$$v_1 \approx v_{T_e} \left\{ 2\ln\left(\frac{\pi}{2}\,\frac{\omega_{L_i}}{\omega_{L_e}}\,\frac{v_1 v_{T_e}}{v_E^2}\right)\right\}^{1/2}.$$

The fast-electron density δN_e corresponding to the distribution function (5) is given by the formula

$$\delta N_e = \frac{\sqrt{2}}{\pi^{3/2}} N_e \frac{\omega_{L_e}}{\omega_{L_i}} \frac{v_E^2}{v_{T_e}^2} \ln^{-1}\left(\frac{\pi}{2}\,\frac{\omega_{L_i}}{\omega_{L_e}}\,\frac{v_1 v_{T_e}}{v_E^2}\right). \tag{6}$$

In a hydrogen plasma $(\omega_{Le}/\omega_{Li}) \simeq 43$, subjected to the action of relatively weak radiation fluxes $(v_E^2/v_{Te}^2) \simeq 5 \times 10^{-4}$, the relative number of fast electrons $(\delta N_e/N_e)$ reaches, according to (6), a value on the order of several tenths of one per cent.

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LOW-TEMPERATURE NEGATIVE DIFFERENTIAL MICROWAVE CONDUCTIVITY IN SEMICONDUCTORS FOLLOWING ELASTIC SCATTERING OF ELECTRONS

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Generation of short-wave microwaves in sufficiently thick samples by using the volume negative differential conductivity (NDC) mechanisms, well known in microwave semiconductor electronics, encounters certain difficulties, particularly because NDC exists also at low frequencies. The volume NDC mechanism proposed in the present article leads to NDC only at sufficiently high frequency, and can hopefully be used to generate short-wave microwave radiation in samples having dimensions determined only by the cooling conditions.

Microwave NDC is possible in "pure" semiconductors at low temperatures in a constant electric field E such that the main mechanism of electron scattering is spontaneous emission of optical phonons by the electrons, namely, if[1)]

$$\nu p_0 << eE << p_0/\tau_0. \tag{1}$$

[1)] Galvanomagnetic effects under such conditions were considered in [1], and effects of "strong" alternating fields were considered in [2].

Here ν is the electron collision frequency at $p < p_0$, p is the electron momentum, $p_0^2/2m = \hbar\omega_0$, ω_0 is the optical-phonon frequency, e and m are the charge and effective mass of the electron, and τ_0 is the time of spontaneous emission of an optical phonon by an electron. Under these conditions the actual proper frequency of the electrons is[2]

$$\omega_E = \frac{2\pi}{\tau_E} \qquad \tau_E = \frac{p_0}{eE} ,$$

and is determined by the time τ_E necessary to accelerate the electron in the field E to an energy $\hbar\omega_0$ and to cause it to stop rapidly by emitting an optical phonon (see [1, 4]); it is when $\omega \gtrsim \omega_E$ that microwave NDC is possible and results from the flight and bunching, in phase space, of the electrons that cause the oscillatory dependence of the alternating part of the distribution function $f_\sim$ on the momentum. Thus, at $\nu = 0$ and $\tau_0 \to 0$ we have $f_\sim = C \exp(-\omega p_z/eE)$, $C = C(\tau_0)$ $(C = 0,\ \tau_0 = 0)$, $\vec{E} \uparrow\uparrow \vec{z}_0$, $0 < p_z < p_0$. Under these conditions, the number of oscillations of $f_\sim$ in the interval $(0, p_0)$ is an important parameter determining the dispersion of the differential conductivity (DC) in the NDC region. The bunching effects that lead to the NDC recall the monotron and klystron effects known in electronics, and also the effects connected with the dependence of the electron collision frequency on the energy ([5, 6]; see also [7, 8]). We consider here the simplest case in which microwave NDC is possible, namely, we assume a lattice temperature T = 0, $\nu = 0$, and $\omega\tau_0 \ll 1$.

At small τ_0, the DC in a homogeneous electric field can be obtained using a modified perturbation method with respect to τ_0 in the kinetic equation for the electrons, by taking into account in this equation, at $p > p_0$, only the term with the electric field and the "departure" term due to the spontaneous emission of the optical phonons. We present the result - an expression for the DC $\sigma = \sigma_{zz}$ under conditions when the electron scattering by the optical phonons is polar[3]: at $\Omega = 0$ and $\Omega = \omega\tau_E$ we have

$$\sigma = \sigma_0 = \frac{\omega_p^2}{4\pi\omega_E} \mu^2 \frac{\Gamma(5/3)}{6} \qquad (2)$$

and at $\Omega \gg 1$

$$\sigma = \sigma_\Omega = \frac{\omega_p^2}{4\pi\omega_E\Omega} Q(x) \frac{[-\sin\Omega + i(R - \cos\Omega)]}{[(R - \cos\Omega)^2 + R^2\sin^2\Omega]} . \qquad (3)$$

In these expressions, ω_p is the Langmuir frequency of the electrons, $\mu = (3E/2E_0)^{1/3}$, E_0 is the characteristic field of polar scattering,

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[2] Singularities in the fluctuations of the current were observed in [3, 4] at $\omega = n\omega_E$, n = 1, 2, 3, ... It is indicated in [4] that the differential conductivity $\sigma = 0$ at $\nu = 0$ and $\tau_0 = 0$.

[3] In deformation scattering, owing to different dependence of the matrix element on the scattering vector, the "arrival" term in the kinetic equation is different at $p < p_0$. Therefore $\sigma < 0$ at $\omega = 0$, but when $\Omega \gg 1$ the change of the "arrival" term is insignificant, so that formula (3) in the appropriate notation, holds true also for deformation scattering.

$$R(x) = x^{-1}\int_0^\infty \sin(xt^{1/3})e^{-t}t^{-1/3}dt;$$
$$Q(x) = x^{-1}\int_0^\infty \sin(xt^{1/3})e^{-t}(1-t)t^{-1/3}dt$$

$x = \mu\Omega$, $Q > 0$. As $x \to 0$ we have $R \simeq 1 - 0.15x^2$ and $Q \simeq 0.1x^2$. It follows from (2) and (3) that $\sigma > 0$ as $\omega \to 0$ and $\sigma < 0$ when $(n + 1/2)\omega_E > \omega > n\omega_E$ (n is a positive integer). Expressions (2) and (3) are valid when $\mu \ll 1$, $\Omega\mu^2 \ll 1$, and $\sigma_\Omega \gg \sigma_0$. We note also that the contribution to the DC from electron scattering by ionized impurities (which is singular at p = 0) can be neglected only if τ_0 is not too small: $\nu_i\tau_E \ll \mu^2$, where ν_i is the frequency of the collisions between the electrons and the ionized impurities at $p = p_0$.

We have disregarded above the influence of a magnetic field $\vec{H} \perp \vec{E}$ on the DC. The role of a weak field H (when the static trajectories are not closed at $p < p_0$ - see [1]) will be considered elsewhere. We note here only that in this case, owing to the change of the static trajectories by an alternating field, the static and microwave NDC are possible also at $\nu = 0$ and $\tau_0 = 0$. As to a strong magnetic field, in this case the electron distribution at $p < p_0$ over the closed trajectories (see [1]) can satisfy the necessary conditions for the functioning of masers at cyclotron resonance (see, e.g., [5, 7, 9, 10]), so that in this case it would be of interest to investigate the DC at $\omega \approx \omega_c$, where ω_c is the cyclotron frequency (NDC at $\omega \approx \omega_c$ was proposed in [11] without advancing any arguments in favor of a nonequilibrium electron distribution).

A suitable material for observation of the considered NDC is n-GaAs with impurity density $N \lesssim 10^{15}$, for which one can have NDC under the conditions in question ($\omega\tau_0 \ll 1$) up to several hundred GHz. Nor is it excluded that microwave NDC effects similar to those discussed here have a bearing on the interpretation of the microwave emission from semiconductors in external fields (see, e.g., [12]).

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