Direct detection of magnetostatic wave excitations in magnetostatic wave device structures by Brillouin light scattering

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The technique of Brillouin light scattering has been used to detect magnetostatic wave (MSW) excitations in MSW microwave device structures. The present results are for a signal-to-noise enhancer consisting of a microstrip transmission line in contact with a yttrium iron garnet film with the applied magnetic field parallel to the microstrip line. At low input microwave power levels, the MSW spectra at 4 GHz consisted of surface excitations with wave numbers from about 80 to 470 cm^{-1}, with the propagation direction perpendicular to the microstrip line. At high power levels, parametric half-frequency MSW excitations were observed, accompanied by a decrease in the scattering of the surface MSW excitations at the pump frequency.

Magnetostatic wave (MSW) propagation in planar magnetic samples[1] has formed the physical basis for a large class of devices for microwave signal processing.[2] The performance of these devices depends on the MSW dispersion characteristics. Until now, device design has relied on the theoretical dispersive properties of such waves. With the technique of Brillouin light scattering (BLS), it is now possible to measure the dispersion properties and energy flow profiles of MSW excitations *in situ* in actual device configurations. The purpose of this letter is to report the first such measurements on an MSW device structure, specifically, on a microwave signal-to-noise enhancer.[3,4] The scattering intensity of surface magnons and parametrically excited half-frequency magnons was measured as a function of input power level and bias field. It was possible to map out the MSW excitation spectra in terms of wave number distribution and propagation direction.

The present data also constitute the first BLS observation of magnetostatic surface waves (MSSW's) in yttrium iron garnet (YIG) films. Although thermally excited MSSW peaks have been reported for iron and nickel[5] (among others), BLS studies have failed to resolve thermal MSSW signals in YIG. The reasons are unclear. Nevertheless, the present data demonstrate that these modes can be detected by the BLS technique when excited externally.

The signal-to-noise enhancer consists of a 26.6-μm-thick yttrium iron garnet (YIG) film on a gadolinium gallium garnet (GGG) substrate in contact with a 110-μm-wide microstrip line. The static magnetic field is applied parallel to the microstrip line. Microwave power in the stripline leads to the excitation of surface magnons in the YIG film for suitable values of the static field and leads to an attenuation of the microwave signal. The power loss due to the magnetostatic surface waves is limited by spin wave instability processes for input powers above some threshold power level. Small signals, such as noise, will therefore experience a large attenuation in the microstrip line while high level signals will have a reduced attenuation. This is the operational basis of the MSW signal-to-noise enhancer.

The light scattering data were obtained with a high contrast multipassed tandem Fabry–Perot interferometer and a forward scattering geometry as in Ref. 5. A small hole was drilled in the alumina ground plane of the signal-to-noise enhancer. The diameter of the access hole was 1 mm and was located at about 1 mm above the stripline and 2 mm from the edge of the garnet film. Laser light was applied to the sample at normal incidence through this access hole, and the forward scattered light was collected by the lens and routed to the interferometer for analysis. Specific magnon wave numbers (k) and in-plane propagation angles (θ_k) could be selected by placing various diaphragms behind the collecting lens.[6] The maximum observable magnon wave number in this geometry was 4×10^4 cm^{-1}.

Surface magnons excited in the YIG film by stripline power were observed for drive frequencies (ω) from 2.8 to 4.0 GHz. An absolute stripline input power calibration was not possible; "high power" in the discussion below means the maximum power available (~40 mW for the Hewlett Packard 8692A signal source) and "low power" corresponds to

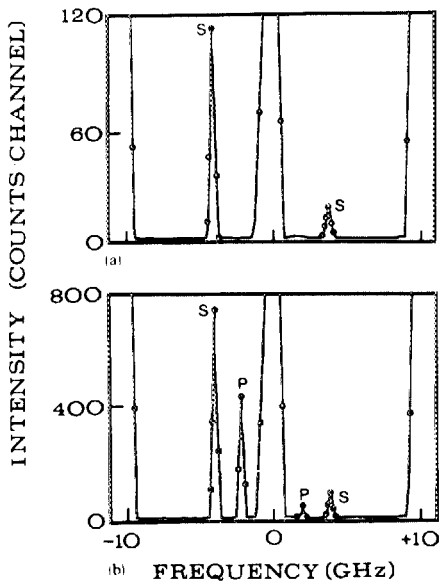

FIG. 1. Brillouin light scattering spectra for scattering on magnetic excitations in a magnetostatic wave signal-to-noise enhancer driven at 4 GHz, with the static field of 600 Oe parallel to the microstrip transmission line and no collection aperture. The input power was 0.4 mW for (a) and 40 mW for (b).

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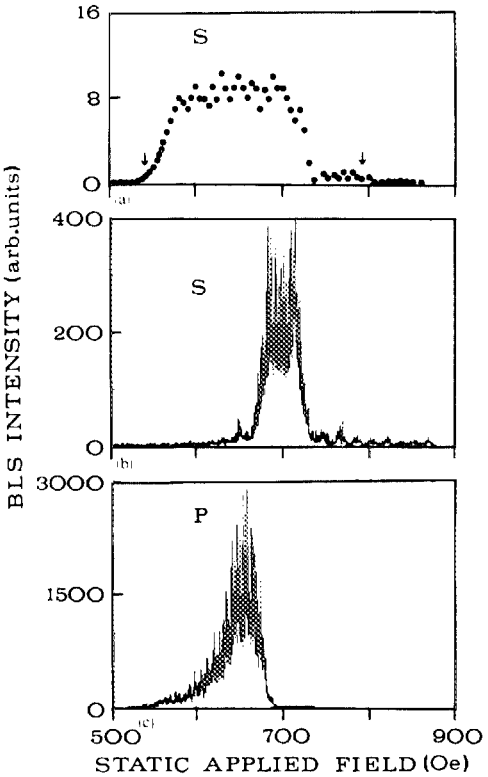

FIG. 2. Variation in the light scattering intensity with applied field at 4 GHz, with no collection aperture, for (a) the S peaks of Fig. 1(a) and 0.4 mW input power and (b) the S and (c) P peaks of Fig. 1(b) and 40 mW input power.

about 1% of the maximum power. For all the results presented below, the drive frequency was 4 GHz. Theoretical values of k and θ_k in the discussion to follow were based on well known magnon dispersion equations for magnetostatic surface wave (MSSW) excitations and spin waves, and values of 1780 G and 2.8 GHz/kG for the saturation induction and g value, respectively, of YIG.

Two spectra examples are shown in Fig. 1, for an applied field H of 600 Oe and no collection aperture restriction. For this field, the theoretical MSSW k value for propagation away from the microstrip line ($\theta_k = 90°$) is about 323 cm^{-1}, well within the accessibility limit of 4×10^4 cm^{-1} discussed above. Figure 1(a) is for low cw input power, and the spectra show distinct magnon peaks at 4 GHz. These peaks (labeled S) correspond to magnetostatic surface waves which are propagating in the film plane. In a tandem Fabry–Perot inteferometer, neighboring interference orders on both sides of the central Rayleigh peak are eliminated and only ghosts of the neighboring orders remain. Hence the magnon peaks associated with the neighboring interference orders were not seen in Fig. 1. Since the propagation of surface magnons is nonreciprocal, the weaker peak to the right of the Rayleigh peak is either due to reflections or due to an oppositely traveling MSSW on the GGG side of the YIG film which is excited by the leakage microwave field at the YIG-GGG interface.

The spectra in Fig. 1(b) are for the same scattering geometry, field, and excitation frequency but for high input power. In addition to the MSSW scattering peaks at $\pm$ 4 GHz, signals are also observed at $\pm$ 2 GHz corresponding to magnetic excitations at one-half the drive frequency. These signals are due to parametric half-frequency magnons excited at high power levels due to spin wave instability processes,[7] and are labeled P.

In addition to simply observing magnon peaks in the BLS spectra at appropriate frequencies, it was also possible to obtain a quantitative map of the k and θ_k distribution of the MSSW excitations. For no aperture, the interferometer "sees" all accessible MSSW excitation below $|\bar{k}| = 4\times10^4$ cm^{-1}. Various apertures were used to map out the k distribution of the excitations which contribute to the S peaks in the low power spectra. For the peaks in Fig. 1(a) ($H = 600$ Oe) the k distribution was found to be centered at the expected theoretical value (~ 320 cm^{-1}) with an aperture-size limited width of about 40 cm^{-1}. By observing the variation in scattered intensity with rotation angle of the scattering aperture, it was possible to verify that the propagation angle of the excited MSSW was $\theta_k = 90° \pm 5°$. Additional data for different values of the applied field yielded an empirical MSSW dispersion relation for ω vs k which was in good agreement with the Damon–Eshbach theory.[1]

One important question for MSW devices concerns the range of k values which are excited for a given stripline geometry in a specific device structure. In order to determine the range of k values which may be excited in the device, intensity data were obtained as a function of field with no selective aperture in place, so that a range of wave numbers from zero to 4×10^4 cm^{-1} could be detected. Intensity versus field profiles for this type of scattering are shown in Fig. 2. Figure 2(a) is for the low input power and the 4 GHz S peaks. The peak intensity was determined from spectra as in Fig. 1(a) for discrete values of the applied field from 500 to 860 Oe, in 5 Oe steps. The magnetostatic surface wave peaks were observed for applied fields from 540 to 795 Oe (indicated by the arrows), corresponding to k values from about 1145 down to 0 cm^{-1}. Microwave measurements on the signal-to-noise enhancer device indicate that the device is efficient for launching surface waves with k values from 0 to greater than 1000 cm^{-1}.[3,4] However, the present data reveal a distinct field interval, 720–570 Oe, over which the BLS signal is especially large. The k value range corresponding to this field "window" is 80–470 cm^{-1}. 470 cm^{-1} corresponds to wavelength of about 130 μm. The BLS data indicate, therefore, that the 110-μm-wide stripline in contact with the YIG film is mainly generating MSW excitations of wavelength 130 μm or more.

Intensity versus field profiles similar to the one in Fig. 2(a), but for the high input power, are shown in Figs. 2(b) and 2(c). Profiles are given for both the MSSW S peaks and the parametric magnon P peaks. The scattering intensity for these high power spectra was much larger than for low power. It was possible, therefore, to use a continuous slow field scan and the frequency selective technique of Ref. 8.

Figures 2(b) and 2(c) reveal some rather intriguing high power effects. First, the intensity for the S peak is relatively large only at the high field end of the low power field window, 680–720 Oe. The strong S peak scattering over the low field region of 540–680 Oe has disappeared, with the simultaneous appearance of P magnons over this same interval. The sharp cutoff in the P magnon profile at 690 Oe is due to the displacement of the spin wave band above the 2 GHz cut-

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off point for the parametric half-frequency magnons. The P magnon profile in Fig. 2(c) is essentially a subsidiary absorption loss profile as considered in the Suhl theory, but specifically associated with scattering from $\omega/2$ magnons.

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