Light scattering from parametric spin waves in $Y_3Fe_5O_{12}$ under longitudinal pumping

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We observed in experiment inelastic scattering of light by parametric spin waves with $k \neq 0$ in $Y_3Fe_5O_{12}$ following excitation of nonlinear ferromagnetic resonance (NFMR) by longitudinal pumping. The scattered-light spectrum contains satellites whose frequencies differ from that of the incident light ($\lambda = 0.63$ μm) by an amount $\nu/2$ (ν is the frequency of the microwave pump field).

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The investigation of magnetic excitations in crystals under parallel pumping ($\mathbf{h}_{\sim} \| \mathbf{H}$) by optical methods has been the subject of relatively few studies.[1–4] These studies consisted essentially of using the magneto-optical Faraday (FE)[1–3] and Cotton-Mouton (CME)[4] effects to register the change of the crystal magnetization component parallel to the external constant magnetic field (the z component) following excitation of nonlinear ferromagnetic resonance (NFMR).

However, the z-component of the magnetization yields information only on the total number of excited magnons (parametric, intermediate, and thermal). Which of the magnons are produced in NFMR can be determined by investigating inelastic scattering of light by spin waves. The only investigation of this type known to us was carried out for the case of transverse pumping in antiferromagnetic $CoCO_3$, where enhancement of the thermal magnons with frequency equal to half the pump frequency was observed.[5]

We report here results of an investigation of the scattering of light ($\lambda = 6328$ Å) by parametric spin waves in a thin plate of $Y_3Fe_5O_{12}$ (thickness 25 μm) magnetized in a plane and longitudinally pumped. All the measurements were made at a fixed microwave ($\Lambda \approx 3$ cm) field power 16 times larger than the minimum threshold level. We were unable to register the scattering reliably at lower pump power levels. The sample was at room temperature. To avoid strong overheating of the crystal, the microwave power was modulated by rectangular pulses of 4 μsec duration at a repetition rate 500 Hz.

The experimental setup was similar in the main to that described in detail in[6], but modernized somewhat as follows: 1) the range of recorded scattering angles was increased (from 0 to 15°), 2) to increase the absolute sensitivity of the photoreceiving channel we introduced, besides the circuit that registered the pulsed component of the light-intensity modulation, also a circuit for selective photon counting.

Measurements of two types were performed.

I. We investigated the pulsed component of the intensity of the scattered light at the output of an analyzer crossed with a polarizer. The light incident on the sample was polarized perpendicular to the constant magnetic field. To exclude masking of the weak scattering effect by the stronger (even at optimal polarization of the incident light) effect of magnetic birefringence, the central beam of the transmitted light was blocked with a diaphragm. The presence of this diaphragm and the dimensions of the entrance aperture of the objective limited the range of quasiparticle wave-vector values at which scattering was registered to $5 \times 10^2 < k < 2.6 \times 10^4$ cm^{-1}.

Figure 1a shows the experimental dependence of the pulsed optical signal on the intensity of the constant magnetic field in the presence of only a central diaphragm. This plot shows distinctly a number of maxima. We call attention first to the maximum at $H \approx 1000$ Oe. It is easy to verify that this field value is close to the critical field $H_{c\|} = 993$ Oe for a sample of this shape and for the known pump frequency $\nu = 9250$ MHz. Namely, as $H \to H_{c\|}$ one expects the production of parametric magnons with $k \to 0$ and $\theta_k = 90°$ (θ_k is the angle between the directions of $\mathbf{k}$ and $\mathbf{H}$),[7] scattering from which we can record.

To measure the angles θ_k of the quasiparticles that cause the observed scattering, we used a sector diaphragm, Fig. 1 (b, c, d). By comparing the field dependences of the optical signal at different orientations of the transparent sector relative to the direction of $\mathbf{H}$, we can draw the following conclusions: 1) at $H \approx H_{c\|}$ the quasiparticles

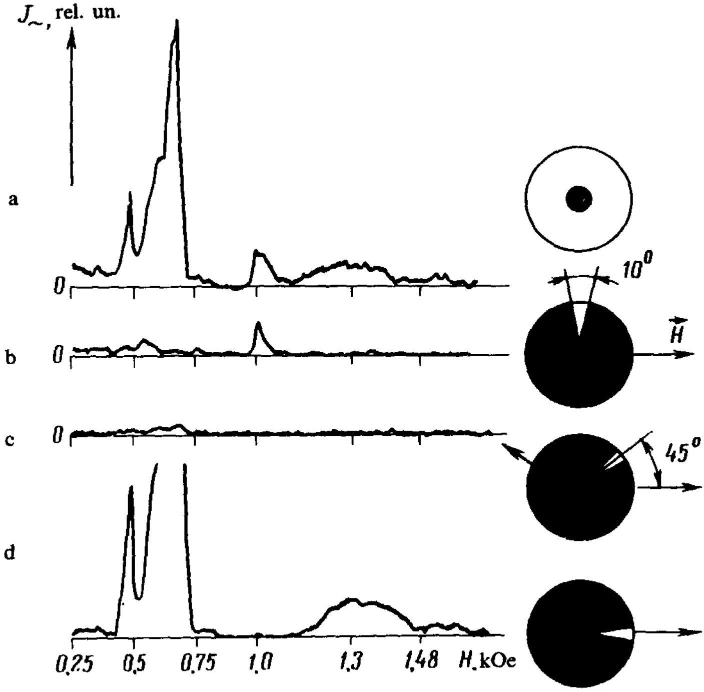

FIG. 1. Distribution of the pulsed component of the intensity of the scattering in a plane perpendicular to the light beam incident on the sample. In case (a) the sensitivity of the photoreceiver is half as large as in cases (b–d).

mainly excited are those with $\mathbf{k}\perp\mathbf{H}$, i.e., with $\theta_k=90°$. 2) In the field intervals $440<H<800$ Oe and $1170<H<1410$ Oe the light scattering is due to quasiparticles with θ_k close to zero. More detailed measurements have shown that in weak fields we have $-30°<\theta_k<30°$, while the maximum signal occurs at $\theta_k=0$.

II. The spectrum of the scattered light was investigated with the aid of a scanned Fabry-Perot interferometer. Figure 2a shows the experimental interference pattern of light scattered at $H\approx H_{c\parallel}$. The recorded spectrum contains a satellite whose frequency differs from that of the incident light by half the microwave-field frequency. The second satellite is much less distinguishable. The observed asymmetry of the satellite intensity is due to the contribution of the CME.[8] For comparison, Fig. 2 shows the spectrum of the light at the exit from the analyzer when a homogeneous magnetization precession is excited in the crystal with a pump frequency ($\mathbf{h}_\sim\perp\mathbf{H}$). The scattered-light spectrum in fields $H\neq H_{c\parallel}$ revealed no satellites, thus indicating that the frequency of the scattered light is close to the frequency of the incident light (or coincides with the latter).

On the basis of the results of the described experiments, we can draw the following conclusions: 1. The presence of a displaced frequency in the scattered-light spectrum, the change in the angle parameter θ_k, and the form of the field dependence of

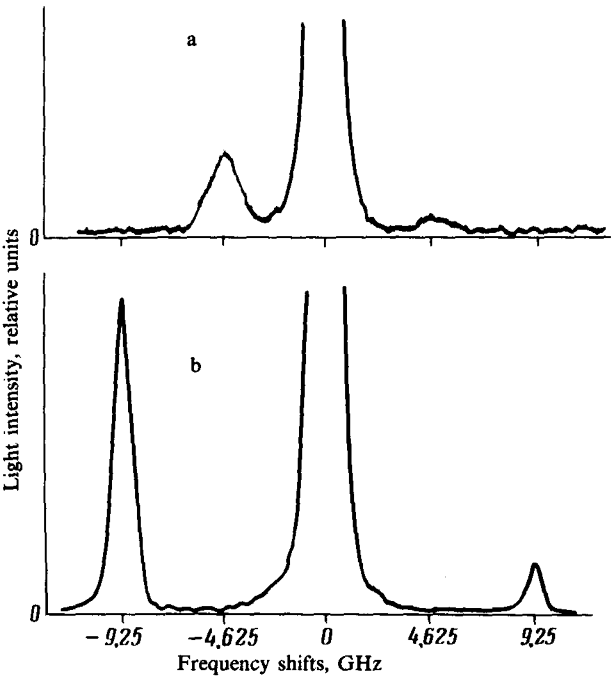

FIG. 2. Light-scattering spectra: a) longitudinal pumping ($\mathbf{h}_{\sim}\|\mathbf{H}$), $H \approx H_{c\|}$; the position of the sector diaphragm corresponds to Fig. 1b. b) Transverse pumping ($\mathbf{h}_{\sim}\perp\mathbf{H}$). The spectra were obtained by selective photon counting.

the intensity of the scattered light at fields close to $H_{c\|}$ allow us to state that we have observed inelastic scattering of light by parametric spin waves with frequency $\nu/2$, $\theta_k = 90°$, and wave vectors in the interval $5\times10^2 < k < 2.6\times10^4$ cm^{-1}. 2. We attribute the scattering of light in the field interval $440 < H < 800$ Oe to excitation of low-frequency phonons. In the considered field region, the NFMR is unstable, and this leads to appearance of low-frequency magnetization oscillations, while magnetostriction causes excitation of sound.

The nature of the scattering in fields $1170 < H < 1410$ Oe is not yet clear.

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