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Dynamic properties of antiferromagnets in alternating magnetic and electric fields

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The dynamics of domain walls in external alternating magnetic and electric fields has been studied in antiferromagnetic materials with linear magnetoelectric interaction. The features of vibrational and drift motion of domain walls depending on the parameters of external fields and the material characteristics are discussed.

Изучена динамика доменных границ во внешних переменных магнитном и электрическом полях в антиферромагнитных материалах с линейным магнитоэлектрическим взаимодействием. Обсуждаются особенности колебательного и дрейфового движения доменных границ в зависимости от параметров внешних полей и характеристик материала.

1. Introduction

The investigations of magnetic domain structure and domain walls (DW) in magnetic materials which combine ferromagnetic and ferroelectric properties (multiferroics) are of great interest now both from theoretical and applied standpoints [1, 2]. There is a growing attention to the investigations of dynamical properties of magnetic inhomogeneities [3-7]. The influence of magnetic field on the DW dynamics has been studied best of all. The effect of other factors (electrical field, etc.) has been less investigated. The influence of *stationary* electrical field on the density of DW surface energy and the velocity of its motion in ferroelectromagnetics were studied in [8]. In the case of spin reorientation first order phase transition of Morin type in rhombic ferroelectric antiferromagnetics, the magnetoelectric interaction excites vibrations of 90-deg DW. The vibration amplitude of such DW is proportional to the electric field amplitude [9]. The drift of 180-deg DW occurs in magnetics with a linear magnetoelectric interaction under the influence of external alternating electric and magnetic fields [10]. The drift speed in this case is proportional to the square of the alternating field amplitude.

At the same time, the controlled DW displacement under the influence of *stationary* electrical field in garnet ferrite films was observed experimentally in [11]. The direction of DW displacement is reversed as the electric field polarity changes. We have proposed the non-uniform magnetoelectric effect as the mechanism of the observed phenomenon. The experimental observations of dynamical transformations in a magnetic stripe domain structure in a bilayer thin film ferromagnetic-Ni/ferroelectric-lead zirconate titanate heterostructure in electric field are presented in [12]. In this work, the nonlinear dynamics of 180-degrees DW in antiferromagnetic with linear magnetoelectric interaction is studied analytically. As the study object, two-sublattice model of antiferromagnetic (AFM) [4] is used which can describe the magnetic subsystem of rhombic ferroelectromagnetics [13].

2. The model and equations of motion

Let the Lagrange density function $L(\mathbf{l})$ of a two-sublattice AFM be expressed in terms of the unit antiferromagnetic vector $\mathbf{l}$, $\mathbf{l}^2 = 1$ [3, 4]:

$$L(\mathbf{l}) = M_0^2\left[\frac{\alpha}{2c^2}\left(\dot{\mathbf{l}}\right)^2 - \frac{\alpha}{2}(\nabla\mathbf{l})^2 - \left(\frac{\beta_1}{2}l_z^2 + \frac{\beta_2}{2}l_y^2\right) - w_{me}(\mathbf{l}) + \right. \\ \left. + \frac{4}{\delta g M_0}\left(\mathbf{h}\cdot\left[\dot{\mathbf{l}}\times\mathbf{l}\right]\right) - \frac{2}{\delta}(\mathbf{l}\cdot\mathbf{h})^2\right], \tag{1}$$

where $\dot{\mathbf{l}}$ denotes the derivative with respect to time; $M_0^2 = \left(M_1^2 + M_2^2\right)/2$; M_0 is the length of the sublattice magnetization vector; $c = gM_0\sqrt{\alpha\delta}/2$, the minimum spin-wave phase velocity; δ and α, the homogeneous and inhomogeneous exchange coupling constants, respectively; g, the gyromagnetic ratio (the same for each sublattice); β_1 and β_2, the effective constants of rhombic anisotropy; $\mathbf{h} = \mathbf{H}/M_0$; $\mathbf{H} = \mathbf{H}_0\cos(\omega t + \chi)$, the external alternating magnetic field with frequency ω and phase shift χ.

The magnetoelectric interaction energy density $w_{me}(\mathbf{l})$ have the same form as for the magnetic anisotropy one but with other phenomenological constants:

$$w_{me}(\mathbf{l}) = E_y(t)\cdot\left(\frac{b_1}{2}l_z^2 + \frac{b_2}{2}l_y^2\right), \tag{2}$$

where b_1 and b_2 are the magnetoelectric interaction constants.

Let the external electric field $\mathbf{E}(t) = \mathbf{E}_0\cos(\omega t)$ be directed along the pyroelectric axis, which is considered to be directed along the Y-axis.

Let the dissipative function be introduced which takes into account the dynamic stopping of the DW:

$$F = \frac{\lambda M_0}{2g}\dot{\mathbf{l}}^2, \tag{3}$$

where λ is the dimensionless Gilbert damping constant.

Since the components of the vector $\mathbf{l}$ are connected by the relation $\mathbf{l}^2 = 1$, it is convenient to rewrite the Lagrange density function (1) in terms of two independent angle variables θ and φ which parameterize the unit vector $\mathbf{l}$:

$$l_x + il_z = \sin\theta\,\exp(i\varphi), \qquad l_y = \cos\theta. \tag{4}$$

Taking into account the parametrization from Eq. (4) and relaxation attenuation, we obtain from the Lagrange density function (1) the following equations of motion for the angle variables θ and φ:

$$\alpha\left(\Delta\theta - \frac{1}{c^2}\ddot{\theta}\right) + \sin\theta\cos\theta\left[\alpha\left(\frac{1}{c^2}(\dot{\varphi})^2 - (\nabla\varphi)^2\right) + \left(\beta_2 + b_2E_y\right) - \right. \\ \left. -\left(\beta_1 + b_1E_y\right)\sin^2\varphi\right] - \frac{4}{\delta}\left(\left(h_x\cos\varphi + h_z\sin\varphi\right)\sin\theta + h_y\cos\theta\right)\cdot \\ \left(h_x\cos\theta\cos\varphi - h_y\sin\theta + h_z\cos\theta\sin\varphi\right) + \\ + \frac{4}{\delta g M_0}\left[\dot{h}_x\sin\varphi - \dot{h}_z\cos\varphi + h_y\dot{\varphi}\sin 2\theta + 2\dot{\varphi}\sin^2\theta\left(h_z\sin\varphi + h_x\cos\varphi\right)\right] = \frac{\lambda}{g M_0}\dot{\theta}, \tag{5}$$

$$\alpha\nabla\left((\nabla\varphi)\sin^2\theta\right)-\frac{\alpha}{c^2}\frac{d}{dt}\left(\dot{\varphi}\sin^2\theta\right)-\left(\beta_1+b_1E_y\right)\sin^2\theta\sin\varphi\cos\varphi+$$
$$+\frac{4}{\delta}\left[(h_x\cos\varphi+h_z\sin\varphi)\sin\theta+h_y\cos\theta\right](h_z\cos\varphi-h_x\sin\varphi)\sin\theta+$$
$$+\frac{4}{\delta g M_0}\left[\left(\dot{h}_x\cos\varphi+\dot{h}_z\sin\varphi\right)\sin\theta\cos\theta-\right.$$
$$\left.-\dot{h}_y\sin^2\theta-h_y\dot{\theta}\sin 2\theta-2\dot{\theta}\sin^2\theta\left(h_z\sin\varphi+h_x\cos\varphi\right)\right]=\frac{\lambda}{gM_0}\dot{\varphi}\sin^2\theta. \tag{6}$$

In the case of $\beta_1>\beta_2>0$, the DW is stable in the absence of external fields. This DW corresponds to $\varphi=\varphi_0=0$, and the angle variable $\theta=\theta_0(y)$ satisfies the equation

$$\alpha\theta_0^{//}+\beta_2\sin\theta_0\cos\theta_0=0 \tag{7}$$

and boundary conditions $\theta_0(\pm\infty)=\pm\pi/2$. Let the magnetization distribution be considered to be inhomogeneous along the *Y*-axis (the prime denotes differentiation with respect to this coordinate).

The solution of Eq. (7) that describes the static 180-deg DW with the rotation of the vector **l** in the *xy* plane has the following form:

$$\theta_0^{/}=-\frac{1}{y_0}\cos\theta_0(y)=-\frac{1}{y_0}\cosh^{-1}\left(\frac{y}{y_0}\right),\quad \sin\theta_0(y)=-\tanh\left(\frac{y}{y_0}\right), \tag{8}$$

where $y_0=\sqrt{\alpha/\beta_2}$ is the DW thickness.

3. Induced motion of domain walls

To describe the nonlinear macroscopic DW dynamics, let one of perturbation theory versions be used for solitons [5-7]. Let a collective variable $Y(t)$ be introduced which has the meaning of the DW center coordinate at the point of time t, the derivative of which defines the instantaneous velocity of DW $V(t)=\dot{Y}(t)$. The DW drift speed is defined as the instantaneous DW speed $V(t)$ averaged over the oscillation period $V_{\rm dr}=\bar{V}(t)$ (the bar denotes averaging over the external-field oscillation period). Assuming the amplitude of external electric E_y and magnetic $\mathbf{h}$ fields to be small, we represent the functions $\theta(y,t)$, $\varphi(y,t)$ and $V(t)$ by series in powers of the field amplitude

$$\begin{cases}\theta(y,t)=\theta_0(\xi)+\theta_1(\xi,t)+\theta_2(\xi,t)+\dots,\\ \varphi(y,t)=\varphi_1(\xi,t)+\varphi_2(\xi,t)+\dots,\\ V=V_1(t)+V_2(t)+\dots,\end{cases} \tag{9}$$

where $\xi=y-Y(t)$; subscripts $n=1,2,\dots$ denote the smallness order of the quantity to the field amplitude θ_n, φ_n, $V_n\sim h^n$. The function $\theta_0(\xi)$ describes the motion of an undistorted DW. The functions of higher orders $\theta_n(\xi,t)$ and $\varphi_n(\xi,t)$, $n=1,2,\dots$ describe the distortions of the DW shape and the excitation of spin waves.

Let the expansions (9) be substituted in Eqs. (5)-(6) and terms of different orders of smallness be separated. Obviously, in the zero approximation we get Eq. (7) which describes a DW at rest.

The perturbation theory first-order equations can be written in the form

$$\left(\hat{L}+\hat{T}\right)\theta_1(\xi,t)=\frac{b_2}{\beta_2}E_y\sin\theta_0\cos\theta_0-\frac{4}{\beta_2\delta gM_0}\dot{h}_z+\frac{\cos\theta_0(\xi)}{y_0\omega_1^2}\left(\dot{V}_1+\omega_r V_1\right), \tag{10}$$

$$\left(\hat{L}+\sigma+\hat{T}\right)\mu_1(\xi,t)=\frac{2d}{\beta_2\delta}h_x+\frac{4}{\beta_2\delta gM_0}\left[\dot{h}_x\cos\theta_0(\xi)-\dot{h}_y\sin\theta_0(\xi)\right], \tag{11}$$

where we denote

$$\mu_1(\xi,t)=\varphi_1(\xi,t)\sin\theta_0(\xi), \quad \hat{T}=\frac{1}{\omega_1^2}\frac{\partial^2}{\partial t^2}+\frac{\omega_r}{\omega_1^2}\frac{\partial}{\partial t}, \quad \sigma=(\beta_1-\beta_2)/\beta_2,$$

$\omega_1=c/y_0=gM_0\sqrt{\beta_2\delta}/2$ is the activation frequency of the lower spin-wave mode, and $\omega_r=\lambda\delta gM_0/4$ is the characteristic relaxation frequency.

The operator $\hat{L}$ has the form of a Schrödinger operator with a non-reflecting potential:

$$\hat{L}=-y_0^2\frac{d^2}{d\xi^2}+1-\frac{2}{\mathrm{ch}^2\left(\xi/y_0\right)}.$$

The spectrum and the eigenfunctions of $\hat{L}$ are well known. It has one discrete level with eigenvalue $\lambda_0=0$ corresponding to a localized wave function

$$f_0(\xi)=\frac{1}{\sqrt{2y_0}\,\mathrm{ch}(\xi/y_0)}$$

and also a continuous spectrum $\lambda_p=1+p^2y_0^2$ corresponding to the eigenfunctions

$$f_p(\xi)=\frac{1}{b_p\sqrt{L}}\left(\mathrm{th}\frac{\xi}{y_0}-ipy_0\right)\exp(ip\xi),$$

where $b_p=\sqrt{1+p^2y_0^2}$, and L is the crystal length.

We seek the solution of the system of equations of the first approximation (10)-(11) as an expansion over a complete orthonormalized set of the eigenfunctions $\{f_0(\xi), f_k(\xi)\}$:

$$\theta_1(\xi,t)=\mathrm{Re}\left\{\sum_p\left[c_p^{(1)}f_p(\xi)+c_0^{(1)}f_0(\xi)\right]\exp[i(ky-\omega t)]\right\},$$

$$\varphi_1(\xi,t)=\mathrm{Re}\left\{\sum_p\left[d_p^{(1)}f_p(\xi)+d_0^{(1)}f_0(\xi)\right]\exp[i(ky-\omega t)]\right\}.$$

For a monochromatic external magnetic field of frequency ω, with all three components different from zero, we obtain

$$\begin{cases}\theta_1(\xi,t)=a_1(t)G_1(\xi)+a_2(t)G_2(\xi),\\ \mu_1(\xi,t)=a_3(t)\cos\theta_0(\xi)+a_4(t)\sin\theta_0(\xi).\end{cases} \tag{12}$$

Here we introduce the following notations:

$$a_1(t)=\frac{b_2}{4\beta_2}E_y, \quad a_2(t)=-\frac{2}{\beta_2 gM_0\delta}\dot{h}_z, \quad a_3(t)=\frac{4\dot{h}_x}{\beta_2 gM_0\delta[\sigma-q_1+iq_2]},$$

$$a_4(t)=\frac{-4\dot{h}_y}{\beta_2 gM_0\delta[1+\sigma-q_1+iq_2]},$$

$$G_1(\xi)=y_0\int_{-\infty}^{+\infty}\frac{\cos(p\xi)\cdot\mathrm{th}(\xi/y_0)+(py_0)\sin(p\xi)}{\mathrm{ch}(\pi py_0/2)}\frac{dp}{\Omega_1(p,\omega)},$$

$$G_2(\xi)=y_0\int_{-\infty}^{+\infty}\frac{\sin(p\xi)\cdot\mathrm{th}(\xi/y_0)-(py_0)\cos(p\xi)}{\mathrm{sh}(\pi py_0/2)}\frac{dp}{\lambda_p\Omega_1(p,\omega)},$$

where

$$q_1=(\omega/\omega_1)^2, \quad q_2=\left(\omega\omega_r/\omega_1^2\right),$$

$$\Omega_1(p,\omega)=\lambda_p-q_1+iq_2\,,\quad \Omega_2(p,\omega)=\lambda_p\left(\lambda_p+\sigma-q_1+iq_2\right).$$

Basing on the requirement of vanishing of Goldstone mode amplitude $\left(d_0^{(1)}=0\right)$ [14], we come to the equation for defining the DW speed

$$\dot{V}_1+\omega_r V_1=\frac{\pi\, y_0 g\, M_0}{2}\dot{h}_z\,. \tag{13}$$

The solution of this equation describes the DW vibrations in an external oscillating field and has the form

$$Y(t)=\mathrm{Re}\left[\frac{\pi}{2}\cdot\frac{y_0 g M_0}{(\omega_r+i\omega)}h_{0z}\exp\left[i\left(\omega t+\chi_z\right)\right]\right]. \tag{14}$$

Let the real part in the expression (14) be separated. Then the solution can be rewritted in the following form:

$$Y(t)=A\cos\left(\omega t+\chi_0\right), \tag{15}$$

where $A=\dfrac{\pi\, y_0 g\, M_0 h_{0z}}{2\omega_r\cdot\sqrt{1+\left(\omega/\omega_r\right)^2}}$ is the DW vibration amplitude, and χ_0 is the initial phase shift.

The DW drift motion is a second-order effect relative to the field amplitude. Consequently, the DW drift velocity is defined from the equation of the second order of perturbation theory:

$$\begin{aligned}\left(\hat{L}+\hat{T}\right)\theta_2(\xi,t)=&\frac{\cos\theta_0}{y_0\omega_1^2}\left(\dot{V}_2+\omega_r V_2\right)+\frac{\theta_1'}{\omega_1^2}\left(\dot{V}_1+\omega_r V_1\right)+\\&+\frac{2V_1}{\omega_1^2}\dot{\theta}_1'+\frac{\cos 2\theta_0}{\beta_2}\left(b_2E_y\theta_1-\frac{4}{\delta}h_xh_y\right)+\\&+\frac{4}{\beta_2\delta\, g\, M_0}\left(\varphi_1\dot{h}_x+2\dot{\varphi}_1h_x\sin^2\theta_0\right)+\frac{\sin 2\theta_0}{2}\left[\frac{V_1^2}{c^2}-\frac{4}{\beta_2\delta}\left(h_x^2-h_y^2\right)-\right.\\&\left.-(\sigma+1)\varphi_1^2+\frac{\left(\dot{\varphi}_1\right)^2}{\omega_1^2}-y_0^2\left(\varphi_1'\right)^2-2\theta_1^2+\frac{8}{\beta_2\delta\, g\, M_0}h_y\dot{\varphi}_1\right],\end{aligned} \tag{16}$$

where a prime denotes the differentiation with respect to variable ξ.

Since we are interested only in forced motion of DW, then for the determination of the velocity $V_2(t)$, it is sufficient to find the coefficient corresponding to the Goldstone mode in the expansion of $\theta_2(\xi,t)$ by eigenfunctions of the operator $\hat{L}$ and to equate it to zero. Substituting the functions $\theta_1(\xi,t)$ and $\varphi_1(\xi,t)$ (12) into Eq. (16), averaging it over the vibration period and integrating, we get the following expression for the drift speed $V_{\mathrm{dr}}=\overline{V_2}$:

$$V_{\mathrm{dr}}=\nu_0A_1(\omega;\chi)H_{0x}H_{0y}+\tilde{\nu}_0A_2(\omega;\chi_z)H_{0z}E_{0y}\,. \tag{17}$$

Here

$$A_1(\omega;\chi)=-\frac{\pi}{4}\frac{q_1q_2}{Q_1}\left[q_2\cos\chi-\left(B_1B_2+q_2^2\right)\sin\chi\right],$$

$$A_2(\omega;\chi_z)=-\frac{\omega}{4gQ_2}\left[q_1\left(\eta_1\omega_1^2+\omega^2\eta_2\right)\cos\chi_z-\left(\omega_r^2\eta_3+\omega^2\left(1+q_1\right)\right)\sin\chi_z\right],$$

$$Q_1 = \left[(1+\sigma-q_1)(\sigma-q_1)+q_2^2\right]^2 + q_2^2, \qquad Q_2 = \left[(1-q_1)^2+q_2^2\right]\cdot\left(\omega^2+\omega_r^2\right),$$

$\nu_0 = \dfrac{g^2 y_0}{\omega_r}$ and $\tilde{\nu}_0 = \dfrac{b_2}{\beta_2}\nu_0$ are the DW motilities; $\chi = \chi_x - \chi_y$ is the comparative phase displacement; $\eta_1 \approx 2.5$, $\eta_2 \approx 0.1$, $\eta_3 = 2.6$.

It should be noted that $A_1(\omega;\chi)$ is dimensionless quantity, and $A_2(\omega;\chi_z)$ have the units Oe.

4. Discussion

1. First, let certain features of solutions (12) and (14) of the first-order equations (10)-(11) be discussed. The eigenfunctions of operator $\hat{L}$ were obtained by Winter [15] in the problem on spin excitations of magnetics. In a 180-deg DW, spins may be involved in the vibrations of two types. The first vibration type is associated directly with DW. These vibrations are referred to as the intra-wall vibrations and are corresponded to the localized wave function $f_0(\xi)$. The second vibration type is the analog of common spin waves inside the domains. These vibrations correspond to the continuous spectrum which is described by the wave functions $f_p(\xi)$.

It follows from the relationships (12) and (14) that the components of an external magnetic field h_y and h_z and the electric field component E_y excite the second type vibrations (while the component h_y excites only the state with $p = 0$). The components h_x and h_z also excite the first type vibrations. The features of DW vibratory motion are the consequence of the fact that the electric field in the linear approximation does not cause any DW motion (see also [10]), while a variable electric field excites vibrations of 90-deg DW near the spin-reorientation phase transition [9]. From the relationship (15), it is easy to find the vibratory motion speed of DW: $V = \omega A$. Note that the amplitude of DW vibrations (A) has a relaxation drop that is in agreement with [16].

2. Now let the features of DW drift motion be considered. For an estimation of the DW drift speed for different values of the frequency and phase shift, we will use the characteristic values of the parameters of ferroelectromagnetics [13]: $\sigma = 2$, $M_0 = 10$ Oe, $y_0 = 10^{-5}$ cm, $g = 2\cdot 10^7$ (s·Oe)$^{-1}$, $\omega_r \sim 10^9$ s^{-1}, $\omega_1 \sim 10^{11}$ s^{-1}, $\dfrac{b_2}{\beta_2} \sim 10^{-4}$. Then the DW mobility is $\nu_0 \approx 4$ cm/(s Oe) (accordingly, $\tilde{\nu}_0$,is four orders less). Let the DW dynamics in the magnetic field $H_x H_y$ be considered. The dependence $A_1(\omega;\chi)$ on the external magnetic field frequency is presented in Fig. for different values of phase shift $\left(\chi = 0, \dfrac{\pi}{4}, \dfrac{\pi}{2}\right)$ in the field $H_{0x} = H_{0y} = 1$ Oe.

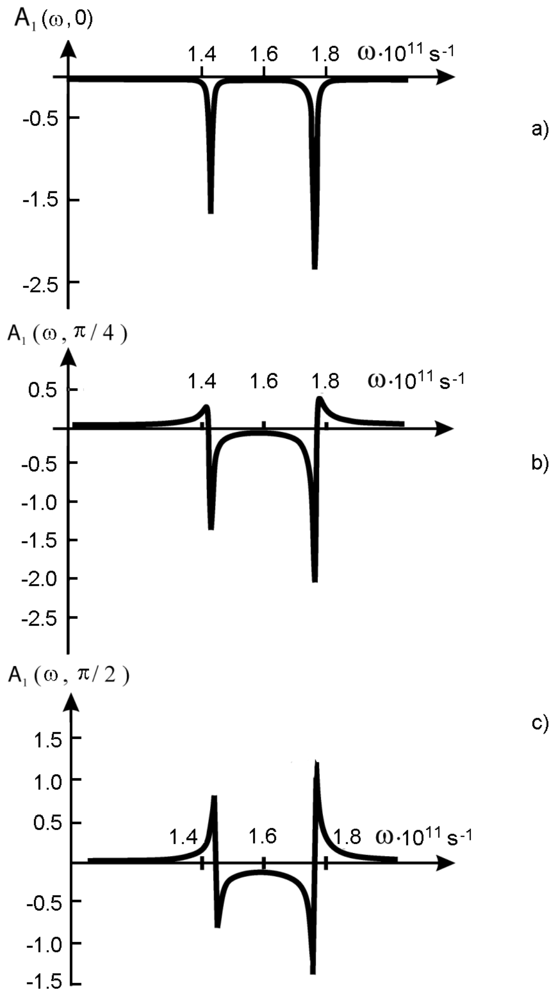

Fig. Dependences of $A_1(\omega;\chi)$ on the external field frequency at $\chi = 0$ (a), $\chi = \pi/4$ (b) and $\chi = \pi/2$ (c).

Two typical resonances at the frequencies $\omega=\omega_1\sqrt{\sigma}$ and $\omega=\omega_1\sqrt{\sigma+1}$ take place in the case $\chi=0$. Thus, $A_1\left(\omega_1\sqrt{\sigma};0\right)\approx-1.6$ and $A_1\left(\omega_1\sqrt{\sigma+1};0\right)\approx-2.4$ which provides the absolute values of DW drift speed 6.3 cm/s and 9.4 cm/s, respectively. In the case $\chi=\pi/4$, the peculiarities of "resonance-antiresonance" type arise at the same frequencies. The resonances in those regions of the dependence which took place at $\chi=0$ (the area of function A_1 negative values) remain pronounced. The width of the resonance-antiresonance region in this case is $\Delta\omega\approx1.4\cdot10^9$ s^{-1}. The function $A_1(\omega;\pi/4)$ possesses the values $A_1\left(\omega_1\sqrt{\sigma};\frac{\pi}{4}\right)\approx\begin{cases}0.2\\-1.3\end{cases}$, $A_1\left(\omega_1\sqrt{\sigma+1};\frac{\pi}{4}\right)\approx\begin{cases}-2.0\\0.4\end{cases}$. The maximum drift speed (8 cm/s) in this case is attained at the frequency $\omega_1\sqrt{\sigma+1}$.

In the case $\chi=\pi/2$, the resonance-antiresonance behavior of the function $A_1(\omega;\pi/2)$ holds, and $A_1\left(\omega_1\sqrt{\sigma};\frac{\pi}{2}\right)\approx\pm0.8$ and $A_1\left(\omega_1\sqrt{\sigma+1};\frac{\pi}{2}\right)\approx\mp1.2$. The absolute values of drift speed 3.2 cm/s and 4.7 cm/s correspond to these values, respectively. Near these frequencies, the DW changes the motion direction into the opposite one. The transition between the resonance and antiresonance behaviors occurs in a narrow frequency region which is of the same order for both peculiarities and is equal to $\Delta\omega\approx10^9$ s^{-1}.

Let us consider now the features of DW dynamics in electric and magnetic fields $H_{0z}E_{0y}$. The dependence $A_2(\omega;\chi_z)$ has the only resonance at the frequency $\omega=\omega_1$. At the resonance frequency for the values $H_{0z}=1.0$ Oe, $E_{0y}=0.1$ CGSE units, the DW drift speed is 12 cm/s, 61 cm/s, 1 m/s for the phase shifts $\chi=0$, $\chi=\pi/4$, $\chi=\pi/2$, respectively.

5. Conclusion

The nonlinear dynamics of DW in magnetic materials with linear magnetoelectric interaction in external alternating fields has been considered. It is established that, against the background of DW fast vibrations, a slow component of translatory (drift) motion of DW exists. The drift motion of DW can be caused either by the crossed alternating magnetic field polarized in the XY plane or by the crossed electric E_{0y} and magnetic H_{0z} fields.

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Динамічні властивості антиферомагнетиків у змінних полях

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Досліджено динаміку доменних меж у зовнішніх змінних магнітному та електричному полях в антиферомагнітних матеріалах з лінійною магнітоелектричною взаємодією. Обговорюються особливості коливального та дрейфового руху доменних меж залежно від параметрів зовнішніх полів і характеристик матеріала.