CURRENT OSCILLATIONS AND GENERATION OF ENERGY IN CONDUCTING MATERIALS WITH FALLING CURRENT - VOLTAGE CHARACTERISTIC

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ABCTRACT

The impedance of the many valley semiconductors is calculated. It is shown that in the presence of an external magnetic field the energy generation deigns at the lower values of electric fields than that of the absence of magnetic field.

Keywords: impedance, semiconductors, generation, magnetic field

I. INTRODUCTION

Generation energy (i.e. radiation of energy) of the certain frequency is a basis for making of Gunn devices. These devices work in the certain interval of an external electric field. In *GaAs* and *InP* the high frequency oscillations electric field were observed (MICROWAVE) in [1].

II. MAIN PART

Current – voltage characteristic (CVC) of these compounds is falling i.e.

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

At $\sigma_d < 0$ redistribution of a volume charge carries begins, and this process leads to the MICROWAVE radiation. However, influence of an external magnetic field on oscillations of a current is not investigated. In this work we shall theoretically study the influence of an external magnetic field on oscillations of a current, and also we shall calculate an impedance of *GaAs* , *InP* at presence of an external magnetic field. Energy spectrum in the absence of external fields in *GaAs* has are two valleys and the density of a current is defined as follows

$$J = J_1 + J_2 \qquad (2)$$

where J_1 - density of a current in the first valley, J_2 - density of a current of carriers in the second valley. In the absence of external fields concentrations of charge carriers in valleys are $n_2 << n_1$ and density of a current is equal

$$\vec{J} = e\mu\vec{E} + en\mu_1[\vec{E}\vec{H}] + eD\nabla n + eD_1[\vec{\nabla} n\vec{H}] \qquad (3)$$

Introducing the designations

$$n = X(E)N(E),\, X = x_0 + x_1, \quad N = N_0 + N_1,\, E = E_0 + E_1 \qquad (4)$$

from equations (3) we shall receive

$$\vec{J}_1 = \sigma_0\left(\frac{H_{xar}}{H_0}\right)^2 \vec{A}(x_1, E_1, N_1) + \sigma_0\left(\frac{H_{xar}}{H_0}\right)\vec{B}(x_1, E_1, N_1) \qquad (5)$$

Substituting equation (4) in the formula (3) we shall easily receive the expression for $\vec{A}(x_1, E_1, N_1)$ and $\vec{B}(x_1, E_1, N_1)$, $H_x = \frac{c}{\mu_0}$.

The equation (5) with account of Puassons equation $J_1 = \varepsilon\frac{\partial E_1}{\partial t}$ and $\frac{N_1}{N_0} = Y$ lead to the following equation:

$$\frac{\partial^2 Y}{\partial \tau^2} + Y = r\left[\alpha\sin\psi + \beta\sin\psi\cos\psi + \gamma\sin^2\psi + \delta\cos\psi + \sin^2\psi\cos\psi\right] \qquad (6)$$

a is an amplitude of a current oscillations.

The solution of the nonlinear equation (6) for values of small parameter $r << 1$ by means of the first approximation of Bogolubov – Mitropolski method [2] has the form:

$$\frac{da}{dt} = -\frac{\omega_0 r}{2\pi}\int_0^{2\pi} \Phi \sin\psi\, d\psi \qquad (7)$$

After some calculations from formula (7) we shall receive

$$a = a_0 e^{-\frac{r\omega_0 d}{2}} \qquad (8)$$

where m is the number which is determined from experiment and can have values 3,4,5. From eqs. (8) it is easily seen, that for values $L_x \le L_y$ with increasing of an external magnetic field the amplitude a raises and the generation of current oscillations takes place . For at values of an electric field E_a at which the oscillations of current begins, with raise of an external magnetic field

H_0 the amplitude a increases, and this case corresponds to the value of an electric field $\frac{E_0}{E_a} = \left(\frac{E_0}{E_1}\right)^{1/2m}$;

$$\left(\frac{1}{E_1}\right)^{1/2} = \frac{m(m-1)}{3}\frac{L_x}{L_y}\frac{H_x}{H_0}\left(\frac{\alpha x_0 \sigma_0 \mu_0}{\varepsilon k^3 D_0}\right)^{1/2}$$

For frequency of the current oscillations in the first approximation we find:

$$\frac{d\psi}{dt} = \omega_0\left[1 - \frac{\omega_0}{2\pi k u_0 a}\int_0^{2\pi} \Phi \cos\psi \, d\psi\right] = \omega_0\left[1 - \frac{1}{8}\left(\frac{\omega_0 a}{k u_0}\right)^2\right] \quad (9)$$

Thus, in an external magnetic field it is possible to reduce a critical electric field at which the current oscillation takes place. It is follow from (9), the frequency in the first approximation decreases.

For calculation of an impedance of *GaAs* the continuity equation $\frac{\partial J}{\partial x} = e\frac{\partial N}{\partial t}$ and eq. (3) gives the following equation

$$\frac{\partial^2 J_1}{\partial^2 x^2} + U_0 \frac{\partial J_1}{\partial x} + U_1 J_1 = 0 \quad (10)$$

The evident dependence of U_0 and U_1 on constant physical magnitude easily received from equation (10).

Supposing $J_1 \sim e^{kx}$ from (10) we shall receive for a wave vector the values k_1 and k_2: $k_{1,2} = k_{1,2}^0 + ik'_{1,2}$. In the case of $\sigma_d < 0$ we have increase of the arising waves. The wave with a vector $k_2 = k_{20} + ik'_2$ has the phase speed $\upsilon_\Phi = -\frac{\omega}{k'_2}$.

In the one-dimensional case divergation of the full current is equal to zero and consequently

$$\frac{J_{внеш}}{S} = i\omega'\varepsilon E_1 + J_{10}e^{k_1 x} + J_{20}e^{k_2 x} \quad (11)$$

where S is the cross-section area of a sample $\omega' = \omega\left(1 - i\frac{S_0 \omega_c}{\omega}\right)$, J_{10} also J_{20} are defined from boundary conditions. The wave which is distributed in a direction opposite to drift speed, is strongly damped and consequently we shall simplify the equation (11), taking into account, $x = 0$, $E_{1x} = 0$, $J_{20} = \frac{J_{внеш}}{S'}$. Then

$$E_1 = -i\frac{J_{внеш}}{\omega'\varepsilon A}\left(1 - e^{k_2 x}\right).$$

An impedance of a crystal: $Z = \frac{1}{J_{вн}}\int_0^l E_1 dx$, where l is the size of a crystal.

$$Z = Z_0 + iZ_1 = \frac{1}{k'_2 l\omega' c\left(1 + i\frac{k_{20}}{k'_2}\right)}\left(1 + \frac{k_{20}}{k'_2}k'_2 l - ik'_2 l - e^{k_{20}l + ik'_2 l}\right)$$

$$c = \frac{\varepsilon A}{l} ;$$

For the series connection $Z = Z_0 + iZ_1$. For the parallel connection $\frac{1}{Z_0 + iZ_1} = \frac{1}{\mathrm{Re}} - i\frac{1}{Xe}$, where

$$Xe = Z_1\left(1 + \frac{Z_0^2}{Z_1^2}\right), \quad \mathrm{Re} = Z_0\left(1 + \frac{Z_0^2}{Z_1^2}\right)$$

From a condition of increase of waves with increment receive interval of change of an electric field

$$E > E_0\left\{(m-1)\left[d\left(\frac{H_0}{H_x}\right)^2\left(\frac{H_0}{H_x} + \frac{m}{d}\right)\left(\frac{m}{d}\right)\right]^{1/2}\right\}^{1/m}$$

$$\mathrm{Re}\,Z = Z_0 = \frac{k_2 l + \frac{2\pi S_0}{d}}{B}, \quad \mathrm{Im}\,Z = Z_1 = \frac{2\pi\left(\frac{k_2 l S_0}{2\pi d} - 1\right)}{B}$$

$$B = c\omega\left(1 + \frac{S_0^2}{d^2}\right)\left(1 + \frac{k_{20}^2 l^2}{4\pi}\right)$$

It is follow from Z_0 that oscillations of a current arise at values $|S_0| > \frac{k_{20} l}{2\pi d}$.

III. CONCLUSION

In conclusion, note that the energy generation threshold in *GaAs* in uniform magnetic fields remove towards lower values of electric fields.

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