equal to 4×10^6 cm^{-1}. The estimate given in[9] from the experimental data is equal to $\sim3\times10^6$ cm^{-1}. The width $\Delta\omega$ in our estimate ≈ 0.24 eV, and the absolute position of this peak is not predicted due to rejection from the dynamical investigation of the contribution due to non van der Waals interactions of the atoms. The shape of the absorption line for the given transition in[9] differs somewhat from that predicted by the ideas under consideration—in the first place by its width which is approximately twice as large in[9]. Nevertheless it is possible that in regard to lower temperatures ($T=20$ K in[9]) the mechanism under consideration retains a certain competitive ability with regard to the other absorption mechanisms. The experimentally observed narrowing of the lines at very low temperatures attests to this. In any case, allowance for the natural decay in the region of the resonances associated with natural absorption is essential. As to the initial general equations of the collective approximation proposed here and also possible generalizations of this method, their application to problems specific to quantum electronics such as the coherence of laser radiation, super-radiance, etc., is of particular interest.

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Sound generation in a multidomain ferromagnet

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The generation of sound by a radio-frequency field in a multidomain structure, formed by 180-degree Bloch walls, is treated by simultaneous solution of the equations of motion for the magnetization and for elastic waves. It is shown that the effectiveness of the generation depends strongly on the orientation of the radio-frequency field. Emphasis is placed on the large role played in the amplification of acoustic oscillations by a magnetoacoustic resonator that involves both the acoustic properties of the specimen and also the multidomain structure. From the results of the paper it follows that excitation of acoustic oscillations by Bloch walls in a multidomain structure is quite effective and that these oscillations can be detected experimentally.

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1. INTRODUCTION

For detection of weak ultrasonic (US) vibrations, there has recently been increasingly broad application of the method of US modulation of Mössbauer radiation. This method offers the possibility of measuring amplitudes of the order of magnitude of a fraction of an angstrom. US Mössbauer spectroscopy has received its greatest development in the study of ultrasound excited by a radio-frequency (rf) field in ferromagnets. As has been established, the principal mechanism of excitation of sound is magnetostriction.[1] At the same time, experiment shows that the theory of excitation of sound in a single-domain structure (see, for example,[2,3]) does not fully describe the experiment of[1]. Additional clarity in the understanding of the physical picture of the effect can be achieved by use of the mechanism of excitation of sound by Bloch walls.[4] In this connection, it is of interest to investigate this mechanism on the basis of a multidomain structure of the specimen.

2. HIGH-FREQUENCY OSCILLATIONS OF A BLOCH WALL

We consider a uniaxial cubic crystal of a ferromagnetic material in the form of a plate with dimensions $L\times d_1\times d_2$. We direct the axis of easy magnetization along x; then the plane of the absorber will be the xz or yz plane when the smallest dimension of the plate is d_1 or d_2 respectively (see Fig. 1). For simplicity we restrict ourselves to the case in which the specimen consists of plane-parallel domains, separated by domain walls perpendicular to the z axis. In an equilibrium state, all the domains have the same thickness D; the wall thickness is Δ. For absorber thicknesses characteristic of Mössbauer spectroscopy, the Landau-Lifshitz[5] model of the transition layer may be considered

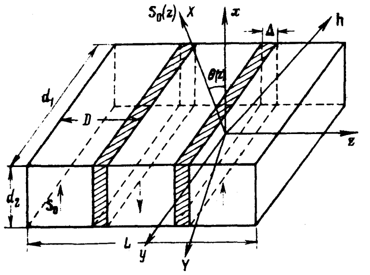

FIG. 1. Representation of the domain structure and of the geometry of the problem.

applicable; that is, it may be treated as a Bloch wall.

In the original coordinate system, the axis of quantization has not been fixed. Following Winter,[6] we introduce a local coordinate system XYz rotated through an angle $\theta(z)$ with respect to the xyz system, with the x axis directed along the equilibrium direction of the spin $\mathbf{S}_0(z)$. The angle $\theta(z)$ is measured from the x axis; the origins of the two coordinate systems coincide and are located at the center of one of the walls. Outside the Bloch walls, the systems coincide. We shall suppose that the external biasing magnetic field $H_0=0$, and that the rf field has an arbitrary direction and projections $h_x e^{i\omega t}$, $h_y e^{i\omega t}$, $h_z e^{i\omega t}$. Here h_x, h_y, and h_z are amplitudes of the rf field, and ω is its frequency. Then the Hamiltonian of the system, with allowance for magnetostriction, can be written as follows:

$$\mathscr{H}=-2J\sum_{ij}(\mathbf{S}^i\mathbf{S}^j)+K\sum_i[(S_y^i)^2+(S_z^i)^2]+K'\sum_i(S_Y^i)^2+2\pi(g\beta)^2\sum_i(S_z^i)^2+\mathscr{H}_{ms}+\mathscr{H}_L+g\beta\sum_i\mathbf{S}^i\mathbf{h}, \qquad (1)$$

where the first term corresponds to the exchange interaction, the second to the anisotropy energy, the third to the quasielastic[6] energy of the wall; the fourth gives the effective mass of the wall,[6] the seventh the energy of interaction of the magnetization with the rf field; $\mathscr{H}_{ms}$ is the magnetostriction energy.

$$\mathscr{H}_{ms}=\gamma\sum_i[(S_x^i)^2u_{xx}+(S_y^i)^2u_{yy}+(S_z^i)^2u_{zz}]+\gamma_0\sum_i[(S_x^iS_y^i+S_y^iS_x^i)u_{xy}+(S_x^iS_z^i+S_z^iS_x^i)u_{xz}+(S_y^iS_z^i+S_z^iS_y^i)u_{yz}];$$

$\mathscr{H}_L$ is the elastic energy,

$$\mathscr{H}_L={}^1/_2c_{11}(u_{xx}^2+u_{yy}^2+u_{zz}^2)+c_{12}(u_{xx}u_{yy}+u_{yy}u_{zz}+u_{zz}u_{xx})+2c_{44}(u_{xy}^2+u_{xz}^2+u_{yz}^2).$$

Here u_{ik} are the components of the deformation tensor; S_x, S_y, S_z are the components of the spin; γ and γ_0 are the components of the magnetostriction; and c_{ij} are the elastic constants. The system of equations of motion for the magnetization and for elastic waves, for a small uniform rf field, can in our case be written in the form

$$\frac{\partial S_i}{\partial t}=\frac{1}{i\hbar}[S_i,\mathscr{H}],\quad \rho\frac{\partial^2u_i}{\partial t^2}=\frac{\partial\tau_{ik}}{\partial x_k}, \qquad (2)$$

where ρ is the density of the material, and where τ_{ik} are the components of the stress tensor, which are found by differentiation of the free energy with respect to the corresponding components of the deformation:

$$\begin{aligned}
\tau_{xy}&=2c_{44}u_{xy}+{}^1/_2\gamma_0(S_xS_y+S_yS_x),\\
\tau_{xz}&=2c_{44}u_{xz}+{}^1/_2\gamma_0(S_xS_z+S_zS_x),\\
\tau_{xx}&=c_{11}u_{xx}+c_{12}(u_{yy}+u_{zz})+\gamma(S_x)^2,\\
\tau_{yy}&=c_{11}u_{yy}+c_{12}(u_{xx}+u_{zz})+\gamma(S_y)^2,\\
\tau_{zz}&=c_{11}u_{zz}+c_{12}(u_{xx}+u_{yy})+\gamma(S_z)^2,\\
\tau_{yz}&=2c_{44}u_{yz}+{}^1/_2\gamma_0(S_yS_z+S_zS_y).
\end{aligned} \qquad (3)$$

We shall take account of attenuation of the magnetic and elastic waves phenomenologically.

On expressing $\mathscr{H}$ in terms of S_X, S_Y, and S_z and retaining only terms linear in S_Y, S_z, and h (since h is small, therefore S_Y and S_z are small, while $S_X\approx S$, where S corresponds to the saturation magnetization), we obtain the system of equations

$$\begin{aligned}
\rho\frac{\partial^2u_x}{\partial t^2}&=c_{44}\frac{\partial^2u_x}{\partial z^2}+\gamma_0\frac{\partial}{\partial z}(SS_z\cos\theta),\\
\rho\frac{\partial^2u_y}{\partial t^2}&=c_{44}\frac{\partial^2u_y}{\partial z^2}+\gamma_0\frac{\partial}{\partial z}(SS_z\sin\theta),\\
\rho\frac{\partial^2u_z}{\partial t^2}&=c_{11}\frac{\partial^2u_z}{\partial z^2},\\
\hbar\frac{\partial S_Y}{\partial t}&=-2JSa^2\frac{\partial^2S_z}{\partial z^2}+2KSS_z(\cos^2\theta-\sin^2\theta)\\
&\quad+4\pi(g\beta)^2SS_z+2\gamma_0S^2(u_{xz}\cos\theta+u_{yz}\sin\theta)+g\beta h_zS,\\
\hbar\frac{\partial S_z}{\partial t}&=2JSa^2\frac{\partial^2S_Y}{\partial z^2}-2KSS_Y(\cos^2\theta-\sin^2\theta)\\
&\quad-2K'SS_Y-\Gamma S_z+g\beta h_xS\sin\theta-g\beta h_yS\cos\theta,
\end{aligned} \qquad (4)$$

where Γ is introduced in order to allow for attenuation in the Landau-Lifshitz form, and where a is the lattice constant.

In the derivation of the system (4), use has been made of the fact that the magnetization distribution depends only on z, and therefore the solution must depend only on z. The third equation in (4) is not coupled with the others: $u_z=0$; in the linear approximation, there are no elastic oscillations perpendicular to the Bloch wall. Hereafter we shall restrict ourselves to the case of quite low frequencies, when the acoustic wavelength is much larger than the domain-wall thickness, that is $q\Delta\ll1$ (this is satisfied for $\omega\leq10^{10}$ rad/sec); we shall also suppose that the magnetic and elastic branches of the oscillations are coupled weakly.

We now find the component of spin perpendicular to the Bloch wall, since it is it that occurs in the equations for the elastic displacements:

$$S_z=-\frac{i\hbar\omega g\beta S}{\hbar^2(\omega^2-\omega_{01}^2)-i\hbar\omega\Gamma}h_x\sin\theta e^{i\omega t}+\frac{i\hbar\omega g\beta S}{\hbar^2(\omega^2-\omega_{02}^2)-i\hbar\omega\Gamma}h_y\cos\theta e^{i\omega t}+\frac{2KSg\beta S}{\hbar^2(\omega^2-\omega_{02}^2)-i\hbar\omega\Gamma}h_ze^{i\omega t}, \qquad (5)$$

where, if we adopt the usual conditions $K\gg K'$ and $4\pi(g\beta)^2S\gg2KS$,[6] then $\omega_{01}=\hbar^{-1}(2K'S\cdot4\pi(g\beta)^2S)^{1/2}$ is the resonance frequency of oscillations of the magnetic moment in the walls, and $\omega_{02}=\hbar^{-1}(2KS\cdot4\pi(g\beta)^2S)^{1/2}$ is the resonance frequency of oscillations in the domains.

The first and second terms in (5) describe standing oscillations of the magnetization localized, respectively, in the walls and in the domains; the third corresponds to a uniform precession, since the z component of the rf field does not sense the domain structure. On substituting S_z in the first two equations of the system (4), we obtain the following wave equations:

$$\frac{\partial^2 u_y}{\partial z^2}+q^2u_y=-iB_x\frac{\partial}{\partial z}(\sin^2\theta)e^{i\omega t}+B_z\frac{\partial}{\partial z}(\sin\theta)e^{i\omega t},$$
$$\frac{\partial^2 u_x}{\partial z^2}+q^2u_x=iB_y\frac{\partial}{\partial z}(\cos^2\theta)e^{i\omega t}+B_z\frac{\partial}{\partial z}(\cos\theta)e^{i\omega t}, \qquad (5a)$$

where

$$B_x=-\frac{\hbar\omega g\beta h_x}{\hbar^2(\omega^2-\omega_{01}^2)-i\hbar\omega\Gamma}\frac{\gamma_0S^2}{c_{44}},\quad B_y=-\frac{\hbar\omega g\beta h_y}{\hbar^2(\omega^2-\omega_{02}^2)-i\hbar\omega\Gamma}\frac{\gamma_0S^2}{c_{44}}$$
$$B_z=-\frac{2KSg\beta h_z}{\hbar^2(\omega^2-\omega_{02}^2)-i\hbar\omega\Gamma}\frac{\gamma_0S^2}{c_{44}},$$

$q=\omega/v_t$ is the wave vector of a transverse sound wave, and $v_t=(c_{44}/\rho)^{1/2}$ is the velocity of a transverse sound wave.

The solution of (5a) can be obtained by use of Green's function for the wave equation[8]:

$$u_y=e^{i\omega t}\int_{-\infty}^{+\infty}G(z,z')\left[-iB_x\frac{\partial}{\partial z'}(\sin^2\theta)+B_z\frac{\partial}{\partial z'}(\sin\theta)\right]dz',$$
$$u_x=e^{i\omega t}\int_{-\infty}^{+\infty}G(z,z')\left[iB_y\frac{\partial}{\partial z'}(\cos^2\theta)+B_z\frac{\partial}{\partial z'}(\cos\theta)\right]dz', \qquad (6)$$

where Green's function is

$$G(z,z')=\frac{i}{2q}\exp(-iq|z-z'|).$$

Knowing the explicit form of $\theta(z)$, which is determined by the equations[5]

$$\sin\theta=\operatorname{sech}(z/\mu),\quad \cos\theta=-\operatorname{th}(z/\mu), \qquad (7)$$

we obtain for a single Bloch wall, in the lowest nonvanishing approximation with respect to $q\Delta$, for sound waves traveling along the z axis

$$u_y=-iB_x\mu e^{i(\omega t-q|z|)}\operatorname{sign}(z)\pm{}^1/_2B_z\mu\pi e^{i(\omega t-q|z|)}\operatorname{sign}(z),$$
$$u_x=-iB_y\mu e^{i(\omega t-q|z|)}\operatorname{sign}(z)\mp iB_zq^{-1}e^{i(\omega t-q|z|)}, \qquad (8)$$

where $\mu=(2J/Ka)^{1/2}$ is a parameter characteristic of the domain-wall thickness, a quantity approximately an order of magnitude smaller than Δ; the upper sign corresponds to Bloch walls with $0\leqslant\theta\leqslant\pi$, the lower with $\pi\leqslant\theta\leqslant 2\pi$.

It is seen that in the case under consideration, in which the external biasing field $H=0$, it is possible to excite transverse sound waves polarized in the plane of a Bloch wall; the polarization may be perpendicular or parallel to the magnetization in the domains.[1)] We note that the components h_x and h_y of the rf field, as distinguished from h_z, excite only oscillations polarized along the y and x axes, respectively.

3. MULTIDOMAIN STRUCTURE

We pass now to the consideration of a multidomain structure. In using the results of the calculations for a single Bloch wall, we may approximate it by a δ-function sound source:

$$\sin^2\theta=2\mu\delta(z),\ \cos^2\theta=2\mu[1-\delta(z)],$$
$$\sin\theta=\pm\mu\pi\delta(z),\ \partial(\cos\theta)/\partial z=\mp 2\delta(z). \qquad (9)$$

In this approximation, we obtain for a multidomain structure the following wave equations:

$$\frac{\partial^2 u_y}{\partial z^2}+q^2u_y=-\sum_{k=1}^{m}2iB_x\mu\frac{\partial}{\partial z}[\delta(z-Dk)]e^{i\omega t}+\sum_{k=1}^{m}(-1)^{k+1}B_z\mu\pi\frac{\partial}{\partial z}[\delta(z-Dk)]e^{i\omega t},$$
$$\frac{\partial^2 u_x}{\partial z^2}+q^2u_x=-\sum_{k=1}^{m}2iB_y\mu\frac{\partial}{\partial z}[\delta(z-Dk)]e^{i\omega t}+\sum_{k=1}^{m}(-1)^k\cdot 2B_z\delta(z-Dk)e^{i\omega t}, \qquad (10)$$

Here $m=L/D-1$ is the number of walls; for definiteness, we suppose that the spin in the edge domain is directed along the positive direction of the x axis, whose origin we shall hereafter place at the edge of the plate.

We shall consider two different forms of the boundary conditions for acoustic oscillations along the z axis: clamped boundaries, when the displacement at the boundary vanishes, and free boundaries, when the stress at the boundary vanishes. This corresponds at $z=0$ and L to

$$u_x=u_y=0,$$
$$\frac{\partial u_y}{\partial z}=0,\quad \frac{\partial u_x}{\partial z}=iB_ye^{i\omega t}+B_ze^{i\omega t}. \qquad (11)$$

On solving the equations by the Fourier method,[3,9] we finally obtain the displacement in the form of standing waves:

a) clamped boundaries:

$$u_y=\sum_{\substack{n=2\\ \text{even}}}^{\infty}\operatorname{Im}[B_x\mu\sigma_n\sin(q_nz)e^{i\omega t}]-\sum_{\substack{n=1\\ \text{odd}}}^{\infty}\operatorname{Re}\left[B_z\frac{\mu\pi}{2}\sigma_n\sin(q_nz)e^{i\omega t}\right], \qquad (12a)$$

$$u_x=\sum_{\substack{n=2\\ \text{even}}}^{\infty}\operatorname{Im}[B_y\mu\sigma_n\sin(q_nz)e^{i\omega t}]-\sum_{\substack{n=2\\ \text{even}}}^{\infty}\operatorname{Re}\left[B_z\frac{1}{q_n}\sigma_n\operatorname{tg}\left(\frac{\omega_nD}{2v_t}\right)\sin(q_nz)e^{i\omega t}\right], \qquad (13a)$$

b) free boundaries:

$$u_y=\sum_{\substack{n=1\\ \text{odd}}}^{\infty}\operatorname{Im}\left[B_x\mu\sigma_n\operatorname{ctg}\left(\frac{\omega_nD}{2v_t}\right)\cos(q_nz)e^{i\omega t}\right]+\sum_{\substack{n=2\\ \text{even}}}^{\infty}\operatorname{Re}\left[B_z\frac{\mu\pi}{2}\sigma_n\operatorname{tg}\left(\frac{\omega_nD}{2v_t}\right)\cos(q_nz)e^{i\omega t}\right], \qquad (12b)$$

$$u_x=-\sum_{\substack{n=1\\ \text{odd}}}^{\infty}\operatorname{Im}\left\{B_y\left[z+\sigma_n\frac{\omega^2\cos(q_nz)}{\omega_n^2q_n}-\sigma_n\mu\operatorname{ctg}\left(\frac{\omega_nD}{2v_t}\right)\cos(q_nz)\right]ie^{i\omega t}\right\}+\sum_{\substack{n=1\\ \text{odd}}}^{\infty}\operatorname{Re}\left\{B_z\left[z+\sigma_n\left(\frac{\omega^2}{\omega_n^2}-1\right)\frac{\cos(q_nz)}{q_n}\right]e^{i\omega t}\right\}. \qquad (13b)$$

Here

$$\sigma_n = \frac{\omega_n v_t}{\omega^2 - \omega_n^2 + i\omega\omega_n/Q_n} \frac{4}{L}$$

are factors that allow for the role of the plate as a resonator and that lead, for $\omega \approx \omega_n < 4v_t Q_n/L$, to amplification of the acoustic oscillations; $\omega_n = n\pi v_t/L = q_n v_t$ is the frequency of mechanical resonance of the n-th mode. The number of a mode is the number of acoustical half-waves spanned by the plate length in the direction perpendicular to the plane of a Bloch wall.

Damping of the sound waves has been taken into account phenomenologically by means of the quality factor Q_n. Resonance occurs at $\omega \approx \omega_n$, and at resonance $\sigma_n \propto n^{-1}$. The functions $\tan(\omega_n D/2v_t)$ and $\cot(\omega_n D/2v_t)$ and a selection that separates even and odd modes take account of the contribution of the whole multidomain structure to the generation. The multidomain property may also play the role of an amplifying resonator in the frequency range

$$\frac{\pi v_t}{2D}(4p+1) < \omega_n < \frac{\pi v_t}{2D}(4p+3)$$

or

$$\frac{\pi v_t}{2D}(4p-1) < \omega_n < \frac{\pi v_t}{2D}(4p+1),$$

where p is a nonnegative integer, when $\tan(\omega_n D/2v_t)$ or $\cot(\omega_n D/dv_t)$, respectively, is larger in modulus than unity. The modes $(2p+1)L/D$ correspond to the case in which the domain thickness spans an odd number of acoustic half-waves; and since they are odd, $\tan(\omega_n D/2v_t)$ does not become infinite. The modes $(2p+1)L/D-1$ and $(2p+1)L/D+1$, when $\tan(\omega_n D/2v_t)$ is present in the sum, correspond to maximum amplification by the multidomain structure, and for them the displacements have opposite signs. Similarly, the modes $2pL/D$ correspond to the case in which the domain thickness contains an even number of acoustic half-waves; and since they are even, $\cot(\omega_n D/2v_t)$ does not become infinite. The modes $2pL/D-1$ and $2pL/D+1$, when $\cot(\omega_n D/2v_t)$ is present in the sum, correspond to maximum amplification by the multidomain structure, and the displacements have opposite signs.

Both the specimen and the multidomain structure may simultaneously take part in the amplification of acoustical oscillations; furthermore, the multidomain structure determines the character of the resonance modes excited in the specimen. In other words, a multidomain medium is a single magnetoacoustical resonator.

The individual terms in the solution obtained have the following physical meaning.

1. Excitation of sound at Bloch walls by magnetization oscillations localized at the walls: the first sums in (12a) and (12b).

2. Excitation of sound at Bloch walls by magnetization oscillations localized in the domains: the first sum in (13a) and the third term of the first sum in (13b).

3. Excitation of sound at Bloch walls by uniform precession: the second sums in (12a), (12b), and (13a) and the third term of the second sum in (13b).

4. Excitation of sound at the plate edges by magnetization oscillations localized in the domains, and by uniform precession: the first two terms of the first sum and the first two terms of the second sum, respectively, in (13b).

4. DISCUSSION

It is known that the intensity of the absorption or radiation line in US Mössbauer spectroscopy is proportional to $J_n^2(u_0/\lambda\!\!\!^-)$, where J_n is the Bessel function of order n, u_0 is the amplitude of the US displacement, and $\lambda\!\!\!^- = \lambda/2\pi$ is the wavelength of the γ radiation.[1] It follows from the properties of the Bessel function that this method is capable of detecting US displacements comparable with the wavelength of the γ radiation (for Fe^{57}, for example, $\lambda\!\!\!^- = 1.4 \cdot 10^{-9}$ cm). Modulation of the γ radiation requires US displacements perpendicular to the plane of the absorber. Two orientations of the magnetization within the domains are possible.

A. Magnetization in the plane of the absorber

This orientation is encountered oftenest in ferromagnets. In this case, since our magnetization is bound to the x axis, we must take the xz plane as the plane of the absorber and examine the expressions (12a) and (12b) for the displacements along the y axis. We shall make a numerical estimate for the isotope Fe^{57} in iron, using the following values of the constants: $c_{44} = 1.12 \cdot 10^{12}$ erg/cm^3, $\gamma_0 S^2 = 6.4 \cdot 10^7$ erg/cm^3, $KS^2 = 4.2 \cdot 10^5$ erg/cm^3, $S = 9.2 \cdot 10^{22}$ cm^{-3}, $v_t = 3.3 \cdot 10^5$ cm/sec, $\mu = 2.3 \cdot 10^{-5}$ cm,[10] $\omega_{01} = 5 \cdot 10^8$ rad/sec, $\omega_{02} = 5 \cdot 10^9$ rad/sec,[6] $Q_n = 580$[11]; and let $h_0 = 1$ G, $L = 1$ cm. If we take $d_2 = 1$ cm and $d_1 = 30$ μm, then we can estimate the domain thickness as $D \approx 5 \cdot 10^{-4}$ cm.[10]

As an example we shall give here only the result of a numerical estimate of the first sum in (12b), which is caused by excitation of sound at Bloch walls by magnetization oscillations localized at the walls. In this case the displacement amplitude at $\omega \approx \omega_{13} \approx 2\pi \cdot 2.15$ MHz can be estimated as

$$u_y^0 \approx \frac{\omega_n g\beta h_x \gamma_0 S^2}{\hbar\omega_{01}^2 c_{44}} \mu\sigma_{13} \operatorname{ctg}\left(\frac{\omega_{13} D}{2v_t}\right) \approx 0.7 \cdot 10^{-9}\,\text{cm} \sim \lambda\!\!\!^-,$$

$$\sigma_{13} \approx 4v_t Q_{13}/\omega_{13} L \approx 56, \ \operatorname{ctg}(\omega_{13} D/2v_t) \approx 2v_t/\omega_{13} D \approx 10^2.$$

Here both factors, the plates and the multidomain structure, play the role of an amplifying resonator; and since $u_y^0 \propto n^{-1}$ when $\omega_n < \omega_{01}$, the effective contribution to modulation of the γ radiation comes from odd modes 1 to 13. In the region of ferromagnetic domain resonance, far from the crossing point of the magnetic and elastic branches of the oscillation, at $\omega_n = \omega_{01} \approx 2\pi \cdot 80$ MHz, the amplitude is small:

$$u_y^0 \approx \frac{g\beta h_x \gamma_0 S^2}{\Gamma c_{44}} \mu\sigma_{01} \operatorname{ctg}\left(\frac{\omega_{01} D}{2v_t}\right) < 0.5 \cdot 10^{-9}\ \text{cm}.$$

In the frequency range in which the acoustic wavelength is comparable with the domain thickness, the displacement amplitude has a maximum. In this case, at

$$\omega_n = \frac{\pi}{L} v_t \left(2\frac{L}{D} \pm 1\right) \approx \frac{2\pi v_t}{D} \approx 2\pi \cdot 660\ \text{MHz},$$

$$u_y{}^0 \approx \frac{g\beta h_x \gamma_0 S^2}{\hbar \omega_n c_{44}} \mu \sigma_n \operatorname{ctg}\left(\frac{\omega_n D}{2v_t}\right) \approx 0.1 \cdot 10^{-9}\ \text{cm} < \lambda\!\!\!^{-},$$

and the contribution to the effect in this range will also be small. Here $\sigma_n \approx 0.2$, $\cot(\omega_n D/2v_t) \approx 1.2 \cdot 10^3$; that is, the role of amplifying resonator is played by the multidomain structure alone.

By use of these and analogous estimates for (12a) and (12b), it can apparently be stated that for ferromagnetic plates magnetized in their plane, US displacements can be detected in the following cases:

1) boundaries clamped in the direction perpendicular to the plane of a Bloch wall, and $\mathbf{h} \parallel 0z$;

2) boundaries free, and $\mathbf{h} \parallel 0x$;

3) boundaries free, and $\mathbf{h} \parallel 0z$.

In the first case, the displacements will be detected in the mechanical resonance range of the first mode. These displacements are excited at Bloch walls by uniform precession of the magnetization; the role of amplifying resonator is played by the plate. In the second case, the displacements will be detected in the mechanical resonance range of 1 to 13 odd modes. These displacements are excited at Bloch walls by magnetization oscillations localized at the walls; the role of amplifying resonator is played both by the plate and by the multidomain structure. In the third case, the displacements will be detected in the mechanical resonance range of two even modes, when the domain thickness is comparable with the half-length of the acoustic wave: $\omega_n = \pi L^{-1} v_t (L/D \pm 1) \approx 2\pi \cdot 330$ MHz. These displacements are excited at Bloch walls by uniform precession, and amplification of them by the multidomain structure is maximal.

B. Magnetization perpendicular to the absorber plane

In this case, we must take the yz plane as the plane of the absorber and examine the expressions (13a) and (13b) for the displacements along the x axis. For estimation, we shall use the same values of the constants, except for the domain thickness, which for $d_2 = 30\ \mu$m and $d_1 = 1$ cm can be estimated as $D \approx 3 \cdot 10^{-5}$ cm.

The displacement amplitude of the first sum in (13b) can be expressed in the form of a resonance contribution from the second and third terms and a nonresonance contribution from the first two terms. The resonance contribution is caused by excitation of sound at the plate edges and at Bloch walls, respectively, by magnetization oscillations localized in domains. The nonresonance contribution is caused by excitation of sound at the plate edges by magnetization oscillations localized in domains. At $\omega \approx \omega_{13} \approx 2\pi \cdot 2.15$ MHz, the resonance component can be estimated as

$$u_x{}^0 \approx \frac{g\beta h_y \gamma_0 S^2}{\hbar \omega_{02}{}^2 c_{44}} \sigma_{13} \approx 0.65 \cdot 10^{-9}\ \text{cm} \sim \lambda\!\!\!^{-}, \quad \sigma_{13} = 56.$$

Here the role of amplifying resonator is played by the plate alone; and since $u_x^0 \propto n^{-1}$ for $\omega < \omega_{02}$ and $u_x^0 \propto n^{-3}$ for $\omega > \omega_{02}$, the effective contribution to the modulation is made by 1 to 13 odd modes. The contribution of the third term is small even at frequencies $\omega_n = \pi L^{-1} v_t (2L/D \pm 1) \approx 2\pi \cdot 11$ GHz, corresponding to maximum amplification of the acoustic oscillations by the multidomain structure. These frequencies now enter the hypersonic range and were not considered by us. In the frequency range $\omega \gtrsim 2\pi \cdot 5$ MHz, the effective component will be the nonresonant one.

The displacement amplitude for the second sum in (13b) can also be expressed in the form of a resonance contribution of the second and third terms and a nonresonance contribution of the first two. The resonance contribution is caused by excitation of sound by uniform precession at the plate edges and at the Bloch walls, respectively. The nonresonance contribution is caused by excitation of sound by uniform precession at the plate edges. At $\omega \approx \omega_{15} \approx 2\pi \cdot 2.48$ MHz, the resonance component can be estimated as

$$u_x{}^0 \approx \frac{2KSg\beta h_z \gamma_0 S^2 v_t}{\hbar^2 \omega_{02}{}^2 c_{44} \omega_{13}} \frac{\sigma_{13}}{Q_{13}} \approx 0.6 \cdot 10^{-9}\ \text{cm} \sim \lambda\!\!\!^{-},$$

where $\sigma_{13}/Q_{13} \approx 8 \cdot 10^{-2}$. Here, in the resonance range, the displacements excited at the plate edges and at the walls partially compensate each other; and since $u_x^0 \propto n^{-2}$ for $\omega_n < \omega_{02}$ and $u_x^0 \propto n^{-4}$ for $\omega > \omega_{02}$, the effective contribution to the modulation comes from 1 to 15 odd modes. If we turn on an external biasing field H_0, which annihilates the domain structure, the compensation disappears, and the resonance component at $\omega \approx \omega_{355} \approx 2\pi \cdot 59$ MHz can be estimated as

$$u_x{}^0 \approx \frac{2KSg\beta h_z \gamma_0 S^2 v_t}{\hbar^2 \omega_{02}{}^2 c_{44} \omega_{355}} \sigma_{355} \approx 0.64 \cdot 10^{-9}\ \text{cm} \sim \lambda\!\!\!^{-}, \quad \sigma_{355} \approx 2.$$

Here the role of amplifying resonator is played by the plate alone; and in consequence of the removal of the compensation, the effective contribution to the modulation will come from odd modes with frequencies up to 59 MHz. The nonresonant component is effective at all frequencies.

By use of these and analogous estimates for (13a) and (13b), it can apparently be stated that for ferromagnetic plates magnetized perpendicular to the absorption plane, US displacements can be detected in the following cases:

1) boundaries clamped in the direction perpendicular to the plane of the Bloch walls, and $\mathbf{h} \parallel 0z$;

2) boundaries free, and $\mathbf{h} \parallel 0y$;

3) boundaries free, and $\mathbf{h} \parallel 0z$.

In the first case, the displacements will be detected in the mechanical resonance range of 2 to 6 even modes. These displacements are excited at the Bloch walls by uniform precession of the magnetization; the role of amplifying resonator is played by the plate. In the second case, the displacements will be detected in the mechanical resonance range of 1 to 13 odd modes, and also for frequencies $\omega \gtrsim 2\pi \cdot 5$ MHz. These displacements are excited at the plate edges by oscillations localized in the domains; the role of amplifying resonator is again played by the plate. In the third case, the displacements will be detected at all frequencies for the nonresonant component and in the mechanical resonance range of 1 to 15 odd modes for the resonance component. The nonresonant component is excited at the plate edges by uniform precession. In the resonance range, displacements excited by uniform precession at the plate edges are partially compensated by displacements excited by uniform precession at the walls. On destruction of the domain structure by an external biasing field, the compensation is removed, and the range of the detectable resonance modes extends to 59 MHz. In both cases the plate is an amplifying resonator.

5. CONCLUSION

From the estimates given, it is evident that excitation of acoustical oscillations by Bloch walls in a multidomain structure is quite effective. These oscillations can be detected experimentally, and investigation of them is useful in the study of multidomain structures. With decrease of the frequency of the rf field, the effectiveness of the excitation of sound at mechanical resonances of the specimen increases. These "low-frequency oscillations" may be responsible for an effect in the hundreds-of-kilohertz range in hematite.[12] The effectiveness of the sound excitation depends strongly on the orientation of the rf field, in accordance with the results of[14]; furthermore, the acoustical signal in a multidomain structure is not determined solely by the intensity of the exciting field and the properties of the specimen as an acoustic resonator. It is necessary to treat a multidomain medium as a single magnetoacoustical resonator.

A similar picture of sound excitation is possible in a domain structure of stripe domains, and also in ferroelectric materials. In the latter case, electric domains must be considered instead of magnetic.

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1) This result differs from that obtained in a paper of Nedlin and Shapiro[7], which appeared while our paper was being prepared for printing. There, in the case $H_0 = 0$, a wall can excite only sound waves with polarization perpendicular to the magnetization in the domains. The difference is apparently due to their use of a more simplified phenomenological model.

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Transient processes in the region where the NMR and FMR overlap

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Transient processes in a nuclear system (spin echo, decay of free induction, etc.) are investigated in the region where the NMR and FMR frequencies overlap. The singularities of the relaxation of a nuclear system via the electron system (NER) is analyzed in detail. It is shown that at small values of the nuclear magnetization μ the character of the transient processes remains unchanged in the region where the NMR and FMR frequencies overlap, but the gain of the high-frequency field and of the nuclear signal increase strongly. At large μ, the transient processes in the nuclear system are determined by the NER mechanism.

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The question of the influence of the overlap of the NMR and FMR frequencies on the NMR signal observed by intermittent methods was considered earlier[1] where electron-nuclear magnetic resonance (ENMR) was predicted, a phenomenon consisting of multiple amplification of the NMR signal by the FMR signal. This result was subsequently observed in experiment.[2] Theoretically, quasistationary transient processes in a nuclear system were investigated under the conditions of overlap of NMR and FMR.[3] It is of interest to examine the sin-

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