Radiation of electromagnetic waves by magnons

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(Submitted 13 May 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **37**, No. 12, 586–589 (20 June 1983)

Magnons have been excited in the weak ferromagnet $FeBO_3$ by a parallel-pumping method. Electromagnetic waves with a frequency $\omega_p/2$, where ω_p is the pump frequency, were found to be radiated from these magnons. The emission spectrum was studied at various pump power levels, temperatures, and magnetic fields.

PACS numbers: 75.30.Ds, 78.20.Ls, 75.50.Bb

The spectrum of the electromagnetic radiation emitted by parametrically excited magnons can yield valuable information about the excitation mechanism and the nature of the state above the threshold. Although corresponding experiments have been carried out with iron garnets,[1–4] what has been observed in all these studies is the emission from magnetostatic waves (with wave numbers $k \lesssim 10^2$), to which energy is transferred from magnons through a two-magnon scattering by defects and inhomogeneities. The emission spectrum may differ from that of parametric magnons.[2,4] Because of momentum conservation, electromagnetic radiation emitted by parametric magnons with $k = 10^4$–10^5 cm^{-1} should be much weaker than that from magnetostatic modes, and it has not yet been observed experimentally.

The intensity of the emission by magnons from a sample is

$$I \propto k^{-2} N \omega_{\mathbf{k}}^4 M_0 \Delta M, \tag{1}$$

where M_0 is the magnetic moment of the crystal, ΔM is the change in this moment associated with the excitation of a single magnon, N is the number of magnons, and $\omega_{\mathbf{k}}$ and $\mathbf{k}$ are the frequency and wave vector of the magnon.

In the present experiments we observed electromagnetic emission by parametrically excited magnons in the weak ferromagnet $FeBO_3$, and we studied the emission spectrum.

The crystal $FeBO_3$ is an antiferromagnet exhibiting an easy-plane anisotropy. The low-frequency branch of the magnon spectrum, with whose excitation we are concerned here, is described by[5]

$$\left(\frac{\epsilon_{\mathbf{k}}}{\hbar\gamma}\right)^2 = \left(\frac{\omega_{\mathbf{k}}}{\gamma}\right)^2 = H(H+H_D) + H_\Delta^2 + H_{\text{dip}}^2 + 36H_A^{(6)}H_E\cos 6\varphi + \alpha^2 k^2 , \quad (2)$$

where α is the exchange constant, H is the static magnetic field, H_D is the Dzyaloshinskiĭ field, H_Δ^2 is a parameter determined by the hyperfine and magnetoelastic interactions, H_{dip}^2 is a parameter determined by the magnon field,[6] γ is the magnetomechanical ratio, $H_A^{(6)}$ is the hexagonal-anisotropy field, and H_E is the exchange field. For materials of this type with a strong Dzyaloshinskiĭ interaction, the change

$$\Delta M = -\frac{\partial \epsilon_{\mathbf{k}}}{\partial H} = -\frac{g\gamma(2H+H_D)}{2\omega_{\mathbf{k}}}\mu_B \quad (3)$$

(g is the spectroscopic splitting factor, and μ_B is the Bohr magneton) may prove much larger than in ferromagnets, and the emission will be intense enough to be observed experimentally.

The magnon spectrum in $FeBO_3$ and the process by which magnons are excited in this crystal by parallel pumping were described in Ref. 7. According to the present understanding, this pumping mechanism excites magnons with a frequency $\omega_k = \omega_p/2$, where ω_p is the pump frequency. In the present experiments, the pump frequency was $\omega_p/2\pi = 35.6$ GHz. The magnetron pump source operated continuously. The resonator of the spectrometer was tuned to the pump frequency. The single-crystal sample was a cylinder 2 mm in diameter and 2 mm long with ends coinciding with a basis plane of the crystal. The sample was cemented to an exit coupling aperture of the resonator. The microwave output signal was split into two beams, one of which was sent through a 1.5-cm waveguide to an 8-mm-range detector, while the other was sent through a filter, which suppressed the ω_p component by ~ 40 dB, to a superheterodyne receiver. The output voltage from the receiver and the signal from the 8-mm-range microwave detector were fed to a dual-trace oscilloscope. The frequency band emitted was narrower than the passband of the receiver (10 MHz) if the pump intensity was not too far above the threshold for magnon excitation, so that the emission spectrum could be studied by analyzing the intermediate-frequency voltage of the receiver (30 MHz). For this purpose we used an S4-45 spectrum analyzer with a passband of 3 kHz. Measurements were carried out at temperature of 1.2–4.2 K.

These measurements revealed that there is emission in a frequency band $\omega_p/2 \pm 2\pi\cdot 25$ kHz once the pump intensity is raised an arbitrarily small amount above the threshold for parametric excitation of magnons. The bandwidth $\Delta\omega$ is apparently determined in this case by a parasitic deviation of the magnetron frequency. As the pump intensity is rasied, the spectral band of the emission becomes broader. The emission intensity varies in a random way over time: an oscilloscope trace of the output signal from the receiver shows spikes with a typical length $\tau = \Delta\omega^{-1}$. Furthermore, two satellites 0.9 MHz away from this band and positioned symmetrically with respect to it appear in the emission spectrum. The width of these satellites also increases with increasing pump intensity. The frequency 0.9 MHz corresponds to a natural elastic vibration mode of the sample. The appearance of these satellites is in agreement with the results of Ref. 7, according to which elastic vibrations are excited as a result of the decay of parametric magnons.

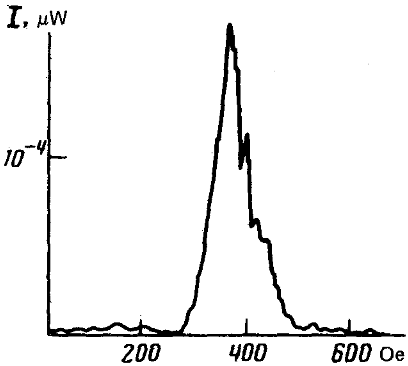

FIG. 1. Emission power at the receiver input vs the magnetic field H. $P/P_c \sim 10$ dB, $T = 1.2$ K.

The emission was observed over the entire range of magnetic fields (from 0 to ~ 500 Oe), in which there was an absorption of pump power corresponding to the excitation of magnons. Figure 1 shows the magnetic-field dependence of the emission power for a constant pump power, roughly ten times the excitation threshold P_c. In a certain field range, with a width approximately equal to the bandwidth of magnetostatic modes ($4\pi M_S = 225$ G, where M_S is the spontaneous magnetization), the emission intensity increases sharply. The emission intensity varies by ~ 20 dB. It follows that we are observing emission not only from magnetostatic modes but also directly from parametric magnons. The spectral widths $\Delta\omega$ of these two types of emission are approximately equal and depend on the pump power P in the same way. Figure 2 shows the dependence $\Delta\omega$ on $(P/P_c)^{1/2}$ in a field $H = 380$ Oe, where the emission is at a maximum. We note that the magnon relaxation parameter $\Delta\omega_k$ found from the threshold for the parametric excitation is[7] $\sim 2\pi \cdot 1$ MHz at $T = 1.2$ K.

When the pump power is raised above the threshold, the absorption of the pump power sets in abruptly.[7] In a field H corresponding to the emission maximum, this threshold is ~ 10 mW. The power of the emission at $\omega_p/2$ is 10^{-10} W at the receiver input in this case.

At this point we do not have a rigorous theory to describe the spectrum of parametrically excited magnons in antiferromagnets. Nevertheless, the significant width

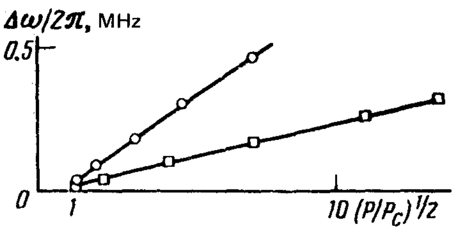

FIG. 2. Spectral width of the emission at the 0.1-power level vs $(P/P_c)^{1/2}$. □—$T = 1.2$ K; ○—$T = 4.2$ K. $H = 380$ Oe.

observed for the emission spectrum is at odds with the present understanding of the spectrum of the system of parametric magnons.[4]

We wish to thank A. S. Borovik-Romanov for interest in this study, A. I. Smirnov for a discussion of results, and L. N. Bezmaternykh for furnishing the $FeBO_3$ single crystals.

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Translated by Dave Parsons
Edited by S. J. Amoretty