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TRANSMISSION SPECTRA IN FERRITE-SEMICONDUCTOR PERIODIC STRUCTURE

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Abstract—The specific features of TE-wave propagation in a structure fabricated by periodic alternating ferrite and semiconductor layers are investigated. Dispersion characteristics of eigenwaves are calculated. The transmission spectra of an electromagnetic wave oblique incident from the uniform medium onto the multilayer periodic ferrite-semiconductor structure is considered. The features of transmission spectra of the structure with periodicity breakdown are studied.

1. INTRODUCTION

The recent advent of artificial electromagnetic materials (metamaterials) has opened new opportunities for creating the media, which could provide an additional control over the properties of propagating waves. Semiconductor and ferromagnetic materials lie at the heat of current information technology. The periodic layered structures with semiconductor and ferromagnetic layers combine different physical properties which do not exist in nature and may be promising for obtaining magnetic systems in semiconductor electronics and spintronics. These structures can easily change their characteristics in an external magnetic field. The results of theoretical investigations of space-inhomogeneous magnetic media were presented in [1–9]. It was considered the reflection from the semiinfinite periodically layered structure composed of alternating semiconductor and insulator layers [10]. The energy reflection for the case of TE-wave normal incidence on a semi-infinite plane-stratified structure comprising magnet and nonmagnetic dielectric layers was examined in [11]. It was shown that an external

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field can be used to control the spectrum and characteristics of reflected waves. The peculiarities in the spectra of bulk and surface electromagnetic waves in a periodic layered ferrite-semiconductor structure in the effective (finely stratified) medium approximation for intrinsic types of waves was studied in [12]. It was shown that ferrite composites have a negative effective refraction index in some microwave frequencies. The periodical metal-ferrite film composite with symmetrical configuration was analyzed in [13]. It was demonstrated that multilayer waveguides composed of ferromagnetic and dielectric materials have the negative effective refraction index for TE- and TM-waveguide mode [14]. The expressions for effective permeability and permittivity were obtained in the long-wave limit. It was shown that in periodic ferromagnet-semiconductor multilayer composite the left-handed behavior is possible [15–17].

In this paper, we derive analytical formulas and perform numerical calculations of the reflection and transmission coefficients for the electromagnetic wave incident onto a finite periodically layered structure composed of the ferrite and semiconductor layers and subjected to an external magnetic field. The external magnetic field is applied parallel to the layers; the waves traveling in the plane normal to the field are considered. It is shown that by analyzing the frequency, angle of incidence, and magnetic field dependences of the above coefficients one can determine the geometrical as well as physical parameters of the layers making up the structure. We look into the peculiarities of transmittivity through the periodic structure with periodicity-violating ferrite layer.

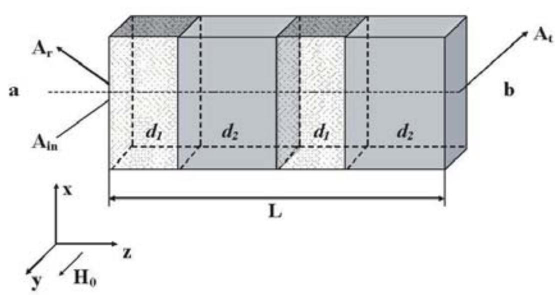


Figure 1. Geometry of the problem.

2. STATEMENT OF THE PROBLEM AND BASIC EQUATIONS

Let us analyze the transmission and reflection of the plane-wave from the magnetoactive periodic structure. Consider a finite periodic structure consisting of alternate ferrite and semiconductor layers (see Fig. 1). We assume that the first layer thickness is d_1, whereas the second layer thickness is d_2 (index 1 refers to the ferrite layers and index 2 to the semiconductor ones). Assume that the thickness of the structure is L ($L = Nd$, where N is the number of periods, $d = d_1 + d_2$ is the period of the structure). We introduce a coordinate system such that the x axis is parallel to the boundaries of the layers and the z axis is perpendicular to the layers. We suppose that the structure is infinite in the x and y directions. Let the structure be exposed to an external magnetic field $\mathbf{H}_0$ parallel to the y axis. Assume the structure to be placed between homogeneous media with the dielectric permittivities ε_a and ε_b. The incident, reflected and transmitted wave vectors lie in the xz plane.

Electromagnetic processes in this structure are described by the Maxwell equations and by the equations of continuity and the motion of charge carriers. We seek the variables in these equations in the form of $\exp(ik_x x + ik_z z - i\omega t)$.

The permeability of ferrite layer is a tensor characteristic for the investigated microwave region. It can be written as [18]

$$\begin{aligned}\mu_{||} &= \mu_{xx} = \mu_{zz} = 1 + \frac{\omega_M\left(\omega_H^2 + \omega_r^2 - i\omega_r\omega\right)}{\omega_H\left(\omega_H^2 + \omega_r^2 - \omega^2 - 2i\omega_r\omega\right)},\\ \mu_{\perp} &= \mu_{xz} = -\mu_{zx} = -\frac{i\omega\omega_M}{\omega_H^2 + \omega_r^2 - \omega^2 - 2i\omega_r\omega},\end{aligned}$$

where $\omega_M = \frac{2\pi eg}{mc}M$, $\omega_H = \frac{eg}{2mc}H_0$, g is the factor of spectroscopic splitting, M is the saturation magnetization, ω_r is the relaxation frequency. The permittivity tensor for the medium has a diagonal form with components $\varepsilon_{ii} = \varepsilon_f$.

The permittivity tensor of the semiconductor layer can be given as [19]

$$\varepsilon_{||} = \varepsilon_{xx} = \varepsilon_{zz} = \varepsilon_0\left[1 - \frac{\omega_p^2(\omega + i\nu)}{\omega\left((\omega + i\nu)^2 - \omega_c^2\right)}\right],$$

$$\varepsilon_\perp = \varepsilon_{xz} = -\varepsilon_{zx} = -i\varepsilon_0 \frac{\omega_p^2 \omega_c}{\omega\left((\omega + i\nu)^2 - \omega_c^2\right)},$$
$$\varepsilon_{yy} = \varepsilon_0 \left[1 - \frac{\omega_p^2}{\omega(\omega + i\nu)}\right].$$

Here ε_0 is the part of the permittivity attributed to the lattice, ω_p is the plasma frequency, ω_c is the cyclotron frequency, and ν is the collision frequency. The tensor of permeability for nonmagnetic semiconductor is $\mu_{ii} = 1$. Suppose that the structure is uniform in the y direction. Then, Maxwell's equations split into independent equations for two modes with different polarizations. We consider the TE-polarization with components H_x, H_z, E_y. Note that the external magnetic field affects the TE-wave properties in a ferrite layer only.

The transversal wavenumbers of the layers take the form:

$$k_{z1} = \sqrt{\frac{\omega^2 \mu_F \varepsilon_f}{c^2} - k_x^2}, \; k_{z2} = \sqrt{\frac{\omega^2 \varepsilon_{yy}}{c^2} - k_x^2},$$

where $\mu_F = \mu_{||} + \frac{\mu_\perp^2}{\mu_{||}}$ is the effective permeability.

Now consider an infinite periodic structure consisting of alternate ferrite and semiconductor layers. The boundary conditions imply that the tangential electric field component and the normal component of the magnetic induction are continuous at the boundaries between the layers. Using the method of the transmission matrix (which relates the fields at the at the beginning and the end of the period of the structure) and applying the Floquet theorem, which takes into account the periodicity of the structure, we arrive at the dispersion relation:

$$\cos \bar{k} d = \cos k_{z1} d_1 \cos k_{z2} d_2 - \frac{1}{2}\left[\frac{k_{z1}}{k_{z2}}\frac{1}{\mu_F} + \frac{k_{z2}}{k_{z1}}\mu_F - \frac{k_x^2}{k_{z1} k_{z2} \mu_F}\left(\frac{\mu_\perp}{\mu_{||}}\right)^2\right] \sin k_{z1} d_1 \sin k_{z2} d_2. \tag{1}$$

Here $\bar{k}$ is the Bloch wavenumber averaged over the period. The analysis of expression for effective permeability reveals 2 characteristic frequencies for magnetic layers: $\omega_1 = \sqrt{\omega_H(\omega_H + \omega_M)}$ is the frequency of ferromagnetic resonance ($\mu_F \to 0$), $\omega_2 = \omega_H + \omega_M$ is the frequency of anti-resonance ($\mu_\perp = 0$). From the dispersion Equation (1) we obtain third characteristic frequency: $\omega_3 = \sqrt{\omega_H^2 + \frac{\omega_M^2}{2} + \omega_H \omega_M}$, for which the expression in square brackets is equal to zero.

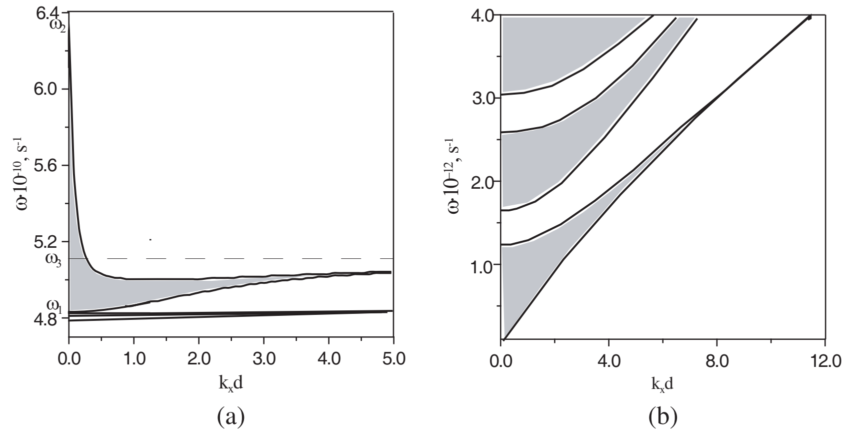


Figure 2. Dispersion dependence for the infinite structure. $\varepsilon_f = 5.5$, $\omega_M = 3.11 \cdot 10^{10}\,\mathrm{s}^{-1}$, $H_0 = 2000\,\mathrm{Oe}$, $\varepsilon_0 = 17.8$, $\omega_p = 1 \cdot 10^{11}\,\mathrm{s}^{-1}$, $g = 2$, $d_1 = 0.02\,\mathrm{cm}$, $d_2 = 0.005\,\mathrm{cm}$.

The band structure of the spectrum is depicted in Fig. 2 [17]. For simplicity, we ignore the collision frequency in the semiconductor layers and magnetic damping in the ferrite. The transmission bands are indicated by hatching. It should be noted that close to the frequency of ferromagnetic resonance (ω_1) the optical width of the ferrite layers ($k_{z1}d_1$) tends to infinity. It leads to the fast oscillations of trigonometric functions in the Equation (1) and to the formation of numerous narrow transmission bands (see Fig. 2(a)). In the frequency region $\omega_1 < \omega < \omega_2$ one transmission band can be highlighted. For $k_x \to \infty$ and $\omega \to \omega_3$ the width of the band tends to zero. The allowed bands for "dielectric" modes take place above the characteristic frequencies (Fig. 2(b)). In this frequency region the semiconductor layer permittivity and ferrite layer permeability almost are not frequency-dependent.

3. REFLECTION AND TRANSMISSION COEFFICIENTS

In this section we present the analytical and numerical investigation of the dependencies of the reflection and transmission coefficients upon parameters of finite periodic ferrite-semiconductor structure.

To describe the finite-in-the z-direction periodic structure we use the Abeles theory [20] and raise the transfer matrix $\hat{m}$ for one period (the components of this matrix are presented in appendix) to the N-th power ($\hat{S} = (\hat{m})^N$):

$$
\begin{aligned}
S_{11} &= m_{11}\frac{\sin N\bar{k}d}{\sin \bar{k}d} - \frac{\sin (N-1)\,\bar{k}d}{\sin \bar{k}d},\\
S_{12} &= m_{12}\frac{\sin N\bar{k}d}{\sin \bar{k}d},\\
S_{21} &= m_{21}\frac{\sin N\bar{k}d}{\sin \bar{k}d},\\
S_{22} &= m_{22}\frac{\sin N\bar{k}d}{\sin \bar{k}d} - \frac{\sin (N-1)\,\bar{k}d}{\sin \bar{k}d}.
\end{aligned}
\tag{2}
$$

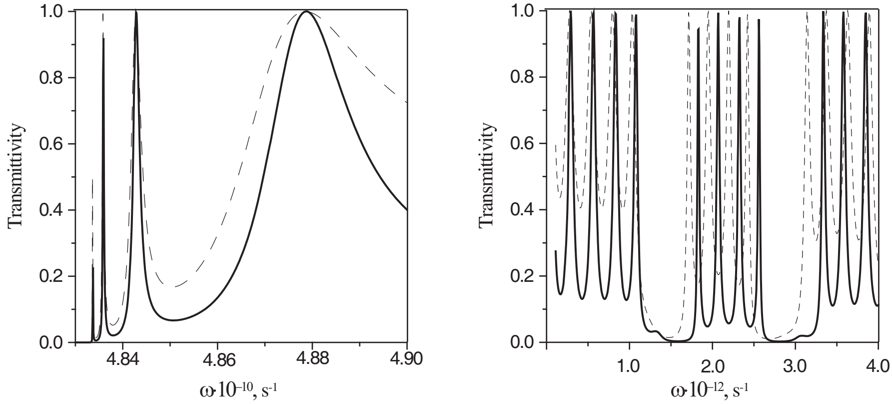
Assume that $k_x = \frac{\omega}{c}\sqrt{\varepsilon_a}\sin\theta$, the transversal wave numbers for the homogeneous media are $k_{za} = \frac{\omega}{c}\sqrt{\varepsilon_a}\cos\theta$ and $k_{zb} = \sqrt{\left(\frac{\omega}{c}\right)^2\varepsilon_b - k_x^2}$, θ is the angle of electromagnetic wave incidence. Using the boundary conditions for tangential components of the electromagnetic field at $z = 0$ and $z = Nd$, we arrive at the expressions for reflection and transmission coefficients

$$
\begin{aligned}
R &= \frac{\frac{c}{\omega}k_{za}S_{11} - \left(\frac{c}{\omega}\right)^2 k_{za}k_{zb}S_{12} + S_{21} - \frac{c}{\omega}k_{zb}S_{22}}{\frac{c}{\omega}k_{za}S_{11} - \left(\frac{c}{\omega}\right)^2 k_{za}k_{zb}S_{12} - S_{21} + \frac{c}{\omega}k_{zb}S_{22}},\\
T &= \frac{2\frac{c}{\omega}k_{za}\exp\left(-ik_{zb}Nd\right)}{\frac{c}{\omega}k_{za}S_{11} - \left(\frac{c}{\omega}\right)^2 k_{za}k_{zb}S_{12} - S_{21} + \frac{c}{\omega}k_{zb}S_{22}}
\end{aligned}
\tag{3}
$$

Let us determine the angle of full passage of electromagnetic waves, for which the reflectance is equal to zero. The correspondent incident angle is called the Bruster angle. Assume that the periodic structure is placed into the vacuum $\varepsilon_a = \varepsilon_b = 1$. In this case $|R|^2 = 0$ ($|T|^2 = 1$) if $N\bar{k}d = \pi q$, $q = 0, \pm 1, \pm 2\ldots$, it implies that the Wolf-Bragg resonance takes place; under this condition the layer thickness is equal to an integer number of half-waves.

The transmittivity for the finite periodic structure, as a function of the frequency, for different frequency ranges, is shown in Fig. 3. The calculations were performed for 5 periods ($N = 5$), $\varepsilon_a = \varepsilon_b = 1$ (i.e., the uniform media are vacuum). The solid curves are for $\theta = \pi/3$ and the dashed curves are for $\theta = \pi/6$. The dependencies are not monotonous, but the curves are similar. It can be seen that we get $N-1$ resonant points in each allowed band of the spectrum corresponding to the Brewster's frequencies.

The band spectrum of periodic structure is determined by the magnetic field strength H_0. Therefore, the reflection depends on the frequency ω_H. The dependencies $|R|^2(H)$ at $\omega = 4 \cdot 10^{10}\,\mathrm{s}^{-1}$ (curve



(a) (b)

Figure 3. Transmissivity as a function of the frequency. $\varepsilon_f = 5.5$, $\omega_M = 3.11 \cdot 10^{10}\,\mathrm{s}^{-1}$, $H_0 = 2000\,\mathrm{Oe}$, $\varepsilon_0 = 17.8$, $\omega_p = 1 \cdot 10^{11}\,\mathrm{s}^{-1}$, $g = 2$, $d_1 = 0.02\,\mathrm{cm}$, $d_2 = 0.005\,\mathrm{cm}$.

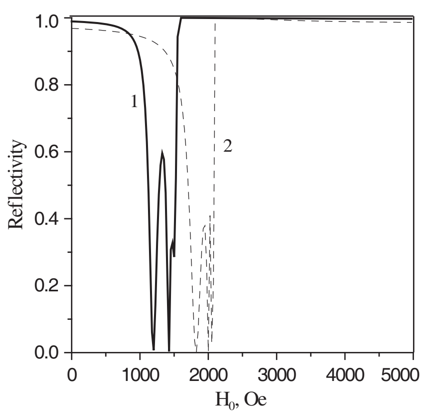


Figure 4. Reflectivity as a function of an external magnetic field ($N = 20$).

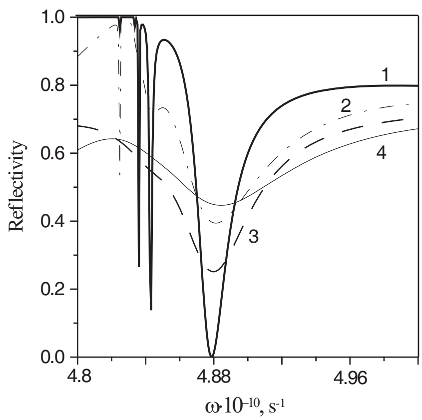


Figure 5. Reflectivity as a function of a frequency. $\theta = \pi/3$, $N = 5$, $\omega_r = (1)0$, $(2)1.06 \cdot 10^8\,\mathrm{s}^{-1}$, $(3)0$, $(4)1.06 \cdot 10^8\,\mathrm{s}^{-1}$, $\nu = (1)0$, $(2)0$, $(3)10^{10}\,\mathrm{s}^{-1}$, $(4)10^{10}\,\mathrm{s}^{-1}$.

1) and $\omega = 5 \cdot 10^{10}\,\mathrm{s}^{-1}$ (curve 2) and at specified value $\theta = \pi/6$ are presented in Fig. 4. The magnetic field ranges of $70\,\mathrm{Oe} < H_0 < 1550\,\mathrm{Oe}$ (curve 1) and $1300\,\mathrm{Oe} < H_0 < 2075\,\mathrm{Oe}$ (curve 2) correspond to the allowed band for the electromagnetic wave. Outside of these ranges the Bloch wave number is imaginary and, as a result, the trigonometrical functions in (2) transform into the hyperbolic ones, and the reflectivity oscillations do not take place. At frequencies $\omega > \omega_p$, the reflection is weakly dependent on the external magnetic field.

Here, we examine how the dissipative processes affect the properties of the reflection and transmission (Fig. 5). Curve 1 corresponds to the nondissipative structure. It can be seen that when the collisions are taken into account, the reflection in the forbidden bands is less than unity, i.e., the energy penetration of the incident wave into the structure occurs. The reason is that the wave numbers of layers $k_{z1,z2}$ and Bloch wave number $\bar{k}$ are complex.

Figure 6 shows the reflectivity versus the wave incidence angle. Different figures ((a) and (b)) correspond to the different frequencies. Consider the influence of dielectric permittivities of homogeneous media on the reflectivity and transmittivity of periodic magnetoactive structure. Assume that $\varepsilon_a = \varepsilon_b$. In the allowed bands (Fig. 6(a)) the reflectivity is seen to increase with the dielectric permittivity of homogeneous media. The penetration of the incident wave increases with $\varepsilon_{a,b}$ as well (Fig. 6(b)).

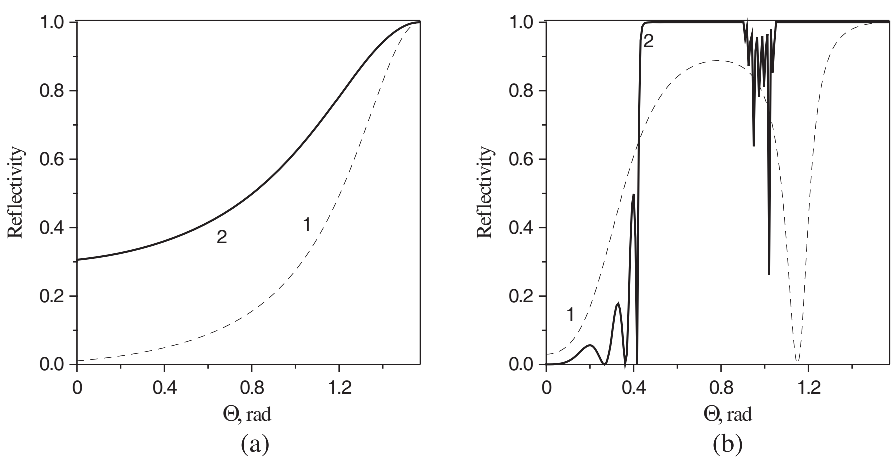


Figure 6. Reflectivity as the function of an angle of an incident wave. $\omega =$ (a) $5 \cdot 10^{10}\,\mathrm{s}^{-1}$, (b) $2 \cdot 10^{11}\,s^{-1}$, $\varepsilon_a = \varepsilon_b =$ (1)1, (2)12.

4. TRANSMISSION SPECTRA OF THE STRUCTURE WITH PERIODICITY BREAKDOWN

Now consider the layered periodic structure with one defect ferrite layer. The parameters of defect ferrite layer do not coincide with those of ferrite layers forming the periodic cell. We assume that the periodicity-violating layer can have another saturation magnetization M_V or frequency ω_{MV}, and another thickness d_V. Let us assume that N_1 is the number of the periods at the left of the defect period, and N_2 is the number of the periods at the right of it. The frequency-dependent transmittivity for $\theta = \pi/3$ is presented in Fig. 7. The dashed curve is for defectless periodic ferrite-semiconductor structure. The simulation was carried out for a layered structure consisting 14 periods ($N = 14$) of alternating layers with the following parameters: $\varepsilon_f = 5.5$, $\omega_M = 3.11 \cdot 10^{10}\,\mathrm{s}^{-1}$, $g = 2$, $\varepsilon_0 = 17.8$, $\omega_p = 1 \cdot 10^{11}\,\mathrm{s}^{-1}$, $d_1 = 0.02\,\mathrm{cm}$, $d_2 = 0.005\,\mathrm{cm}$, $H_0 = 2000\,\mathrm{Oe}$. The frequency range in Fig. 7 corresponds to the allowed band of defectless periodic structure. The solid curve is for the defect structure that consists of a defect period with periodicity-violating ferrite ($\varepsilon_f = 5.5$, $\omega_{MV} = 5 \cdot 10^{10}\,\mathrm{s}^{-1}$ ($\omega_{1V} = 5,47 \cdot 10^{10}\,\mathrm{s}^{-1}$), $g = 2$, $d_V = d_1$) and semiconductor (parameters of this layer coincide with the parameters of all semiconductor layers of the structure) layers, $N_1 = 5$, $N_2 = 8$. It can be seen that the defect structure has the point of full reflectance ($|T|^2 = 0$) close to the frequency of ferromagnetic resonance of defect ferrite layer ω_{1V}. At frequencies $\omega_{1V} < \omega < \omega_{2V}$ the transversal wave number of defect layer is purely imaginary ($k_{zV}^2 < 0$), and the electromagnetic wave tunnel through the layer. If the penetration depth of this wave is higher as compared to the thickness of the periodicity-violating layer or equal to it, then the defect structure transmittivity differ from that for a defectless periodic system in that it has the additional resonance point. The transmittivity in the resonance point decreases with increasing defect layer thickness.

Consider the case where $\omega_M > \omega_{MV}$ and the frequency of the ferromagnetic resonance of the periodicity-violating layer belongs to the forbidden band of defectless periodic structure ($\bar{k}^2 < 0$). Fig. 8 shows the transmittivity versus frequency at different number of periods at the left and right of the defect layer (the whole number of periods is constant). It can be seen that due to a resonance tunneling of an electromagnetic wave through the defectless part of the structure, a narrow transmittivity peak appears [5, 6]. The presence of defect layers in the periodic structure causes the appearance of defect modes in the forbidden bands.

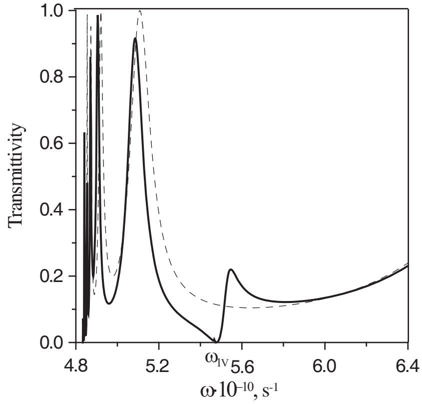


Figure 7. The frequency dependence of transmittivity, ($\omega_M < \omega_{MV}$).

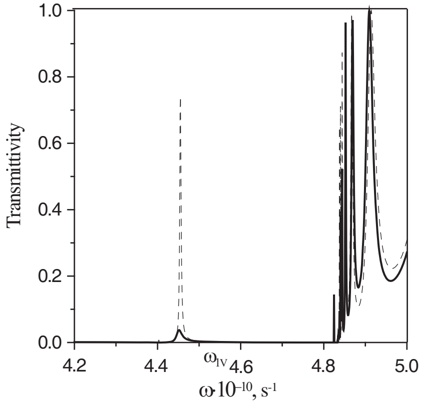


Figure 8. The frequency dependence of transmittivity ($\omega_M > \omega_{MV}$, $\theta = \pi/3$): $N_1 = 5$ and $N_2 = 8$ (solid line), $N_1 = 8$ and $N_2 = 5$ (dashed line).

5. FINE-STRATIFIED PERIODIC STRUCTURE

Let us investigate dispersion relation (1) for a fine-stratified medium, i.e., let us assume that k_{z1}, $k_{z2} \ll 1$. In this case, the dispersion relation for a fine-layered composite is written as

$$k_z^2 \mu_{zz} + k_x^2 \mu_{xx} = \frac{\omega^2}{c^2} \mu_{xx} \mu_{zz} \varepsilon^*, \tag{4}$$

where $\mu_{xx} = \frac{d_1 \mu_F + d_2}{d}$, $\mu_{zz} = \frac{\mu_{xx} \mu_{zz}^*}{(\mu_{xx} + \alpha \mu_{zz}^*)}$, $\mu_{zz}^* = \frac{d \mu_F}{d_2 \mu_F + d_1}$, $\alpha = \frac{d_1 d_2}{\mu_F d^2} \left(\frac{\mu_\perp}{\mu_{||}} \right)^2$, $\varepsilon^* = \frac{d_1 \varepsilon_f + d_2 \varepsilon_{yy}}{d}$. The Bloch wave number $\bar{k} = k_z$ is the transverse wave vector of a bigyrotropic medium [16]. Let us assume that $k_x = 0$. In this case, the dispersion relation takes the form

$$k_z^2 = \frac{\omega^2}{c^2} \mu^* \varepsilon^*, \tag{5}$$

where $\mu^* = \mu_{xx}$. Fig. 9 shows how the effective permittivity ε^* and effective permeability μ^* depend on the frequency. In Fig. 9(a), in the frequency range $\omega_1 < \omega < \omega_4$ ($\omega_4 = \sqrt{\left(\omega_H + \omega_M \frac{d_1}{d}\right) (\omega_H + \omega_M)}$), the effective permeability μ^* is negative. For $\omega < \omega_5$ ($\omega_5 = \frac{\omega_p \sqrt{\varepsilon_0 d_2}}{\sqrt{\varepsilon_0 d_2 + \varepsilon_f d_1}}$),

$\varepsilon^* < 0$. Hence, for $\omega_4 < \omega_5$, in the frequency range $\omega_1 < \omega < \omega_4$ we have the composite with the left-handed behavior. To control the left-handed properties of the structure, we should change the external magnetic field. It was considered the influence of dissipative processes on the effective parameters of the ferrite-semiconductor structure (Fig. 9(b)).

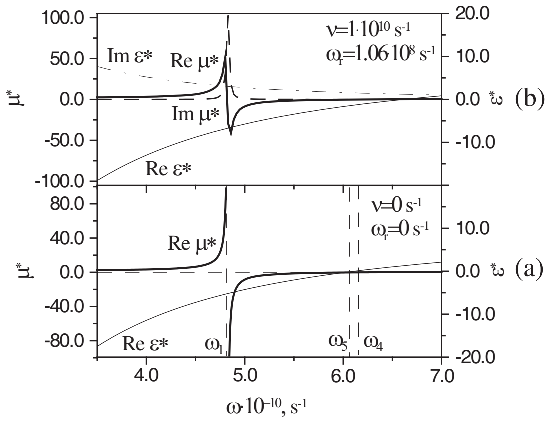


Figure 9. The frequency dependencies of the effective parameters. $\varepsilon_f = 5.5$, $\omega_M = 3.11 \cdot 10^{10}\,\mathrm{s}^{-1}$, $\varepsilon_0 = 17.8$, $H_0 = 2000\,\mathrm{Oe}$, $\omega_p = 1 \cdot 10^{11}\,\mathrm{s}^{-1}$, $g = 2$, $d_1 = 0.002\,\mathrm{cm}$, $d_2 = 0.0005\,\mathrm{cm}$.

The expressions for reflection and transmission coefficients take form

$$\begin{aligned} R &= \frac{k_z \mu_{xx} \cos k_z L\ (k_{za} - k_{zb}) + i \sin k_z L \left(k_z^2 - k_{za} k_{zb} \mu_{xx}^2\right)}{k_z \mu_{xx} \cos k_z L\, (k_{za} + k_{zb}) - i \sin k_z L\, (k_z^2 + k_{za} k_{zb} \mu_{xx}^2)}, \\ T &= \frac{2e^{-ik_{zb}L} k_z k_{za} \mu_{xx}}{k_z \mu_{xx} \cos k_z L\ (k_{za} + k_{zb}) - i \sin k_z L\, (k_z^2 + k_{za} k_{zb} \mu_{xx}^2)}. \end{aligned} \tag{6}$$

The transmittivity for the finite fine-stratified periodic structure as a function of the frequency is shown in Fig. 10. The calculations were performed for 50 periods ($L = 0.125\,\mathrm{cm}$), $\varepsilon_a = \varepsilon_b = 1$. The solid curve is for normal incidence ($\theta = 0$) and the dashed one is for $\theta = \pi/3$.

The analysis of formulas (6) for the case of normal incidence allows us to obtain the additional point of full transmittance, when the condition $\varepsilon_a = \frac{\varepsilon^*}{\mu^*}$ takes place. Maximum of the transmittivity at frequency $\omega = 5.06 \cdot 10^{10}\,\mathrm{s}^{-1}$ (solid curve) is connected with an implementation of this condition. The rest of the maximums are explained by Wolf-Bragg resonances. The minimum value of the

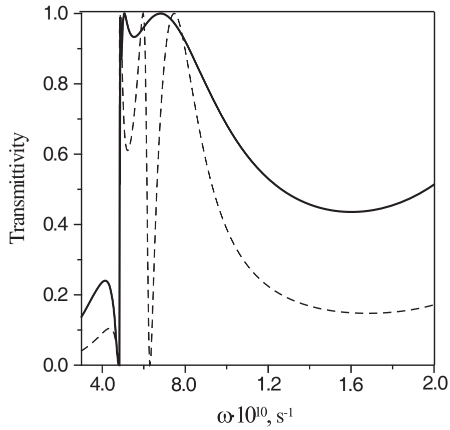


Figure 10. Transmissivity as a function of the frequency. $\varepsilon_f = 5.5$, $\omega_M = 3.11 \cdot 10^{10}\,\text{s}^{-1}$, $H_0 = 2000\,\text{Oe}$, $\varepsilon_0 = 17.8$, $\omega_p = 1 \cdot 10^{11}\,\text{s}^{-1}$, $g = 2$, $d_1 = 0.002\,\text{cm}$, $d_2 = 0.0005\,\text{cm}$, $N = 50$.

transmittivity for $\theta = \pi/3$ (dashed curve) corresponds to the case, where $\mu_{xx} = 0$ ($\omega = \omega_1 = 4.84 \cdot 10^{10}\,\text{s}^{-1}$ and $\omega = \omega_5 = 6.31 \cdot 10^{10}\,\text{s}^{-1}$).

6. CONCLUSION

In summary, we have presented the transmission spectra of electromagnetic waves which propagate through a layered periodic ferrite-semiconductor structure. We have studied peculiarities of bulk waves in such a structure. The effect of dissipation in the layers on the reflectivity (transmittivity) of electromagnetic waves has been examined. It has been shown that by analyzing the frequency, angle of incidence, and magnetic field dependencies of the reflectivity or transmittivity one can determine the geometrical as well as physical parameters of the layers composing the structure. The results of our investigations can be used in the implementation of variety of microwave and optical devices.

ACKNOWLEDGMENT

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APPENDIX A.

Components of the transfer matrix for one period of the ferrite-semiconductor structure:

$$\begin{aligned}
m_{11} =& \cos k_{z1}d_1 \cos k_{z2}d_2 - \frac{k_{z2}}{k_{z1}}\mu_F \sin k_{z1}d_1 \sin k_{z2}d_2 \\
&+ i\frac{k_x}{k_{z1}}\frac{\mu_\perp}{\mu_{||}} \sin k_{z1}d_1 \cos k_{z2}d_2, \\
m_{12} =& i\frac{\omega}{c}\left(\frac{1}{k_{z2}} \cos k_{z1}d_1 \sin k_{z2}d_2 + \frac{\mu_F}{k_{z1}} \sin k_{z1}d_1 \cos k_{z2}d_2\right. \\
&\left.+ i\frac{k_x}{k_{z1}k_{z2}}\frac{\mu_\perp}{\mu_{||}} \sin k_{z1}d_1 \sin k_{z2}d_2\right), \\
m_{21} =& i\frac{c}{\omega}\left(\frac{1}{\mu_F}\left(-\frac{k_x^2}{k_{z1}}\left(\frac{\mu_\perp}{\mu_{||}}\right)^2 + k_{z1}\right) \sin k_{z1}d_1 \cos k_{z2}d_2\right. \\
&\left.+ k_{z2} \cos k_{z1}d_1 \sin k_{z2}d_2 - ik_x\frac{k_{z2}}{k_{z1}}\frac{\mu_\perp}{\mu_{||}} \sin k_{z1}d_1 \sin k_{z2}d_2\right), \\
m_{22} =& -\frac{1}{\mu_F}\frac{1}{k_{z2}}\left(-\frac{k_x^2}{k_{z1}}\left(\frac{\mu_\perp}{\mu_{||}}\right)^2 + k_{z1}\right) \sin k_{z1}d_1 \sin k_{z2}d_2 \\
&+ \cos k_{z1}d_1 \cos k_{z2}d_2 - i\frac{k_x}{k_{z1}}\frac{\mu_\perp}{\mu_{||}} \sin k_{z1}d_1 \cos k_{z2}d_2.
\end{aligned}$$

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