Interaction of electromagnetic H-wave with thin conducting film taking into account anisotropy of isoenergetic surface of conductor

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Abstract

The coefficients of reflection, absorption and transmission of electromagnetic H-wave with thin conducting film located between two dielectric environments are calculated in the framework of the kinetic theory in this article. The case of an anisotropic isoenergetic surface of a conductor is considered. The electromagnetic wave is incident onto the upper surface of the film at an arbitrary angle. The case of different specularity coefficients when reflecting electrons (holes) from the lower and upper surfaces of the film is considered. The isoenergetic surface of the conductor is a three-axis ellipsoid, one main axis of which is parallel to the normal to the boundary of the film, and the other to the electric field of the incident electromagnetic wave. The analysis of the dependences of the reflection, absorption and transmission coefficients on the effective mass for degenerate and non-degenerate gas of free charge carriers is carried out.

1. Introduction

Great attention was paid to the optical properties of thin conductive films, in particular the absorption, reflection, and electromagnetic wave transmission coefficients [1-4]. The calculation of the optical parameters of the metal film was carried out in [1] for the H-wave. In this work, the film is in a vacuum ($\varepsilon=1$), the film surfaces have an equal specularity ratio. In the work [2], which is a continuation of the work [1], different coefficients specularity of surfaces of the film and the presence of different environments on different sides of the film surfaces are taken into account. Spatial dispersion and quantum wave properties of electrons in optical coefficients were taken into account using the dependence of the metal's permittivity on the frequency of the incident electromagnetic wave in the work [3] for the E-wave. The optical parameters of a one-dimensional metal-dielectric photonic crystal in the case of both E-waves and H-waves are calculated in [4] taking into account both the spatial dispersion and the quantum wave properties of the electron plasma.

The Fermi surface of a metal film is a sphere in articles [1-4]. This article is considered a semiconductor film whose isoenergetic surface has an ellipsoidal shape (silicon, germanium), which is a natural generalization of the most commonly used model of a spherical isoenergetic surface.

This article is a continuation of the work [2]. Anisotropy of the isoenergetic surface and an arbitrary degree of degeneration of the gas of free charge carriers are assumed in this paper.
2. Formulation of the problem

We are considering a thin conductive film of thickness $a$, located between two different media. The upper surface of the film has a mirror coefficient $q_1$ when reflecting electrons (holes) of conductivity from it and borders on a medium having a dielectric surface $\varepsilon_1$. The lower surface of the film has a mirror coefficient $q_2$ when reflecting charge carriers from it and borders on the substrate with a dielectric surface $\varepsilon_2$. The field inside the film is uniform, since the layer thickness is much less than the length of the incident electromagnetic wave. We assume that the thickness of the conductive film is greater than the thickness of the skin layer, this allows us to ignore the skin effect. Quantum effects are neglected. A flat monochromatic $H$-wave (the vector of the electric field of the wave is parallel to the surface of the film) falls on the boundary of the film at an angle $\theta$. In non-magnetic media the values of $\varepsilon_1, \varepsilon_2$ are real. Take a Cartesian coordinate system, the beginning of which is on the upper surface of the film, the $Y$-axis is parallel to the electric field strength of the wave, the $X$-axis is perpendicular to the plane of the film.

Expressions for the reflection coefficient $R$, the transmission coefficient $\hat{T}$, and the absorption coefficient $A$ were obtained in [2] in the case of different angles of incidence of an electromagnetic wave $\theta$ on a film enclosed between two media with dielectric permittivity $\varepsilon_1$ and $\varepsilon_2$:

$$R = \left[\frac{\sqrt{\varepsilon_{1,2}} - \sin^2\theta (\bar{p} + P^{(1)} P^{(2)}) + \cos\theta (\bar{p} - P^{(1)} P^{(2)})}{\sqrt{\varepsilon_{1,2}} - \sin^2\theta (1 + \bar{p}) + \cos\theta (1 - \bar{p})}\right]^2,$$  

(1)

$$\hat{T} = \cos\theta \text{Re} \left[\frac{\varepsilon_{1,2} - \sin^2\theta}{\sqrt{\varepsilon_{1,2}} - \sin^2\theta (1 + \bar{p}) + \cos\theta (1 - \bar{p})}\right]^{2},$$  

(2)

$$A = 1 - \hat{T} - R,$$  

(3)

$$\varepsilon_{1,2} = \frac{\varepsilon_2}{\varepsilon_1}, \quad \bar{p} = \frac{1}{2} (P^{(1)} + P^{(2)}).$$  

(4)

$$P^{(1)} = \frac{\sqrt{\varepsilon_1} Z^{(1)} \cos\theta - 1}{\sqrt{\varepsilon_1} Z^{(1)} \cos\theta + 1}, \quad P^{(2)} = \frac{\sqrt{\varepsilon_1} Z^{(2)} \cos\theta - 1}{\sqrt{\varepsilon_1} Z^{(2)} \cos\theta + 1}.$$  

(5)

where $Z^{(1)}$ and $Z^{(2)}$ are the impedances on the lower and upper surfaces of the film, respectively. $Z^{(1)}$ corresponds to the antisymmetric configuration of the electric field and the symmetric magnetic field configuration: $E_y(0) = -E_y(a), H_z(0) = H_z(a)$ and $Z^{(2)}$ corresponds to the symmetric configuration of the electric field and the antisymmetric configuration of magnetic field$E_y(0) = E_y(a), H_z(0) = -H_z(a)$.

Under the assumption, that the wavelength of incident radiation significantly exceeds the thickness of the layer, the impedances have the form [2]

$$Z^{(1)} = 0, \quad Z^{(2)} = \frac{c}{2\pi a \sigma_y},$$  

(6)

where $c$ is the speed of light, $\sigma_y$ is the thickness-averaged specific electrical conductivity of the metal film along the $Y$ axis (along the electric field of the incident electromagnetic wave).

The non-equilibrium distribution function $f$ is represented as two components: the equilibrium Fermi-Dirac distribution function $f_0$ and the non-equilibrium correction $f_1$, which occurs under the action of an external electric field

$$f = f_0 + f_1 \exp(-i\omega t), \quad f = f(r, v, t), \quad f_1 = f_1(r, v),$$  

(7)

$$f_0 = \{1 + \exp[(\varepsilon - \mu)/k_B T]\}^{-1},$$  

(8)

where $r, v$ and $m$ are the radius vector, velocity, and effective mass of the electron (hole).
In the case of a weak external electric field in the approximation of the relaxation time $\tau$ the Boltzmann equation will take the form:

$$-i\omega f_1 + v \frac{\partial f_1}{\partial r} + e(vE) \frac{\partial f_0}{\partial \varepsilon} = -\frac{f_1}{\tau}. \quad (9)$$

The isoenergetic surface is a three-axis ellipsoid, whose main axes coincide with the coordinate axes $(X, Y, Z)$, so the energy of the conduction electrons (holes) is determined as follows:

$$\varepsilon = \frac{m_1 v_x^2}{2} + \frac{m_2 v_y^2}{2} + \frac{m_3 v_z^2}{2}, \quad (10)$$

where $m_1, m_2, m_3$ are the effective masses of the quasiparticle along the $X, Y$ and $Z$ axes, respectively.

The current density $j$ is defined as follows

$$j = e n \langle v \rangle = e \int v f m^3 d^3 v = 2e \frac{m_1 m_2 m_3}{h^3} \int v f_1 d^3 v, \quad (11)$$

where the concentration of $n$ is defined as

$$n = 2 \frac{m_1 m_2 m_3}{h^3} \int f_0 d^3 v. \quad (12)$$

We apply diffuse-specularity boundary conditions for the kinetic equation (9):

$$\begin{cases} f_1^+(0, v_x) = q_1 f_1^-(0, -v_x) \\ f_1^+(a, -v_x) = q_2 f_1^+(a, v_x) \end{cases} \quad (13)$$

where $f_1^+$ and $f_1^-$ are non-equilibrium distribution functions in the cases of positive and negative velocity projection in the direction perpendicular to the film surface, respectively.

We introduce the following dimensionless parameters for further calculations

$$V_x = \sqrt{2m_1 v_x^2}, \quad V_y = \sqrt{2m_2 v_y^2}, \quad V_z = \sqrt{2m_3 v_z^2}. \quad (14)$$

Then it follows from (14) that

$$V = \sqrt{V_x^2 + V_y^2 + V_z^2} = \frac{\varepsilon}{\mu}, \quad \varepsilon = \mu V^2. \quad (15)$$

Projections of the velocity of electrons (holes) can be expressed in parametric form through spherical coordinates, taking into account (14) and (15)

$$\begin{cases} v_x = \frac{2\varepsilon}{m_1} \cos \theta = \frac{2\mu}{m_1} V \cos \theta, \\ v_y = \frac{2\varepsilon}{m_2} \sin \theta \cos \varphi = \frac{2\mu}{m_2} V \sin \theta \cos \varphi, \\ v_z = \frac{2\varepsilon}{m_3} \sin \theta \sin \varphi = \frac{2\mu}{m_3} V \sin \theta \sin \varphi, \end{cases} \quad (16)$$

where $\theta$ and $\varphi$ are the polar and azimuthal angles in the velocity space, respectively.

3. Solution method and mathematical calculation

We obtain an expression for the electrical conductivity $\sigma_y$ of a thin conducting film in the case of an ellipsoidal isoenergetic surface for different coefficients specularity boundaries. This expression is required in the calculation of the optical coefficients.

The Boltzmann equation (9), taking into account the boundary conditions (13), is solved by the method of characteristics:

$$f_1(x, v_x, v_y) = -\frac{eE_x v_x}{v} \frac{\partial f_0}{\partial \varepsilon} \left[ 1 + \chi(v_x) \exp \left( -\frac{v_x}{v_x} \right) \right], \quad (17)$$

where $\chi(v_x)$ is the specularity parameter.
where $\chi(v_x)$ is a function that depends on the $v_x$ component of the electron velocity, which is from the boundary conditions (3.15); $v$ is a value that we will call the complex scattering frequency. Taking into account the expression (17), the boundary conditions (13) will take the form:

$$
\begin{align*}
1 + \chi^+(v_x) &= q_1[1 + \chi^-(v_x)] \\
1 + \chi^+(v_x)\exp(va/v_x) &= q_2[1 + \chi^+(v_x)\exp(-va/v_x)]'
\end{align*}
$$

Where do we find it:

$$
\begin{align*}
\chi^+(v_x) &= \frac{q_1(q_2 - 1) + (q_1 - 1)\exp(va/v_x)}{\exp(va/v_x) - q_1q_2\exp(-va/v_x)} \\
\chi^-(v_x) &= \frac{(q_2 - 1) + q_2(q_1 - 1)\exp(va/v_x)}{\exp(-va/v_x) - q_1q_2\exp(va/v_x)}
\end{align*}
$$

where $\chi^+$ and $\chi^-$ are functions in the cases of positive and negative projection of the velocity in the direction perpendicular to the surface of the film, respectively.

The found distribution function (17, 18) allows us to calculate the current density (11) inside the conductive film. It is convenient to go to the spherical coordinates in the velocity space $(V, \theta, \varphi)$ when calculating the integral (11). The volume element in spherical coordinates in this case taking into account (15) is equal to

$$
d^3V = \left| \frac{\partial(V_x, V_y, V_z)}{\partial(V, \theta, \varphi)} \right| = \frac{(2\mu)^{3/2}}{\sqrt{m_1m_2m_3}}V^2\sin\theta dV d\theta d\varphi. \tag{19}
$$

The current (11) has only a $y$-component, so in this direction lies the vector of the electric field of the electromagnetic wave. Using the spherical coordinates (16, 19), the distribution function (17, 18), the current density (11) is converted to the following form

$$
\begin{align*}
&j_y = 2\varepsilon \left(\frac{2\mu}{\hbar^3}\right)^{1/2} \int \frac{m_1m_2}{m_0}E_y \int_0^{2\pi} \int_0^\infty V^4 \exp[\mu(V^2 - 1)/k_B T] \{1 + \exp[\mu(V^2 - 1)/k_B T]\}^2 \cos^2\varphi \times
\int_0^{\pi/2} \sin^3\theta \left[ 1 + \chi^+ \left(\sqrt{2\mu/m_1} V \cos\theta\right) \exp \left( -\frac{v_x}{\sqrt{2\mu/m_1} V \cos\theta} \right) \right] d\theta \\
+ &\int_0^{\pi/2} \sin^3\theta \left[ 1 + \chi^- \left(\sqrt{2\mu/m_1} V \cos\theta\right) \exp \left( -\frac{v_x}{\sqrt{2\mu/m_1} V \cos\theta} \right) \right] d\theta \right] d\varphi dV \\
= &2\varepsilon \left(\frac{2\mu}{\hbar^3}\right)^{1/2} \int \frac{m_1m_2}{m_0}E_y \int_0^{2\pi} \int_0^\infty V^4 \exp[\mu(V^2 - 1)/k_B T] \{1 + \exp[\mu(V^2 - 1)/k_B T]\}^2 \times
\int_0^1 (1 - \hat{\ell})^2 \left( 2 + \chi^+ \left(\sqrt{2\mu/m_1} V \hat{\ell}\right) \exp \left( -\frac{v_x}{\sqrt{2\mu/m_1} V \hat{\ell}} \right) \right)
\int_0^1 (1 - \hat{\ell})^2 \left( 2 + \chi^- \left(\sqrt{2\mu/m_1} V \hat{\ell}\right) \exp \left( -\frac{v_x}{\sqrt{2\mu/m_1} V \hat{\ell}} \right) \right) d\hat{\ell} dV,
\end{align*}
$$

where the variable $\hat{\ell} = \cos\theta$ is entered.

Let us introduce dimensionless parameters:

$$
m_0 = \frac{3}{\hbar^2} \frac{m_1m_2m_3}{m_0}, \quad k_{m_1} = \frac{m_1}{m_0}, \quad k_{m_2} = \frac{m_2}{m_0}, \quad k_{m_3} = \frac{m_3}{m_0},
$$

$$
x_0 = \frac{a}{\lambda}, \quad \gamma_0 = \frac{\omega a}{v_1}, \quad z_0 = \frac{v_0}{v_1} = x_0 - iy_0, \quad u = \frac{\mu}{k_B T}, \quad u = \frac{e}{k_B T}
$$

Here $k_{m_1}, k_{m_2}, k_{m_3}$ are dimensionless effective masses along the axes $X, Y, Z$ respectively; $x_0$ is the dimensionless inverse free path length; $y_0$ is the dimensionless frequency of the electromagnetic wave; $\lambda = v_1 \tau$ is the free path length of the electrons (holes).
Separately, it is worth noting the relationship of ellipticity parameters, since \(m_0 = \frac{3}{\sqrt{m_1 m_2 m_3}}\), then \(k_{m1} k_{m2} k_{m3} = 1\), so \(k_{m3} = 1/k_{m1} k_{m2}\). Also, when changing the ellipticity parameters, the concentration of free charge carriers (12) is assumed to be constant, hence \(m_1 m_2 m_3 = \text{const}, m_0 = \text{const}\), and \(k_{m1} \sim m_1, k_{m2} \sim m_2, k_{m3} \sim m_3\).

The parameters \(x_0, y_0\) and \(z_0\) are dimensioned by the characteristic velocity \(v_1\) of the charge carriers:

\[
e v_1^2 = \frac{5}{3} \cdot \frac{m_1 m_2 m_3}{\hbar^3} \int v^2 f_0 d^3 v, \quad \bar{v}_1 = \frac{m_0}{2k_B T} v_1,
\]

where \(n\) is the concentration of charge carriers defined by the expression:

\[
n = 2 \frac{m_1 m_2 m_3}{\hbar^3} \int f_0 d^3 v = 4\pi \left( \frac{2m_0 k_B T}{\hbar^2} \right)^{3/2} I_0,
\]

(21)

\[
I_0 = \int_{0}^{+\infty} \frac{\sqrt{u du}}{1 + \exp(u - \mu)},
\]

Note that in the case of a degenerate Fermi gas \((\mu \gg 1)\) \(v_1 \rightarrow \sqrt{2\mu/m_0}\), that is, it has the order of the Fermi velocity, and in the case of a non-degenerate gas of free charge carriers \((\mu \rightarrow -\infty)\) \(v_1 \rightarrow \sqrt{5k_B T/m_0}\), i.e. it has the order of the average quadratic velocity of electrons (holes) [5].

Then, taking into account the entered dimensionless parameters and concentration (21), the current density (20) is converted to the following form:

\[
j_y = \frac{n e^2 \tau x_0 E_y u_m^{5/2}}{m_0 z_0 I_0 k_{m2}} \int_{0}^{\infty} V^4 \exp(\mu(V^2 - 1)/k_B T) \frac{\sqrt{u du}}{1 + \exp(\mu(V^2 - 1)/k_B T)} \times
\]

\[
\int (1 - \tilde{t}^2) \left[2 + \chi^+ \left( \sqrt{2\mu/m_1 V \tilde{t}} \right) \exp(-\frac{v x}{\sqrt{2\mu/m_1 V \tilde{t}}}) \right] d\tilde{t} dV.
\]

(22)

The current averaged over the thickness of the film is usually found under experimental conditions

\[
j_y = \frac{1}{a} \int_{0}^{a} j_y dx.
\]

(23)

Substituting the expression (22) in (23), and formally applying the local Ohm's law in the form \(j_y = \sigma_y E_y\), we obtain an expression for the thickness-averaged specific conductivity:

\[
\sigma_y = \sigma_0 \Sigma(x_0, y_0, \mu, k_{m1}, k_{m2}, q_1, q_2), \quad \sigma_0 = \frac{n e^2 \tau}{m_0},
\]

(24)

\[
\Sigma(x_0, y_0, \mu, k_{m1}, k_{m2}, q_1, q_2) = \frac{u_m^{5/2} x_0}{z_0 k_{m2} I_0} \int_{0}^{+\infty} A_1 dV \int (1 - \tilde{t}^2)[2
\]

\[
- \frac{1}{A_2} 2 - (q_1 + q_2) + \frac{(q_1 + q_2 - 2q_1 q_2 \exp(-A_2))}{1 - q_1 q_2 \exp(-2A_2)} \exp(-A_2) \{1 - \exp(-A_2)\} d\tilde{t},
\]

(25)

Here \(\Sigma(x_0, y_0, \mu, k_{m1}, k_{m2}, q_1, q_2)\) is the dimensionless specific conductivity.

Thus, expressions (1)-(6), (24), (25) completely determine the reflection coefficient \(R\), transmission coefficient \(T\) and absorption coefficient \(A\) of the conductive layer.
4. Limiting case

4.1. The case of a degenerate electron (hole) gas ($e^{\mu} \gg 1$)

The dimensionless specific conductivity (25) is converted to the following expression:

$$\Sigma(x_0, y_0, k_{m1}, k_{m2}, q_1, q_2) = \frac{x_0}{y_0k_{m2}} \left( 1 - \frac{3}{4z_0\sqrt{k_{m1}}} \int_0^1 \hat{\tau}(1 - \hat{\tau}^2) \times \right.$$

$$\left. \frac{2 - (q_1 + q_2) + (q_1 + q_2 - 2q_1q_2)e^{-A_3}}{1 - q_1q_2e^{-A_3}} [1 - \exp(-A_3)]d\hat{\tau} \right)$$

$$A_3 = z_0\sqrt{k_{m1}/\hat{\tau}}. \tag{26}$$

4.2. The case of a nondegenerate electron (hole) gas ($e^{-\mu} \gg 1$)

The dimensionless specific conductivity (25) will take the form:

$$\Sigma(x_0, y_0, k_{m1}, k_{m2}, q_1, q_2) = \frac{x_0}{y_0k_{m2}} \left( 1 - \frac{2\sqrt{2}}{z_0\sqrt{5k_{m1}\pi}} \int_0^{+\infty} \hat{V}\exp(-\hat{V}^2) \int_0^1 \hat{\tau}(1 - \hat{\tau}^2) \times \right.$$

$$\left. \frac{2 - (q_1 + q_2) + (q_1 + q_2 - 2q_1q_2)e^{-A_4}}{1 - q_1q_2e^{-A_4}} [1 - \exp(-A_4)]d\hat{\tau} \right)$$

$$A_4 = z_0\sqrt{5k_{m1}/2\hat{V}\hat{\tau}}. \tag{27}$$

Let's replace the variable $\hat{\tau}$ in the integral (27) with the variable $\hat{u} = \hat{V}\hat{\tau}$:

$$\Sigma(x_0, y_0, k_{m1}, k_{m2}, q_1, q_2) = \frac{x_0}{y_0k_{m2}} \left( 1 - \frac{2\sqrt{2}}{z_0\sqrt{5k_{m1}\pi}} \int_0^{+\infty} \hat{V}\exp(-\hat{V}^2) \int_0^1 \hat{u}(\hat{V}^2 - \hat{u}^2) \times \right.$$

$$\left. \frac{2 - (q_1 + q_2) + (q_1 + q_2 - 2q_1q_2)e^{-A_5}}{1 - q_1q_2e^{-A_5}} [1 - \exp(-A_5)]d\hat{u} \right)$$

$$A_5 = z_0\sqrt{5k_{m1}/2}\hat{u}. \tag{28}$$

4.3. The case of thick film ($x_0 \gg 1$), high frequency ($y_0 \gg 1$), high values of the effective mass parameter along the $X$ axis ($k_{m1} \gg 1$)

If $x_0 \gg 1, y_0 \gg 1$ or $k_{m1} \gg 1$, then in the expression (25) the exponent $\exp(-z_0\hat{V}\sqrt{k_{m1}/\hat{V}\hat{\tau}/\mu})$ strongly attenuates, as a result we get

$$\Sigma(x_0, y_0, k_{m2}) = \frac{x_0}{z_0k_{m2}}. \tag{29}$$

The expression (29) corresponds to the classical result for a conductive film (Drude's formula).

4.4. Case of non-conductive layer ($\sigma_y \to 0$)

$$Z^{(1)} = 0, \quad Z^{(2)} \to \infty,$$

$$p^{(1)} = -1, \quad p^{(2)} \to 1,$$

$$R = \left| \frac{\cos\theta - \sqrt{e_{1,2} - \sin^2\theta}}{\cos\theta + \sqrt{e_{1,2} - \sin^2\theta}} \right|^2, \tag{30}$$
\[
T = \cos \theta \Re \sqrt{\frac{2}{\sqrt{\varepsilon_{1,2} - \sin^2 \theta + \cos \theta}},}
\]

\[
A = 1 - \hat{T} - R. 
\]

For an almost tangent fall, when \(\theta \to \pi/2\), we get \(R \to 1, \hat{T} \to 0, A \to 0\).

4.5. Case of ideal layer conductivity \((\sigma_y \to \infty)\)

\[
Z^{(1)} = 0, \quad Z^{(2)} \to 0.
\]

\[
P^{(1)} = -1, \quad P^{(2)} \to -1.
\]

\[
R = 1, \quad \hat{T} = 0, \quad A = 1 - \hat{T} - R. 
\]

The coefficient of reflection, coefficient of transmission and coefficient of absorption do not depend on the angle of incidence \(\theta\) and on the dielectric permittivity of the environments adjacent to the film \((\varepsilon_1, \varepsilon_2)\) in the case of ideal conductivity.

5. Analysis of results

We are considered the behavior of the reflection coefficient \(R\), the transmission coefficient \(\hat{T}\), and the absorption coefficient \(A\) depending on the dimensionless effective mass of the charge carriers (figures 1-4) for a particular case. Suppose that an electromagnetic wave falls from a vacuum \((\varepsilon_1 = 1)\) on a thin conductive film \(a = 10\) nm thick, located on a glass substrate \((\varepsilon_2 = 5)\), at an angle \(\theta = 20^\circ\). The frequency of the electromagnetic wave lies in the far infrared range: \(\tilde{f} = 1\) THz. Let the free path length for the degenerate case \(\lambda = 50\) nm, and for the nondegenerate case \(\lambda = 500\) nm; the specific static electrical conductivity of a massive sample is equal to \(\sigma_0 = 10^{17}\) s\(^{-1}\). The specularity coefficients of the upper and lower borders of the film are equal to \(q_1 = .5, q_2 = .6\).

Figures 1-4 show the dependence of the reflection coefficient \(R\), the transmission coefficient \(\hat{T}\), and the absorption coefficient \(A\) on the dimensionless effective mass. With ideal conductivity \((k_{m1} \to \infty \text{ или } k_{m2} \to 0)\), the wave does not penetrate the layer \((R \to 1, T \to 0)\), it is completely reflected, and there is no absorption. At "bad conductivity" \((k_{m1} \to 0 \text{ или } k_{m2} \to \infty)\) there is a partial dissipation of energy of an electromagnetic wave in a layer, the layer practically passes a wave \((R \to \min, T \to \max)\).

The dependence of the absorption coefficient on the effective mass has a maximum that occurs in the case of partial reflection and partial light transmission, when the curves of the reflection and transmission coefficients intersect. The position of this maximum depends on the effective masses and the coefficient specularity surfaces of the film. The maximum of the absorption coefficient is shifted towards higher values of \(k_{m1}\) or towards lower values of \(k_{m2}\) with the growth of the mirror coefficient.

In the classical case (curve 3) (29), the reflection, transmission, and absorption coefficients do not depend on the dimensionless effective mass \(k_{m1}\).
Figure 1. Dependence of the reflection $R$ (solid curves), passage $T$ (dotted curves), and absorption $A$ (point curves) coefficients on the dimensionless effective mass $k_{m1}$ along the $X$ axis for the degenerate case (26) at $x_0 = y_0 = .1, k_{m2} = 1$. Curves 1 $- q_1 = q_2 = 0$, curves 2 $- q_1 = .5, q_2 = .6$, curves 3 $- q_1 = q_2 = 1$.

Figure 2. Dependence of the reflection $R$ (solid curves), passage $T$ (dotted curves), and absorption $A$ (point curves) coefficients on the dimensionless effective mass $k_{m1}$ along the $X$ axis for the nondegenerate case (28) at $x_0 = y_0 = .1, k_{m2} = 1$. Curves 1 $- q_1 = q_2 = 0$, curves 2 $- q_1 = .5, q_2 = .6$, curves 3 $- q_1 = q_2 = 1$.

6. Conclusion
Kinetic model of the interaction of an electromagnetic $H$-wave with a thin conductive film is constructed, taking into account the ellipsoidal isoenergetic surface of the conductor material and various specularity coefficients of the lower and upper surfaces of the film in this paper. Analytical expressions are obtained for the reflection, transmission and absorption coefficients of the electromagnetic wave. It is shown that when the effective mass increases along the axis perpendicular to the surface and directed deep into the film, the reflection coefficient increases, and the transmission coefficient decreases. The dependence of the absorption coefficient on the effective mass has a maximum. An increase in the specularity coefficient of the film surfaces leads to a shift of the maximum absorption coefficient in the direction of large values of the effective mass along the axis perpendicular to the surface and directed deep into the film, or in the direction of smaller values of the effective mass along the axis directed along the electric field $E$. 
Figure 3. Dependence of the reflection $R$ (solid curves), passage $T$ (dotted curves), and absorption $A$ (point curves) coefficients on the dimensionless effective mass $k_{m1}$ along the $Y$ axis for the degenerate case (26) at $x_0 = y_0 = .1, k_{m2} = 1$. Curves 1–$q_1 = q_2 = 0$, curves 2–$q_1 = .5, q_2 = .6$, curves 3–$q_1 = q_2 = 1$.

Figure 4. Dependence of the reflection $R$ (solid curves), passage $T$ (dotted curves), and absorption $A$ (point curves) coefficients on the dimensionless effective mass $k_{m1}$ along the $Y$ axis for the nondegenerate case (28) at $x_0 = y_0 = .1, k_{m2} = 1$. Curves 1–$q_1 = q_2 = 0$, curves 2–$q_1 = .5, q_2 = .6$, curves 3–$q_1 = q_2 = 1$.

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References
[1] Latyshev A V, Yushkanov A A 2015 J. Phys. Chem. Solids 16 253
[3] Yushkanov A A, Zverev N V 2017 Phys. Lett. A 381 679
[4] Zverev N V, Yushkanov A A 2017 Opt Spektrosk. 122 202
[5] Kuznetsova I A, Khadchukaev R R, Yushkanov A A 2009 Physics of the Solid State 51 2145