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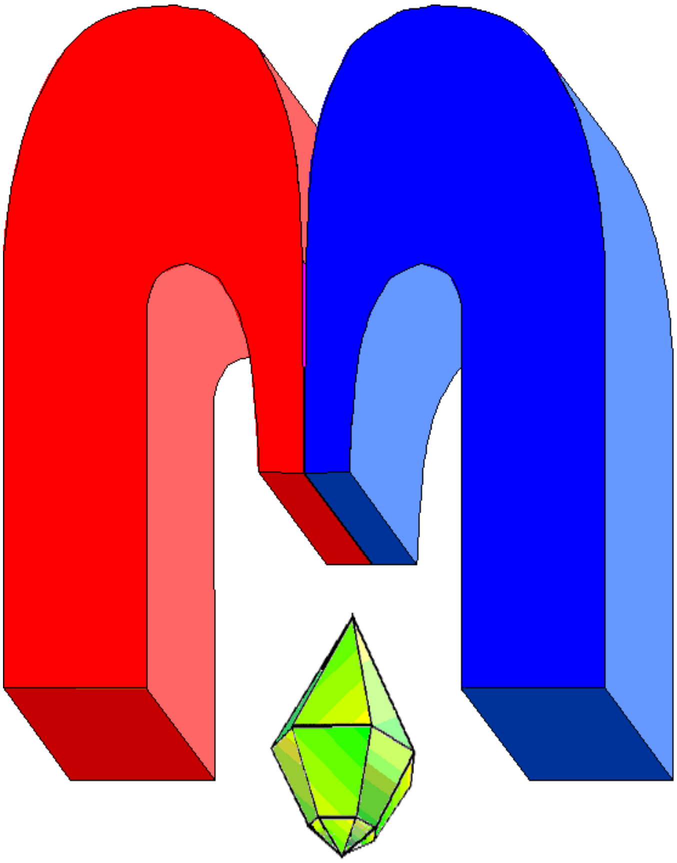

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[*] In Kazan University the Electron Paramagnetic Resonance (EPR) was discovered by Zavoisky E.K. in 1944.

Nonlinear FMR spectra in yttrium iron garnet[†]

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Results of demagnetizing effect studies in yttrium iron garnet $Y_3Fe_5O_{12}$ thin films are reported. Experiments were performed on X-Band of electron paramagnetic resonance spectrometer at room temperature. The ferromagnetic resonance (FMR) spectra were obtained for one-layer single crystal YIG films for different values of the applied microwave power. Nonlinear FMR spectra transformation by the microwave power increasing in various directions of magnetic field sweep was observed. It is explained by the influence of the demagnetization action of nonequilibrium magnons.

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Keywords: yttrium iron garnet, EPR, magnons

The FMR spectra investigations of yttrium iron garnet (YIG) $Y_3Fe_5O_{12}$ single crystal thin films are presented. Experiments were performed on X-band of electron paramagnetic resonance (EPR) spectrometer Varian E-12 ($f \approx 9.3$ GHz) at room temperature. The sample was prepared in Carat company (Lvov, Ukraine) by standard isothermal liquid phase epitaxial (LPE) method during the joint work with the RAS Institute of Kotelnikov Radio Engineering and Electronics [1]. The yttrium iron garnet is a well-studied crystal with a ferrimagnetic ordering ($T_c = 560$ K). The 2D gadolinium gallium garnet ($460 \div 490$ μm) was used as a substrate for the thin film ($6 \div 9$ μm) of yttrium iron garnet. The typical FMR spectrum in the perpendicular orientation of the external magnetic field H to the surface is shown in Fig. 1a. The experiments were performed at the microwave pump power P of 10 mW, modulation amplitude of 5 mOe. Fig. 1b shows the corresponding integrated spectrum. The integrated spectra are presented in Fig. 2a and 2b.

The characteristic "collapse" points in all spectra can be seen. These points correspond to such value of a magnetic field, where the sharp decrease of adsorption is observed. With the increasing of microwave pumping power P the position of "collapse" H_0 shifts to the lower fields. This shift depends linearly on the microwave pumping power (see Fig. 3a). Furthermore, the spectra strongly depend on the field sweep direction (Fig. 3b).

Fig. 3 shows integrated spectra for the various microwave power values in different directions of the magnetic field sweep.

The non-linearity of FMR spectra corresponds to the big value of magnetization deflection angle and decreased demagnetization factor. This effect is clearly seen in the Fig. 2, where the FMR lines at small excitations show the inhomogeneous broadening. With the increasing of

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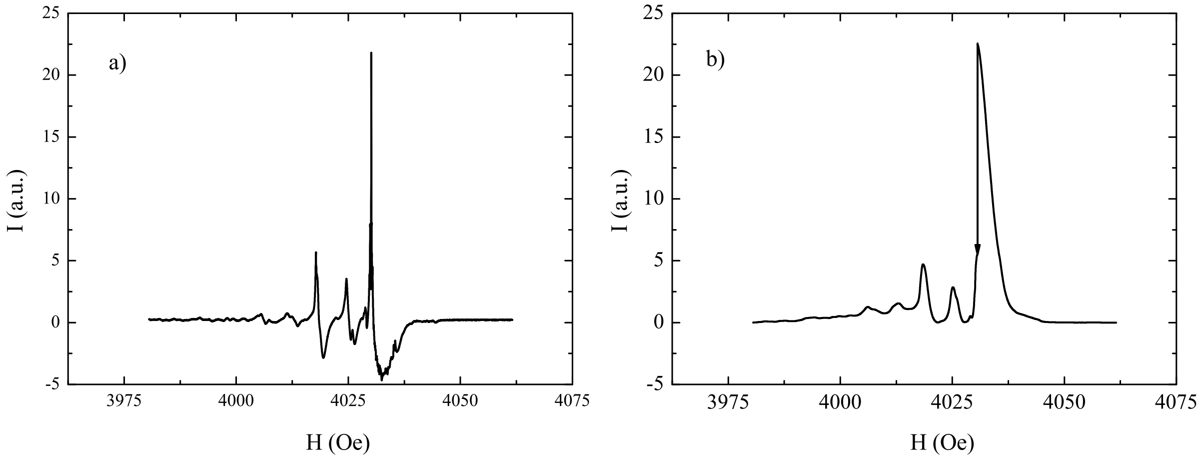

Figure 1. The differential FMR spectrum of YIG thin film in perpendicular orientation of magnetic field to the surface (a) and corresponding integrated spectrum (b).

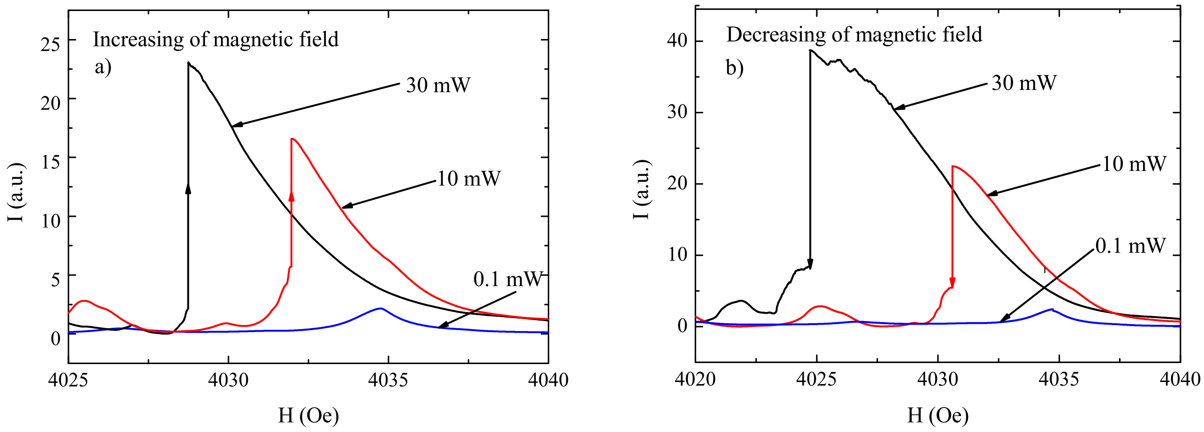

Figure 2. Integrated spectra for various microwave power P in increasing (a) and decreasing (b) of magnetic field.

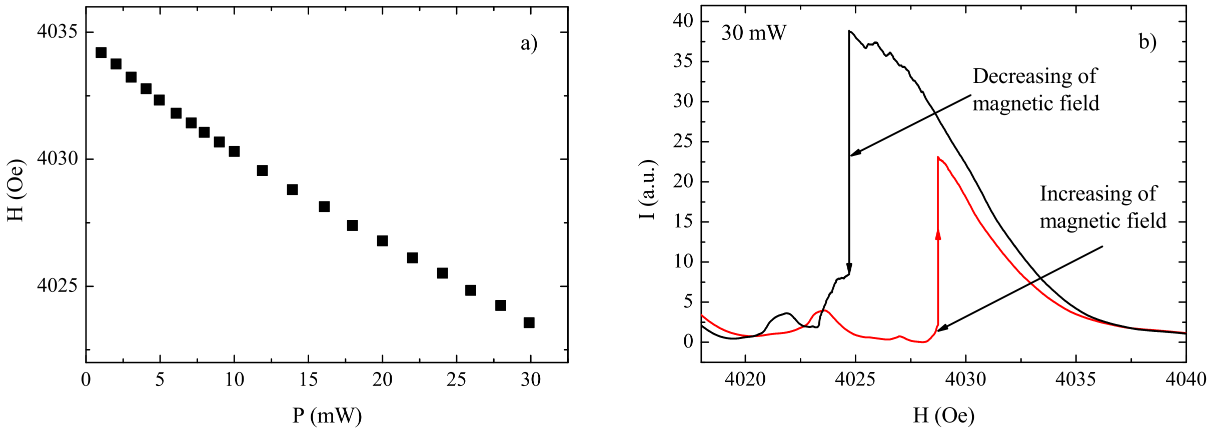

Figure 3. The dependence of the collapse position from the microwave pump power (a); FMR spectra for various direction of magnetic field sweep (b).

excitation the line asymmetry is observed. This asymmetry can be explained by a relatively large angle of magnetization deflection β, which decreases the demagnetization field $4\pi M_s \cos\beta$ and, consequently, increases the frequency of FMR at given field [2]:

$$\omega_{\text{res}} = \gamma(H_0 - 4\pi M_s \cos\beta). \tag{1}$$

The creation of magnon leads to a reducing the sample magnetization M_s to one Bohr magneton β_M. The number of stationary nonequilibrium magnons N_M is proportional to the absorption and microwave power. As a result the signal shifts to the lower field:

$$\Delta H_0 = 4\pi \Delta M_s \cos\beta, \tag{2}$$

where $\Delta M_s = N_M \beta_M$. The excited state has a relaxation rate. At some magnetic field H_0 value the signal disappears ("collapse" points). It can be explained as the microwave pumping power is not enough for supporting the necessary amount of nonequilibrium magnons N_M. In Fig. 2 and Fig. 3 the signal shift from the resonance is seen, which is described in good agreement with equations (1) and (2). The described FMR spectrum behavior was simulated. The results of simulation are shown in Fig. 4 and Fig. 5, $AP = \Delta H_0$, where P is a microwave power, A is a dimensional coefficient.

It is clearly seen an excellent match of simulated spectrum transformation with experimental behavior, but for the total understanding of all nonlinear effects and, consequently, for suggestion of theoretical model it is necessary to provide some additional investigations of magnons dynamics.

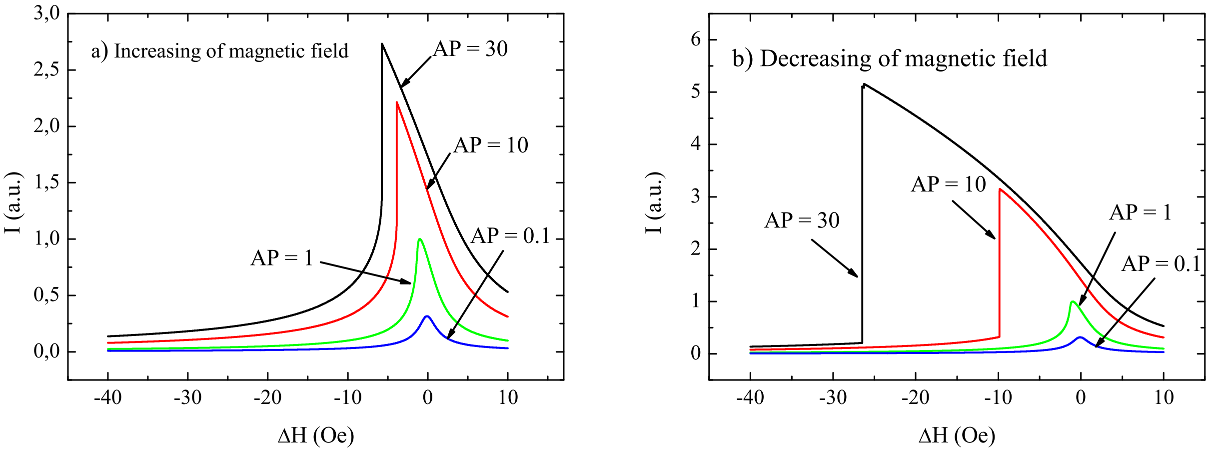

Figure 4. Simulated FMR spectra.

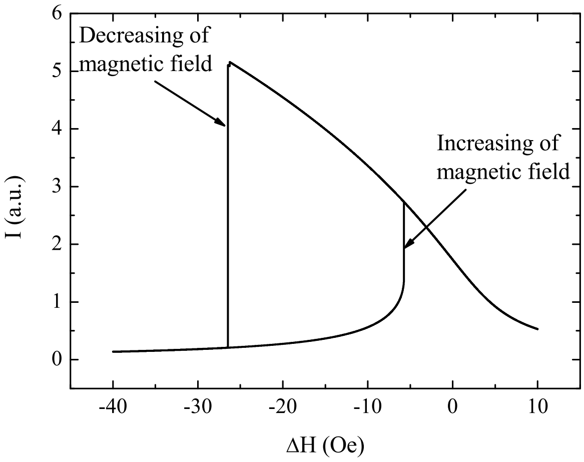

Figure 5. Simulated FMR spectra at the different magnetic field sweep directions ($AP = 30$).

Acknowledgments

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