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Nucleation during photoinduced spin-reorientation transition

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Conditions of new magnetic phase nucleation during photoinduced spin-reorientation transition in homogeneously magnetized volume of doped yttrium-iron garnet are considered. The threshold densities of photoinduced uniaxial magnetic anisotropy and the corresponding critical linear dimensions of the nucleus are established depending on the material properties, magnetic anisotropy of initial state and irradiation conditions of the magnetically ordered medium. The limiting values of the mentioned threshold densities and minimum impurity concentrations defining the existence area of the photoinduced spin-reorientation transition in homogeneously magnetized volume of ferrite-garnets are determined.

Рассмотрены условия образования зародыша новой магнитной фазы в процессе фотоиндуцированного спин-переориентационного перехода в однородно намагниченном объеме легированного иттрий железистого граната. Установлены значения пороговых плотностей энергии фотоиндуцированной одноосной магнитной анизотропии и соответствующие им критические линейные размеры зародыша в зависимости от свойств материала, магнитной анизотропии исходного состояния и условий облучения магнитоупорядоченной среды. Получены предельные значения упомянутых пороговых плотностей и минимальных концентраций примеси, ограничивающие область существования фотоиндуцированного спин-переориентационного перехода в однородно намагниченном объеме феррит гранатов.

Photoinduced spin-reorientation phase transition (PISRT) in single crystals of ferrite-garnets (FG) is due to the appearance of uniaxial photoinduced magnetic anisotropy (PMA) and represents the reorientation of magnetization vector **M** between easy magnetization axes (EMA) of FG [1]. The domain structure (DS) rearrangement during the PISRT occurs via nucleation and growth of a new magnetic phase nucleus [2, 3] in a region with initial metastable magnetization state (MMR), which appears in an irradiated FG volume [4]. The MMR formation results in an increased magnetic anisotropy (MA) energy of a magnetically ordered medium, since in its volume, directions of **M** and easiest magnetization axis coincide with different EMA of FG [4, 5]. The MA energy is minimized at formation of the nucleus [2, 3, 5], that is a subarea with collinear orientation of the **M** and easiest magnetization axis. The aim of this paper is to determine threshold values of the PMA energy density and critical (at the nucleation) linear dimensions of the nucleus depending on the material properties, MA initial state, and irradiation conditions of an homogeneously magnetized volume of the magnetically ordered medium.

The nucleation has threshold nature [2, 3, 5, 6]. In the domain theory approximation [7], the nucleation condition in the MMR volume can be written as [2, 3, 5]:

$$\Delta E_A = \iiint\limits_{V_0} e_A dV - \iiint\limits_{V_0} e_A^0 dV = E_n, \qquad (1)$$

where ΔE_A is reduction of the MA energy due to the nucleus appearance; $e_A = e_K + e_P$; $e_A^0 = e_K^0 + e_P^0$; e_A, e_K, e_P and e_A^0, e_K^0, e_P^0 are energy densities of MA, crystallographic magnetic anisotropy (CMA), PMA before and after nucleation, respectively; V_0, the MMR volume; E_n, the nucleus energy.

The nucleus shape obtained during PISRT experimental research in a homogeneously magnetized local volume of the FG [2, 3] is shown in Fig. 1a. For this nucleus, E_n can be presented as the sum of nucleus domain wall (DW) energy E_ω, demagnetization energy E_g, appearing at violation of div$\mathbf{M} = 0$ condition for the nucleus DW, and magnetoelastic energy E_R, occurs due to magnetostriction. Both from the viewpoint of the surface and that of the mean demagnetization factor, the nucleus volume can be approximated by an ellipsoid of revolution (Fig. 1a) [8]. Then the components of E_n can be written as [9]:

$$E_\omega = \pi^2 R_{kp}^2 \sigma_\omega/\xi; \tag{1}$$

$$E_r = 2\pi R_{kp}^3 (c_{11} + c_{12})(\lambda_{100}/4 + 3\lambda_{111}/2)^2/3\xi;$$

$$E_g = 8\pi^2 \xi\zeta\{\ln(2/\xi) - 1\}\mathrm{M}^2 R_{kp}^3/3,$$

where σ_ω is the surface energy density of the nucleus DW; R_{kp}, critical nucleus radius (minimum value at the nucleation) equal to the ellipsoid half-minor axis (Fig. 1a); ζ, a numerical factor depending on the material permeability [10]; c_{11} and c_{12}, elastic moduli; λ_{100} and λ_{111}, magnetostriction constants; ξ, the ellipsoid a small-to-large axis ratio; M, the saturation magnetization of the medium material.

The energy density e_K is set by the expression $e_K = K_1(\alpha_1\alpha_2 + \alpha_1\alpha_3 + \alpha_2\alpha_3) + K_2\alpha_1^2\alpha_2^2\alpha_3^2$, where K_1 and K_2 are first and second CMA constants; α_1, α_2, α_3, directional cosines of **M** with reaspect to <100>, <010>, <001> crystallographic directions, respectively [7]. As the polarization vector **E** of optical radiation is orientated along one of <111> directions in the (110) plane of the FG, the density e_P at an arbitrary irradiation moment t can be presented as [4]: $e_P = -G_P(I_V,t)\ \Theta_P(I_V,t)$, where $G_P(I_V,t)$ is the PMA constant; $\Theta_P(I_V,t)$, a function characterizing angular dependence of the PMA energy; $I_V = I_0 I_S(x', z')\exp(-\alpha y')$ and $I_S(x', z')$, functions describing the optical radiation intensity distribution in the medium volume and on its surface, respectively; I_0, maximum optical radiation intensity in the cross-section of light spot at the medium surface; α, optical absorption of the medium material; x', y', z', space coordinates (Oy' axis is collinear to the optical radiation wave vector **k**). The MMR formation results from a spatially inhomogeneous distribution of I_V, caused by non-zero α value and inhomogeneous $I_S(x', z')$ distribution. As the PMA symmetry axis is oriented along a crystallographic direction of <111> type, then the density e_P can be written as [4, 11] $e_P = -G(x', y', z')\cos^2\theta/3$, where $G(x', \mathbf{y}', z')$ is the PMA constant; θ, the polar angle of **M** (θ is counted from <$\bar{1}$11> direction collinear with **M** orientation in the nucleus volume after nucleation). Then $\Delta E_A = -\overline{G}_P(\cos^2\theta_1 - \cos^2\theta_2)V_{n,kp}$, where θ_1 and θ_2 are angles defining the **M** orientation in the nucleus volume prior to and after nucleation; $\overline{G}_P$, the average value of $G_P(I_V,t)$ in V_0; $V_{n,kp}$, the critical (at the nucleation) nucleus volume.

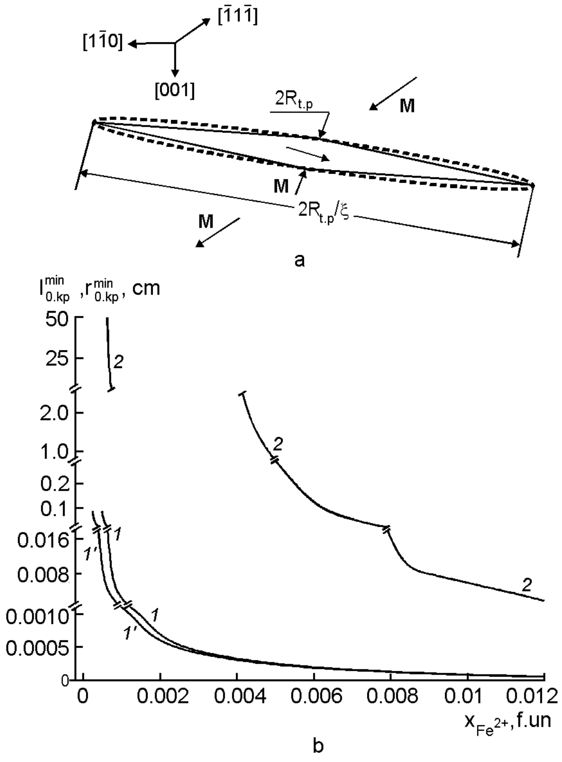

Fig. 1. New magnetic phase nucleus shape a (a) and concentration dependences (b) of minimum $l_{0,kp}^{\min}$ values (curves 1 and 1′) and $r_{0,kp}^{\min}$ (curve 2) of the MMR dimensions in a homogeneously magnetized volume of YIG:Fe^{2+} at $T = 77$ K. The $r_{0,kp}$ values (cm): 0.05 (1); 50 (1′); $r_{0,kp}^{\min} = L'_0/2\xi$ (2).

The nucleus is formed in volume V_0 [5] having maximum linear dimensions $2r_0$ and l_0 in the medium plane and in its depth, respectively [4]. These sizes limit the corresponding maximum linear dimensions $2R_{kp}/\xi$ and $2R_{kp}$ of the nucleus (Fig. 1a). Thus, the ξ parameter and the nucleus critical radius should simultaneously met the conditions:

$$R_{kp} \le l_0/2, \quad R_{kp} \le \xi r_0. \tag{2}$$

As the irradiation duration increases, the sizes r_0 and l_0, the MMR volume, as well as the $\overline{G}_P$ value increase sequentially to coincidence with the corresponding parameters of irradiated volume as well as with the maximum value G_{max} of the PMA constant [4], respectively. That value $G_{max} = -8\bar{\lambda}NB/3(9A_0 + 7B)$, where N is the total amount of transition metal (TM) ions with orbitally degenerated ground state in FG [12, 13]; $\bar{\lambda}$, the spin-orbit splitting constant; $A_0 = [1 + [\nu_1/A \exp(-E_{a1}/kT) + \nu_2/A \exp(-E_{a2}/kT)]$; E_{a1} and E_{a2}, low- and high-temperature activation energy, respectively; ν_1 and ν_2, corresponding frequency factors; k, the Boltzmann constant; T, temperature; A and B, phenomenological constants [14]. Thus, all the listed MMR parameters (r_0, l_0, V_0 and $\overline{G}_P$) are interdependent for an arbitrary irradiation moment t. The nucleus is formed only in a critical (minimum) MMR volume $V_{0,\mathrm{kp}}$ where $\overline{G}_P \ge G_{thr}$ and $r_0 = r_{0,kp}$ at $r_{0,kp} \le l_{0,kp}/2\xi$ and/or $l_0 = l_{0,kp}$ at $l_{0,kp} \le 2\xi r_{0,kp}$ (where G_{thr} is the threshold value of the PMA energy density for which the condition (1) is satisfied). Taking into account (1) and (2), the density G_{thr} depends on the correlation between $2\xi r_{0,kp}$ and $l_{0,kp}$ and is defined by minimum of those:

$$\overline{G}_{thr} = \begin{cases} \dfrac{\dfrac{3\pi\sigma_\omega}{2l_{0,kp}} + 2\pi\xi^2\zeta[\ln(2/\xi) - 1]M^2 + e_R}{\cos^2\theta_1 - \cos^2\theta_2} \ \text{at } l_{0,kp} \le 2\xi r_{0,kp} & (3a) \\ \overline{G}_{thr} = \dfrac{\dfrac{3\pi\sigma_\omega}{4\xi r_{0,kp}} + 2\pi\xi^2\zeta[\ln(\frac{2}{\xi}) - 1]M^2 + e_R}{\cos^2\theta_1 - \cos^2\theta_2} \ \text{at } r_{0,kp} \le l_{0,kp}/2\xi & (3c) \end{cases}$$

where e_R is the magnetoelastic energy density [9]. The ξ parameter and critical nucleus radius are defined by equations:

$$\xi^3\{2\ln(2/\xi) - 3\} = 3\sigma_\omega/8r_0M^2\zeta, \tag{4a}$$

$$R_{kp} = r_{0,kp}/\xi \quad \text{at } r_{0,kp} < l_{0,kp}/2\xi \tag{4b}$$

$$R_{kp} = l_{0,kp}/2 \quad \text{at } l_{0,kp} < 2\xi r_{0,kp}. \tag{4c}$$

At photoinduced nucleation in FG with CMA in initial state, the initial and new magnetic phases are energetically identical outside of the volume V_0. In this case, as well as under condition that $r_{0,kp} \ge D_0'/2$ and/or $l_{0,kp} \ge L_0'$, the linear dimensions of $V_{0,kp}$ are determined by the corresponding medium linear dimensions: $r_{0,kp} = D_0'/2$, $l_{0,kp} = L_0'$, where L_0' and D_0' are the medium thickness and its minimum size in its plane.

Since the values $r_{0,kp}$ and $l_{0,kp}$ depend on the initial MA state and conditions of the medium irradiation, then the threshold energy density G_{thr} and critical nucleus radius R_{kp} can change within some ranges of values, $G_{thr}^{\min} \le G_{thr} \le G_{thr}^{\max}$ and $R_{kp}^{\min} \le R_{kp} \le R_{kp}^{\max}$, respectively. Thus, the value G_{thr} and the linear nucleus dimensions R_{kp} and $2R_{kp}/\xi$ (Fig. 1a) decrease and increase as $r_{0,kp}$ or $l_{0,kp}$ rise, respectively, i.e. the nucleus of a minimum volume is formed at a maximum value of the threshold PMA energy density. In a medium with initial CMA, the nucleus with $R_{kp}^{\max}$ is formed as $G_{thr}^{\min}$ is attained during irradiation of spatially unrestricted (L_0', $D_0' \to \infty$) medium:

$$R_{kp}^{\max} = \hat{R}_{kp}^{\max} \to \infty; \quad \xi_{\min} = \hat{\xi}_{\min}', \tag{5a}$$

$$G_{thr}^{\min} = \hat{G}_{thr}^{\min} = \tag{5b}$$

$$= \frac{2\pi\zeta\xi'^2_{\min}[\ln(2/\xi'_{\min}) - 1]M^2 + e_R}{\cos^2\theta_1 - \cos^2\theta_2}.$$

For $\hat{\xi}'_{\min} < \sqrt{e_R/\pi\zeta M^2}$, the $\hat{\xi}'_{\min}$ value is defined by the equation:

$$\hat{\xi}'^2_{\min}[\ln(2/\hat{\xi}'_{\min}) - 2] = e_R/2\pi\zeta M^2. \tag{6}$$

In medium with a combined (CMA and FMA) magnetic anisotropy (CPMA) in the initial state, the nucleus with $R_{kp}^{\max}$ appears as $G_{thr}^{\min}$ is attained during irradiation of the medium spatially unrestricted in its plane ($L_0' > 1/\alpha$, $D'_0 \to \infty$):

$$R_{kp}^{\max} = \tilde{R}_{kp}^{\max} = 1/2\alpha; \ \xi_{\min} = 0, \tag{7a}$$

$$G_{thr}^{\min} = \tilde{G}_{thr}^{\min} = \frac{3\pi\sigma_\omega\alpha/2 + e_R}{\cos^2\theta_1 - \cos^2\theta_2}. \tag{7b}$$

The nucleus with $R_{kp}^{\min}$ appears at $G_{thr}^{\max} = \hat{G}_{thr}^{\max} = \tilde{G}_{thr}^{\max} = G_{\max}$ in the critical volume of the MMR with the minimum sizes $r_{0,kp} = r_{0,kp}^{\min}$ or/and $l_{0,kp} = l_{0,kp}^{\min}$:

$$l_{0,kp}^{\min} = \tag{8a}$$

$$= \frac{3\pi\sigma_{\omega}}{2\left\{G_{\max}(\cos^2\theta_1 - \cos^2\theta_2) - 2\pi\xi_{\max}^2\zeta[\ln\frac{(2}{\xi_{\max}}) - 1]M^2 - e_R\right\}},$$

$$r_{0,kp}^{\max} = \tag{8b}$$

$$= \frac{3\pi\sigma_{\omega}}{4\left\{\xi_{\max}G_{\max}(\cos^2\theta_1 - \cos^2\theta_2) - 2\pi\xi_{\max}^2\zeta[\ln\frac{(2}{\xi_{\max}}) - 1]M^2 - e_R\right\}},$$

where $\hat{G}_{thr}^{\max}$ or $\tilde{G}_{thr}^{\max}$ is maximum G_{thr} value in media with CMA or CPMA, respectively. The nucleus linear dimensions are defined by equations:

$$R_{kp}^{\min} = \hat{R}_{kp}^{\min} = \tilde{R}_{kp}^{\min} = l_{0,kp}^{\min}/2, \tag{9}$$
$$\xi_{\max} = \hat{\xi}_{\max} = \tilde{\xi}_{\max},$$

where $\hat{R}_{kp}^{\min}$ or $\tilde{R}_{kp}^{\min}$ is the minimum value of $R_{kp}^{\min}$ accordingly in mediums with CMA or CPMA.

The ξ_{max} value is defined by the equation:

$$(\xi_{\max})^3\left\{2\ln(2/\xi_{\max}) - 3\right\} = 3\sigma_{\omega}/8r_{0,kp}^{\min}M^2\zeta. \tag{10}$$

The values $l_{0,kp}^{\min}$ and $2r_{0,kp}^{\min}$ define the minimum values of medium thickness $L_0^{\min}$ and the linear size of an irradiated medium volume in its plane, respectively, at which PISRT is still possible. A general trend to reduction of the above-mentioned parameters in a yttrium-iron garnet (YIG) is observed as the TM ion concentration x_{Me} rises (Fig. 1b).

The DS photoinduced rearrangement is observed in YIG doped with Fe^{2+} ions [1–3, 6, 15] and Co^{2+} ones [16] at 77 K and 295 K, respectively. At T = 295 K, such rearrangement was observed only in an irradiated FG volume containing DW of the initial DS [16, 17]. The DS rearrangement in YIG:Co^{2+} was explained by the high contribution of Co^{2+} ions into MA energy and by slow PMA relaxation [18, 19]. From this viewpoint, YIG:Ru^{2+} could be found to be a photomagnetic of good prospects: the Ru^{2+} ions give maximum contribution into CMA energy of YIG among TM ions of iron and palladium groups [13]. The concentration dependences of the threshold PMA energy density in YIG:Me (Me≡Fe^{2+}, Co^{2+}, Ru^{3+}) and critical nucleus parameters in YIG:Fe^{2+} for various initial MA states and FG irradiation conditions are shown in Figs. 2 through 4 and 5, respectively. The $\hat{G}_{thr}^{\min}$ or $\tilde{G}_{thr}^{\min}$ and G_{max} values limit a region of the threshold PMA energy density, wherein the PISRT is possible in a homogeneously magnetized volume of YIG:Me with initial CMA or CPMA, respectively. The PISRT is also possible only in a limited range of TM ion concentrations $x_{\text{Me}}^{\min} \le x_{\text{Me}} \le x_{\text{Me}}^{\max}$ where $\overline{G}_P \ge G_{thr}$. The points $\overline{1}$–$\overline{10}$ in Fig. 2–4 correspond to minimum concentrations $x_{\text{Me}}^{\min}$ for various MA initial states and FG irradiation conditions:

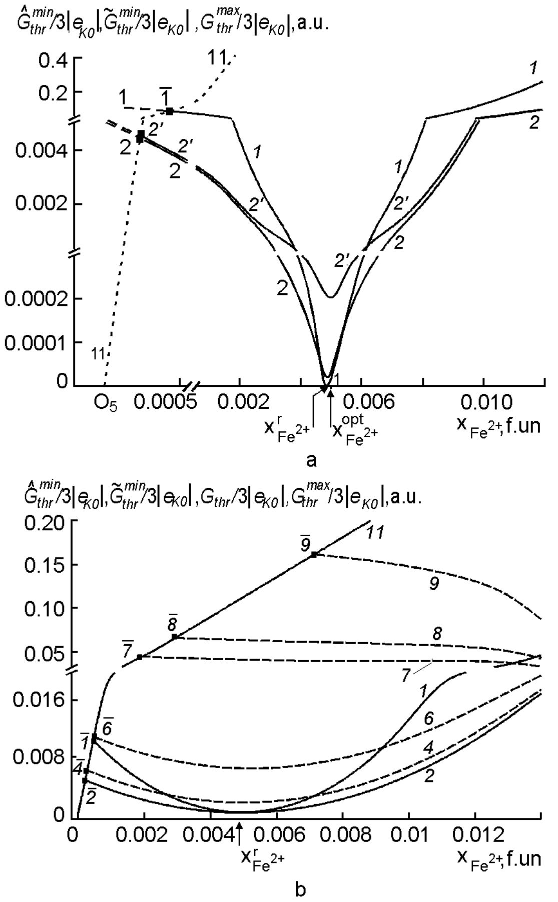

Fig. 2. Concentration dependences of threshold densities $\hat{G}_{thr}^{\min}$ (curve 1), $\tilde{G}_{thr}^{\min}$ (curves 2 and 2′), G_{thr} (curves 4–9) and $G_{thr}^{\max}$ (curve 11) of the PMA constant in YIG:Fe^{2+} at T = 77K. The dependences 2 and 2′ are obtained for optical radiation wavelength λ = 1.15 and 1.06 μm, respectively. The relations 4 through 9 are obtained at $r_{0,kp}^{\min} < L'_0/2\xi$ for $r_{0,kp}$, mm: 20 (4); 2 (6); 0.1 (7); 0.05 (8); 0.01 (9).

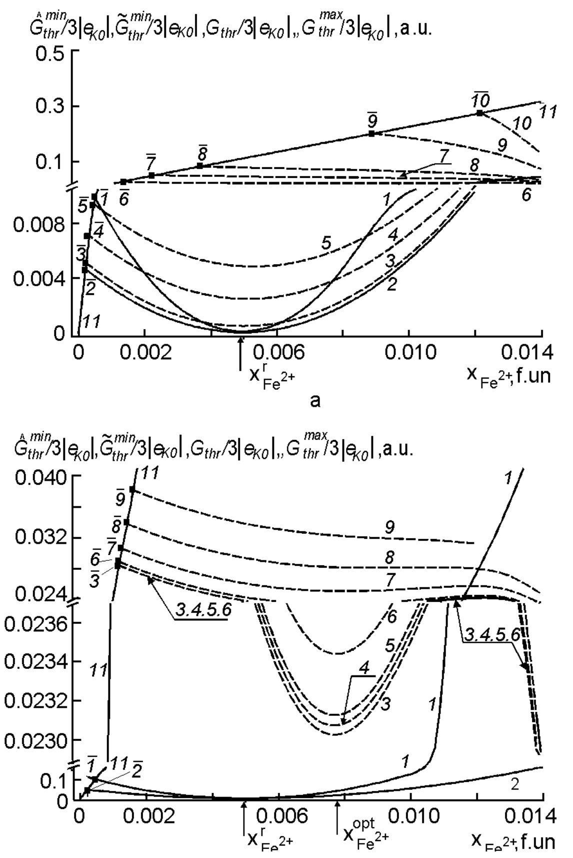

Fig. 3. Concentration dependences of the threshold densities $\hat{G}_{thr}^{min}$ (curve 1), $\tilde{G}_{thr}^{min}$ (curve 2′), G_{thr} (curves 3 through 10) and G_{thr}^{max} (curve 11) of the PMA constant in YIG:Fe^{2+} at $T = 77$ K for $L'_0 < 2\xi r_{0,kp}$. The dependences 3 through 10 (Fig.a) are obtained at $L'_0 < \alpha^{-1}$ and $r_{0,kp} = 50$ cm for L'_0, mm: 0.6 (3); 0.1 (4); 0.05 (5); 0.01 (6); 0.005 (7); 0.003 (8); 0.001 (9); 0.0005 (10). The dependences 3 through 9 (Fig.b) are obtained at $L'_0 = \alpha^{-1}$ ($\lambda = 1.15$ μm) for $r_{0,kp}$, cm: 50 (3); 20 (4); 10 (5); 2 (6); 0.2 (7); 0.05 (8); 0.01 (9).

$$x_{Me}^{min} = \qquad (11)$$
$$= 8.886 \cdot 10^{-23} G_{thr} \{9[1 + (\nu_1/A)\exp(-E_{a1}/kT) + (\nu_2/A)\exp(-E_{a2}/kT)] + 7B\}/\bar{\lambda}B^2.$$

These TM ion concentrations in YIG is a sufficient condition for PISRT in the RMM volume with threshold density G_{thr}. Irrespective of MA in the FG initial state, any limitations of the MMR volume result in increased G_{thr} and, as a consequence, x_{Me}^{min} values (curves 3–10 in Figs. 2 and 3). Increase of the latter results in reduced concentration region of PISRT existence from

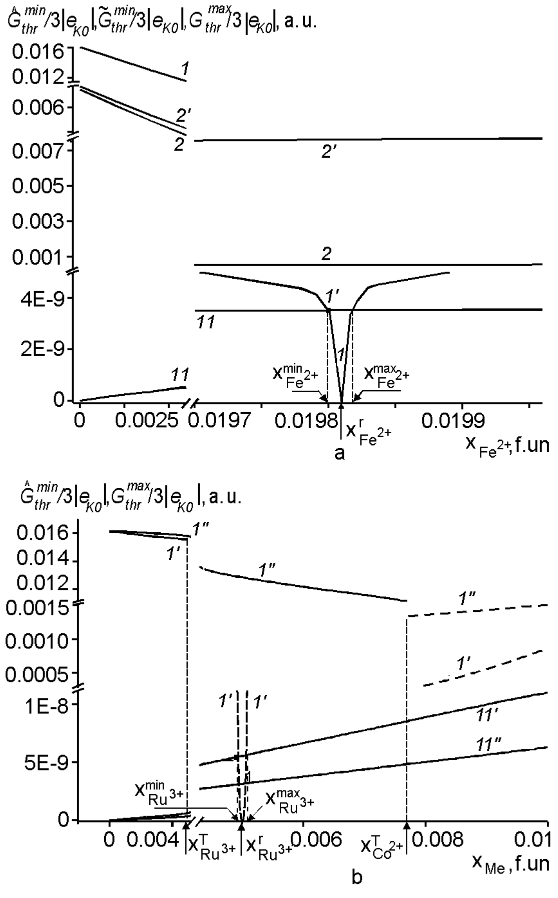

Fig. 4. Concentration dependences of the threshold density (curves 1, 1′ and 1″), G_{thr}^{min} (curve 2′ and 2″) and $\tilde{G}_{thr}^{min}$ (curves 11, 11′ and 11″) of the PMA constant in YIG:Fe^{2+} (Fig.a), YIG:Co^{2+} (curves 1′ and 11′) and YIG:Fe^{2+} (curves 1″ and 11″) (Fig.b) at $T = 295$ K. The dependencis 2 and 2′ are obtained for $\lambda = 1.15$ and 1.06 μm, respectively.

maximum value in spatially unrestricted MMR volumes down to a single concentration in the case of MMR volume with $r_{0,kp}^{min}$ or/and $l_{0,kp}^{min}$.

The qualitative nature of concentration dependences of G_{thr} depends on the limitation extent of the RMM volume (Figs. 2–4). This is due to the different relative contribution from energy E_n components. At considerable MMR volumes ($l_{0,kp} \geq \bar{l}_{0,kp}$ and/or $r_{0,kp} \geq \bar{r}_{0,kp}$), it is just the energy E_R that predominates among the E_n components. For a fixed MMR volume, its concentration dependence causes non-monotonous nature of the corresponding dependence of G_{thr} with minimum value at $x_{Me} = x_{Me}^{opt}$ (Figs. 2–4).

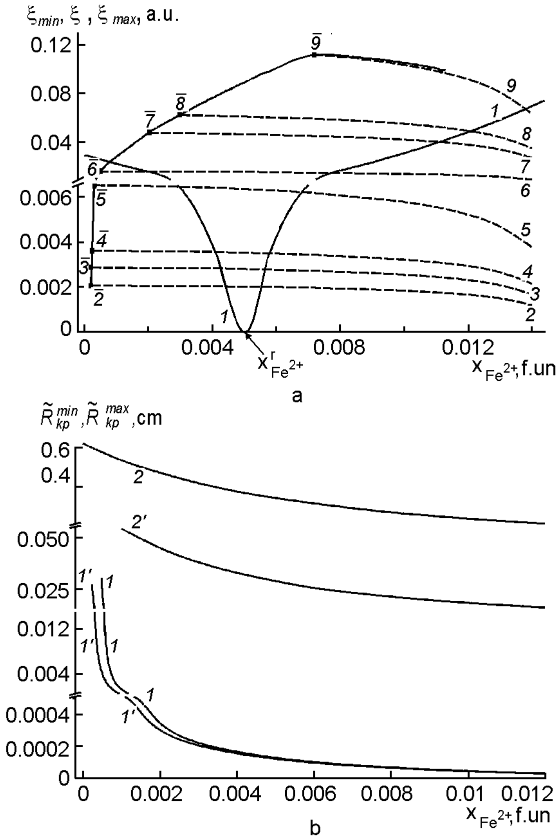

Fig. 5. Concentration dependences of ξ_{min} (curve 1), ξ (curves 2 through 9) and ξ_{max} (curve 10) of the ξ-parameter (Fig.a), and $\tilde{R}^{\min}_{kp}$ (curves 1 and 1') and $\tilde{R}^{\max}_{kp}$ (curves 2 and 2′) of the critical nucleus radius (Fig.b) in YIG:Fe^{2+} at $T = 77$ K. The dependences 2 through 10 (Fig.a) are obtained for $r_{0,kp}$, cm: 50 (2); 20 (3); 10 (4); 2 (5); 0.2 (6); 0.01 (7); 0.005 (8); 0.001 (9); $r^{\min}_{0,kp}$ (10). The relations 1 and 1′ (2 and 2′) in Fig.b are obtained for $r_{0,kp}$, cm: 0.05 (1); 50 (1′); λ, μm: 1.15 (2); 1.06 (2′).

The x^{opt}_{Me} value depends on the impurity type, the MA in theinitial state, and the FG irradiation conditions. The minimum value $G^{\min}_{thr}$ is attained at $x^{opt}_{\mathrm{Me}} \approx x^{T}_{\mathrm{Me}}$ or x^{R}_{Me} in FG containing TM ions, giving contributions to YIG constants λ_{100} and λ_{111} of different sign (Co^{2+}) or positive (Fe^{2+}), respectively [19]. Here, x^{R}_{Me} is Fe^{2+} or Ru^{3+} ion concentration at which $e_R = 0$ [9, 13, 20], and x^{T}_{Me}, the concentration at which a spontaneous spin-reorientation transition between magnetic phases <111> and <100> in YIG:Co^{2+} takes place [13]. In YIG:Me (Me≡Fe^{2+}, Ru^{3+}) with $x_{\mathrm{Me}} = x^{R}_{\mathrm{Me}}$, $\hat{G}^{\min}_{thr} = 0$, i.e. PISRT in this FG has not the threshold nature (Figs. 2–4). In FG with CPMA in initial state, the $G^{\min}_{thr}$ always exceeds zero. A reduction of $l_{0,kp}$ and/or $r_{0,kp}$ results in increased energy E_g. A consequence thereof is the increase of minimum value G_{thr} and values x^{opt}_{Me} (Fig. 3a). The concentration dependence of E_g defines monotonous character of the corresponding G_{thr} dependences at $l_{0,kp} < \bar{l}_{0,kp}$ and/or $r_{0,kp} < \bar{r}_{0,kp}$ (Figs. 2b and 3). For YIG:Fe^{2+} at $T = 77$ K, the values of $\bar{l}_{0,kp}$ and $\bar{r}_{0,kp}$ are 8 to 9 μm and 100 μm, respectively.

At $T = 77$ K, PISRT is possible in YIG:Fe^{2+} both with CMA and CPMA in the initial state (Figs. 2 and 3). As to $T = 295$ K, the PISRT conditions are not met in the mentioned FG with CPMA in the initial state. At room temperature, it is potentially possible only in YIG:Fe^{2+} and YIG:Ru^{3+} with initial CMA (Fig. 4). However, this possibility will be realized in a very narrow range of TM ion concentrations ($\Delta x_{\mathrm{Me}} = x^{\min}_{\mathrm{Me}} - x^{\max}_{\mathrm{Me}} < 10^{-5}$) in MMR volumes hardly realizable in practice ($l^{\min}_{0,kp} > 10^4$ cm). At $T = 295$ K, the PISRT conditions are not met in homogeneously magnetized YIG:Co^{2+} at any concentrations $x_{\mathrm{Co}}{}^{2+}$, initial state MA, size and FG irradiation conditions. For YIG:Co^{2+}, even the minimum possible threshold value $\hat{G}^{\min}_{thr} = 0.33 e_{\mathrm{Ko}}$ at $x_{\mathrm{Co}}{}^{2+} = x^{opt}_{\mathrm{Co}^{2+}} \approx x^{T}_{\mathrm{Co}^{2+}}$ exceeds essentially the crresponding value $G_{max} \approx 1.4 \cdot 10^{-8}$ e_{Ko} (Fig. 4), where $e_{\mathrm{Ko}} = K_1/3 + K_2/27$.

In spatially unrestricted MMR with initial CMA or CPMA, the nucleus parameters $\tilde{R}^{\max}_{kp}$ or ξ do not depend on the medium material properties and have infinite and zero values, respectively. The concentration dependences of $\tilde{R}^{\max}_{kp}$ and $\xi'_{\min}$, as well as of $\tilde{R}^{\min}_{kp}$, are defined by the corresponding dependences of optical absorption and energy density e_R of the medium material, as well as on its minimum thickness, respectively (Fig. 5). The linear dimensions $r_{0,kp}$ of the volume $V_{0,kp}$ defines the ξ parameter in a spatially restricted MMR volume. Its concentration dependence is monotonous. The reduction of ξ parameter as x_{Me} rises is due to a corresponding reduction of the nucleus DW energy, noticeable especially as x_{Me} approaches to x^T_{Me}. The ξ value increases at decreasing $r_{0,kp}$. Such increase is due to a rising E_ω with increasing deviation of the nucleus DW planes from equilibrium orientation in FG with CMA [7] at decreasing MMR volume.

To conclude, PISRT in a homogeneously magnetized medium starts with formation of a nucleus of a new magnetic phase as the threshold density of PMA energy is attained in the critical (minimum) MMR volume. The PMA energy threshold density is defined by the minimum linear dimension of the volume mentioned. Depending on the MA in the initial state and conditions of medium irradiation, the PMA energy threshold density varies between limiting (minimum and maximum) values, which are attained in spatially unrestricted and minimum possible critical MMR volumes, respectively. These minimum and maximum values limit the region of PISRT existence in a homogeneously magnetized medium. The threshold density of the PMA energy is defined by the medium magnetoelastic properties and nucleus demagnetization energy at considerable and minor RMM volumes, respectively. The minimum threshold energy densities are attained in media with a minimum magnetization and magnetoelastic energy, in particular, in FG with strongly anisotropic TM ions providing positive contributions to magnetostriction constants of YIG. The critical (at the nucleation) nucleus linear dimensions are defined by the corresponding maximum linear dimensions of the critical MMR volume in depth and in the plane of the medium.

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Зародкоутворення у процесі фотоіндукованого спін-переорієнтаційного переходу

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Розглянуто умови утворення зародка нової магнітної фази у процесі фотоіндукованого спін-переорієнтаційного переходу в однорідно намагніченому об'ємі легованого ітрій залізистого гранату. Встановлено значення порогових густин енергії фотоіндукованої одновісної магнітної анізотропії і відповідні їм критичні лінейні розміри зародка в залежності від властивостей матеріалу, магнітної анізотропії вихідного стану і умов опромінення магнітоупорядкованого середовища. Отримано граничні значення згаданих порогових густин і мінімальних концентрацій домішки, що обмежують область існування фотоіндукованого спін-переорієнтаційного переходу в однорідно намагніченому об'ємі ферит-гранатів.