RESONANCE PHENOMENA IN FERRITE SINGLE CRYSTALS IN THE PRESENCE OF A DOMAIN STRUCTURE

V. I. DUDKIN and A. I. PIL'SHCHIKOV

Moscow State University

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A theoretical and experimental investigation is carried out on the magnetization oscillations in the domains and resonance of domain boundaries in cubic ferrite single crystals with a negative anisotropy constant K_1 in the presence of a domain structure. The external stationary magnetic field H is directed along the [100] axis of the crystal. A lamellar domain structure with walls parallel to the field H is considered. The calculations show that six oscillation modes exist. Four of them correspond to FMR and two to resonance of the domain-boundary shift. Two oscillation modes corresponding to FMR are detected experimentally in lithium and magnesium—manganese ferrites. They are found to be related to the oscillations of the domain boundaries.

INTRODUCTION

In[1] we reported a theoretical and experimental investigation of ferromagnetic resonance (FMR) in the presence of a domain structure, in the case when the constant magnetic field H is directed along the [100] axis of a cubic single crystal with negative anisotropy constant. In the theoretical calculation we considered a lamellar domain structure with boundaries perpendicular to the constant field. It was assumed that in this case there exist four types of domains, making up two groups: in the first group of domains the magnetization vectors lie in the (011) plane, and in the second in the (011) plane. The experimental dependence of the FMR frequency on the constant field in the case of transverse excitation corresponded to the theoretical dependence for the resonant frequency of one of the transverse magnetization-oscillation modes. It should be noted that no account was taken in the theoretical calculation of the domain-boundary motion and its influence on the FMR conditions.

Investigations of FMR in the presence of the domain structure for the same single crystals, in the case when the constant field is directed along the [011] axis, have shown that the resonant frequencies of the boundary displacement are close to the FMR frequencies, and that a strong coupling appears between the oscillations of the magnetization in the domains, and the oscillations produced by the boundary displacements. This coupling is effected primarily with those FMR oscillation modes which are excited by the transverse microwave field. The presence of the coupling leads to a sharp decrease in the dependence of the resonant frequency of the transverse modes of the FMR on the magnitude of the constant field. The coupling between the boundary displacements and the magnetization oscillations in the domains, which are excited by a longitudinal microwave field, is very small and has no noticeable influence on the resonant frequency of this type of oscillation. Therefore the most definite information concerning the domain structure is obtained from the variation of the dependence of the resonant frequencies of the longitudinal modes on the constant field. The results of[2] and of subsequent experimental studies of FMR with the constant field H oriented along the [100] axis, using both transverse and longitudinal excitation, have shown that in this case it is also necessary to take into account the displacement of the boundaries and that the most probable is a lamellar domain structure with boundaries parallel to the field.

THEORY

The calculation of the conditions for FMR and for resonance of the boundary displacement is carried out by the method proposed by Vlasov and Onoprienko[3]. We consider a lamellar domain structure, similar to that of[1], but with boundaries parallel to the field. This means that the boundaries in each group are parallel to the same plane in

which the magnetization vectors of the given group are located. We write the Lagrange function for this case in the form

$$L = T - G, \qquad T = T_M + T_\gamma,$$

where $T = T_M + T_\gamma$ is the density of the "kinetic" energy, T_M the density of the "kinetic" energy of the domains, T_γ the density of the "kinetic" energy of the domain boundaries, and G the density of the thermodynamic potential.

For a sample in the form of an ellipsoid of revolution with an axis coinciding with the [100] direction (Fig. 1), the Lagrange function is

$$\begin{aligned} L = {} & \sum_{i=1}^{4} \nu_i \cos\theta_i \dot{\varphi}_i + \sum_{i=1}^{2} \frac{1}{4} m_\gamma d \dot{\nu}_i^2 \\ & - \frac{K_1}{4} \sum_{i=1}^{4} \nu_i (\sin^2 2\theta_i + \sin^4\theta_i \sin^2 2\varphi_i) \\ & + MH \sum_{i=1}^{4} \nu_i \cos\theta_i - \frac{M^2}{2} \Big\{ N \Big(\sum_{i=1}^{4} \nu_i \sin\theta_i \cos\varphi_i \Big)^2 \\ & + N_t \Big(\sum_{i=1}^{4} \nu_i \sin\theta_i \sin\varphi_i \Big)^2 + N_z \Big(\sum_{i=1}^{4} \nu_i \cos\theta_i \Big)^2 \Big\} \\ & - \pi M^2 \Big[\sin\theta_1 \sin\Big(\frac{\pi}{4} - \varphi_1\Big) - \sin\theta_3 \sin\Big(\frac{\pi}{4} - \varphi_3\Big) \Big] \\ & \times \Big[\nu_1 \sin\theta_1 \sin\Big(\frac{\pi}{4} - \varphi_1\Big) - \Big(\frac{1}{2} - \nu_1\Big) \\ & \times \sin\theta_3 \sin\Big(\frac{\pi}{4} - \varphi_3\Big) \Big] - \pi M^2 \Big[\sin\theta_2 \sin\Big(\frac{3\pi}{4} - \varphi_2\Big) \\ & - \sin\theta_4 \sin\Big(\frac{3\pi}{4} - \varphi_4\Big) \Big] \Big[\nu_2 \sin\theta_2 \sin\Big(\frac{3\pi}{4} - \varphi_2\Big) \\ & - \Big(\frac{1}{2} - \nu_2\Big) \sin\theta_4 \sin\Big(\frac{3\pi}{4} - \varphi_4\Big) \Big] \\ & + Mh \Big[\sin\beta \cos\alpha \sum_{i=1}^{4} \nu_i \sin\theta_i \cos\varphi_i \\ & + \sin\beta \sin\alpha \sum_{i=1}^{4} \nu_i \sin\theta_i \sin\varphi_i + \cos\beta \sum_{i=1}^{4} \nu_i \cos\theta_i \Big]. \end{aligned} \quad (1)$$

We have introduced here the following notation: M—saturation magnetization, K_1—first anisotropic constant; N_t, N_z—transverse and longitudinal demagnetization factors of the sample; m_γ—surface density of the effective mass of the boundary, d—average width of the domain; $\nu_1 + \nu_3 = \nu_2 + \nu_4 = 1/2$, where ν_i is the relative volume of one of the domain types; θ_i, φ_i, β, and α are the polar and azimuthal angles of the magnetization vectors in the domains, and the polar and azimuthal angles of the external alternating magnetic field vector. The demagnetizing factor of the domains is assumed equal to 4π.

We took into account in the thermodynamic potential the following types of energy: the anisotropy energy, the energy of interaction with the external constant magnetic field, the energy of the demagnetizing fields of the sample and of the domains, and the energy of interaction with the alternating magnetic field.

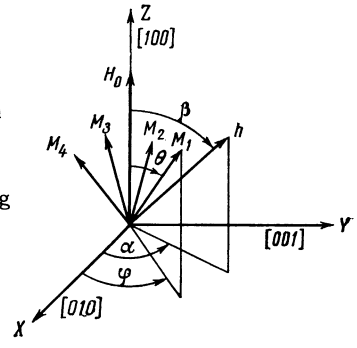

FIG. 1. Coordinate system and relative placement of the vectors of magnetization and of the constant and alternating magnetic fields.

The equilibrium state of the system is determined from the conditions:

$$\frac{\partial G}{\partial \theta_i} = \frac{\partial G}{\partial \varphi_i} = 0 \quad (i = 1,2,3,4), \qquad \frac{\partial G}{\partial \nu_1} = \frac{\partial G}{\partial \nu_2} = 0 \quad (2)$$

with h = 0. From the solution of this system of equations we get

$$\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta, \qquad \nu_1 = \nu_2 = \nu_3 = \nu_4 = 1/4,$$
$$\varphi_1 = \pi/4, \quad \varphi_2 = 3\pi/4, \quad \varphi_3 = 5\pi/4, \quad \varphi_4 = 7\pi/4. \quad (3)$$

for the magnetization curve we obtain the expression

$$H' = \cos\theta (N_z M' + 2 - 3\sin^2\theta), \quad (4)$$

where $H' = H|K_1/M|^{-1}$ is the reduced magnetic field and $M' = M|K_1/M|^{-1}$ is the reduced magnetization.

Using the calculation scheme proposed in[3], we obtain two independent systems of equations of motion:

$$\begin{aligned} & A\Delta\theta_{13}^{+} + N_1\Delta\theta_{24}^{+} - {}^1/_2 iz\Delta\varphi_{13}^{+} = -{}^1/_2 h' \cos\beta \sin\theta, \\ & N_1\Delta\theta_{13}^{+} + A\Delta\theta_{24}^{+} - {}^1/_2 iz\Delta\varphi_{24}^{+} = -{}^1/_2 h' \cos\beta \sin\theta, \\ & {}^1/_2 iz\Delta\theta_{13}^{+} + C\Delta\varphi_{13}^{+} = 0, \qquad {}^1/_2 iz\Delta\theta_{24}^{+} + C\Delta\varphi_{24}^{+} = 0; \end{aligned} \quad (5)$$

and

$$\begin{aligned} & B\Delta\theta_{13}^{-} - \frac{iz}{2}\Delta\varphi_{13}^{-} + N_2\Delta\varphi_{24}^{-} - 4N_2\Delta\nu_1 \\ & \quad = \frac{\sqrt{2}}{4} h' \sin\beta \cos\theta (\sin\alpha + \cos\alpha), \\ & B\Delta\theta_{24}^{-} - N_2\Delta\varphi_{13}^{-} - \frac{iz}{2}\Delta\varphi_{24}^{-} - 4N_2\Delta\nu_2 \\ & \quad = \frac{\sqrt{2}}{2} h' \sin\beta \cos\theta (\sin\alpha - \cos\alpha). \\ & \frac{iz}{2}\Delta\theta_{13}^{-} - N_2\Delta\theta_{24}^{-} + D\Delta\varphi_{13}^{-} + N_3\Delta\nu_2 \\ & \quad = \frac{\sqrt{2}}{4} h' \sin\beta \sin\theta (\sin\alpha - \cos\alpha), \end{aligned}$$

$$N_2\Delta\theta_{13}^- + \frac{iz}{2}\Delta\theta_{24}^- + D\Delta\varphi_{24}^- + N_3\Delta\nu_1 = -\frac{\sqrt{2}}{4}h'\sin\beta\sin\theta(\sin\alpha+\cos\alpha),$$

$$-4N_2\Delta\theta_{13}^- - N_3\Delta\varphi_{24}^- + \left(G_{\nu_1\nu_1} - \frac{1}{2}\frac{z^2 m_\gamma d\gamma^2}{M'\sin^2\theta}\right)\Delta\nu_1 = \sqrt{2}\,h'\sin\beta\sin\theta(\cos\alpha+\sin\alpha),$$

$$-4N_2\Delta\theta_{24}^- + N_3\Delta\varphi_{13}^- + \left(G_{\nu_1\nu_1} - \frac{1}{2}\frac{z^2 m_\gamma d\gamma^2}{M'\sin^2\theta}\right)\Delta\nu_2 = -\sqrt{2}\,h'\sin\beta\sin\theta(\cos\alpha-\sin\alpha); \quad (6)$$

here

$$A = 2(G_{\theta_1\theta_1} + G_{\theta_1\theta_3}) = {}^1/_2(8 - 9\sin^2\theta) + {}^1/_4 M' N_z \sin^2\theta,$$
$$B = 2(G_{\theta_1\theta_1} - G_{\theta_1\theta_3}) = {}^1/_2[\sin^2\theta(8 - 9\sin^2\theta) + {}^1/_2 M' N_t(1-\sin^2\theta)],$$
$$C = (\sin^2\theta + 2\pi M')\sin^2\theta, \quad D = \sin^2\theta(\sin^2\theta + {}^1/_4 M' N_t),$$
$$N_1 = {}^1/_4 M' N_z \sin^2\theta, \quad N_2 = -{}^1/_8 M' N_t \sin 2\theta,$$
$$N_3 = M' N_t \sin^2\theta, \quad h' = h|K_1/M|^{-1}, \quad G_{\nu_1\nu_1} = 4M' N_t \sin^2\theta,$$
$$z = \omega'\sin\theta, \quad \omega' = \frac{\omega}{\omega_a}, \quad \omega_a = \gamma|K_1/M|,$$
$$\Delta\theta_{13}^{\pm} = (\Delta\theta_1 \pm \Delta\theta_3)/2, \quad \Delta\theta_{24}^{\pm} = (\Delta\theta_2 \pm \Delta\theta_4)/2,$$
$$\Delta\varphi_{13}^{\pm} = (\Delta\varphi_1 \pm \Delta\varphi_3)/2, \quad \Delta\varphi_{24}^{\pm} = (\Delta\varphi_2 \pm \Delta\varphi_4)/2.$$

All the derivatives are calculated in the equilibrium position.

As can be seen from the system of equations (5) and (6), there exist six types of oscillations. Four of them correspond to precession of the magnetization inside the domains, and are described by the variables $\Delta\theta_i$ and $\Delta\varphi_i$, and the other two correspond to the boundary displacement and are described by $\Delta\nu_1$ and $\Delta\nu_2$. Oscillations with + sign are excited by the longitudinal field ($\beta = 0$), and all the remaining oscillations are excited by the transverse field ($\beta = \pi/2$). The longitudinal (+) and transverse (−) oscillation modes are independent, just as in the case of a perpendicular domain structure.[1] Coupling between these modes is possible as a result of the demagnetizing field of the domains, in the case when the angle between the domain boundaries and the external field differs from 0 or 90°[2]. The transverse oscillations of the magnetization (−) are coupled with the oscillations of the boundary (see (6)) via the transverse demagnetizing field of the sample (the coupling coefficients are N_2 and N_3), since only such fields can produce displacements of the boundaries. This coupling is maximal for a cylinder ($N_t = 2\pi$) and is zero for a disc ($N_t = 0$). There is no such coupling for longitudinal oscillations, in the same manner as in the case when H ∥ [011].[2]

The resonant frequencies are determined from the conditions that the determinants of the systems (5) and (6) vanish. When the excitation is longitudinal, we obtain for the frequencies from (5):

$$\omega'^2_{\parallel 1} = (\sin^2\theta + 2\pi M')(16 - 18\sin^2\theta + 2M' N_z)\sin^2\theta, \quad (7)$$

$$\omega'^2_{\parallel 2} = (\sin^2\theta + 2\pi M')(16 - 18\sin^2\theta)\sin^2\theta. \quad (8)$$

The region of stability of the domain structure is determined by the values of the field H′ at which $\omega'_{\parallel 2} > 0$[4], that is, $0 < \sin^2\theta < {}^8/_9$. It can be shown that the oscillation mode corresponding to the frequency $\omega'_{\parallel 2}$ constitutes precession of the magnetization in the domains, such that the phases of the precessing magnetic moments in the two groups of domains are opposite. Because of this, excitation of this mode by a homogeneous microwave magnetic field is impossible.

To calculate the resonant frequencies in transverse excitation, it is necessary to use the value of the parameter $l^2 = \gamma^2 m_\gamma d$ for the entire range of fields in which the domain structure under consideration exists. However, it was shown in[2] that an analogous parameter for the domain structure, in the case when the constant field H is parallel to the [011] axis, depends strongly on the magnitude of this field, and apparently differs greatly from its value at H = 0. We therefore present an expression for the resonant frequencies for oscillations corresponding to the precession of the magnetization in the domains, without allowance for the coupling with the boundary displacement:

$$\omega'_{\perp 1,2} = \{[(16 - 18\sin^2\theta)\sin^2\theta + M' N_t(1 - \sin^2\theta)] \times [\sin^2\theta + {}^1/_4 M' N_t]\}^{1/2} \pm {}^1/_2 M' N_t \cos\theta. \quad (9)$$

We note that this expression is rigorously valid for a disc whose axis coincides with the [100] direction and with the H direction ($N_t = 0$, and consequently $N_2 = N_3 = 0$).

Figures 2 and 3 show plots of the transverse and longitudinal reduced resonant frequencies, without allowance for the boundary displacement, while the dashed lines show parts of the curves in the region of the fields from which the domain structure in question is unstable.

EXPERIMENTAL RESULTS

The experimental investigation of FMR in the presence of a domain structure was carried out on spherical samples of MgMn single crystals and Li ferrites. The measurement procedure was similar to that used in[1,2]. Unlike in[1], we extended the frequency range and used longitudinal excitation. This has made it possible to obtain a more complete

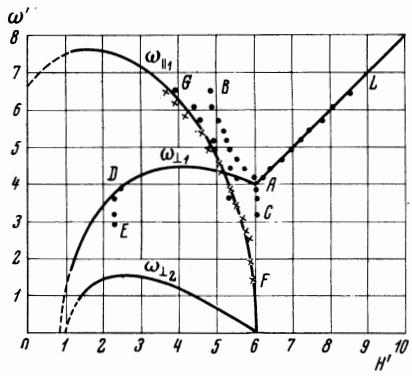

FIG. 2. Reduced resonant frequencies vs. reduced constant magnetic field for a spherical Li ferrite sample. Curves – theoretical, points – experiment: • – $\mathbf{h} \perp \mathbf{H}$, × – $\mathbf{h} \parallel \mathbf{H}$.

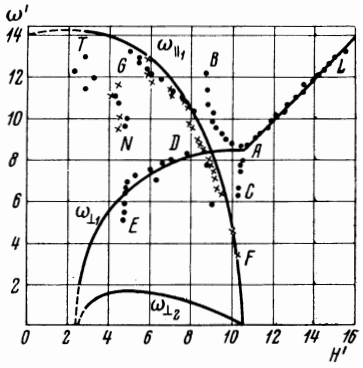

FIG. 3. Reduced resonance frequencies vs. reduced constant magnetic field for spherical sample of MgMn ferrite, M′ = 2.03. Curves – theoretical, points – experiment: • – $\mathbf{h} \perp \mathbf{H}$, × – $\mathbf{h} \parallel \mathbf{H}$.

picture of the FMR. In the analysis of the experimental data we shall use the results of the earlier investigations[2] of the coupled magnetization oscillations with the field H oriented along the [011] axis.

1. Lithium Ferrite

The measurements were made on two samples: Sample No. 1—diameter 1.15 m, $4\pi M = 3650$ g, $|K_1/M| = 300$ Oe, $\Delta H = 506$ Oe; Sample No. 2—diameter 1 mm, $4\pi M = 3650$, $|K_1/M| = 300$ Oe, $\Delta H = 14$ Oe.

The experimental results obtained with sample No. 1 as shown in Figs. 2 and 4 in the form of plots of the resonant frequencies against the constant field and in the form of absorption curves for different excitation methods.

Figure 2 shows theoretical plots of $\omega' = f(H')$, calculated for a parallel domain structure without allowance for the influence of the resonance of the domain-boundary displacement. The resonance absorption corresponding to branches of the resonant frequencies AL, AB, AC and DE was observed only under transverse excitation, and those of the branch GF for both longitudinal and transverse excitation. The branch AL corresponds to FMR in a sample magnetized to saturation.

Let us consider certain singularities of the absorption curves for the remaining branches. The longitudinal-excitation absorption curves, for all the frequencies of the branch GF (Fig. 4b), have a relatively high intensity and a small width, making it possible to determine the resonance field rather accurately. In the case of perpendicular excitation, the absorption curves corresponding to the branch in the region of low frequencies, $\omega' < 3.5$, could not be observed. Starting with $\omega' \approx 3.5$, very weak resonant absorption appears (Fig. 4a, $\omega' = 3.63$), and its intensity increases with increasing frequency. These absorption curves are very complicated in form, but exhibit a rather clearly pronounced maximum (Fig. 4a). Near point A, the absorption curves of branch AB are very narrow and have the same intensity as the absorption curves in the saturated sample ($\omega' = 4.55$). With increasing frequency, their intensity decreases rapidly, and when $\omega' > 5$ they are observed in the form of weak peaks on the slope of the broad absorption curve of branch GF (Fig. 4a, $\omega' = 5.47$). For frequencies $\omega' > 6.2$, the absorption curves of branch AB have so low an intensity that they cannot be observed.

At point A, the absorption curves of branches AB and AL coalesce into one absorption curve of branch AC. The intensity of these curves decreases rapidly with decreasing frequency, the resonant field remaining practically unchanged for all frequencies. At frequencies $\omega' < 4.4$ and transverse excitation, there appears a broad absorption band with a weakly pronounced maximum of the branch GF; this maximum decreases with decreasing frequency and goes over into a rather steep front. The resonant absorption of branch DE in weak fields appears only starting with $\omega' \approx 4$; its intensity decreases rapidly with decreasing frequency (Fig. 4a, $\omega' = 3.63$, $\omega' = 3.45$). Similar results were obtained with Sample No. 2.

Let us compare the obtained relations with the theoretical ones. We must note first that good agreement exists in the entire frequency band between the experimental values of the resonant frequencies of longitudinal oscillations (branch GF) with the theoretical values for a parallel domain structure. As noted in the introduction and in the section headed "Theory," the longitudinal oscillations have no coupling with the domain-boundary oscillations, and for these oscillations the dependence of the resonant frequencies on the constant

field is the most definite information concerning the domain structure. In this connection we can assume that the lithium ferrite has a parallel domain structure. However, the presence of resonant absorption of the GF branch under transverse excitation signifies that the oscillations corresponding to this branch are coupled. Apparently, just as in the case when H ∥ [011] for MgMn-ferrite[5,2], there is a small angle between the field and the boundary. This leads to appearance of a coupling and changes the frequency relatively little[5,2].

The dependence of the resonant frequencies of branch AB is typical for the frequency of transverse oscillations of the magnetization in domains in the presence of a coupling with the oscillations of the boundaries. This becomes particularly clear if one compares the character of the dependence of the resonant frequencies of the branch AB with the analogous dependence for the transverse modes with allowance for the influence of the resonance of the domain boundaries in MgMn ferrites for the case H ∥ [011][2]. If we assume that we deal with a domain structure whose walls are practically parallel to the field H, then the causes for the appearance of a broad absorption band in the region $4 < \omega' < 4.4$ and $2.5 < H' < 5.25$ become clear.

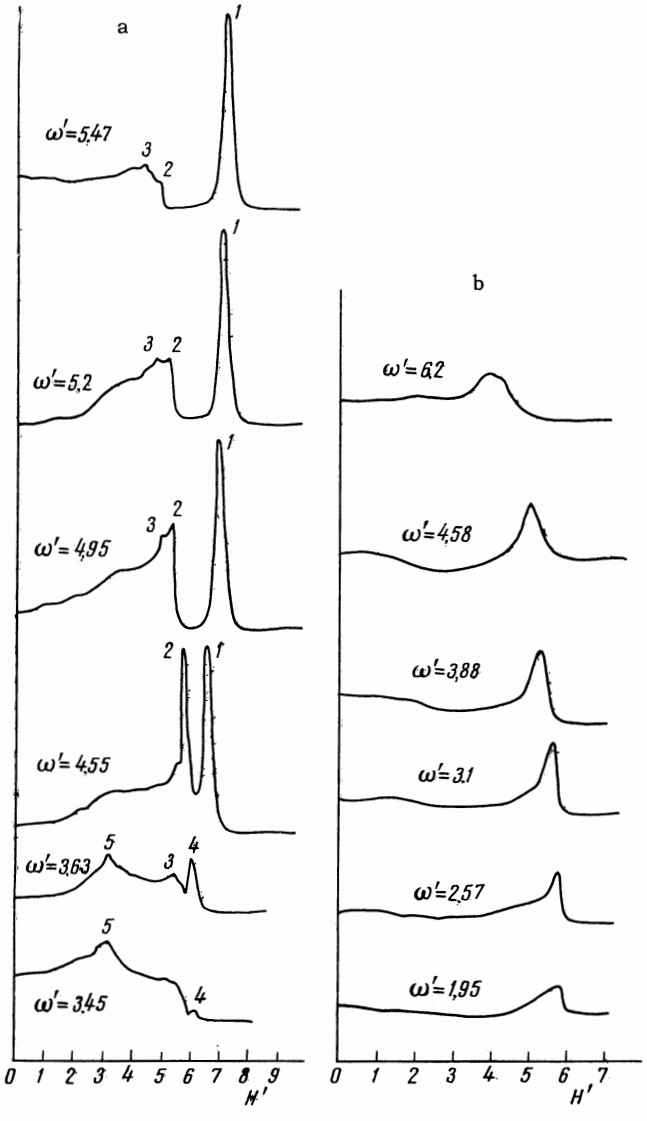

FIG. 4. Absorption curves for lithium ferrite, a – transverse excitation: 1 – resonant peak of branch AL, 2 – resonant peak of branch AB, 3 – resonant peak of branch GF, 4 – resonant peak of branch AC, 5 – resonant peak of branch DE; b – longitudinal excitation.

Indeed, from the theoretical variation of the frequency $\omega_\perp$ we see that in this field region the resonant frequency changes very little, and we have obtained, with broad absorption curves, the absorption band corresponding to this range of fields. Although we did not observe a clearcut resonant absorption connected with the motion of the domain boundaries, there exists at the frequencies $\omega' < 4$ and fields $H' < 5.5$ a broad band of rather intense absorption. A clearly pronounced absorption maximum, corresponding to the branch DE, is observed against the background of this band. The existence of this absorption band may be connected with the resonance of the domain-boundary displacement. The branch DE is a transverse mode with frequency $\omega_{\perp 1}$, although the agreement between the experimental values of the frequencies and the theoretical ones is worse for it than for the branches AL and GF. The assumption that couplings exist between the – and + oscillations denotes that the resonant absorption for the branch DE should be excited also by a longitudinal field. As seen from Fig. 4b, there is a very weak increase of the absorption under longitudinal excitation in this region of fields. This type of oscillation should be excited predominantly by a transverse field, and therefore excitation by a longitudinal field is not very effective.

2. Magnesium-manganese Ferrites

Two spherical samples were used in the measurements. Sample No. 1 had a diameter 1.0 mm, $M' = 1.61$, and $\Delta H = 12$ Oe; Sample No. 2 had a diameter 1.54 mm, $H' = 2.03$, and $\Delta H = 17$ Oe. The results of the experimental investigations for Sample No. 2 of the MgMn ferrite are shown in Figs. 3 and 5. Just as for the Li ferrite, the same branches of the resonant frequencies are observed. The character of the excitation and the behavior of the intensities of the absorption curves are perfectly analogous to the case of the Li ferrite. However, in the frequency band $\omega' = 9.5$—13 and in fields $H < 4.7$ there exists one more branch of resonant frequencies, NT, excited by both longi-

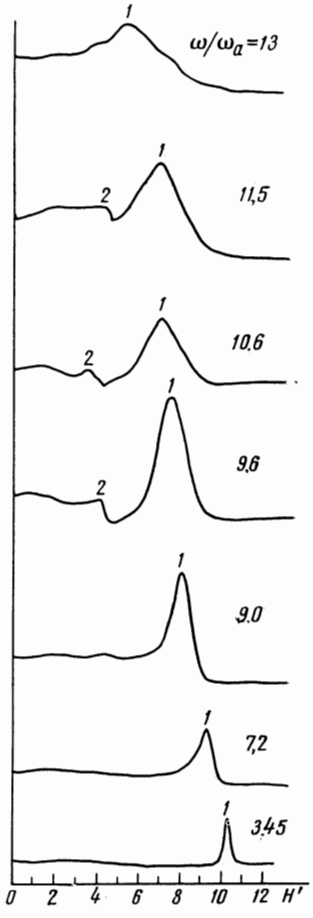

FIG. 5. Absorption curves for MgMn ferrite sample, M′ = 2.03, under longitudinal excitation; 1 – resonant peak of branch GF, 2 – resonant peak of branch NT.

tudinal and transverse microwave fields. The intensity of the absorption curves in this branch is much smaller than for GF branch (Fig. 5, see also Fig. 4 of[1]).

It should be noted that for sample No. 2 of the MgMn ferrite, owing to the large value of ΔH compared with the Li ferrite, there is no good resolution of the resonance-absorption curves of branches AB and GF under transverse excitation at frequencies $\omega' > 10$. The absorption curve of branch AB is observed in the form of a kink against the background of the broad peak of the GF background.

Unlike the Li ferrite, the resonant absorption corresponding to the branch DE is observed also in a broader range of fields H′. This can be attributed to the stronger dependence of the theoretical values of the frequency $\omega_{\perp 1}$ on the field H′, compared with the Li ferrite, which has a much lower reduced magnetization. The satisfactory agreement between the experimental frequencies of branch DE and the theoretical values of $\omega_{\perp 1}$ is obtained also for $\omega' > 7$. At lower frequencies, the branch DE deviates strongly from the theoretical curve, and this takes place in that region of fields where the resonant absorption corresponding to the branch NT appears. It can be assumed that in this region of fields a coupling again is produced between the transverse oscillations and the oscillations of the domain boundaries, whose frequency is now higher than $\omega_{\perp 1}$. It is quite probable that the resonant absorption for the NT branch is connected with the resonance of the domain boundaries. The resonant absorption of NT branch for sample No. 1 was not observed, probably as a result of the smaller dimensions of this sample compared with sample No. 2.

In conclusion we find it necessary to make a remark concerning the consideration of coupled oscillations as proposed in the present article. In the theoretical calculation we took into account only one type of coupling between the magnetization oscillations in the domains and the boundary oscillations, namely the one resulting from the demagnetizing fields of the samples. Apparently, however, other types of coupling are also possible: direct dipole-dipole interaction of the precessing magnetic moments in the domains and in the boundary, as well as stray fields at the inhomogeneities. These types of coupling should depend little on the form of the sample, whereas the coupling due to the demagnetizing fields of the sample depends very strongly on it. The relative weight of these types of coupling can be estimated experimentally by comparing the dependences of the resonant frequencies on the magnetizing field for a disc (there is no coupling via the demagnetizing fields) and a sphere or cylinder, for which this type of coupling plays an appreciable role. We propose to make such a comparison in the future.

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