PROOF OF STAGE-BY-STAGE EXCITATION OF PARAMETRIC SPIN WAVES

V.V. Zaushkin, V.S. L'vov, S.L. Musher, and S.S. Starobinets
Computation Center, Siberian Division of the Academy of Sciences
Submitted 28 July 1971
ZhETF Pis. Red. 14, No. 5, 310 - 313 (5 September 1971)

In a theoretical paper [1], Zakharov, L'vov, and Starobinets have shown that the development of parametric instability in a continuous medium occurs by stages. Namely, at a slight excess above threshold h_1 one pair of waves (or a group of equivalent pairs) is excited; with further increase of the pump amplitude, at $h = h_2, h_3, h_4, \ldots$ there occurs a successive production of a second, third, etc. pair (group of pairs).

We present here the results of an experiment confirming these general considerations, using as an example parallel pumping of spin waves in single-crystal yttrium iron garnet (YIG).

The YIG sample was placed in a TE_{112} cylindrical resonator with two degenerate orthogonal modes, the microwave magnetic field of which $h_\parallel$ and $h_\perp$ was respectively parallel and perpendicular to the constant magnetic field H_0. The necessary polarization of the modes and the decoupling between them was attained by rotating the feeding waveguides on the ends of the resonator about its cylindrical axis.

The parallel channel $h_\parallel$ was used for parametric excitation of pairs of spin waves with frequency $\omega_p/2 = 2\pi \times 4.70$ GHz. The perpendicular channel $h_\perp$ was used to register the radiation of the sample at the pump frequency ω_p. Up to the threshold of excitation of the spin waves, the decoupling between the channels was ~55 dB. We observed (Fig. 1) a sharp increase of the radiation power in the perpendicular channel at a rise above threshold $h_\parallel^2 \sim 8 - 12$ dB (the different numbers correspond to the change of the constant field, the orientation, and shape of the sample).

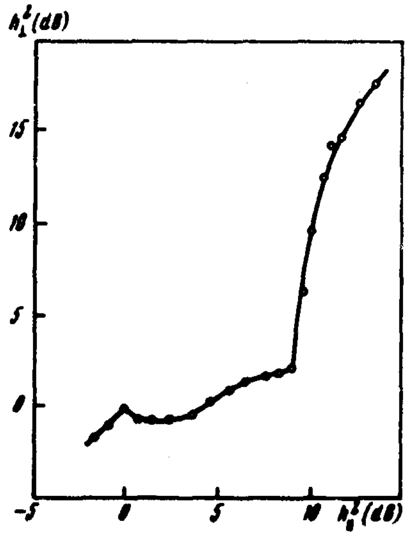

Fig. 1. Dependence of the radiation power in the perpendicular channel on the pump power for a YIG sphere: $H_0 = 1600$ Oe and is parallel to the [100] axis.

The radiation in the perpendicular channel is the result of the interaction of pairs of spin waves $a_{\pm k}$ with uniform magnetization precession a_0, described by the Hamiltonian

$$\mathcal{H} = \frac{1}{2}\sum_k \{ V_{0k}^* a_0^* a_k a_{-k} + \text{c.c.}\}.$$

The radiation power is

$$h_\perp^2 \sim |\sum V_{0k}^* a_k a_{-k}|^2, \tag{1}$$

where $V_{0k} = V_0 \sin 2\theta_k \exp(i\phi_k)$, and θ_k and ϕ_k are the polar and azimuthal angles of the vector $\vec{k}$ of the pair.

To observe the radiation (1) it is necessary to have, first, $\sin 2\theta_k \neq 0$, i.e., the pairs with $\theta_k = \pi/2$ must not radiate in the perpendicular channel. Second, it is necessary to have some asymmetry in the placement of the pairs relative to the azimuthal angle ϕ_k; it can be shown that in the axially-

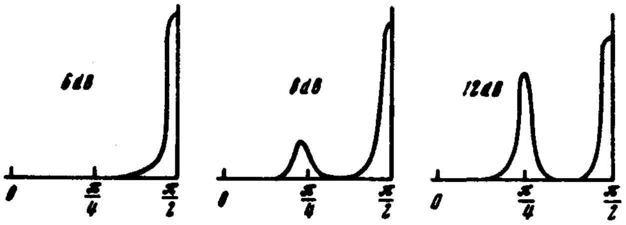

Fig. 2

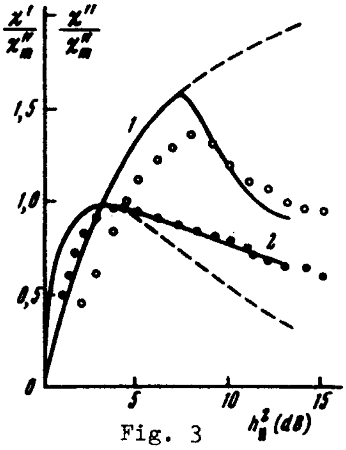

Fig. 3

Fig. 2. Distribution function of the pairs with respect to θ_k at different excesses above threshold. The widths of the packets are due to the "intrinsic" noise of the parametric spin waves [2].

Fig. 3. Dependences of the real (χ', curve 1) and imaginary (χ'', curve 2) parts of the longitudinal susceptibility on the pump power. Dashed - theoretical plots in the approximation of one group with $\theta_k = \pi/2$. Light circles - results of measurement of χ'; dots - χ''. The experimental conditions are the same as in Figs. 1 and 2.

symmetrical case the sum in (1) vanishes. The observed radiation $h_\perp^2$ is obviously connected with the crystallographic anisotropy and with other factors that violate the strict symmetry.

Of practical importance is also a complete absence of radiation up to excesses $h_\parallel^2 \simeq 9$ dB (Fig. 1). We assume that this fact is evidence that only pairs with $\theta_k = \pi/2$ are excited in the interval 0 - 9 dB, in spite of the fact that the pump amplitude $h_\parallel$ exceeds the threshold level for pairs in a wide region of θ_k.

To verify this interpretation of the experimental results, we simulated numberically (using the BESM-6 computer of our Center) the behavior of the pairs of spin waves under parallel pumping in YIG. The equations of motion were solved for interacting pairs (their number was 40) with the Hamiltonian

$$\mathcal{H}_{int} = \frac{1}{2} \sum_{kk'} S_{kk'} a_k^* a_{-k}^* a_{k'} a_{-k'} , \tag{2}$$

which was investigated in [1]. The coefficients $S_{kk'}$ were calculated beforehand for a concrete experimental situation with allowance for the dipole, Zeeman, and exchange interactions.

As shown in [1], the interaction (2) is equivalent to the action of an internal self-consistent pump exerted on each pair by the other pairs, which tend to weaken the action of the external pump. Namely, this circumstance prevents the spreading of the packet of pairs with $\theta_k = \pi/2$.

The results of the computer experiment are shown in Figs. 2 and 3. It is seen from Fig. 2 that up to a certain excess h_2 there is excited a narrow packet of pairs near $\theta_k = \pi/2$. At $h_2^2 \simeq 8$ dB there is excited a second group of pairs with $\theta_2 \simeq 45°$. We used here the model dependence of the spin-wave damping $\Delta H_k = \Delta H(1 + 2\sin^2\theta_k)$. The simplifying assumption $\Delta H_k = \text{const}$ results in a worse agreement between the physical ($h_2^2 \simeq 9$ dB) and the computer ($h_2^2 \simeq 6$ dB) experiments.

The physical and computer experiments have shown that the second threshold can be revealed also by some indirect attributes, for example, by the characteristic distortion of the top of the pump pulse and by the kink on the plot of the real susceptibility χ' against the pump power. It can therefore be assumed that the series of successive thresholds, first deduced by Petrakovskii and Berzhanskii from the distortion of the pump pulse [3], is connected with a stage-by-stage excitation of parametric spin waves.

Figure 3 illustrates the fact that the production of the second group of waves exerts a strong influence on χ', which goes through a maximum as a result, whereas in the model of one pair it increases monotonically. The imaginary part χ'' of the susceptibility hardly senses the second threshold.

The authors are grateful to V. Zakharov for a useful discussion.

[1] V.E. Zakharov, V.S. L'vov, and S.S. Starobinets, Zh. Eksp. Teor. Fiz. 59, 1200 (1970) [Sov. Phys.-JETP 32, 656 (1971)].
[2] V.E. Zakharov and V.S. L'vov, ibid. 60, 2066 (1971) [33, No. 6 (1971).
[3] G.A. Petrakovskii and V.N. Berzhanskii, ZhETF Pis. Red. 12, 429 (1970) [JETP Lett. 12, 298 (1970)].

EFFECT OF A 400-kOe MAGNETIC FIELD ON A LASER-SPARK PLASMA

S.D. Kaitmazov, A.A. Medvedev, and A.M. Prokhorov
P.N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 28 July 1971
ZhETF Pis. Red. 14, No. 5, 314 - 316 (5 September 1971)

We have previously observed [1] an increase in the intensity of the glow of a laser spark in a magnetic field H = 200 kOe. No change in the spark geometry was observed in that case.

The possibility of active action of a magnetic field on the geometry of a laser spark is connected, in our opinion, with the need for simultaneously satisfying two conditions: the magnetic pressure must be higher than the gas-kinetic pressure of the plasma, and consequently the relation between the field and the plasma temperature is determined by the condition $T < H^2/8\pi nk$; on the other hand, in order to prevent noticeable diffusion of plasma in the field, the skin layer must not exceed the spark radius (r). This leads to the relation $T > 6.3 \times 10^8 \tau^{2/3} r^{-4/3}$ (where τ is the time constant of the spark), since the skin layer is $d = c\sqrt{\tau/2\pi\lambda}$ and the electric conductivity of the plasma is $\lambda = 10^7 T^{3/2}/z$. Without the first condition the plasma spreads and forces out the magnetic field, and without the second it diffuses in the field. In other words, in order to exert a noticeable effect on the spark geometry, the magnetic field must be so strong that when the pressure plasma drops to the level of the magnetic pressure the plasma temperature remains high enough to prevent noticeable diffusion of the plasma in the field. This leads to the conclusion that there exists a threshold value of the magnetic field, starting with which the field influences actively the spreading of the spark. Under reasonable assumptions concerning the parameters of the spark obtained by us, an estimate leads to a threshold magnetic field on the order of 300 kOe.

Bearing this estimate in mind, we investigated laser breakdown in fields stronger than before (400 kOe). A special installation (which will be described in Trudy FIAN) was developed to produce such fields. The structural features of the installation were determined by the requirements of mechanical strength,