Oscillations of past-threshold susceptibility in parametric excitation of electron magnons in antiferromagnetic $CsMnF_3$

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Parametric excitation of the electron magnons in antiferromagnetic $CsMnF_3$ was investigated at a pump frequency 18 GHz in the temperature range 1.2–2.2 K in the case of strong supercriticality. Oscillations of the past-threshold susceptibility χ were observed. The dependences of the oscillation period τ on H and P/P_c were measured.

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Parametric excitation of electron magnons in antiferromagnets has been under intensive study in recent years. The most detailed investigations were made on the easy-plane antiferromagnets $CsMnF_3$ and $MnCO_3$, for which studies were made of the conditions of parametric excitation (the dependence of the threshold power P_c on the static magnetic field H, on the wave vector **k** of the excited magnons, and on the temperature T) and of the properties of the stationary state of the system of paramagnetic magnons [dependence of the real and imaginary parts (χ' and χ'') of the past-threshold susceptibility and of the time phase Φ of the excited pairs on the supercriticality P/P_c]. It turned out that the stationary state is preserved up to $P/P_c \approx 10$.

The present paper is devoted to an investigation of the behavior of an antiferromagnet beyond the threshold of the parametric excitation in the case of a strong supercriticality $P/P_c > 10$.

The experiments were performed on the hexagonal easy-plane ferromagnet $CsMnF_3$ in the temperature range 1.2—2.1 K at a pump frequency $\nu_p = 18$ GHz, using long pulses with $\tau_p \approx 2$ msec. Single-crystal samples with volume 10 mm^3 were placed in the cylindrical resonator of a magnetic direct-amplification spectrometer in the antinode of the magnetic field h of the H_{011} mode. The "parallel pumping" conditions $\mathbf{h} \parallel \mathbf{H} \perp C_6$ were satisfied in the experiment.

FIG. 1. Oscillogram of microwave pulse passing through the resonator: $\tau_p = 1.8$ msec, $T = 1.2$ K, $H = 2.1$ kOe, $P/P_c = 14$ dB.

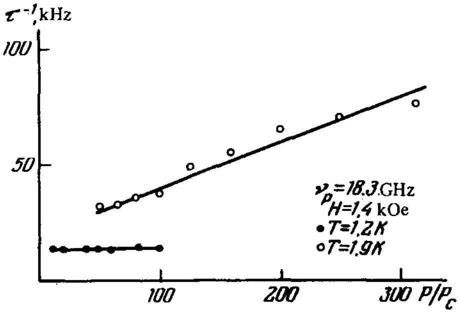

FIG. 2. Plot of $\tau^{-1}(P/P_c)$.

Investigations have shown that in the case of strong supercriticality $P/P_c > 10$, the oscillogram of the microwave pulse passing through the resonator with the sample reveals signal oscillations in the form of peaks of duration that varies with the temperature and with the magnetic field in the range 10—20 μsec (see Fig. 1). The oscillations appear at a certain value of the microwave power $\tilde{P}(H, T)$ with only the first pulse appearing at first, $\tilde{P} = P$, and then, with increasing P, the number of peaks increases rapidly and they cover the entire pulse regardless of its duration. It is important that at not too small a value of $P/\tilde{P}$ all the peaks (the number of which reached 30) turn out to be synchronized with the start of the pump pulse—they are regularly repeated, at equal time intervals. Thus, the oscillograms of the pulse with the peaks are quite stable.

The observed oscillations of the power absorbed by the sample correspond to a periodic time variation of the real and imaginary parts χ' and χ'' of the past-threshold susceptibility, having the characteristic shape of relaxation oscillations. Observations have shown that at the instant of time corresponding to the peak on the pulse, the values of $|\chi'|$ and χ'' increase above their stationary values.

It follows from the experiment that when the external conditions (T, H, P) are altered, the relative magnitude of the peaks remains practically constant, whereas the time interval τ between peaks changes in a wide range.

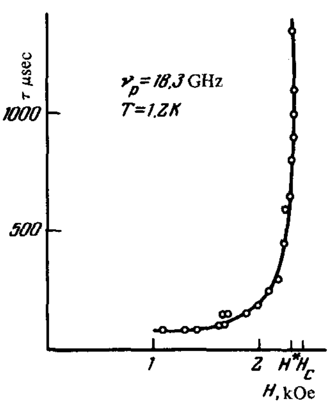

FIG. 3. Plot of $\tau^{-1}(H)$.

An investigation of the $\tau(P)$ dependence has revealed that in the lower part of the investigated temperature interval the value of τ remains constant within the limits of the experimental accuracy when P is increased all the way to $P/\tilde{P} \approx 10$, whereas at higher temperatures this dependence becomes appreciable. Figure 2 shows plots of $\tau^{-1}(P)$ at $T = 1.2$ and 1.9 K. We note that the ratio of the threshold powers of the parametric excitation of the magnons, corresponding to these temperatures, is $P_c(1.9\ \text{K}) : P_c(1.2\ \text{K}) = 2.2$.

Figure 3 shows the results of an investigation of the dependence of the interval τ on the static magnetic field H at a constant power P and at $T = 1.2$ K. It is seen that with increasing field H the interval τ increases monotonically and $\tau(H)$ has a vertical asymptote in a field H^*. The field H^* is smaller by approximately 0.1 kOe that the field H_c corresponding to excitation of magnons with $K = 0$. A similar plot of $\tau(H)$ is observed also at higher temperatures.

The results of our experiments seem to indicate that in the case of strong supercriticality a certain hitherto unknown type of oscillations is excited in $CsMnF_3$.

When magnons are parametrically excited in a ferromagnet by the method of parallel pumping, oscillations of the power absorbed by the sample are also observed—self-modulation.[1] A theoretical analysis of the past-threshold state in a ferromagnet, carried out in[2], has shown that this phenomenon can be attributed to excitation, in the system of parametric magnons, of collective oscillations that comprise changes, periodic in space and in time, of the number and phase of the pairwise coupled parametric magnons. The theory of[2] yielded an expression for the frequency Ω of the collective oscillations in terms of the magnon relaxation γ and the excess above the parametric-excitation threshold P_c. In the simplest case this expression takes the form

$$\Omega = 2\gamma\sqrt{\frac{2T + S}{S}(P/P_c - 1)}, \tag{1}$$

where T and S are the coefficients of the Hamiltonian that describes the interaction in the system of parametric magnons. The necessary conditions for the excitation of self-modulation is the relation

$$S(2T + S) < 0. \tag{2}$$

It was shown in[3] that the theory developed in[2] for the past-threshold state is applicable also to aniferromagnets under supercriticality conditions, but it follows from these studies that in our case the relation between the coefficients T and S does not satisfy the condition (2), and consequently there should be no self-modulation. It must be borne in mind, however, that in the case of strong supercriticality the values of T and S can change substantially.

Let us note the main difference between oscillations in $CsMnF_3$ and in yttrium iron garnet (YIG).

First, in $CsMnF_3$ the oscillations of the absorbed power have a regular character up to an excess above threshold $P/P_c \approx 20$ dB. Second, in YIG the oscillation frequency is $\tau^{-1} \approx 10^4$—10^7 Hz whereas in $CsMnF_3$ it is much lower, $\tau^{-1} \approx 0$—10^4. We note that in $CsMnF_3$ the period of the oscillations is longer than the magnon lifetime by more than two orders of magnitude. Third, when the temperature is lowered the value of τ in $CsMnF_3$ ceases to depend on the pump power P, although the reason may be that the lower the temperature the larger the role played by scattering from the crystal boundary in magnon relaxation.

It is likewise not excluded that the observed phenomon is connected with excitation of a second group of magnons in the case of supercriticality.[2] It is is assumed that periodic energy transfer takes place in this case from one group of magnons to the other, then the phase mechanism of limitation of the number of magnons can lead to oscillations of the absorbed power.

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