for a useful discussion.

[1] G. I. Peterson, A. A. Ballman, P. V. Lenzo, P. M. Bridenbaugh, Appl. Phys. Lett. 5, 62 (1964).

[2] G. M. Boyd, R. C. Miller, K. Nassau, W. L. Bond, and A. Savage, ibid. 5, 234 (1964).

[3] R. C. Miller, G. M. Boyd, and A. Savage, ibid. 6, 77 (1965).

[4] K. Nassau and H. J. Levinstein, ibid. 7, 69, 1965.

NONLINEAR FERROMAGNETIC RESONANCE

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We consider a ferromagnetic sample acted upon by both an alternating and a constant magnetic field ($\vec{h}$ and $\vec{H}$, respectively). When the constant magnetic field has a value $H_1 = \omega/\gamma$ (ω - frequency of ac field, γ - gyromagnetic ratio), linear ferromagnetic resonance sets in. The ferromagnetic-resonance (FMR) phenomenon consists in excitation, by an incident photon, of a spin wave having the same energy as the photon. It is obvious that, in addition to this process, a spin wave can be excited with simultaneous absorption of n incident photons, and then the spin-wave energy is n times the photon energy. We shall call such a process nonlinear ferromagnetic resonance (NFMR) of order n. The value of the constant magnetic field, which determines the energy of the spin waves and which is necessary to observe resonance of order n, is obviously $H_n = n\omega/\gamma$.

The probability of production of one spin wave upon absorption of n photons differs from zero in n-th order perturbation theory.

Let us investigate second-order NFMR, i. e., n = 2. The interaction Hamiltonian can be written in the form

$$H = \vec{h}\cdot\vec{M}, \tag{1}$$

where $\vec{M}$ is the magnetization vector of the sample (the direction of the equilibrium magnetization $\vec{M}_0$ coincides with the z axis).

Using the standard procedure, going over from (1) to the second-quantization representation [1], and using second-order perturbation theory, we obtain the following expression for the probability of the production of one spin wave with simultaneous absorption of two photons:

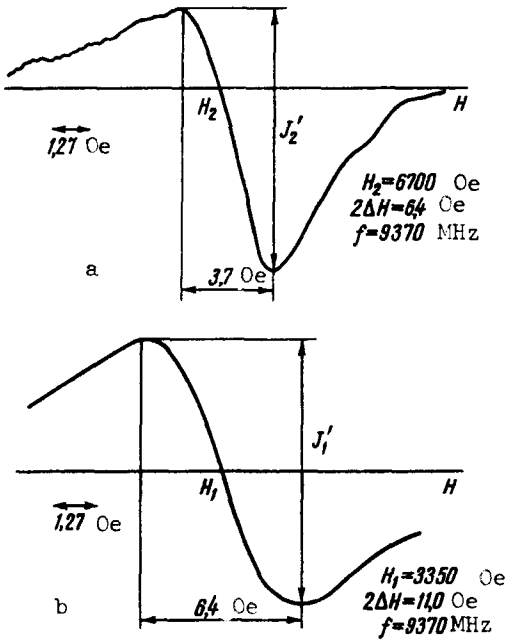
$$W = \frac{\pi\gamma^3 M_0}{4\omega^2} V f(\omega) h_x^2 h_z^2, \tag{2}$$

where V is the volume of the sample and $f(\omega)$ is the form factor of the line. The power absorbed in the nonlinear resonance is

$$P_{abs} = \chi''_{res} \frac{\gamma^2 h_x^2 h_z^2}{4\omega} V, \tag{3}$$

where χ''_{res} is the resonant susceptibility in linear FMR [2]. According to (2), the NFMR

absorption line shape should coincide with the linear FMR line shape.



a - derivative of NFMR absorption line, b - derivative of linear FMR absorption line. Intensity ratio $I_1'/I_2' = 10^6$.

The experimental observation of the NFMR was made with a standard radio spectroscope (RE 1301) at 9370 MHz. The use of a reflex resonator with Q = 500 and with a radiated power on the order of 15 W has made it possible to register, at the sensitivity limit of the spectrometer, the NFMR absorption line in a single-crystal sphere made of yttrium iron garnet. The sphere diameter was 3.3 mm. The derivative of the absorption line was recorded on the chart of the automatic plotter (Fig. 1a). The NFMR plotting was followed, under the same conditions (orientation and location of the ferrite sphere in the cavity), by a plotting of the derivative of the absorption line for the linear FMR (Fig. 1b). In this case, the high-frequency energy source was the klystron oscillator of the spectrometer, to prevent heating of the sample.

The NFMR and linear FMR absorption line widths are 6.4 and 11.0 Oe, respectively. The large experimentally obtained NFMR line width is due to distortion of the hf field in the cavity as a result of the strong microwave absorption in the ferrite.

We see therefore that NFMR can be used to study the FMR line shape of large-size samples. In addition, this phenomenon is of considerable interest from the point of view of the study of nonlinear interactions occurring in solids.

[1] A. I. Akhiezer, V. G. Bar'yakhtar, and M. I. Kaganov, UFN 71, 533 (1960), Soviet Phys. Uspekhi 3, 567 (1961).

[2] A. G. Gurevich, Ferrity na SVCh (Ferrites at Microwave Frequencies), Fizmatgiz, 1960.

LASER WITH FREQUENCY SCANNING DURING THE GENERATION PROCESS

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We have observed the effect of frequency variation and the emission kinetics of a laser with a dispersive resonator, in which the maximum Q was displaced along the frequency scale during the course of the generation, within the limits of the luminescence spectrum of the active medium. For resonators with dispersive prisms [1,2], a controlled frequency variation (scanning) can be accomplished by rotation or angular vibration of the end reflector (Fig. 1), and for resonators with selector-interferometers operating in the transmission mode [3] it can be accomplished by rotating the selector. In the latter case repeated scanning with variable