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Excitation of unstable waves in impurity semiconductors with two types of charge carriers

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Abstract: *From the linear theory, analytical formulas of the electric field are obtained for the excitation of growing waves in semiconductors with two types of charge carriers. The frequencies and increment of the vibrational waves are determined. Analytical formulas are obtained for the electron capture frequency and for the hole emission frequency. It is proved that in the presence of an external strong magnetic field, the excitation of growing waves is amplified. The appearance of growing waves in a semiconductor requires more number of holes than the number of electrons*.

Keywords: *semiconductor, electric field, magnetic field, electrons, holes, frequency*

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I. Introduction

Theoretical research of excited waves inside an impurity semiconductor has practical implications for the preparation of high-frequency devices. Determining the conditions for the excitation of oscillations of physical quantities inside a semiconductor is fundamental to the creation of high-frequency generators and amplifiers.

In [1-6], some conditions for the appearance of fluctuations in physical quantities in impurity semiconductors with specific impurity levels under the influence of an external electric field and under the influence of an electric and magnetic field are theoretically analyzed. In these works, the critical values of the electric and magnetic fields were calculated theoretically when vibrations appear in semiconductors with two types of current carriers, when the semiconductor has singly and doubly charged impurity centers.

These impurity centers can be captured (recombined) or emitted (generated) by current carriers under the influence of external influences. As a result of recombination and generation of current carriers, a redistribution of charges occurs and unstable waves are excited inside the semiconductor. In this case, the semiconductor goes into a nonequilibrium state. In a nonequilibrium state, a semiconductor emits high-frequency waves from itself, and becomes a source of energy. The frequency of the excited waves and the values of the electric and magnetic fields when an oscillation occurs inside the semiconductor is determined from the solution of the dispersion equation obtained from the basic equations. Due to the high degree of the dispersion equation, its solutions are possible in certain approximations.

We will show in this theoretical paper that when solving the dispersion equation, the use of physical approximations makes it easier to find the critical values of the electric and magnetic fields corresponding to the beginning of the oscillations inside the semiconductor. The found values of the oscillation frequency, the ratio of the equilibrium values of the concentrations of the charge carriers, create convenient conditions for new experimental work.

Basic equations

There are impurities in the semiconductor $N_0 = const$. From

$$N_0 = N + N_- \quad (1)$$

N_0 is repeatedly negatively, N_- is twice negatively charged centers.

The concentration of electrons n_- and holes n_+ is much lower than the concentration of impurities, i.e.

$$n_+ << N, N_-,\ n_- << N, N_- \text{ и } N >> N_- \quad (2)$$

The continuity equations for electrons in the indicated semiconductor will have the form:

$$\frac{\partial n_-}{\partial t} + div\vec{j}_- = \gamma_-(0)n_{1-}N_- - \gamma_-(E)n_-N = \left(\frac{\partial n_-}{\partial t}\right)_{rek} \quad (3)$$

$$\vec{j} = -n_-\mu_-(E)\vec{E} - \vec{D}_-\vec{\nabla}n_-$$

Here: $\gamma_-(0)$ is the electron capture coefficient in the absence of an electric field, $\gamma_-(E)$ is the electron capture coefficient, $n_{1-}=\frac{N_-^0 N_0}{N_-^0}$ is the concentration obtained from the stationary condition, i.e. $\left(\frac{\partial n_-}{\partial t}\right)_{rek}=0$.

The continuity equation for holes will look like:

$$\frac{\partial n_+}{\partial t}+div\vec{j}_+=\gamma_+(E)n_{1+}N_--\gamma_+(0)n_+N_-=\left(\frac{\partial n_-}{\partial t}\right)_{rek} \qquad (4)$$

$$\vec{j}_+=-n_+\mu_+(E)\vec{E}-\vec{D}_+\vec{\nabla}n_+$$

$\mu_\pm(E)$-подвижности дырок и электронов, $\vec{D}_\pm$ -коэффициент диффузии дырок и электронов.

$\mu_\pm(E)$ is mobility of holes and electrons; $\vec{D}_\pm$ is diffusion coefficient of holes and electrons.

In the presence of recombination and generation of charge carriers, the condition of quasineutrality means that the total current does not depend on the coordinates, but depends on the time

$$div\vec{J}=ediv\left(\vec{j}_+-\vec{j}_-\right)=0 \qquad (5)$$

In the presence of recombination and generation of charge carriers, the number of once and twice negatively charged centers changes, and therefore the equations determining the changes in the centers with time have the form:

$$\frac{\partial N_-}{\partial t}=\left(\frac{\partial n_+}{\partial t}\right)_{rek}-\left(\frac{\partial n_-}{\partial t}\right)_{rek} \qquad (6)$$

II. Theory

To determine the dispersion equation, we must solve together (3-4-5). However, due to the nonlinearity of equations (3-4-5), we first need to linearize them as follows.

$$n_\pm=n_\pm^0+n'_\pm,\ N_-=N_-^0+N'_-,\ \vec{E}=\vec{E}_0+\vec{E}',\ n'_\pm<<n_\pm^0,\ N'_-<<N_-^0\ \vec{E}'<<\vec{E}_0 \qquad (7)$$

We introduce the following characteristic frequencies:

$\nu_-=\gamma_-\left(E_0\right)N_0$ is frequency of electron capture;

$\nu_+=\gamma_+\left(0\right)N_-^0$ is frequency of hole capture;

$\nu_+^E=\gamma_+\left(E_0\right)N_0$ is frequency of emission of holes;

$\nu=\nu'_++\nu'_-=\gamma_+(0)n_+^0+\gamma_+(E_0)n_{1+}+\gamma_-(E_0)n_-+\gamma_-(0)n_{1-}$ are combined capture and emission frequencies by nonequilibrium centers.

Linearizing (3-4-5) considering

$$n'_\pm\sim e^{i(kx-\varpi t)},E'\sim e^{i(kx-\varpi t)} \qquad (8)$$

(k is wave vector, ω is frequency) we obtain the following dispersion equation

$$\omega^3+\omega_1^0\omega^2+\left(\omega_2^0\right)\omega+\left(\omega_3^0\right)^3=0 \qquad (9)$$

Here:

$$\omega_1^0=\frac{1}{\sigma^\mu}\left[k\upsilon_+\left(\sigma_+^\mu-\sigma_-^\mu\right)+i\left(\sigma_+^\gamma\nu_+^E-\sigma_-^\mu\nu_-\right)\right]$$

$$\left(\omega_2^0\right)^2=\frac{1}{\sigma^\mu}\left[\sigma_-^\gamma\nu_-\nu'_+-\sigma_+^\gamma\nu'_-\frac{\mu_-}{\mu_+}+i\left(\sigma_-^\gamma\nu_-k\upsilon_++\sigma_+^\gamma\nu_-^Ek\upsilon_-\right)\right]$$

Here:

$$\left(\omega_3^0\right)^3=-\frac{1}{\sigma^\mu}\left[\sigma_-^\gamma\nu_-k\upsilon_++\sigma_+^\gamma\nu_+^Ek\upsilon_-\right]$$

$$\sigma^\mu=\sigma_-\beta_-^\mu+\sigma_+\beta_+^\mu,\ \beta_\pm^\gamma=1+2\frac{d\ln\mu_\mp}{d\ln\left(E_0^2\right)},\ \sigma_-^\gamma=\sigma_-\gamma_-,\ \sigma_+^\gamma=\sigma_+\gamma_+,\ \gamma_\mp=2\frac{d\ln\gamma_\mp\left(E\right)}{d\ln\left(E_0^2\right)},\ \sigma_\mp=en_\mp\mu_\mp$$

To obtain dispersion equation (9), we used the following inequalities

$$\beta_{\pm}^{\gamma} > \beta_{\pm}^{\mu} \text{ и } \frac{\beta_{\pm}^{\gamma}}{\beta_{\pm}^{\mu}} \cdot \frac{\nu_-}{\nu_+^E} >> 1 \,,\; \frac{T}{eE_0} \cdot \frac{\pi}{L} m << 1 \,,\; \nu_{\pm}' << \nu_{\pm}, \nu_+^E \tag{10}$$

It should be noted that when oscillations occur inside the semiconductor, the complex oscillation frequency is a quantity, and the wave vector is a real quantity, i.e.

$$\omega = \omega_0 + i\omega_1, k = k_0 = \frac{2\pi m}{L}, (m = 0, \pm 1, \pm 2, ...) \tag{11}$$

L is linear sample size.

Substituting (11) into (9) we obtain the following equations for determining ϖ_0 and ϖ_1.

$$\omega_0^3 - 3\omega_0\omega_1^2\left(\gamma_{1_0} - \gamma_{2_0}\right)\left(\omega_0^2 - \omega_1^2\right) - 2\left(\gamma_{3_+} - \gamma_{3_-}\right)\omega_0\omega_1 + \left(\gamma_{3_-}\nu_+' - \gamma_{3_+}\nu_-'\frac{\mu_+}{\mu_-}\right)\omega_0 - \left(\gamma_{3_-}k\upsilon_+ + \gamma_{3_+}k\upsilon_-\right)\left(\nu + \omega_1\right) = 0 \tag{12}$$

$$3\omega_0^2\omega_1 - \omega_1^3 + \left(\gamma_{1_-} - \gamma_{2_0}\right)2\omega_0\omega_1 + \left(\gamma_{3_+} - \gamma_{3_-}\right)\left(\omega_0^2 - \omega_1^2\right) + \left(\gamma_{3_-}\nu_+' - \gamma_{3_+}\nu_-'\frac{\mu_-}{\mu_+}\right)\omega_1 + \left(\gamma_{3_-}k\upsilon_+ + \gamma_{3_+}k\upsilon_-\right)\omega_0 = 0 \tag{13}$$

It is easy to verify that at $\gamma_{3_+}^2 = 4\gamma_{1_0}\gamma_{2_0}$ equation (13) it has the form:

$$\omega_1^3 + \gamma_{3_-}\left(\omega_0^2 - \omega_1^2\right) - \left(\gamma_{3_-}\nu_+' - \gamma_{3_+}\nu_-'\frac{\mu_-}{\mu_+}\right)\omega_1 - \left(\gamma_{3_-}k\upsilon_+ + \gamma_{3_+}k\upsilon_-\right)\omega_0 = 0 \tag{14}$$

If

$$\frac{\mu_-}{\mu_+} > \frac{\sigma_-^{\gamma}\nu_-}{\sigma_+^{\gamma}\nu_+^E}\left(\frac{\sigma_-^{\gamma}\nu_-}{\sigma^{\mu}\nu_+'}\right)^{1/2} \tag{15}$$

form (14) we obtain:

$$k^2\mu_+^2E_0^2 = \left(\frac{\mu_-}{\mu_+}\right)^2\left(\frac{\sigma_+^{\gamma}\nu_+}{\sigma_-^{\gamma}\nu_-}\right)^2\frac{\sigma_-^{\mu}}{\sigma_-^{\gamma}} \cdot \frac{\left(\nu_-'\right)^3}{\nu_-} \tag{16}$$

In obtaining formula (15), we took into account that

$$k^2\mu_+^2E_0^2 = \left(\frac{\sigma_+^{\gamma}\nu_+^E}{2}\right)^2\frac{1}{\sigma_+^{\mu}\sigma_-^{\mu}} \cdot \frac{\mu_-}{\mu_+} \tag{17}$$

Equating (16) and (17) we get:

$$\frac{\mu_-}{\mu_+} = \frac{\left(\sigma_-^{\gamma}\right)^3}{4\sigma_+^{\mu}\left(\sigma_-^{\mu}\right)^2}\left(\frac{\nu_-}{\nu_-'}\right)^3 \tag{18}$$

From (15) and (18) we easily obtain:

$$\nu_+^{\varepsilon} = 4\nu_-'\frac{\beta_+^{\mu}}{\gamma_+}\left(\frac{\beta_-^{\mu}\nu_-'}{\gamma_-\nu_-}\right)^{3/2}\left(\frac{\sigma_-^{\mu}\nu_-'}{\sigma^{\mu}\nu_+'}\right)^{1/2} \tag{19}$$

Thus, relations $\frac{\mu_-}{\mu_+}$ (18) and the hole emission frequency ν_+^{ε} (19) are found from equation (14).

Putting (18) in (17) we obtain the electric field

$$E_0 = \frac{4\nu_-'}{k\mu_+} \cdot \frac{\sigma_+^{\gamma}}{\left(\sigma_+^{\mu}\sigma^{\mu}\right)^{1/2}} \cdot \left(\frac{\beta_-^{\mu}\nu_-'}{\gamma_-\nu_-}\right)^{3/2}\left(\frac{\nu_-'}{\nu_+'}\right)^{1/2} \tag{20}$$

$$\omega_1 = \frac{n_+\beta_+^{\mu}}{n_-\gamma_-}\left(\frac{\nu_-'}{\nu_-}\right)^3 \cdot \left(\frac{\beta_-^{\mu}}{\gamma_-}\right)^{3/2} \cdot \left(\frac{\sigma_-^{\mu}}{\sigma^{\mu}}\right)^{1/2} 4\nu_-' \tag{21}$$

Substituting the values ω_0 and ω_0 from (21), taking $\gamma_{3_+}^2 = 4\gamma_{1_0}\gamma_{2_0}$ into account equation (12), we easily obtain:

$$\left(k\upsilon_+\right)^3 - 3k\upsilon_+\alpha^2\left(\nu'_-\right)^2 + \left(\gamma_{1_0} - \gamma_{2_0}\right)\left(k^2\upsilon_+^2 - \alpha^2\nu'^2_-\right) - 2\left[2\left(\gamma_{1_0}\gamma_{2_0}\right)^{1/2}\gamma_{3_-}\right]k\upsilon_+\alpha\nu'_- +$$
$$+\left[\gamma_{3_-}\nu'_+ - 2\left(\gamma_{1_0}\gamma_{2_0}\right)^{1/2}\nu'_-\frac{\mu_+}{\mu_-}\right]k\upsilon_+ - \left(\gamma_{3_-}k\upsilon_+ + k^2\upsilon_-\upsilon_+\right)\left(\nu_+\alpha\nu'_-\right) = 0 \quad (22)$$

From (22) we obtain

$$\frac{n_+}{n_-} = \left(\frac{\sqrt{3}\gamma_-}{\beta_-^{\mu}}\right)^{3/2}\cdot\frac{\mu_-\beta_-^{\mu}}{\mu_+\beta_+^{\mu}}$$

III. Oscillations in the above semiconductor in the presence of a strong ($\mu_\pm H_0 > c$) extermal magnetic field

The current flux density in the presence of a magnetic field is:

$$\vec{j}_+ = n_+\mu_+\vec{E} + n_+\mu_{1+}[\vec{E}\vec{H}] + n_+\mu_{2+}\vec{H}(\vec{E}\vec{H}) - D_+\nabla n_+ - D_{1+}[\nabla n_+ H] - D_{2+}H(\nabla n_+ H)$$
$$\vec{j}_- = -n_-\mu_-\vec{E} + n_-\mu_{1-}[\vec{E}\vec{H}] - n_-\mu_{2-}\vec{H}(\vec{E}\vec{H}) - D_-\nabla n_- + D_{1-}[\nabla n_- H] - D_{2-}H(\nabla n_- H) \quad (23)$$

We investigate the excitations of longitudinal waves, for which the Maxwell equations $\frac{\partial H'}{\partial t} = -ic[\vec{k}\vec{E}'], H' = 0$ are valid. Linearizing equations (4,5,6) with allowance for (23), we obtain the following dispersion equations

$$\omega^3 + \Omega_1\omega^2 + \Omega_2^2\omega + \Omega_3^3 = 0 \quad (24)$$

Here:

$$\Omega_1 = \frac{\sigma_+^{\mu}\upsilon_- - \sigma_-^{\mu}\upsilon_+}{\sigma^{\mu}}k_x + \frac{\sigma_+\upsilon_{1-} - \sigma_-\upsilon_{1+}}{\sigma^{\mu}}k_y + i(\omega_+ - \omega_-),$$
$$\Omega_2^2 = \omega_-\nu'_+ - \omega_+\nu'_-\frac{\mu_-}{\mu_+} + i(\omega_+\upsilon_- + \omega_-\upsilon_+)k_x +$$
$$+i\omega_+\left(\frac{\sigma_+\upsilon_{1-}}{\sigma} - \frac{\sigma_-\upsilon_{1+}}{\sigma}\frac{\mu_-}{\mu_+}\right)k_y + i\omega_-\left(\frac{\sigma_+\upsilon_{1-}}{\sigma}\frac{\mu_-}{\mu_+} - \frac{\sigma_-\upsilon_{1+}}{\sigma}\right)k_y, \quad (25)$$
$$\Omega_3^3 = -\nu(\omega_+\upsilon_- + \omega_-\upsilon_+)k_x - \omega_+\nu\left(\frac{\sigma_+\upsilon_{1-}}{\sigma} - \frac{\sigma_-\upsilon_{1+}}{\sigma}\frac{\mu_-}{\mu_+}\right) - \omega_-\nu\left(\frac{\sigma_+\upsilon_{1-}}{\sigma}\frac{\mu_+}{\mu_-} - \frac{\sigma_-\upsilon_{1+}}{\sigma}\right)k_y$$
$$\omega_+ = \frac{\sigma_+^{\gamma}}{\sigma^{\mu}}\nu_+^{E}, \omega_- = \frac{\sigma_-^{\gamma}}{\sigma^{\mu}}\nu_-, \upsilon_\pm = \mu_{1\pm}E_0$$

It is known that in a strong magnetic field

$$\mu_{1\pm} = \mu_\pm\frac{\mu_\pm H_0}{c} \quad (26)$$

Equating the real and imaginary parts of the dispersion equation to zero, taking into account (26), we easily obtain:

$$\omega_0^3 - 2\omega_0^2\omega_1 + \frac{\sigma_+^{\mu}k_x\upsilon_-}{\sigma^{\mu}}\left(\omega_0^2 - \omega_1^2\right) - 2\omega_0\omega_1\left(\omega_+ - \omega_-\right) + \omega_0\left(\omega_-\nu'_+ - \omega_+\nu'_+\frac{\mu_-}{\mu_+}\right) -$$
$$-\omega_1\left(\omega_+\upsilon_- - \omega_-\upsilon_+\right)k_x - k_x\nu\left(\omega_+\upsilon_- - \omega_+\upsilon_+\right) = 0 \quad (27)$$

$$3\omega_0^2\omega_1 - \omega_1^3 + \frac{\sigma_+^{\mu}\upsilon_-k_x}{\sigma^{\mu}}2\omega_0\omega_1 + \left(\omega_+ - \omega_-\right)\left(\omega_0^2 - \omega_1^2\right) + \omega_1\left(\omega_-\nu'_+ - \omega_+\nu'_-\frac{\mu_-}{\mu_+}\right) +$$
$$+\omega_0\left(\omega_+\upsilon_- + \omega_-\upsilon_+\right)k_x = 0 \quad (28)$$

It can easily be verified that equation (28) is satisfied if the following expressions hold

$$\omega_0 = \frac{\sigma^{\mu}}{6\sigma_+^{\mu}}\nu'_-, \omega_1 = \frac{\omega_-}{3}, E_0 = \frac{3\omega_+L_x}{2\pi\mu_+}, L_x = \frac{\sigma}{\sigma^{\mu}}\frac{\mu_+}{\mu_-}\beta_-^{\mu}\frac{c}{\mu_+H_0}L_y, \frac{n_+}{n_-} = \frac{\mu_-}{\mu_+} \quad (29)$$

Substituting (29) into (27), we easily obtain:

$$\nu_+^E = \frac{\sigma^\mu}{\sigma_+^\mu} \cdot \frac{\nu'_- \mu_-}{\nu'_+ \mu_+} \cdot \nu'_-, \nu_- = \nu'_- \left(\frac{\mu_- \nu'_-}{\mu_+ \nu'_+} \right)^2$$

Let us direct the external constant magnetic field and the electric field as follows $\vec{H}_0 = \vec{h} H_{0z} = \vec{h} H_0$, $\vec{E}_0 = \vec{i} E_{0x} = \vec{i} E_0$ ($\vec{i}, \vec{h}$ are the unit vectors in x and z).

From (1) we easily obtain:

$$\vec{E}_0^{*\prime} = \vec{i} E_0 - \vec{j} \frac{\upsilon_{0x} H_0}{c} + \vec{i} \frac{\upsilon_{0y} H_0}{c}, \ \vec{E}^{*\prime} = E' - \vec{j} \frac{H_0}{c} \upsilon'_y + \frac{T}{e} i \vec{k} \left(\frac{n'_+}{n_+} - \frac{n'_-}{n_-} \right) \qquad (10)$$

Here: $\vec{j}$ is the unit vectors in y, $\vec{k}$ is the wave vectors in, $\vec{\upsilon} = \vec{\upsilon}_0 + \vec{\upsilon}'$

From (10) we easily obtain:

$$\vec{E}_0^* E^{*\prime} = E_0 E'_x - \frac{\upsilon_{0x} H_0}{c} E'_y + i E_1 \left(\frac{n'_+}{n_+^0} - \frac{n'_-}{n_-^0} \right) E_0 k_x L_x + \frac{H_0 E_0}{c} \upsilon'_y + \frac{H_0^2 \upsilon_{0x}}{c^2} \upsilon'_x$$

$$\left(E_0^* \right)^2 = E_0^2 \left(1 + \frac{H_0 \upsilon_{0y}}{c E_0} \right) \qquad (11)$$

We consider longitudinal oscillations and therefore from the Maxwell equation $\frac{\partial H'}{\partial t} = -crot E^*$ we find

$$\left[\vec{k} E^* \right] = 0 \qquad (12)$$

Substituting (1) in (12) we obtain:

$$k_y E'_z - k_z E'_y + \frac{k_z H_0}{c} \upsilon'_x = 0 \qquad (13)$$

$$k_z E'_x - k_x E'_z + \frac{k_z H_0}{c} \upsilon'_y = 0 \qquad (14)$$

$$k_x E'_y - k_y E'_x + \frac{k_z H_0}{c} \upsilon'_z - H_0 \left(k_x \upsilon'_x + k_y \upsilon'_y + k_z \upsilon'_z \right) = 0 \qquad (15)$$

We consider a one-dimensional problem and therefore

$$J'_y = 0 \qquad (16)$$

$$J'_z = 0 \qquad (17)$$

$$\frac{\partial J'_x}{\partial x} = 0 \qquad (18)$$

From (13-18), after algebraic calculations, we obtain for the components of the variable electric field E'_x, E'_y, E'_z and for the components of the velocity of hydrodynamic movement υ'_x, υ'_y, υ'_z the following expressions

$$E'_x = \frac{L_x^2 E_1}{L_y L_z} u, \ E'_y = -E_0 f, \ \upsilon'_x = -c \frac{E_0}{H_0} \left(\frac{a'_1}{a} + \frac{i E_1 \varphi'}{a E_0} \frac{c}{\mu_- H_0} + \frac{b}{a} \frac{E}{E_0} \frac{L_x}{L_z} u + \frac{L_x^2}{L_y^2} u \right)$$

$$E'_z = \frac{L_x}{L_z} u, \ \varphi' = \frac{n'_+}{n_+^0} - \frac{n'_-}{n_-^0}, \ E_1 = \frac{T}{e} k_x, \ u = \frac{\mu_{1+} n'_+ - \mu_{1-} n'_-}{n_- \mu_1} \frac{H_0}{E_1} \frac{\upsilon_{0y}}{c} - i \varphi' - \frac{\mu_+ n'_+ - \mu_- n'_-}{n_- \mu_{1-}} \frac{H_0 \upsilon_{0y}}{c E_1}$$

$$\upsilon'_y = \frac{c E_1}{H_0} \left(1 - \frac{L_x^2}{L_y L_z} \right) u, \ \upsilon'_z = \frac{c}{\mu_- H_0} c \frac{E_1}{E_0} \left(\frac{L_x}{L_z} u + i \varphi' \right) \qquad (19)$$

We assume that

$$\upsilon_{0x} = \upsilon_{0y} = \upsilon_{0z}, \ E_0 >> H_0 \frac{\upsilon_{0y}}{c} \qquad (20)$$

Substituting (20) in (6) we obtain:

$$\begin{cases} \left(-\frac{L_x^2}{L_y L_z}+\frac{H_0}{E_1}\theta_1+ik_x L_x\right)\frac{n'_+}{n_+^0}+\left(\alpha\frac{L_x^2}{L_y L_z}+\frac{H_0}{E_1}\theta_2-ik_x L_x\right)\frac{n'_-}{n_-^0}=0 \\ \left(-r+\frac{H_0}{E_0}R_1+i\frac{E_1}{E_0}k_x L_x\right)\frac{n'_+}{n_+^0}+\left(-\delta+\frac{H_0}{E_0}R_2-i\frac{E_1}{E_0}k_x L_x\right)\frac{n'_-}{n_-^0}=0 \end{cases} \quad (21)$$

Substituting (20) into (6), expressions for dimensionless constants $\theta_1, \theta_2, r, R_1, R_2$ are easily obtained. Due to the bulkiness of their expression, we do not write out. Equating the real and imaginary parts to zero the dispersion equation obtained from (21) we obtain for the external electric field E_0, for the magnetic field H_0 the following expressions

$$E_0 = H_0\frac{\mu_- H_0}{c}\left(1+\frac{2\mu_- H_0}{c}\right); \quad \frac{\mu_- H_0}{c}=\left(\frac{E_1}{E_0}\right)^{1/2} \quad (22)$$

From (22) it is easily seen that $\mu_- H_0 << c$ and

$$E_0 = H_0\left(\frac{E_1}{H_0}\right)^{1/2} \quad (23)$$

In obtaining (23), we used expressions for the sample length

$$L_x = \frac{2\pi T}{eH_0}\left(\frac{c}{\mu_- H_0}\right)^2 \quad (24)$$

If (23-24) is valid from the dispersion equation (21) for

$$L_y = 2\pi L_z = (2\pi)^4\frac{T\mu_-}{ec} \quad (25)$$

For frequency ω_0 and slew increment ω_1, the following values

$$\omega_0 = 2\nu_+, \ \omega_1 = \nu_+ \quad (26)$$

(25) it is true if the magnetic field and the velocities of hydrodynamic motions have values

$$H_0 = \frac{c}{\mu_-}\frac{1}{2\pi} \quad (27)$$

$$\upsilon_{0x} = \upsilon_{0y} = \upsilon_{0z} = \frac{\upsilon_T(\alpha_{1+}+\alpha_{1-})\gamma}{\Lambda'\sigma_0 H_0} \quad (28)$$

Where υ_T is the speed of propagation of thermomagnetic waves

$$\upsilon_T = c\Lambda'\nabla T \quad (29)$$

The ratio of electron and hole concentrations is determined by the expression

$$\frac{n_-^0}{n_+^0} = \frac{\mu_+}{\mu_-}\frac{\left(1+\frac{\alpha_-}{\alpha_+}\right)\left(1+\frac{\gamma_-}{\gamma_+}\right)}{1+\frac{\beta_-}{\beta_+}} \quad (29)$$

IV. Discussion

Thus, the theory of the excitation of vibrational waves inside a semiconductor with two types of charge carriers in an external constant electric field is constructed. Analytical formulas for the wave frequency are obtained. It is shown that the increment of the growing wave is greater than the propagation frequency of this wave. This is due to the presence of recombination and generation of charge carriers. The values of the electric field, electron capture frequency, and hole emission frequency are determined. It was found that the ratio of the equilibrium values of holes and electrons has certain values when oscillations appear inside the indicated semiconductor. In the presence of a constant strong external magnetic field, for the appearance of growing waves inside the specified semiconductor, more holes are required than electrons. In a magnetic field, analytical formulas are obtained for the capture frequency m of the hole emission frequency. In the presence of a magnetic field, the growing wave is excited in a semiconductor with a certain size. An analytical formula is found for determining the size of a semiconductor. It was found that with an increase in the external magnetic field, the growing waves are excited at lower values of the external electric field. This means that the magnetic field quickly redistributes the charges in the sample and the semiconductor goes into a nonequilibrium state.

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