THE SEMICONDUCTOR IMPEDANCE OF ELECTRON TYPE CHARGE CARRIERS WITH HOMOGENEOUS BOUNDARY CONDITIONS

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The semiconductor impedance of electron type charge carriers with homogeneous boundary conditions for electric field has been calculated. The criteria of electric field values, at which the current oscillations in the circuit with definite frequency take place, has been found.

The homogeneous sample with falling branch on volt-ampere characteristic is used as active element in amplifiers and electric oscillation generator. The properties of such sample as the element of electric circuit is comfortable to describe with the help of impedance conception *Z(ω)*. We will investigate the properties of homogeneous semiconductor for one oscillation period, i.e. when $kL=2\pi$, k is wave vector, L is sample length. If the small alternating voltage is given on the sample

$$\delta V(t) = \int_{-\infty}^{+\infty} V(t) e^{-i\omega t} \ d\omega \qquad (1)$$

then by the definition we have:

$$z(\omega)\delta J(\omega) = \delta v(\omega) \ . \qquad (2)$$

The total current is the sum of conduction and displacement currents

$$\vec{J} = \vec{j} + \frac{\varepsilon}{4\pi}\frac{D\vec{E}}{Dt}, \ j = e\mu n E \quad \partial\frac{\partial n}{\partial x}, \qquad (3)$$

where ε is sample dielectric constant, E is electric field. We limit by the one-D case and that's why

$$\delta V(t) = \int_0^L \delta E(x,t)dx \, . \qquad (4)$$

We obtain from (3) for small inclinations from equilibrium state as follows:

$$J(t) = \frac{\varepsilon}{4\pi}\frac{\partial E^{(x,t)}}{\partial t} + j(x,t) \qquad (5)$$

$$\partial j = \sigma_0 n + \sigma\delta E - e\frac{\partial}{\partial x}\left(\sigma_0\delta + n_0\frac{\partial D}{\partial E}\delta E\right). \qquad (6)$$

$$\sigma = en_0\frac{d(\mu E)}{d(E_n)}\Big|_{E=E0}$$

The continuity equation and Poisson's equation have the form:

$$\frac{\partial \rho}{\partial t} + div\vec{j} = 0$$
$$div\vec{E} = \frac{4\pi}{\varepsilon}(\rho - \rho_0). \qquad (7)$$

In one-*D* case the total current according to (7) depends only on *t* and *J=J(t)*. Considering that $E = E_0 + \delta E, n = n_0 + \delta n$ from (5-7), we obtain

$$R^{\wedge}\,\delta E(x,w) = -\frac{4\pi}{\varepsilon}\,\delta J(\omega)$$

$$R^{\wedge} = D\frac{d^2}{dx^2} - U_0\frac{d}{dx} + i\omega - \frac{4\pi}{\varepsilon}\sigma \, . \qquad (8)$$

If fluctuations of the field and charge density take place homogeneously, then

$$\delta E(0,t) = \delta E(L,t) = 0 \, . \qquad (9)$$

The solution of inhomogeneous equation (8) with taking into consideration of boundary conditions (9) has the form

$$\delta E(x,\omega) = -\frac{4\pi}{\varepsilon(i\omega - \frac{4\pi\sigma}{\varepsilon})}\left[1 + \frac{(e^{ir_2}-1)e^{ik_1x} - (e^{ir_1}-1)e^{ik_2x}}{e^{ir_1} - e^{ir_2}}\right] \qquad (10)$$

$$r_1 - k_1 l, r_2 - k_2 l, k_1 - \frac{1}{2D}\left[-i\mu_0 E_0 + \sqrt{-(\mu_0 E_0)^2 + 4D(i\mu - \frac{4\pi\sigma}{\varepsilon})}\right]$$

$$k_2=\frac{1}{2D}\left[-i\mu_0E_0+\sqrt{-(\mu_0E_0)^2+4D(i\mu-\frac{4\pi\sigma}{\varepsilon})}\right].$$

Integrating the expression (10) over *x*, we find impedance

$$Z(\omega)=+\frac{4\pi LS\left(i\frac{\omega}{\sigma}+\frac{4\pi}{\varepsilon}\right)}{\varepsilon\sigma\left[\left(\frac{\omega}{\sigma}\right)^2+\left(\frac{4\pi}{\varepsilon}\right)^2\right]}*\left\{1+\frac{k_2-k_1}{ik_1k_2}*\frac{\left(e^{ir_1}-1\right)\left(e^{ir_2}-1\right)}{e^{ir_1}-e^{ir_2}}\right\} \qquad (11)$$

Designating $Z_0=\frac{4\pi LS}{\varepsilon\sigma\left[\left(\frac{\omega}{\sigma}\right)^2+\left(\frac{4\pi}{\varepsilon}\right)^2\right]}$, (*S* is sample cross-section) and taking into consideration r_1, r_2, k_1, k_2, we obtain the expression for impedance

$$\frac{Z(\omega)}{Z_0}=\left[\frac{4\pi}{\varepsilon}+i\frac{\omega}{\sigma}+\frac{(k_2-k_1)\left(i\frac{\omega}{\sigma}+\frac{4\pi}{\varepsilon}\right)}{iLk_1k_2}\right]. \qquad (12)$$

The expression (12) is correct for one oscillation period, i.e.

$$K_1{}^0L=2\pi \qquad (13)$$

we easily obtain the following expression from expressions k_1, k_2

$$K_1=\frac{\propto}{2D}+i\frac{\beta-\mu_0\varepsilon_0}{2D};\ K_1=-\frac{\propto}{2D}+i\frac{\mu_0\varepsilon_0+\beta}{2D};$$

$$\propto=\frac{1}{\sqrt{2}}\left[\sqrt{(\mu_0\varepsilon_0)^4+16D^2\omega^2}-(\mu_0\varepsilon_0)^2\right]^{\frac{1}{2}}$$

$$\beta-\frac{1}{\sqrt{2}}\left[\sqrt{(\mu_0\varepsilon_0)^4+16D^2\omega^2}-(\mu_0\varepsilon_0)^2\right]^{\frac{1}{2}}. \qquad (14)$$

Substituting $k_1{}^0$ value in (13) we easily obtain the frequency values for one current oscillation period in the sample

$$\omega=\frac{2\pi\mu_0E_0}{L}. \qquad (15)$$

We obtain the following expression for real and imaginary parts of impedance from expression (12) with taking into consideration k_1k_2 values

$$\frac{ReZ}{Z_0}=\left(\frac{4\pi}{\varepsilon}+\frac{4\pi}{\varepsilon}\frac{\propto}{\omega\varepsilon}-\frac{\beta}{\sigma\varepsilon}\right) \qquad (16)$$

$$\frac{ReZ}{Z_0}=\left[\frac{\omega}{\sigma}+\frac{\propto}{\sigma\iota}+\frac{4\pi}{c}\frac{\beta}{\omega\iota}\right]$$

From (16) it is seen, that at $E>E_{char}$ the real part of impedance has the negative sign, i.e. the current oscillation with frequency (15) takes place:

$$E_{char}=\frac{4\pi}{\varepsilon}\sigma_0 l$$

Under experimental conditions in the sample with concentration $n\approx3\cdot10^{15}$, length 0,01 cm and mobility $\mu\approx3\cdot10^{14}$, $E_{char}\approx2\cdot10^3$ V/cm.

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BİRCİNS SƏRHƏD ŞƏRTLƏRİNİ ÖDƏYƏN ELEKTRON KEÇİRİCİLİKLİ YARIMKEÇİRİCİNİN İMPEDANSI

Elektrik sahəsi üçün bircins sərhəd şərtləri ödənilən electron tip keçiriciliyə malik yarımkeçiricilərdə impedans hesablanmışdır. Dövrədə müəyyən tezliklə yaranan rəqslərə uyğun elektrik sahəsinin dəyişmə kriteriyası tapılmışdır.

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ИМПЕДАНС ПОЛУПРОВОДНИКА ЭЛЕКТРОННОГО ТИПА НОСИТЕЛЕЙ ЗАРЯДА С ОДНОРОДНЫМИ ГРАНИЧНЫМИ УСЛОВИЯМИ

Вычислен импеданс полупроводника электронного типа носителей заряда с однородными граничными условиями для электрического поля. Найдены критерии значений электрического поля, при которых происходят колебания тока в цепи с определенной частотой.

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