Inelastic scattering of a surface spin wave from a surface acoustic wave in a thin, iron-yttrium-garnet film

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The propagation of surface spin waves (SSW) in a ferrite film in the presence of a surface acoustic Rayleigh wave (SAW) is studied experimentally. A considerable scattering of SSW in the presence of SAW was observed in a narrow resonance region. The results of an experiment are compared with the theoretical calculation.

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Interacting spin and acoustic waves can propagate in yttrium-iron-garnet (YIG) films. The interaction between them is usually studied in the region in which the dispersion curves corresponding to them cross and an associated, magnetoelastic wave is formed. We have investigated the interaction between the surface magnetostatic spin waves and the Rayleigh surface acoustic waves (SAW), which propagate collinearly in an YIG film at some distance from magnetoacoustic resonance when the SAW frequency is much lower than that of surface spin waves (SSW) and a fast spin wave is scattered inelastically on a slowly traveling SAW. The theory of collinear scattering of exchange spin waves in unlimited ferrite due to parametric pumping in the region of stable interactions was formulated by Kiryukhin and Lisovskiĭ.[1] Experimental evidence of Mandel'stam-Brillouin scattering of spin waves by acoustic body waves in an YIG rod was initially reported by Zubkov *et al.*[2] The scattering of spin waves in thin films due to acoustic pumping, however, has not been investigated until now. We have demonstrated that a much stronger scattering effect can be produced in a thin YIG film by using a SAW.

Because of magnetostriction, the acoustically pumped propagation of spin waves has properties characteristic of wave propagation in periodic structures.[3] Rejection bands, inside of which the Floquet harmonics are transformed, appear on the dispersion curve $\omega(k)$ for spin waves. These harmonics undergo a multiple shift in frequency and in wave number with respect to the frequency Ω and the wave number K of an acoustic wave. The SSW transformation is most effective at the phase-matching points of interacting waves when the energy and momentum conservation laws for inelastic scattering are in effect. These conditions are satisfied on the (ω, k) plane at the points of intersection of the reference curves $\omega_l(k)$ for interacting Floquet harmonics. Figure 1 shows the reference curves for the first Floquet harmonic $l=0$ and for the neighboring Floquet harmonic $l=-1$ of a SSW for two cases: 1) When the transmitted SSW and SAW propagate in the same direction and 2) when

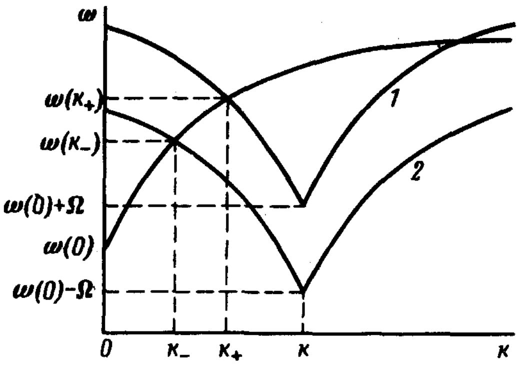

FIG. 1. Reference curves for two neighboring Floquet harmonics of surface spin waves for a parallel (1) and counter (2) propagation of a SAW and a signal SSW.

they propagate in the opposite directions. Because of inelastic Bragg reflection, the signal SSW inside the rejection band, which is formed in the neighborhood of the point of intersection of the reference curves, is scattered into a bucking wave, which causes it to be attenuated. The reflected wave is shifted in frequency by ±Ω. According to the theory of associated waves, the power of a wave transmitted in the Y direction varies according to the law

$$P(Y)/P(0) = 1 - \tanh^2 (Y \sqrt{\omega_B^2 - \Delta\omega^2}/v_g), \tag{1}$$

where $\Delta\omega$ is the frequency difference, ω_B is the halfwidth of the rejection band, and v_g is the group velocity of the wave. A calculation based on the equations of motion of the magnetic moment and magnetostatics equations, allowing for the boundary conditions, leads to the following formula for frequency splitting:

$$\omega_B = \frac{\gamma B}{M}\left\{\left[\frac{(\chi_2^2 - \chi_1^2)}{(1-\chi_1)}\,\frac{v_g k}{\omega_M} + \frac{(\chi_2^2 + \chi_1^2 - 2\chi_1)}{\chi_2}\right](\epsilon_{xx} - \epsilon_{yy}) + \right.$$

$$\left. + (\epsilon_{xx} + \epsilon_{yy})\left[\frac{(\chi_1^2 + \chi_2^2)(\chi_1^2 + \chi_2^2 - 2\chi_1) - 4\chi_1\chi_2^2(1-\chi_1)}{2\chi_1(\chi_2^2 - \chi_1^2)}\right]\right\}, \tag{2}$$

where γ is the gyromagnetic ratio, B is the magnetostriction energy,

$$\chi_1 = \frac{\omega_H \omega_M}{\omega^2 - \omega_H^2}, \quad \chi_2 = \frac{\omega \omega_M}{\omega^2 - \omega_H^2}, \quad \omega_H = \gamma H, \quad \omega_M = \gamma 4\pi M,$$

M is the magnetization, and ϵ_{xx} and ϵ_{yy} are the components of the elastic strain tensor. In deriving Eq. (2) we assumed that the Rayleigh wave is slightly nonuniform within the magnetic film parallel to the (Y, Z) plane, so that $\epsilon_{xy} \approx 0$ and $c_{11}\epsilon_{xx} + c_{12}\epsilon_{yy} \approx 0$, where c_{11} and c_{12} are elastic constants.

Experimental studies were conducted at room temperature using a 4.9 μm X 0.5

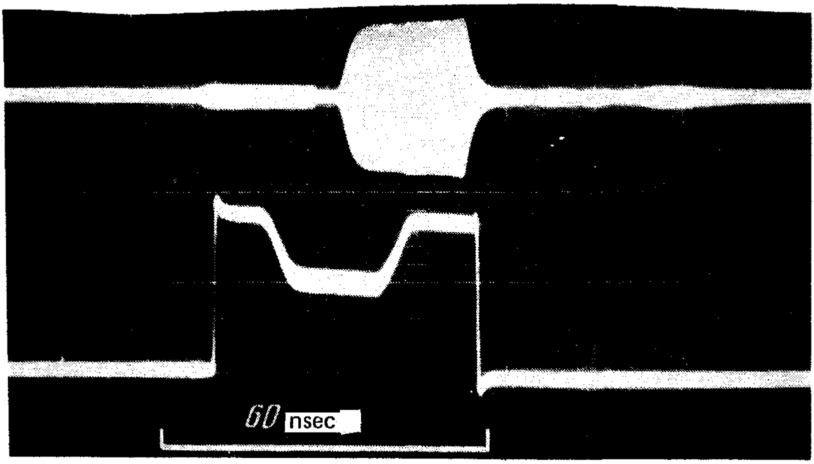

FIG. 2. Oscillograms of a SAW pulse (upper part) and a SSW pulse (lower part) in the middle of the rejection band.

cm × 2 cm YIG film grown on a 450-μm-thick gadolinium-gallium garnet substrate cut in the (111) plane. A ferrite-air surface spin wave was excited and received by 10-μm-wide microband converters which were spaced 0.6 cm apart. A surface acoustic wave was excited and received by two CdS wedges. To match the interacting waves in frequency and wave number, we changed the external magnetic field applied parallel to the plane of the film and at right angles to the direction of wave propagation. In the presence of a traveling SAW the power of a SSW transmitted from one converter to another diminished inside the rejection band. A typical oscillogram of received signals of the delayed pulses of an SAW (upper part) and of an SSW envelope (lower part) is illustrated in Fig. 2 for the case when the laws of inelastic scattering are satisfied for counter propagation of a signal SSW and acoustic pump wave. In this case the external field $H = 790$ Oe, $f_{\mathrm{ssw}} = 4.1$ GHz, $f_{\mathrm{saw}} = 39$ MHz, the pulse duration of an SSW is $\tau_{\mathrm{ssw}} = 15$ μsec and that of an SAW is $\tau_{\mathrm{saw}} = 7$ μsec. The SAW power was approximately 10 mW. The shift of an SAW pulse relative to the dip of an SSW pulse was caused by the delay in their propagation between the SSW and SAW receiving converters. Using a spectrum analyzer and SSW converters, we have also observed a signal from a scattered SSW whose frequency was shifted toward that of the acoustic wave. The signal was weak because the scattered wave propagated along the film-substrate boundary and was loosely coupled to the converters. Figure 3 shows the relative variation of power of a transmitted SSW as a function of the external magnetic field for a parallel (1) and counter (2) propagation of an SAW and a received SSW. The wave frequencies and SAW power are the same here as those in Fig. 2. As expected, according to Fig. 1, there is a frequency shift that shifts the resonance field. The scattering effect was proportional to the SAW power, in agreement with Eqs. (1) and (2). The effect decreased fourfold when the distance between the SSW converters was reduced to 0.3 cm. When the SAW frequency varied from 30 MHz to 70 MHz the SSW varied from 10 to 70%, which is attributable to the variation of the SAW amplitude.

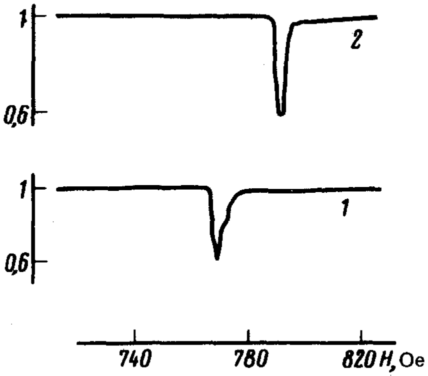

FIG. 3. Relative variation of the power of a transmitted SSW as a function of the external magnetic field for a parallel (1) and counter (2) propagation of a SAW and a received SSW.

A calculation based on Eqs. (1) and (2) for YIG, in which $B = 3.4 \times 10^6$ erg/cm^3 and $4\pi M = 1750$ G, is in agreement with the experiment when the SAW power is ~10 mW, in which case $\omega_B = 0.5 \times 10^7$ Hz ($\omega_B/\gamma \sim 0.2$ Oe). The experimental width of the rejection band $\Delta H \sim 6$ Oe, however, is clearly at variance with the theoretical estimates. This descrepancy is accounted for by the broadening of the rejection band because of the presence of nonuniform internal fields in the film.

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