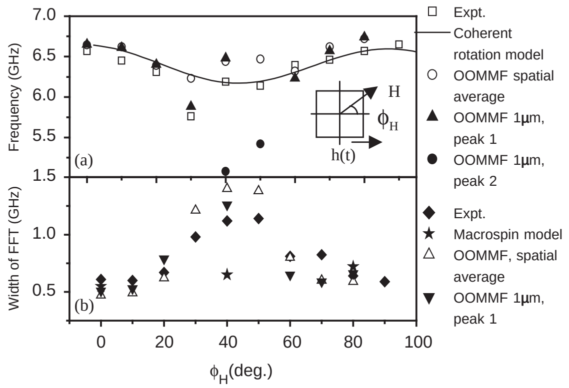

Fig. 2. (a) Frequencies and (b) widths of the FFT spectra are plotted as function of ϕ_H. The inset in (a) shows the measurement geometry.

used in experiment and simulation contributes to about 30% of the width of the peak in the FFT. The simulated frequencies show a strong four-fold dependence and a weak eight-fold dependence that was observed before both experimentally and in micromagnetic simulations [5]. The measured and simulated linewidths follow a similar trend although the angular variation of the simulated linewidth is slightly stronger. The widths obtained from a macrospin model did not show any significant variation with ϕ_H.

In order to reproduce the experimental conditions, the average M_Z value from a square of 1 μm^2 area at the centre of the element is plotted in Fig. 1(c). The FFTs show a lower frequency mode which has greater amplitude than the uniform mode when $\phi_H = 40-50^\circ$. This mode was not observed consistently in the experiment. This may explain why the damping is apparently stronger in Fig. 1(c) than in the experiment and suggests that a complete characterisation of the mode spectrum is needed.

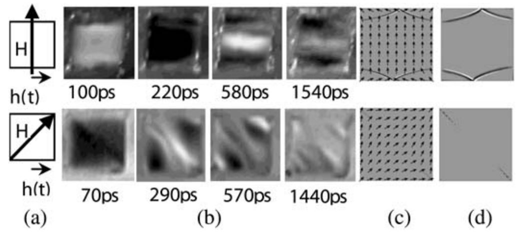

Fig. 3. (a) Experimental geometries and (b) dynamic Kerr images at four time delays are shown. (c) Simulated static magnetic images (M_Z) and (d) internal field ($H_{\text{int}(Z)}$) distributions are shown.

Dynamic magnetic images were acquired to elucidate the variations in the apparent damping. Fig. 3(a) shows the two configurations ($\phi_H = 0^\circ$ and 45°) used. Fig. 3(b) shows images at four different delay times. The non-uniformity develops from the edge regions perpendicular to **H** for $\phi_H = 0^\circ$ and from the central region of the element for $\phi_H = 45^\circ$. Consequently, dephasing at the position of the probe spot occurs more quickly for $\phi_H = 45^\circ$ than for $\phi_H = 0^\circ$. The dominance of the lower frequency mode for ϕ_H close to 45° in Fig. 1(c) also supports this observation. Simulated images of M_Z and the out of plane component of the total internal field $H_{\text{int}(Z)}$ in the static configuration are shown in Figs. 3(c) and (d). They show that M_Z and $H_{\text{int}(Z)}$ are non-uniform in the regions from which the non-uniformity spreads. This indicates that the sample shape has a major influence in determining the spatial variation of the static magnetisation, which affects the precession of the magnetisation.

In conclusion, we observed a four-fold variation of the damping and precession frequency in a square element of 10 μm length by TRSKEM. Dynamic images and micromagnetic simulations were used to understand this behaviour. As ϕ_H varies from 0° to 45°, regions of non-uniform magnetisation move from near the edge of the element to its centre, causing the internal field and precession frequency to vary. The non-uniformity that develops from the demagnetised regions leads to the observed variation of the damping.

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