ELECTROABSORPTION IN AMORPHOUS SEMICONDUCTORS AND GLASSES

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In amorphous and vitreous semiconductors, the electrons fill the localized states in the forbidden band at low temperatures and can move in space only by hopping between localization centers, with absorption of energy, since the levels of the individual centers coincide. Under these conditions, absorption of infrared quanta with energy $\hbar\omega$ brings about a transfer of the electron from one center to another. At quantum energies $\hbar\omega \gg \bar{\varepsilon}$ ($\bar{\varepsilon}$ is the activation energy of the hopping conductivity) the average length of the electron hops is determined by the energy conservation law, $\hbar\omega = \bar{\varepsilon}(R)$, where the average level difference $\bar{\varepsilon}(R)$ between centers located a distance R apart is, according to Mott, $\bar{\varepsilon}(R) = \bar{\varepsilon}(\bar{R}/R)^3$ [1], and $\bar{R} \sim n^{-1/3}$.

In the presence of a constant field F, this difference is $\varepsilon(R, \theta) = \bar{\varepsilon}(\bar{R}/R)^3 + FR\cos\theta$, where θ is the angle between the direction of the field and the straight line joining two centers. In this case, the electroabsorption coefficient will be different in directions parallel and perpendicular to the field, and will depend quite strongly on the applied constant field F, owing to the overlap factor $\exp(-2\alpha R)$.

We shall calculate the electric conductivity $\sigma(\omega)$, since $\alpha(\omega) = 4\pi\sigma(\omega)/c\sqrt{\varepsilon_0}$. We write the expression for the hopping electric conductivity $\sigma(\omega)$ in an alternating field at T = 0 in the form (see [2])

$$\sigma(\omega) = \frac{2\pi e^2}{m^2\omega}\int_0^\infty dR \int_0^\pi d\theta \int_0^{2\pi} d\phi \sin\theta\, |p(R,\theta)|^2 F(\omega, R, \theta), \tag{1}$$

where

$$F(\omega, R, \theta) = \sum_{i,j} \delta(R - R_{ij})\,\delta(\hbar\omega + \epsilon_i - \epsilon_j + FR\cos\theta)\, n_i(1 - n_j), \tag{2}$$

n_i are the Fermi occupation numbers, and the matrix element of the momentum $p(R, \theta)$ is given by

$$p(R,\theta) = \int dv\, \psi(r - R)(\mathbf{e}\,\mathbf{p})\psi(r) = \frac{i\hbar\alpha^2}{3}\alpha R(\mathbf{e}\mathbf{R})e^{-\alpha R}.$$

Here $\vec{e}$ is the vector of the electromagnetic-wave polarization and $a_B = \alpha^{-1}$ is the Bohr radius. The occupation numbers separate in the sum (2) only centers with energy close to the Fermi energy ε_F. According to its meaning, $F(\omega, R)$ is proportional to the probability that the distance between the pairs of centers is equal to R and the difference of their energies is $\hbar\omega$. This function has a sharp maximum near the average distance $\bar{\varepsilon}(R)$ between the energies of two centers located a distance R apart [3]. As already stated, $\varepsilon(R) = \bar{\varepsilon}(\bar{R}/R)^3$ in the absence of a field and $\varepsilon(R, \theta) = \bar{\varepsilon}(\bar{R}/R)^3 + FR\cos\theta$ in the presence of a constant field. In practice, the function $F(\omega, R, \theta)$ can be replaced by

$$\frac{n_F}{4\pi}\frac{d}{dR}\delta[\hbar\omega - \epsilon(R,\theta)],$$

where n_F is the concentration of the localization centers with energy close to ε_F. For an arbitrary electric conductivity $\sigma_{\parallel}(\omega)$, for which the polarization vector $\vec{e}$ is parallel to the field F, we obtain by integration, with exponential accuracy,

$$\sigma_{\parallel}(\omega) \approx \frac{\lambda}{2} x_0^3 e^{-2x_0}, \qquad \lambda = \frac{2\pi}{9} \frac{e^2}{m^2} n_F \frac{\hbar^2 a^3}{F\omega}. \tag{3}$$

Here x_0 is the only positive root of the equation

$$x^4 + ax^3 - d = 0, \quad a = \frac{\hbar\omega}{F a_B}, \quad d = \frac{\bar{\varepsilon}}{F a_B} (a\bar{R})^3. \tag{4}$$

If $a^4 \ll d$, i.e., $\hbar\omega \ll [\bar{\varepsilon}(FR)^3]^{1/4}$ and $x_0 \approx d^{1/4} - a/4 \gg 1$, we have

$$\alpha_{\parallel}(\omega) \sim \exp\left\{-2\left[\frac{\bar{\varepsilon}(a\bar{R})^3}{F a_B}\right]^{1/4} + \frac{\hbar\omega}{2F a_B}\right\}. \tag{5}$$

According to [2], the absorption coefficient in the absence of a constant field is $\alpha(\omega) \sim \exp(-\text{const}\cdot\omega^{-1/3})$. As seen from (5), the constant field alters this relation quite strongly.

For the transverse electric conductivity $\sigma_{\perp}(\omega)$ (the polarization vector $\vec{e}$ is perpendicular to the direction of the field F) we obtain similarly

$$\sigma_{\perp}(\omega) \approx \frac{3}{4} \lambda x_0^2 e^{-2x_0} \tag{6}$$

with the same x_0 as in (3). The ratio of the longitudinal conductivity to the transverse one is

$$\sigma_{\parallel}/\sigma_{\perp} = (2/3) x_0 \gg 1. \tag{7}$$

In conclusion, I am grateful to V.L. Pokrovskii for a discussion of the work.

[1] N.F. Mott, Phil. Mag. 19, 835 (1969).
[2] I.Z. Kostadinov, ZhETF Pis. Red. 14, 345 (1971) [JETP Lett. 14, 231 (1971)].
[3] V.L. Pokrovskii, ibid. 4, 140 (1966) [4, 96 (1966)].

QUASISTATIONARY NOISE IN THERMIONIC EMISSION OF SEMICONDUCTORS

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As is well known [1], the quasistationary thermoinic field at the surface of a heated body makes the main contribution to the density of the electromagnetic energy and to the Maxwell stresses, but does not take part in the production of the energy flux. In particular, the quasistationary thermionic field makes the main constribution to the adhesion forces between two closely located bodies [2].