THE INFLUENCE OF THE HEATING OF THE CHARGE CARRIES ON PROPAGATION OF HIGH-FREQUENCY ELECTROMAGNETIC WAVES IN ELECTRON TYPE SEMICONDUCTORS

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The influence of the heating of the charge carries on propagation of electromagnetic waves of high frequency in non-degenerate electron type semiconductors is considered. It is considered the case when the long wave phonons form "the thermal reservoir" in the lattice. The case of normal skin effect is investigated. It is shown that the heating of the electrons leads to the considerable non-linear problem. The dependence of the penetration depth of the wave on the amplitude of the incident wave is obtained in the mechanisms of the scattering of the electrons both at the deformation potential and at the piezoelectric potential of the acoustical phonons.

Let us consider the propagation of high-frequency electromagnetic waves in degenerate semiconductors having one-type charge carriers (electrons) in the following model. Let us suppose that the electron-phonon system are heated by the field of the wave propagating in semiconductive crystal and the subsystem of long wave phonons forms "the thermal reservoir". In this case in the boundary of the crystal the energy got from the field are transferred to the medium at the expense of the electron- phonon scattering. Let us accept that the electron-electron scattering frequency is much less than the electron-phonon scattering frequency. In this case phonons are described by the Planck distribution of the temperature T_e and electrons are described by the Maxwell distribution of the same temperature.

Besides, we accept than the characteristic length of field change is much less than the linear size of the pattern in the direction of the propagation of the wave. It enables to consider the semiconductor in which the wave is propagated as a half endless one. To be satisfied the normal skin effect the characteristic length is to be much greater than the wave length in the medium and the characteristic length is to be much greater than the electron mean free path by transferring energy and momentum. Let us consider the case when the falling onto the semiconductor and propagating in it is circular polarized. This condition provides the time independence of the isotropic part of the distribution function for the electrons in the kinetic equation. Within all these conditions on the charge-drift velocity of the electrons found from the kinetic equation we obtain the following expression for the electric conductivity of high frequency:

$$\sigma = \frac{\Gamma\left(\frac{t+5}{2}\right)}{3\pi^{3/2}}\left(\frac{\omega_p}{\omega}\right)^2\left(\frac{T_e}{T_p}\right)^{t/2}\nu(T_p)\left(1+2\frac{\omega_H}{\omega}\right)+i\frac{1}{4\pi}\frac{\omega_p^2}{\omega}\left(1+\frac{\omega_H}{\omega}\right), \tag{1}$$

where ω is the frequency of the external electromagnetic field, $\nu(T_p)$ is the electron-phonon scattering frequency when the phonons are not heated and $\omega_H = eH/mc$ is the cyclotron frequency of the electrons, where c is the velocity of light in the vacuum, $\omega_p = (4\pi ne^2/m)^{1/2}$ is the plasma frequency of electrons, $\Gamma(z)$ is the Gamma-function,

$$T_e(E) = T_p\left(1+\frac{E^2}{E_1^2}\right) \tag{2}$$

is the electron temperature, T_p is the phonon temperature, $E_1 = \sqrt{3}s_0 m(\omega-\omega_H)/e$ is the strength of the characteristic field, t is the parameter characterizing the scattering mechanism. When we have dealings with the high-frequency waves $\omega_H/\omega << 1$ and the electromagnetic waves propagate in the direction of $k\|H\|Oz$, the Maxwell equation is given by

$$\frac{d^2E(z)}{dz^2}+\frac{\omega^2}{c^2}\left[\left(\varepsilon_0-\frac{\omega_p^2}{\omega^2}\right)+i\frac{4\Gamma\left(\frac{t+5}{2}\right)}{3\sqrt{\pi}}\frac{\omega_p^2}{\omega^2}\nu(T_p)\left(\frac{T_e}{T_p}\right)^{\frac{1}{2}}\right]E(z)=0, \tag{3}$$

where ε_0 is the relative permittivity of the crystalline lattice.

From the comparison of the expressions (1) and (2) it is visible that the electric conductivity depends on the strength of the electric field considerably. This dependence leads to the non-linearity.

Using [2], if we look for the solution of the equation (3) as

$$E(z) = U(z)\exp\left(i\frac{\omega}{c}\right)\int_0^z n(z)dz, \tag{4}$$

we can obtain the equation

$$2n(z)\frac{dU(z)}{dz}+U(z)\frac{dn(z)}{dz}+\frac{4\Gamma\left(\frac{t+5}{2}\right)}{3\sqrt{\pi}}\left(\frac{T_e}{T_p}\right)^{\frac{1}{2}}\frac{\omega_p^2}{\omega^2}\frac{\nu(T_p)}{c}U(z)=0, \qquad (5)$$

where $n(z)$ is refractive index of the medium. The condition $L_e >> \lambda$ refuses the transformation of the wave energy to the Joule heat by absorbing in the small thickness of the medium. Here λ is the wave length of the electromagnetic wave in the medium. It means that the electromagnetic waves penetrate till the definite depth. In that case the coordinate dependence of the refractive index of the medium can be neglected and the equation (5) can be easily integrated

$$U(z)=U_0\exp\left(-\frac{Z}{L_E}\right). \qquad (6)$$

Here

$$L_E=\frac{3\sqrt{\pi}}{2\Gamma\left(\frac{5+t}{2}\right)}\frac{\omega^2 cn_0}{\omega_p^2\nu(T_p)}\left(\frac{1}{1+\frac{E^2}{E_1^2}}\right)^{\frac{t}{2}} \qquad (7)$$

is the penetration depth of the electromagnetic wave. In a strong electric field $\left(\frac{E}{E_1}>>1\right)$, when the electrons scatter by the deformation potential of the acoustical oscillation of the lattice, i. e. when $t=+1$,

$$L_E=\frac{3\sqrt{\pi}}{4}\left(\frac{\omega}{\omega_p}\right)^2\frac{cn_0E_1}{\nu(T_p)}\frac{1}{E} \qquad (8)$$

and in the case of scattering by the piezoelectric potential $t=-1$

$$L_E=\frac{3\sqrt{\pi}}{2}\left(\frac{\omega}{\omega_p}\right)^2\frac{cn_0}{\nu(T_p)E_1}E \qquad (9)$$

And now let us perform the numerical estimation. For the strength $E=10E_1$ of the electric field, if we take into consideration the parameters $n_0=4$, $m=0.56m_e$, $n=2.5x10^{13}cm^{-3}$ of Ge and the field frequency $\omega\approx 3.2x10^{11}Hz$ in the formula (8), we obtain $L_E\approx 1.3x10^{-2}$ cm for the attenuation depth of the electromagnetic wave.

[1] *B.M. Askerov*. Electron transport phenomena in semiconductors, Singapore, World Scientific Publishing Company, 1994.

[2] *F.G. Bass, Y.G. Gurevich*. Goriachiie electroni i sil'nyie elektromagnitnyie volny v plazme polurovodnikov i gazovogo razriada (Hot electrons and strong electromagnetic waves in the plasma of the semiconductors and gas discharge), Moscow, Nauka, 1975.

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ELEKTRON TİPLİ YARIMKEÇİRİCİLƏRDƏ YÜKSƏK TEZLİKİLİ ELEKTROMAQNİT DALĞALARININ YAYILMASINA YÜKDAŞIYICILARIN QIZDIRILMASININ TƏSİRİ

İşdə elektron-fonon sisteminin qızmasının elektron-keçiricilikli cırlaşmamış yarımkeçiricilərdə yüksək tezlikli elektromaqnit dalğalarının yayılmasına təsirinə baxılmışdır. Bu zaman qəfəsdə uzundalğalı fononların “istilik rezervuarı” yaratdıqları nəzərə alınmışdır. Normal skin-effekt araşdırılmışdır. Göstərilmişdir ki, elektronların qızdırılması nəzərə çarpacaq qeyri-xəttilik yaradır. Elektronların həm akustik fononların deformasiya potensialından, həm də pyezoelektrik potensialdan səpilmə mexanizmlərində dalğanın nüfuzetmə dərinliyinin düşən dalğanın amplitudundan asılılıqları tapılmışdır.

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ВЛИЯНИЕ НАГРЕВА НОСИТЕЛЕЙ ЗАРЯДА НА РАСПРОСТРАНЕНИЕ ВЫСОКОЧАСТОТНЫХ ЭЛЕКТРОМАГНИТНЫХ ВОЛН В ПОЛУПРОВОДНИКАХ ЭЛЕКТРОННОГО ТИПА

В работе рассмотрено влияние нагрева системы электрон-фонон на распространение высокочастотной электромагнитной волны в невырожденных электронных полупроводниках. При этом, рассмотрен случай, когда в решетке длинноволновые фононы образуют “тепловой резервуар”. Исследуется случай нормального скин-эффекта. Показано, что разогрев электронов приводит к существенно нелинейной задаче.

Найдена зависимость глубины проникновения волны от амплитуды падающей волны в механизмах рассеяния электронов как на деформационном потенциале, так и на пьезоэлектрическом потенциале акустических фононов.

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