Change in the magnon distribution function in yttrium iron garnet during nonresonant parallel pumping

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Nonresonant parallel pumping has been observed to change the distribution function of low-frequency spin waves. The effect is shown to be a consequence of a frequency redistribution of the magnons, in the direction of higher frequencies, in the rf field.

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By "nonresonant parallel pumping" we mean the situation in which an alternating magnetic field at a frequency $\Omega < 2\epsilon_0$ (ϵ_0 is the activation energy of the magnon spectrum) is applied parallel to a constant field. Nonresonant parallel pumping of magnetic materials has effects which reduce to changes in the probabilities for the interactions of magnons with each other, with phonons, and with defects, so that nonequilibrium states are produced in the magnon system.[1–3] Depending on which of these processes goes most efficiently under the given conditions, various types of nonequilibrium magnon distributions in the energy ϵ_k can occur in the spin-wave system. If, for example, the interactions of magnons with defects (impurities or dislocations) are the most efficient, then the nonresonant parallel pumping induces processes which conserve the magnon number.[2,3] As shown in Refs. 2 and 3, the absorption of quanta of the external field shifts the magnon energy distribution toward higher energies. This shift is accompanied by a decrease in the values of the distribution function in the low-energy region (at small wave vectors) because of an increase in the magnon distribution function at large values of k. This nonequilibrium state of the magnon system can lead to a stimulated magnetization,[2,3] i.e., to a magnetization stronger than the thermodynamic equilibrium value, during nonresonant parallel pumping. It would apparently be difficult to observe this stimulated-magnetization effect directly, because the magnetization is an integral characteristic over the magnon spectrum. Accordingly, in an effort to observe the effect of Refs. 2 and 3 we took the approach of studying the local characteristics ("local" in the energy sense) of nonequilibrium magnon states during nonresonant parallel pumping. We observed experimentally that the local emission intensity falls off by an amount on the order of 10% in yttrium iron garnet at room temperature, with a constant magnetic field $H = 1.5$ kOe, during nonresonant parallel pumping at the frequency $\Omega = 140$ MHz with an alternating-field amplitude $h = 1$ Oe in the wave-vector region $\epsilon_k - \epsilon_0 \sim \gamma$, where γ is the magnon damping.

The procedure of Ref. 4 was used to measure the local emission intensity. The measurements were carried out in a frequency band $\Delta f = 10^6$ Hz (with a carrier frequency of 4.7 GHz) by detecting the intrinsic emission of the ferrite samples at this

frequency (see Ref. 4 and the literature cited there). We studied single-crystal samples of yttrium iron ferrite garnet 1.2 mm in diameter exhibiting a ferromagnetic-resonance line with a width $\Delta H = 0.7$ Oe. The samples were placed at the center of the four-turn coil which was used to pump them. Because of the rather high pump frequency, the sample and the coil were placed directly in the waveguide section of a power meter. The pump field applied to the sample reduced the intensity of the intrinsic-emission line.

To explain this result, let us analyze all possible processes which could lead to the absorption of quanta of the external field by magnons during nonresonant parallel pumping. If we assume that the sample contains no magnetic inhomogeneities, then the most important processes which lead to nonequilibrium states[1] are the ternary magnon—magnon interactions of the type $\epsilon_1 + \epsilon_2 \pm \Omega \rightleftarrows \epsilon_3$, induced by the nonresonant parallel pumping. Since these processes do not conserve the magnon number, we can easily show, using the results of Ref. 1, that they lead to an increase in the distribution function. If the sample contains impurity magnetic inhomogeneities, we can easily calculate the impurity concentration required to explain the magnitude of the observed effect, for the given field amplitude, 1 Oe. This concentration would have to be on the order of 10%; this was clearly not the case for the sample used in these experiments.

We will now show that the scattering of magnons by dislocations, stimulated by the external field,[3] is responsible for the observed effect: the decrease in the magnon distribution function in the energy interval $\epsilon_k - \epsilon_0 \sim \gamma$.

The relative change in the local emission intensity for slightly nonequilibrium states corresponds directly to a relative change in the magnon distribution function $\delta f/f$, where δ is the equilibrium distribution function.

We see, however, that in the present experiments the wave-vector interval $\epsilon_k - \epsilon_0 \sim \gamma$, in which the change in the distribution function was studied, was such that the magnon wavelength was much longer than the average distance between dislocations (in any reasonable concentration). In order to study the scattering of magnons by deformations created by dislocations in this situation, we must bear in mind the increase in the general level of internal stress which results from the superposition of elastic fields. Using the kinetic equation of Ref. 3 and the procedure of Ref. 5 for calculating the amplitude for the scattering of a magnon by dislocation-produced deformations, we find the following expression for the relative change in the magnon distribution function:

$$\frac{\delta f}{f} = -7.4\times 10^{-3} \frac{\omega_M B^2 (\mu h)^2}{c_s L^{-1} \sqrt{\Omega}\, \epsilon_0^3\, \Omega} \left\{ 1 - J_0\left(\frac{\sqrt{\Omega}}{c_s L^{-1}} \right) \right\} (n_d b^2) \frac{\omega_M}{\mu (\Delta H)}, \qquad (1)$$

where $\omega_M = 4\pi\mu M_0$, M_0 is the magnetization, $B = \mu M_0^{-1} B_1$, B_1 is the magnetoelastic constant, $c_s^2 = \mu M_0 \alpha$, α is the constant of the inhomogeneous exchange interaction, $J_0(z)$ is the Bessel function, b is the average Burgers vector, n_d is the dislocation concentration, $\mu = g\mu_B$ and L is the size of the crystal.

The relative change in the distribution function observed experimentally,

$\delta f/f \sim 10\%$, can be explained by a dislocation density $n_d \sim 3 \times 10^8$ cm^{-2} according to Eq. (1) (for this estimate we assumed that $b = a$, where a is the lattice constant).

Using the results calculated in Ref. 5 for the width of the ferromagnetic resonance line, we can evaluate the dislocation density which corresponds to the sample used in the present experiments ($\Delta H = 0.7$ Oe). Equation (21b) for ΔH in Ref. 5 leads to $n_d \sim 1.5 \times 10^8$ cm^{-2}.

For a further confirmation of the dislocation mechanism, we annealed the sample. The effect faded significantly as a result.

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