Observation of a size effect produced as a result of parametric excitation of spin waves in $FeBO_3$

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A parametric excitation of spin waves in $FeBO_3$ produced by using parallel pumping method at $\nu_p = 35$ GHz for $T = 1.2$–4.2 K was observed. A fine structure was observed in the magnetic-field dependence of the power absorbed by a sample, which is attributable to the size effect.

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It follows from static[1] and resonance[2] studies that $FeBO_3$ is an easy-plane antiferromagnet with a weak ferromagnetism. Because it has a high Néel temperature ($T_n = 348$ K)[1] and is transparent to visible light, $FeBO_3$ has become one of the principal objects for the study of elementary excitations. Wettling and Jantz investigated the Mandelshtam-Brillouin scattering of light by thermal magnons[3] and phonons that were parametrically excited via uniform precession of the magnetic moments in $FeBO_3$.[4] Thus far, however, spin waves in this material could not be excited.

This paper reports the parametric excitation of spin waves in $FeBO_3$ by using the parallel-pumping method.

The $FeBO_3$ single crystals used by us were naturally faceted thin, hexagonal plates. The $FeBO_3$ growth plane coincided with the basal plane of the crystal. The single crystals were grown at the Institute of Physics, Siberian Branch, USSR Academy of Sciences.

The experiments were performed at liquid helium temperatures (1.2–4.2 K) using a direct-amplification spectrometer[5] with a pumping frequency $\nu_p = 35$ GHz. The sample was placed in a high-Q ($Q = 16\,000$) cavity. To eliminate elastic tension to which the $FeBO_3$ single crystals are highly sensitive,[2] we placed the sample at the bottom of the cavity on a small pocket of tissue paper.

During parametric excitation the spin waves of the low-frequency branch were excited by using the parallel-pumping method. The spectrum of this branch in an easy-plane antiferromagnet is described by the equation[6]

$$(\nu_{1k}/\gamma)^2 = H(H + H_D) + H_\Delta^2 + \alpha_\parallel^2 k_\parallel^2 + \alpha_\perp^2 k_\perp^2 , \qquad (1)$$

where ν_{1k} and **k** are the frequency and wave vector, γ is the gyromagnetic ratio, H_D is the Dzyaloshinskiĭ field, $\alpha_\parallel$ and $\alpha_\perp$ are the inhomogeneous exchange constants in the direction of the principal axis of the crystal and perpendicular to it, respectively, and H_Δ^2 is the gap in the spin-wave spectrum, which is determined in the $FeBO_3$ by the magnetoelastic interaction.[2] For $FeBO_3$ $\gamma = 2.8$ GHz/kOe, $H_D(T \to 0) = 100$ kOe, and

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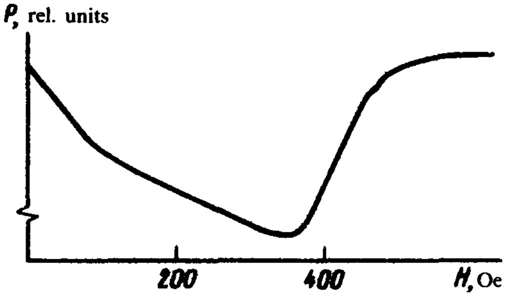

FIG. 1. Recorder trace of the SHF power P transmitted through a cavity with the sample for $P \gg P_c$.

$H^2 = 4.9$ kOe^2 for $T = 4.2$ K.[2] We omitted in Eq. (1) the term describing the hexagonal anisotropy in the basal plane, since Velikov *et al.*[2] did not observe it. We must bear in mind, however, that it can markedly affect the spectrum at low frequencies ($\nu_{1k} \sim 17$ GHz).

The studies showed that when a certain threshold h_c of the SHF field was exceeded, an absorption appeared in the crystal in the range of static fields corresponding to the excitation of spin waves with a frequency $\nu_{1k} = \nu_p/2$ (see Fig. 1), i.e., when $H \leqslant H_c$, where H_c is determined from Eq. (1) for $k = 0$. The threshold field h_c changed slightly with the temperature and decreased with increasing magnetic field H. The minimum value of h_c was ≈ 0.2 Oe. The relaxation $\Delta\nu_{1k} \approx 4.5$ MHz of the excited spin waves can be calculated from h_c using the equation[7]

$$h_c = \nu_p \Delta\nu_{1k} / \gamma^2 (2H + H_D) \tag{2}$$

The excitation of the spin waves had a hard nature,[8] and the magnitude of the cutoff part of the relaxation increased with decreasing temperature to $\sim 70\%$ of $\Delta\nu_{1k}$.

In addition, we observed that the dependence of the power transmitted through the cavity with the sample on the static magnetic field is not a monotonic function in a certain range of fields $H_1 \leqslant H \leqslant H_c$ at a slightly elevated threshold field h_c, although it has resonance-type dips at certain values of H. Figure 2 shows a small part of the $h_c(H)$ dependence. As the temperature decreases, the range of fields, in which the nonmonotonic behavior is observed, expands (H_1 decreases) to zero fields, and the location of each individual dip remains the same.

The observed effect can be explained by additional conditions imposed on the

FIG. 2. Recorder trace of the SHF power P transmitted through a cavity for P close to P_c.

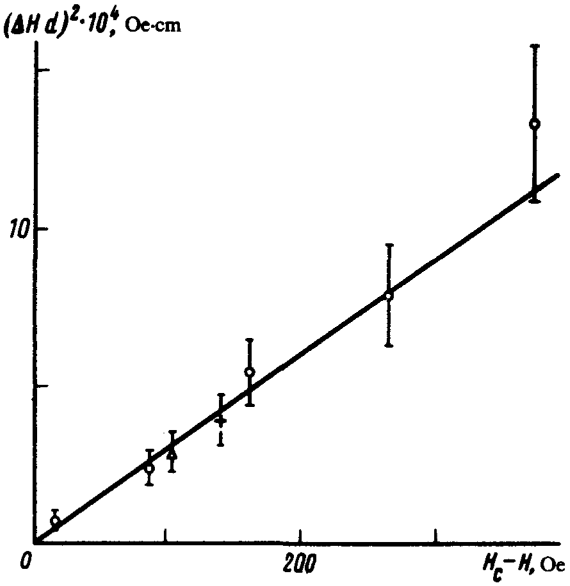

FIG. 3. Magnetic-field dependence of the interval ΔH between the peaks, reduced to one plate thickness. ●, $d = 0.5$ mm; ▲, 0.49 mm; +, 0.08 mm.

excited spin waves by the sample boundaries, which lead to the known selection rules.

$$N \lambda / 2 = d, \tag{3}$$

where d is the plate thickness and $\lambda = 2\pi/k$ is the wavelength. In our experiment we excited the spin waves with $k \sim 10^4$–10^5 cm^{-1}, which corresponds to $N \sim 10^3$.

A similar size effect was observed as a result of parametric excitation of spin waves in YIG.[9,10]

It follows from Eqs. (1) and (3) that the interval ΔH between the adjacent peaks must be defined by the dependence

$$\Delta H^2 = (2\pi \alpha_i / d)^2 (H_c - H)/H_D , \tag{4}$$

where α_i is the corresponding component of α. Since d is the sample size along the principal axis, we must use $\alpha_{\parallel}$ as α_i in Eq. (4).

The measurements were performed using three samples with thicknesses of 0.5, 0.49, and 0.08 mm. Figure 3 shows the experimental results in the $(\Delta H d)^2$ vs H coordinates. The linear dependence obtained confirms our assumption.

The inhomogeneous exchange constant $\alpha_{\parallel}$ can be determined from the experimental data. The value of $\alpha_{\parallel} = 8.8 \times 10^{-2}$ Oe·cm $\pm 5\%$ is in agreement with the value $\alpha_{\parallel} = 8.7 \times 10^{-2}$ Oe·cm, which was determined by Jantz and Wettling from the light scattering at $T = 77$ K and recalculated for $T = 4.2$ K.

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