6.5 Excitation and propagation of spin wave packets in thin garnet films by a short field pulse studied by space- and time-resolved magneto-optic Kerr effect magnetometry

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Linear and nonlinear wave phenomena (e.g. self-focusing, solitons, bullets, etc.) are important subjects in both basic research and applications. Nonlinear wave effects have been experimentally observed in a large number of different physical systems. Specifically, for investigations of excitation and propagation of wave packets in linear as well as in nonlinear media, thin magnetic garnet films with very low damping have proven to be a nearly perfect laboratory test system. By variation of the propagation direction and wavelength of the spin waves and/or the strength and direction of the applied magnetic field a large parameter space (e.g., group- and phase velocity, dispersion, diffraction, non-linearity, damping) is accessible with the same sample. Recently, we have developed an advanced Brillouin light scattering (TRBLS) setup, which allows one to map the spatial spin wave intensity distribution across the sample with time resolution [1].

It is also advantageous to test spin wave excitations by a short field pulse and the propagation by an independent method, working directly on the time scale, which is the subject of this report. Utilizing a newly developed space- and time-resolved magneto-optic Kerr effect vector magnetometer setup [2] the excitation and propagation of spin wave packets in a thin bismuth substituted lutetium iron garnet (BiLuIG, Bi_{0.96}Lu_{2.04}Fe_{5}O_{12}) film grown on a gadolinium gallium garnet substrate have been investigated [3].

Figure 1 shows the experimental setup. A 8 mm long, 2 mm wide and 1.5 μm thin BiLuIG film was saturated by a static magnetic field of $H_{\text{stat}} = 40$ Oe along the $y$-direction, the short dimension of the film. A narrow, 50 μm wide microstrip transmission line was used for the pulse excitation. Magnetic field pulses of about 3 ns duration, 100 ps rise time, 200 ps fall time and $H_{\text{pulse}} \approx 1$ Oe field amplitude were applied along the $x$-direction with a repetition rate of 100 kHz. The magneto-optic (MO) response of the generated spin waves was measured with an angle of light incidence of 55 deg.

![Sample geometry, plane of light incidence, and magnetic field configuration used in the experiment.](image-url)
Figure 2 shows the time evolution of the excitation and propagation of spin wave packets in a grayscale representation of the MO signal at different times $t$. At $t = 1$ ns the pulse excitation starts. For $t = 1.4$ ns the maximum deflection of the magnetization is reached on the microstrip.

$v_{gr} = 6.6$ cm/µs

$T_{pulse} \approx 3$ ns

$t$ [ns] 3.2 mm

1 4.25 7.1

1.4 4.75 7.6

1.85 5.2 8.05

2.35 5.7 8.55

2.85 6.15 9

3.3 6.65 9.5

10

Fig. 2: Time evolution of the excitation and propagation of spin wave packets. Shown here is a sequence of the mapped magneto-optic signal in a grayscale representation at different times $t$. Bright (dark) areas indicate a positive (negative) deflection of the magnetization from the equilibrium direction. The field pulses of $\approx 3$ ns duration start at $t = 1$ ns. The arrows indicate the propagation of the wave packets with a group velocity of $v_{gr} = 6.6$ cm/µs.
indicated by the white strip. Two spin wave packets begin to form on each side of the strip, and they propagate from the localized field region near the microstrip away to both sides. The propagation of the spin wave packets is clearly noticeable. From the data a group velocity of $v_{gr} = 6.6 \text{ cm/µs}$ is determined.

In Fig. 3 the response of the MO signal is shown as a function of time (a) and frequency (b) for different distances to the microstrip transmission line. The frequency of the uniform and the propagating spin wave mode were determined to be $v_0 = 0.83 \text{ GHz}$ and $v_k = 1.05 \text{ GHz}$, respectively.

Figure 4 shows the MO signal averaged over the $y$-direction as a function of the distance $x$ from the microstrip for different times. The dotted arrows indicate points with constant phase. From their slope the phase velocity has been determined to $v_{ph} = 34 \text{ cm/µs}$. The distance between consecutive arrows in $x$-direction at a constant time corresponds to a wavelength of $\lambda = 0.03 \text{ cm}$ and a wave vector of $k_x = 210 \text{ cm}^{-1}$, respectively. The gray arrow on the left represents the center of gravity of the spin wave packet. It moves with the group velocity, which is much slower than
the phase velocity. The marker on the right is used to determine the carrier precession period to $T_k = 0.95$ ns and the frequency to $\nu_k = 1.05$ GHz.

Finally, the measured parameters presented above are compared to a simple model calculation. In the present case the propagating spin wave mode is a magneto-static surface wave (MSSW) mode, since both the direction of the magnetic field and the wave vector lie perpendicular to each other in the film plane. From the dispersion relation of the MSSW mode

$$\omega_k = \sqrt{H_{\text{stat}} \left( H_{\text{stat}} + 4\pi M_s \right) + \left( 2\pi M_s \right)^2 \left( 1 - \exp\left( -2k_X d \right) \right)}$$

(1)

the phase and group velocities are calculated as

$$v_{\text{gr}} = \frac{\partial \omega_k}{\partial k_X} \Bigg|_{k_X} = 6.3 \text{ cm/\mu s}$$

(2)

and

$$v_{\text{ph}} = \frac{\omega_k}{k_X} = 31 \text{ cm/\mu s}$$

(3)

respectively. $|\gamma| = 0.0176$ (Oe ns)$^{-1}$ denotes the gyromagnetic ratio, $H_{\text{stat}} = 40$ Oe is the applied static magnetic field, $k_X = 210$ cm$^{-1}$ is the wave vector and $d = 1.5$ $\mu$m is the film thickness.
6 Experimental Results

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Tab. 1: Comparison between measured and calculated values.

Only the saturation magnetization has been adjusted to 4πMₛ = 1950 Oe. Table 1 shows a comparison between the measured and calculated values. Within the limits of this model there is a good agreement between the measured and calculated values.

The presented method has several advantages compared to measurements with conventional microwave techniques utilizing miniaturized pickup coils. The lateral resolution is better and it is practically free of cross talk, i.e., a direct electromagnetic coupling between the microstrip and a pickup coil. Compared to space- and time-resolved Brillouin light scattering, where the intensity is measured, the phase of the spin waves is directly accessible. The time resolution is improved by two orders of magnitude. Furthermore all three components of the magnetization can be measured [4]. On the other hand, a much longer acquisition time and the loss of direct wave vector selectivity must be taken into account.

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References