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G.M. Mammadova

Institute of Physics, Baku, *Azerbaijan Republic*
(E_mail: gizbesmamedova@gmail.com*)*

The frequency of current fluctuations in two-valley semiconductors in an external electric and strong magnetic ($\mu H > c$) fields

Boltzmann's kinetic equations have not been used to date to study nonequilibrium phenomena in semiconductors, and therefore, to obtain analytical expressions for the oscillation frequency inside the semiconductor and the critical external electric field, it is of theoretical interest. In this theoretical work, the frequency of oscillations occurring inside a two-valley semiconductor of the GaAs type in an external constant electric field and in an external strong magnetic field ($\mu H \gg c$, μ-mobility of charge carriers, H-magnetic field strength, c-speed of light) is calculated. It has been proved that the critical values of the external electric field fully correspond to the values of the electric field, which were obtained by the Gunn experiment. It is proved that unstable waves are excited in GaAs if the crystal dimensions are $L_y > 4L_z$ and $L_x \ll L_y$. Analytical expressions are obtained by theoretical calculation for an external constant magnetic field, when unstable oscillations are excited inside the sample. It is proved that the growth rate of the excited waves is much less than the wave propagation frequency$\gamma \ll \omega_0$. Numerical comparisons of theoretical expressions for the frequency of oscillations are carried out using the data of the Gunn experiment $\omega_0 \sim 10^7 \div 10^9$ Hz.

Keywords: oscillations, frequency, distribution function, electric field, magnetic field, current-voltage characteristic, multi-line semiconductors, Boltzmann's kinetic equations.

Introduction

In theoretical works [1-4], current oscillations in two-valley semiconductors of the GaAs type in an external electric field, and in external electric and strong magnetic fields are investigated by solving the Boltzmann kinetic equation. In these works, the critical values of the electric and magnetic fields were calculated from the condition

$$\frac{dj}{dE} = \sigma_d = 0 \quad (1)$$

(j is the current flux density, E is the electric field, σ_d is the differential conductivity). However, from condition (1) it is impossible to determine the frequency of the current oscillation. Therefore, it is of great interest to determine the current fluctuation in the presence of condition (1). In this theoretical work, we will calculate the frequency of current oscillation and the critical value of the electric and magnetic fields by applying the Boltzmann kinetic equation.

In [5] a theoretical study was made of the radiation of energy in strong electric and magnetic fields from two valley semiconductors of the GaAs type, in which the Gunn effect was discovered. It is known that during radiation a GaAs sample is in a nonequilibrium (unstable) state. In this theoretical work, the condition for the emission of energy from two valley semiconductors is theoretically investigated by applying the Boltzmann kinetic equation. Such a theoretical approach is not considered in periodic and theoretical works and is of scientific interest. The application of the Boltzmann equation proves that the condition of energy emission from the GaAs sample, (i.e. the frequency of the current oscillation corresponding to the value of the electric field in this case), fully corresponds to the Gunn experiment.

Theory

Typical examples of the dependence of the current density in a spatially uniform system on the field strength under conditions when there is a falling section on the current-voltage characteristic are shown in

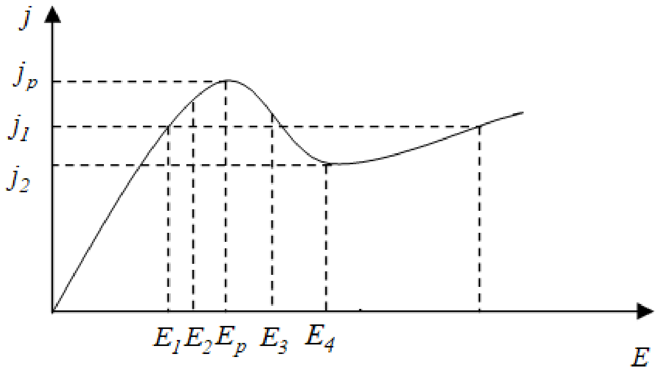

Figure 1. The dependence of the current density on the electric field in two-valley semiconductors of the GaAs type is an N-shaped characteristic.

An essential feature of the characteristic in Figure 1 is that in a certain range of currents $j_2 < j < j_p$, the field strength is a multivalued function of the current density. In this current range, the system can be in one of three spatially homogeneous states. The Gunn effect is associated with an N-shaped characteristic. With negative differential conductivity, electric charges in the system are distributed unevenly, i.e. spatial regions with different values of charges appear in the system (i.e., electrical domains appear). One of the mechanisms for the appearance of domains is the Ridley-Watkins-Hillsum mechanism [6, 7]. In electronic gallium arsenide GaAs, the dispersion law is as follows

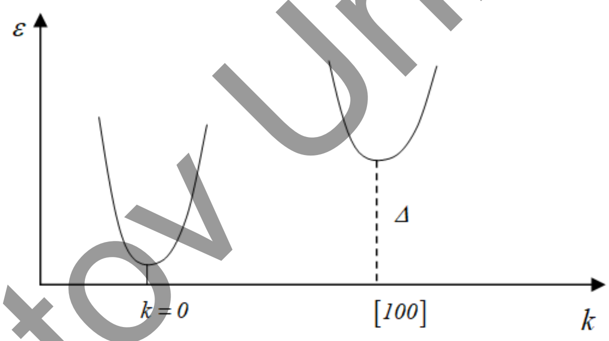

Figure 2. Electron energy versus wave vector in GaAs.

Since the energy distance between the minima is relatively large ($\Delta = 0{,}36 eV, \Delta \gg T_p$, T_p is the lattice temperature) under conditions of thermodynamic equilibrium, the presence of upper valleys (minima) practically does not affect the statistics of electrons.

However, with a sufficiently strong heating of electrons by an electric field, some of them pass into the upper minimum. The effective mass of electrons in the lower valley m_a is much less than the mass of electrons in the upper valley m_b. Therefore, the electron mobilities in the corresponding valleys are related by the relation

$$\mu_b \gg \mu_a \quad (2)$$

If we designate the concentrations in the valleys n_a and $n_б$, we can write an expression for the current in the form

$$\vec{j} = en_a\mu_a\vec{E} + en_b\mu_b\vec{E} \quad (3)$$

$$n = n_a + n_b = const \quad (4)$$

(we neglect the diffusion current due to $eEl \gg k_0T, e$ is the elementary charge, is the electron mean free path). In works [5-6], without taking into account the intervalley scattering (it is considered small in comparison with the intravalley one), by solving the Boltzmann equation, more specific conditions for the appearance of current oscillations were obtained. In the scientific literature, there are no works devoted to theoretical studies of the Gunn effect taking into account the intervalley scattering based on the solution of the Boltzmann kinetic equation. We will theoretically analyze the influence of a strong magnetic field on the Gunn effect, taking into account the intervalley scattering, and calculate the frequency of the current oscillation under the above conditions by solving the Boltzmann kinetic equation.

Basic Equations Of The Problem

Under the action of external forces, the state of charge carriers is described by the distribution function $f(\vec{k},\vec{r})$, the value that is necessary when considering transport phenomena, $f(\vec{k},\vec{r})$ is the probability that an electron with a wave vector $\vec{k}$ (quasimomentum $\hbar\vec{k}$) is located near the point $\vec{r}$. We consider stationary processes, then $f(\vec{k},\vec{r})$ is clearly independent of time. The distribution function is found from the kinetic Boltzmann equation. It is known that the distribution function changes under the influence of external factors and under the influence of collisions with lattice vibrations (phonons) and crystal defects. In the considered stationary state, the influence of these factors mutually compensate each other.

$$\left(\frac{\partial f}{\partial t}\right)_{external} + \left(\frac{\partial f}{\partial t}\right)_{coll} = 0 \quad (5)$$

In the presence of external electric and magnetic fields, equation (5) has the form [8]

$$\vec{v}\nabla_{\vec{r}} f + \frac{e}{\hbar}\left\{\vec{E} + \frac{1}{c}\left[\vec{v}\vec{H}\right]\right\}\nabla_{\vec{k}} f = \left(\frac{\partial f}{\partial t}\right)_{coll} \quad (6)$$

Here $\vec{v} = \frac{1}{\hbar}\nabla_k \varepsilon(\vec{k})$ is the electron velocity, $\nabla_{\vec{r}}$ *u* $\nabla_{\vec{k}}$ is the gradient in the space of coordinates and wave vectors.

When solving the problem, we neglect the anisotropy. The fact that no orientation dependence was found in studies of the Gunn effect on GaAs samples speaks in favor of this assumption. We will assume that for the lower valley the intervalley scattering prevails over the intravalley one, and for the upper valley, the intravalley scattering prevails over the intervalley one. Then the Boltzmann equation for the lower valley can be written in the form

$$\left(\frac{\partial f^a}{\partial t}\right)_{internal} + \left(\frac{\partial f^a}{\partial t}\right)_{intervalley} = 0 \quad (7)$$

And for the upper valley — in the form

$$\left(\frac{\partial f^b}{\partial t}\right)_{internal} + \left(\frac{\partial f^b}{\partial t}\right) = 0 \quad (8)$$

Davydov [8] showed that in a strong electric field the distribution function has the form:

$$f = f_0 + \frac{\vec{p}}{p}\overrightarrow{f_1} \quad (9)$$

f_0 is the equilibrium distribution function, is the momentum of charge carriers. It is clear that you can write

$$f^a = f_0^a + \frac{\vec{p}}{p}\vec{f}_1^a, f^b = f_0^b + \frac{\vec{p}}{p}\vec{f}_1^b \quad (10)$$

Distribution function f^b found from equation (8) in [9]

$$f_0^a = Be^{-\alpha_a(\varepsilon-\Delta)^2} \quad (11) \quad f_1^b = -\frac{e m_b l_b}{p}\vec{p}\frac{\partial f_0^b}{\partial p} \quad (12)$$

Here

$$l_b = \frac{\pi\hbar^4\rho u_0^2}{D^2 m_b^2 k_0 T} \quad (13) \quad \alpha_b = \frac{3D^4 m_b^5 k_0 T}{e^2\pi^2\hbar^8\rho^2 u_0^2} \quad (14)$$

It is clear that for the valley "a" you can write similar formulas (13-14) replacing "a" with "b". l_b is the mean free path, D is the deformation potential, T is the temperature of the lattice, ρ is the density of the crystal, u_0 is the speed of sound in the crystal.

Let's calculate the total current

$$\vec{j} = \vec{j}_a + \vec{j}_b \quad (15)$$

$$\vec{j} = \frac{2e}{(2\pi)^3}\int_0^\infty \frac{\vec{p}}{p}\vec{f}\,\vec{v}d\vec{k} \quad (16)$$

Davydov [9] showed that in the case of intravalley scattering f_1^b in an external electric and magnetic field f_1^b has the following form

$$f_1^b = -\frac{el_b m_b}{p}\frac{\partial f_0^b}{\partial p}\cdot\frac{\vec{E}+\left(\frac{el_b}{cp}\right)[\vec{E}\vec{H}]+\left(\frac{el_b}{cp}\right)^2\vec{H}(\vec{E}\vec{H})}{1+\left(\frac{el_b}{cp}\right)^2 H^2} \quad (17)$$

$$\alpha_b = \frac{3D^4 m_b^5 k_0 T\left[1+\left(\frac{el_b}{cp}\right)^2 H^2\right]}{e^2\pi^2\hbar^8\rho^2 u_0^2\left[E^2+\left(\frac{el_b}{cp}\right)^2(\vec{E}\vec{H})^2\right]} \quad (18)$$

f_1^a and α_a are obtained if we replace "b" with "a" in (17-18). After an easy calculation of the current density j_a and j_b from (16) we get:

$$\vec{j}_a = \frac{e^2 l_a\alpha_a A}{12\pi^2\hbar^2 m_a^2}\left\{\vec{E}\frac{c^2}{e^2 l_a^2 H^2}\left(\frac{4m_a^2}{\alpha_a}\right)^2 + [\vec{E}\vec{H}]\frac{c\Gamma(7/4)}{el_a H^2}\left(\frac{4m_a^2}{\alpha_a}\right)^{7/4} + \vec{H}(\vec{E}\vec{H})\frac{\Gamma(3/2)}{H^2}\left(\frac{4m_a^2}{\alpha_a}\right)^{3/2}\right\} \quad (19)$$

After calculating the total current by the formula

$$\vec{j} = \vec{j}_a + \vec{j}_b \quad (20)$$

$$j_z' = \frac{8nc^2 m_a^{1/2}}{3\sqrt{2}\Gamma(3/2)l_a}\frac{E_z'}{H^2}\cdot\frac{\alpha_a^{-1/4}}{1+\gamma^{-3/2}z^{3/4}\beta}\left\{1 + t\gamma_z^{-2}\beta + \frac{e^2 l_a^2\alpha_a^{1/2}}{2c^2 m_a}H^2\Gamma(3/2)\left[1 + t\gamma^{-1}z^{1/2}\beta\right]\right\} \quad (21)$$

Here

$$A = tz^{-1/2}\gamma^{-1} = \frac{m_b}{m_a}, \gamma = \frac{m_a}{m_b},\ z = \frac{\alpha_a}{\alpha_b}, t = \frac{l_b}{l_a}, \beta = z^{-1}e^{-\alpha_a\Delta^2}$$

$$e^{-\alpha_a\Delta^2} = e^{-\left(\frac{E_x}{E}\right)^2} = \left(1-\frac{E_x}{E}\right)^2, E_x^2 = \frac{3D^4 m_0 m_a^3 k_0 T}{\pi^2 e^2\hbar^8\rho^2 u_0^2} \quad (22)$$

We write (21) in the following form

$$\vec{j} = \sigma\vec{E} + \sigma_1[\vec{E}\vec{h}] + \sigma_2\vec{h}[\vec{E}\vec{h}] \quad (23)$$

$\vec{h}$ is unit vector in the magnetic field. Comparing (23) with (21), one can easily write the expressions $\sigma+\sigma,\ \sigma_1,\sigma_2$. When obtaining an expression for the current density j_z' (21) we direct the electric field and the magnetic field H_0 as follows

$$\vec{E}_0 = \vec{h}E_0, \vec{H}_0 = \vec{h}H_0 \quad (24)$$

The E_x value is obtained from the following condition

$$\frac{dj_z'}{dE_z'} = 0 \quad (25)$$

When estimating E_x^2 for GaAs, the value

$$E_x^2 = 43{,}84\left(V/_{SM}\right)^2 \quad (26)$$

For all strong electric fields

$$E \gg E_x \quad (27)$$

quite satisfied. Now let's calculate the frequency of the current oscillation. When an alternating electric field E' is excited inside the medium, an alternating magnetic field H' arises, which satisfies Maxwell's equation

$$\frac{\partial\vec{H}'}{\partial t} = -crot\vec{E}' \quad (28)$$

The current density in the presence of electric and magnetic fields has the form

$$\vec{j} = \sigma\vec{E} + \sigma_1[\vec{E}\vec{H}] + \sigma_2\vec{H}[\vec{E}\vec{H}] \quad (29)$$

Let us direct the external electric and magnetic field as follows

$$\vec{E}_0 = \vec{h}E_0, \vec{H}_0 = \vec{h}H_0 \quad (30)$$

($\vec{h}$ is the unit vector in z). We find the variable value j_x', j_y', j_z' from (29) taking into account (28-30), then we get

$$j_x' = \sigma\left(1-\frac{\mu k_z E_0}{\omega}\right)E_x' + \sigma_1\left[\left(1+\frac{ck_x E_0}{\omega H_0}\right) - \frac{2\sigma_2 ck_z E_0}{\omega H_0}\right]E_y' + \frac{2\sigma_2 ck_y E_0}{\omega H_0}E_z' \quad (31)$$

$$j_y' = -\sigma_1 E_x' + \left(\sigma - \frac{\sigma_1 ck_z E_0}{\omega H_0}\right)E_y' + \sigma_1\left(1+\frac{ck_y E_0}{\omega H_0}\right)E_z' \quad (32)$$

$$j_z' = (\sigma+\sigma_2)E_z' - \frac{2\sigma_2 ck_y E_0}{\omega H_0}\left(E_x' + E_y'\right) \quad (33)$$

Equating $j_x^{'} = 0$ and $j_y^{'} = 0$ to zero, we find $E_z^{'}$ and $E_y^{'}$ from (31-32) and supplying $E_z^{'}, E_y^{'}$ in (33), we obtain for $j_z^{'}$ the following expressions

$$j_z^{'} = \left[\sigma_2 + \frac{2\sigma_2 ck_x E_0}{\omega H_0}\left(1 + \frac{c}{\mu H}\frac{ck_z\mu E_0}{\omega} + \frac{c}{\mu H_0}\frac{ck_y k_z \mu E_0}{\omega^2}\cdot\frac{E_0}{H_0} - \frac{ck_y}{\omega}\frac{c}{\mu H_0}\frac{E_0}{H_0}\right) + \frac{2\sigma_2 ck_y}{\omega}\frac{E_0}{H_0}\left(\frac{ck_y}{\omega} + \frac{c\mu k_z ck_y E_0}{\omega^2}\right)\frac{E_0}{H_0}\right] E_z^{'} \quad (34)$$

When deriving expression (34), we used the conditions of a strong magnetic field $\mu H_0 \gg c$. Equating expressions (34) and (21), we obtain the following dispersion equation for determining the frequency of current oscillation

$$(\sigma_2 - \tilde{\sigma}\Phi)\omega^3 + \frac{2\sigma_2 ck_x E_0}{H_0}\left(1 + \frac{E_0}{H_0}\right)\omega^2 + \frac{2\sigma_2 ck_x E_0}{H_0}\omega + \frac{\sigma_2 ck_x E_0}{H_0} ck_y \mu k_z E_0\left(\frac{c}{\mu H_0}\cdot\frac{E_0}{H_0} + 2\frac{E_0}{H_0}\right) = 0 \quad (35)$$

Here

$$\tilde{\sigma} = \frac{8nc^2 m_a^{1/2}\alpha_a^{-1/4}}{3\sqrt{2}\Gamma(3/2) l_a H^2},\ \Phi = \frac{1}{1+\gamma^{-3/2}Z^{9/4}\beta}\left[1 + t\gamma^{-2}Z\beta + \frac{e^2 l_a^2 H^2 \alpha_a^{1/2}}{2c^2 m_a}\Gamma(3/2) + \left(1 + t\gamma^{-1}Z^{1/2}\beta\right)\right] \quad (36)$$

Equating $\sigma_2 = \tilde{\sigma}\Phi$ we easily obtain

$$\left(\frac{H_x}{H_0}\right)^2 = 1, \text{ т.е. } H_x = H_0 = \left[\frac{8c^2 m_a^{1/2}\alpha_a^{-1/4}}{3\sqrt{2}\Gamma(3/2) e\mu l_a}\right]^{1/2} \quad (37)$$

Putting the values of $\alpha_a^{-1/4}$ in (37), we easily obtain

$$H_0 = \left[\frac{8}{3\sqrt{2}\Gamma(3/2)}\right]^{1/2}\cdot\left(\frac{k_0 T}{3m_0 u_0^2}\right)^{1/8}\cdot\left(\frac{c^2 m_a^{1/2}}{\mu}\right)^{1/2}\cdot\left(\frac{1}{el_a}\right)^{1/4} E_0^{1/4} \quad (38)$$

From (38) we get

$$E_0 = \left(\frac{\mu}{c^2 m_a^{1/2}}\right)^2 el_a\left(\frac{H_0}{\varphi}\right)^4 \quad (39)$$

$$\varphi = \left[\frac{8}{3\sqrt{2}\Gamma(3/2)}\right]^{1/2}\cdot\left(\frac{k_0 T}{m_0 u_0^2}\right)^{1/8}$$

Thus, the value of the electric field is obtained during current fluctuations in the above two-valley semiconductors of the GaAs type. In [8], it was obtained that taking into account (26)

$$E_0 = E_{кр} = 1500\ {}^{V}/_{SM} \quad (40)$$

Supplying (40) to (39), it is easy to see that

$$\mu H_0 \gg c$$

From the solution of the dispersion equation (35), we easily obtain

$$\omega_{1,2} = -\frac{ck_z E_0}{2H_0} \pm i\frac{ck_z E_0}{H_0}\left(\frac{L_z}{L_y}\right)^{1/2} \quad (41)$$

For growing fluctuations

$$\omega = -\frac{ck_z E_0}{2H_0} + i\frac{ck_z E_0}{H_0}\left(\frac{L_z}{L_y}\right)^{1/2} = \omega_0 + i\gamma \quad (42)$$

From (42) it is seen that in the crystal $L_y > 4L_z$ (43)

$$\gamma \ll \omega_0$$

Thus, with the size (43) (L_x-can be any), current oscillations (i.e., instability) are excited under an electric field (39) In the calculation, we direct E_0 along H_0. Of course, any orientation of the electric and magnetic fields could be chosen. For other orientations, it is necessary to obtain expressions (21) and (34) in the same orientations, and then find the vibration frequencies in the same orientations.

Discussion Of The Results

In valley semiconductors of the GaAs type, current oscillations occur under the influence of an external electric and strong ($\mu H_0 \gg c$) magnetic field. The frequency of this oscillation ω_0 (42) is close to the frequency of the Gunn effect, i.e. $\omega_0 \sim 10^7 \div 10^9\ Herz$. This proves that the application of the Boltzmann equation is quite valid, although the Boltzmann equation in strong fields is not always applied. By directing

$E_0 = \vec{\imath}E_0, E_0 = \vec{\jmath}E_0, H_0 = \vec{\imath}H_0, H_0 = \vec{\jmath}H_0$, one can carry out a theoretical calculation and determine the critical value of the electric field (including the magnetic field) and the frequency of current oscillation. Of course, with such calculations, conditions (43) will most likely change. Theoretical analysis of current fluctuations in multi-valley semiconductors of the GaAs type shows that the sample size at current fluctuations is significant. This fact was confirmed in the experiment of Gunn. It should be noted that it is necessary to solve the problem in a non-linear approximation, which requires the solution of partial differential equations. This problem can be solved only by the asymptotic solution of a differential equation with the Bogolyubov-Metropolsky method. The conclusion is to obtain an expression for the critical value of the electric field (39) and for the oscillation frequency (42). They are indicated in the derivation and evaluated numerically using experimental data.

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Г.М. Мамедова

Сыртқы электрлік және күшті магниттік өрістердегі (μh>c) екі валентті жартылайөткізгіштердегі токтың флуктуация жиілігі

Жартылайөткізгіштердегі тепе-теңсіз құбылыстарды зерттеу үшін қазіргі уақытқа дейін Больцманның кинетикалық теңдеуі қолданылмады және жартылай өткізгіштегі тербеліс жиілігінің және критикалық сыртқы электр өрісінің аналитикалық өрнегін алу теориялық қызығушылық тудырады. Бұл теориялық жұмыста сыртқы тұрақты электр өрісі мен сыртқы күшті магнит өрістерінде екі жолақты GaAs типтегі жартылайөткізгіш ішінде туындайтын тербеліс жиілігі есептелген (μH>>*c* — зарядты тасымалдаушылардың қозғалғыштығы, *H* — магнит өрісінің кернеуі, *c* — жарық жылдамдығы). Ішкі және сыртқы тізбектің жиілігін қоздыру үшін үлгінің өлшемі анықталған болуы қажет екені дәлелденді. Үлгі ішінде және сыртқы тізбекте тұрақсыз тербелістердің пайда болуы үшін үлгінің белгілі бір ұзындығы болуы керек. Сыртқы электр өрісінің критикалық мәндері Ганн тәжірибесімен алынған электр өрісінің мәндеріне толық сәйкес келетіні айқындалды. Егер кристалдың өлшемі $L_y>4L_z$, $L_x<<L_y$ болса, тұрақсыз толқындар GaAs-де қоздырылатыны дәлелденген. Теориялық есептеу арқылы үлгінің ішінде тұрақсыз тербелістер қозған кезде сыртқы тұрақты магнит өрісінің аналитикалық өрнегі алынды. Теориялық есептеулер сыртқы тұрақты электр өрісі мен сыртқы магнит өрісі бір бағытта бағытталған кезде орындалады, яғни, $\vec{H}_0 = \vec{h}H_{0z}$, $\vec{E}_0 = \vec{h}E_{0z}$. Қоздыратын толқынның өсуі толқынның таралуымен $\gamma << \omega_0$ салыстырғанда әлдеқайда аз екені нақтыланды. Ганн тәжірибесінің деректерін пайдалана отырып $\omega_0 \sim 10^7 \pm 10^9$ Hz тербеліс жиілігінің теориялық өрнектерін сандық салыстыру жүзеге асырылды. Үлгі ішіндегі тербелістерді қоздыру үшін сыртқы электр өрісі мен сыртқы магнит өрісінің бағыты маңызды рөл атқаратыны анықталған.

Кілт сөздер: тербеліс, жиілік, таралу функциясы, электр өрісі, магнит өрісі, вольт-амперлік сипаттамасы, көп сызықты жартылай өткізгіштер, Больцманның кинетикалық теңдеуі.

Г.М. Мамедова

Частота флуктуаций тока в двухвалентных полупроводниках во внешних электрических и сильных магнитных (μh>c) полях

Кинетические уравнения Больцмана до настоящего времени для исследования неравновесных явлений в полупроводниках не использованы и поэтому для получения аналитических выражений для частоты колебания внутри полупроводника и критического внешнего электрического поля представляют теоретический интерес. В настоящей работе вычисляется частота возникающих колебаний внутри двухдолинного полупроводника типа GaAs во внешнем постоянном электрическом поле и во внешнем сильном магнитном поле ($\mu H \gg c$ — подвижность носителей заряда; H — напряженность магнитного поля; c — скорость света). Доказано, что размер образца для возбуждения колебаний внутри и во внешней цепи должны быть определенным. Показано, что для появления неустойчивых колебаний внутри образца и во внешней цепи образец должен иметь определенную длину. Определено, что критические значения внешнего электрического поля вполне соответствуют значению электрического поля, которые получены экспериментом Ганна. Доказано, что неустойчивые волны возбуждаются в GaAs, если размеры кристалла $L_y > 4L_z$;$L_x \ll L_y$Lx≪Ly. Теоретическим расчетом получены аналитические выражения для внешнего постоянного магнитного поля, при возбуждении неустойчивых колебаний внутри образца. Теоретические расчеты выполнены, когда внешнее постоянное электрическое поле и внешнее магнитное поле направлены одинаково, то есть $\vec{H}_0 = \vec{h}H_{0z}$; $\vec{E}_0 = \vec{h}E_{0z}$. Доказано, что инкремент нарастания возбуждаемых волн намного меньше, чем частота распространения волны $\gamma \ll \omega_0$. Проведены численные сравнения теоретических выражений для частоты колебаний с помощью данных эксперимента Ганна $\omega_0 \sim 10^7 \div 10^9$ Hz. Доказано, что направление внешнего электрического поля и внешнего магнитного поля для возбуждения колебаний внутри образца играют существенную роль.

Ключевые слова: колебания, частота, функция распределения, электрическое поле, магнитное поле, вольт-амперная характеристика, многолинейные полупроводники, кинетические уравнения Больцмана.

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