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Time domain MOKE detection of spin wave modes and precession control for magnetization switching in ferrite films

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Abstract

The dynamic magnetization response to pulse fields for magnetic garnet films was measured by time-resolved magneto-optical Kerr effect techniques. A damped precession, or ringing, is found when the pulse is turned on or off. The ringing amplitude after turn off shows alternating maxima and minima as the static field is changed. A fast Fourier transform analysis gives peaks at frequencies which match those expected from ferromagnetic and spin wave resonance for fields above 25 Oe. Lower frequency modes indicative of surface anisotropy are also found. The change in intensity with field for the two strongest peaks tracks the variation in the ringing amplitude.

Keywords: Spin waves; Spin dynamics; Magneto-optics; Garnets

The upward trend in data rates for magnetic recording shows that a better understanding of the dynamic magnetization response on a nanosecond time scale is needed. The damped precession which occurs when field pulses are turned on or off, often termed ringing, introduces lower limits on the practical time between switching events. Up to now, the only known way to overcome such limits has been to increase the damping [1–3]. Recent work, however, shows that the ringing can be suppressed by adjustment of the pulse duration or timing, or by tuning the static field [4–7].

New results on the dynamic magnetization response obtained by time resolved magneto-optical Kerr effect (MOKE) techniques are reported here. There are two new effects. First, the fast Fourier transform (FFT) of the response gives peaks in the frequency spectrum which match modes expected from ferromagnetic and spin wave resonance considerations. Second, the two strongest peaks in the spectrum for the ringing after pulse turn off rise and fall as the field is changed. The variations for *both* modes match the change in the overall ringing response with field.

The MOKE data were obtained on a 1 mm square, 1.5 μm thick (1 1 1) film of $Lu_{2.04}Bi_{0.96}Fe_5O_{12}$. The film had a nominal saturation induction of 1750 G and a half-power ferromagnetic resonance (FMR) linewidth of 0.9 Oe at 8.1 GHz [8]. Static hysteresis loop measurements indicated no significant anisotropy other than shape anisotropy. The time resolved MOKE magnetometer is described in Ref. [5]. The initial magnetization state is set by an in-plane static field H_{stat}. A fast rise time current pulse at a 100 kHz repetition rate is applied to a 0.3 mm wide microstrip antenna with the film on top, face up. This pulse produces the in-plane switching field in the plane of incidence and perpendicular to H_{stat}. Second, a 10 pJ laser probe pulse with a 15 ps duration and a wavelength of 810 nm is applied after some electronic delay time. The MOKE signal as a function of the delay time yields the magnetization dynamics.

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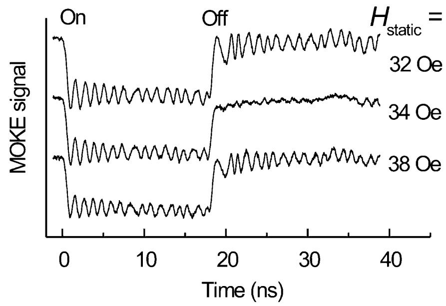

Fig. 1. Typical MOKE signal time responses.

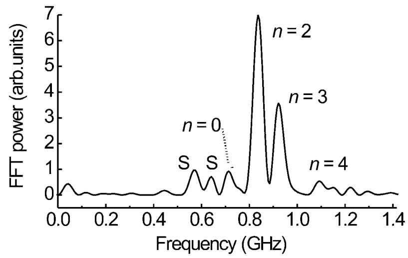

Fig. 2. Representative fast Fourier transform spectrum for a ringing signal. The static field was 37 Oe. The n and S labels indicate the various modes with which the peaks may be identified.

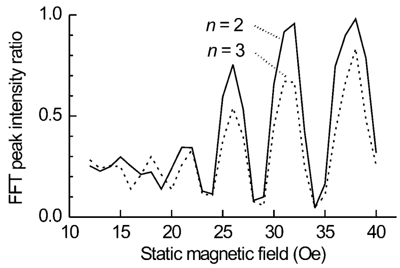

Fig. 3. Fast Fourier transform intensity ratio vs. static field for the $n = 2$ and 3 peaks in Fig. 2. The vertical axis scale gives the ratio of the peak intensities for the pulse off signals and the pulse on signals.

The current pulses were 18 ns wide and with rise and fall times of 0.4 ns. The switching field pulse amplitude was 1.6 Oe. The light was s-polarized and applied at a 55° angle of incidence. This arrangement was verified to yield a signal of the longitudinal magnetization component only, that is, from the component of the dynamic magnetization along the pulsed-field direction. The jitter limited time resolution was better than 100 ps.

The dynamic magnetization response during and after the field pulse was measured for a range of static fields. Fig. 1 shows typical data for three H_{stat} values, as indicated. The data show a pronounced ringing when the pulse is turned on for all three fields. After turn off, however, the ringing is suppressed for $H_{stat} = 34$ Oe. The sequence of ringing amplitude maxima and minima extends over a wide range of fields [6]. The minima occur when the precession frequency is such that the magnetization is lined up with the static field at the pulse off point [5,6].

An FFT analysis with zero padding [9] was done to quantify the precessional response. Fig. 2 shows a representative power spectrum. The spectrum shows six pronounced peaks between 0.55 and 1.1 GHz, as indicated. For H_{stat} above 25 Oe, the $n = 0$ peak tracks the predicted uniform mode FMR frequency. The three higher frequency n labeled peaks track the predicted spin wave resonance frequencies for unpinned surface spins and two, three, and four standing wave half wavelengths across the film. The S peaks in Fig. 2 fall below the FMR peak. This is suggestive of surface modes created by partial pinning and surface anisotropy [10].

Fig. 3 shows results on the variation in the FFT peak intensities as a function of static field. The vertical axis shows ratios of the peak intensities for the ringing after pulse turn off, where suppression is active, to the corresponding intensities for ringing after turn on, where suppression is not active. The data are for the two strongest peaks in Fig. 2. These data provide an explicit and quantitative map of the ringing suppression as a function of field. The maxima and minima occur at the same field values for both components of the FFT response. These maximum and minimum positions also match those field positions where the overall ringing amplitudes are maximum and minimum. Note that the maxima increase with static field and the minima decrease with field. This means that the ringing suppression is actually enhanced for higher static fields.

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