INFLUENCE OF PARALLEL PUMPING ON THE NUCLEAR ECHO IN YTTRIUM IRON GARNET

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We report here experimental observation of certain new effects due to the interaction of the nuclear magnetic moments with the parametric spin waves in yttrium iron garnet.

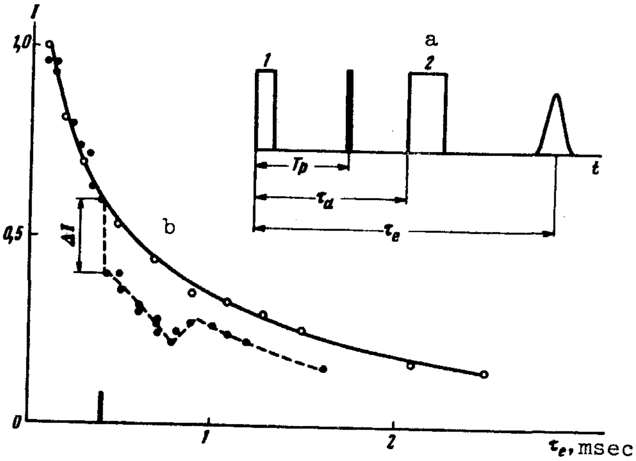

Fig. 1. a) Time diagram of successive turning-on of the radio-frequency pulses (No. 1 and 2), the microwave pulse T_p, and the appearance of the echo ($\tau_e = 2\tau_d$); b) dependence of the echo-signal intensity (in relative units) on the echo delay time for Fe^{57} nuclei in the d-sublattice of $Y_3Fe_5O_{12}$, T = 140°K, external field H = 800 Oe. Solid line - in the absence of microwave pumping, dashed line - microwave pulse applied at the instant T_p = 400 μsec and exceeds the threshold power by 7 dB.

The experiment consists of the following: The nuclear spin-echo from the Fe^{57} nuclei in $Y_3Fe_5O_{12}$ is observed. Besides the radio-frequency pulses at the NMR frequency, a powerful microwave pulse (frequency 9640 MHz, duration 1 μsec), exceeding the spin-wave instability threshold, is applied to the sample (Fig. 1a). The microwave field is applied parallel to the external magnetic field. The change (ΔI) of the intensity of the echo signal under the influence of the microwave pump was observed.

The appearance of the nuclear echo can be represented in the following manner [1]. The first radio pulse, which rotates the nuclear magnetization by 90° relative to the equilibrium direction (the z axis), is followed by a "spreading" of the total nuclear-magnetization vector into a fan of individual components, since the resonant frequencies are different for the different components, owing to the inhomogeneous broadening of the NMR line. Then, after the second (180°) pulse the fan closes up and the resultant nuclear magnetization reappears and rotates in a plane perpendicular to the z axis. In order for the echo to be produced it is necessary to satisfy rigorously the phase relations for the different components. Namely, the difference between the precession phase shifts of the individual components, which build up during the time interval τ_d, should be fully canceled out as a result of the motion of the nuclear moments after the second pulse. The echo signal appears only when the precession phase shifts of the individual components coincide. The transverse nuclear relaxation is due to the irreversible de-phasing of the nuclear components, and causes the decrease of the echo signal with increasing delay time τ_e.

Figure 1b shows the dependence of the echo signal intensity on τ_e without the microwave pulse and in the presence of a pulse applied at a time T_p = 400 μsec after the pulse 1. It is seen from the figure that when $\tau_e \geq T_p$ the intensity of the echo signal is lower than in the absence of pumping. The change of intensity (ΔI) appears in this diagram when the microwave pulse coincides

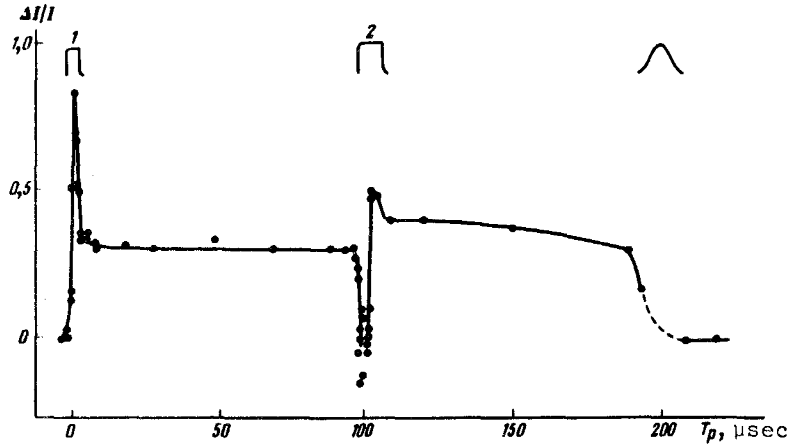

Fig. 2. Intensity of the effect $\Delta I/I = (I - I')/I$ for the ordinary echo vs. the position of the microwave pulse, I - intensity of signal without pump, I' - intensity of signal with pump.

with the echo pulse, and then ΔI exists at any position of the microwave pulse within the interval $T_p \leq \tau_e$. In addition, a certain anomaly is observed in the intensity of the echo when the microwave pulse coincides with radio-frequency pulse 2. As seen from Fig. 2, the effect takes place when the nuclear magnetization is deflected from its equilibrium direction. The effect decreases when the microwave pulse coincides with the center of the second radio-frequency pulse. We recall that at that instant the nuclear magnetization components contributing to the echo are directed along the z axis (parallel and antiparallel).

Such a behavior of the echo signal intensity can be explained by assuming that the microwave pumping decreases the time of the transverse nuclear relaxation T_2. The observed change of the echo signal intensity when the instability threshold is exceeded by 5 - 10 dB corresponds to a change of T_2 from an initial value $\sim 10^{-3}$ sec to a value $T_2 \sim 10^{-5} - 10^{-6}$ sec. It is possible to calculate the value of T_2 due to parametric spin waves, and it turns out that for the simplest ferromagnet we have

$$\frac{1}{T_2} = \frac{\omega_0^2}{S^2} \frac{n_k^2}{N^2} \frac{1}{\gamma \Delta H_K},$$

where ω_0 is the NMR frequency, S the electron spin, n_K the number of parametric spin waves with a specified wave vector K, γ the gyromagnetic ratio for electrons, ΔH_K the damping of the parametric spin wave, and N the number of magnetic ions.

Assuming $\omega_0 = 2\pi \times 63.7 \times 10^6$ sec^{-1}, S = 5/2, $n_K/N \simeq 10^{-2}$, and $\Delta H_K = 0.2$ Oe [2], we get $T_2 = 1.4 \times 10^{-6}$ sec, which agrees with experiment.

If the proposed mechanism is valid, then the microwave pulse should not influence on the so-called stimulated echo at certain values T_p [1]. Stimulated echo arises when three radio-frequency pulses are applied to the sample. In the simplest case all three are assumed to be 90° pulses. Then in the interval between the second and third pulses the nuclear magnetization has components directed along the z axis. During this period, the phase coherence of the individual components is conserved, since there is no transverse relaxation. Consequently, there should be no change in the echo intensity if the

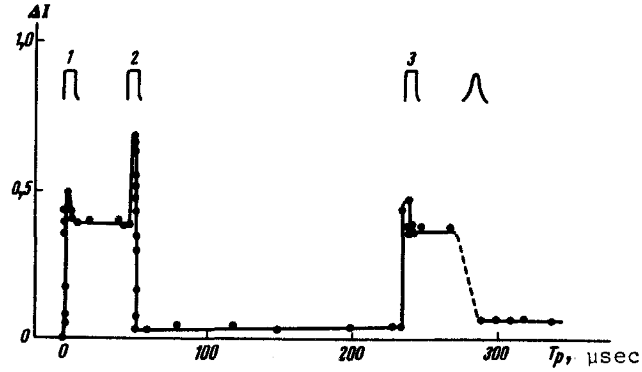

Fig. 3. Intensity of the effect ΔI/I for stimulated echo vs. the position of the microwave pulse.

microwave pulse is applied within this time interval. This conclusion turns out in full agreement with the experimental check (Fig. 3). It was established in the experiment that the intensity of the stimulated echo remains practically unchanged ($\Delta I/I \simeq 0$) when the microwave pulse is located between the second and third radio-frequency pulses. At the same time, the effect exists ($\Delta I/I \neq 0$) at other values of T_p.

Besides the described phenomena, we investigated also the dependence of the effect ΔI/I on the microwave-pulse power and on the magnitude of the wave vector of the parametric spin waves. It was established that ΔI/I increases with increasing power after the instability threshold is reached, and also increases with decreasing K.

The observed effects can be used to investigate the state beyond threshold in a magnetically-ordered crystal, to determine the damping parameters of spin waves, to study electron-nuclear interactions, to observe the dynamics of motion of nuclear magnetization, and also to suppress crossover echo signal in multipulse experiments.

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THERMAL SELF-FOCUSING AND BREAKDOWN INDUCED IN NaCl, KBr, AND CsI CRYSTALS BY CO_2-LASER RADIATION

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We report in this article an effect obtained for the first time, that of thermal self-focusing at 10 μ wavelength and breakdown of crystals transparent in the infrared, induced by radiation from a pulsed CO_2 laser. It was observed that when the crystals NaCl, KBr, and CsI are exposed to focused strong radiation from a pulsed CO_2 laser, two types of breakdown occur in the interior of the crystal (electric and thermal). In the case of electric breakdown, a focal region is traced out in the crystal, and its length is larger by one order of magnitude than the value given by geometric-optics calculations. When powerful thermal breakdown sets in, a rather rapid displacement of the breakdown point, in a direction opposite that of the radiation, is observed. The magnitude of the displacement is comparable with the visible focal length obtained in electric breakdown. When the power is increased, the trace in the focal region breaks up into several (up to four) thin glowing strips with a total thickness ~1 mm.

The thermal self-focusing and defocusing have been investigated in sufficient detail in gases and in liquids [1 - 3]. External thermal self-focusing in crystals at $dn/dT < 0$ was observed in [4].