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TO THE THEORY OF VOLT-AMPER CHARACTERISTICS OF THE THREE-LAYER STRUCTURE OF SEMICONDUCTORS IN DIODE SWITCHING

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Annotation. A generalized theory of the current-voltage characteristics of a three-layer semiconductor structure in a diode inclusion is proposed. It is believed that the base of this structure is made of compensated semiconductor. The results obtained are generalized for structures with different conductivities.

Key words: Current-voltage characteristic, three-layer semiconductor structure, diode, compensated semiconductor.

The volt – ampere characteristic (CVC) of the three-layer structure of semiconductors in a diode inclusion, in which the base is made of a compensated semiconductor, has been considered in a number of works (see, for example, [1–4] and the references therein). In [4], in particular, a number of phenomena are listed that explain the appearance of a section of negative resistance (OC) in the volt – ampere characteristic in the through direction in $p-n-p$ structures.

In this paper, following [2], expressions are obtained for the distribution of current densities and concentrations of current carriers along the length of the base. To determine the relationship between these parameters, the Poisson equations, the conditions of electroneutrality and continuity of flows for current carriers in the stationary case are taken into account [1-3]. Then the distribution of current densities along the length of the base of the three-layer structure is described by the equation (in the one-dimensional approximation, i.e., along the axis Ox):

$$L_n^2 \frac{2n+\delta\theta p_0+n_0}{\left(1+b\delta\theta\right)p+\delta\theta(p_0+bn_0)}\frac{d^2 j_n}{d\,x^2}-j_n+\frac{b\left(n+n_0\right)}{\left(b+\dfrac{1}{\delta\theta}\right)p+n_0 b+p_0}j=0, \qquad (1)$$

where the notation of [1, 2], $j = j_n + j_p$ is the density of the total current of electrons and holes are used. Here it is believed that the base of the structure is made of a semiconductor compensated by impurities that create deep levels in the forbidden zone. Then in the region of strong injection (1) takes the form

$$\frac{2L_n^2}{1+b\delta\theta}\frac{d^2 j_n}{d\,x^2}-j_n+\frac{b}{\left(b+\dfrac{1}{\delta\theta}\right)}j=0. \qquad (2)$$

To solve the latter, it is convenient to go to $y = j_n/j = j_n\Big/\left(j_n+j_p\right)$. Then it's easy to get

$$\frac{d^2y}{dx} - \frac{b\delta\theta + 1}{2}\left(y - \frac{b\delta\theta}{b\delta\theta + 1}\right) = 0 \quad , \tag{3}$$

whose solution we are looking for in the form

$$y = \frac{b\delta\theta}{b\delta\theta + 1} + c_1 chx\sqrt{a} + c_2 chx\sqrt{a} \quad , \tag{4}$$

Where $a = \frac{b\delta\theta + 1}{2}; \quad L = \sqrt{\frac{2L_n}{b\delta\theta + 1}}$. From the condition $y(0) = j_n(0)/j = m_1$ (electron fraction of the total current density in $x = 0$) we have

$$c_1 = \frac{(m_2 + 1)b\delta\theta + m_2 - \left[b\delta\theta(m_1 - 1) - m_1\right]ch\frac{d}{L}}{(b\delta\theta + 1)sh\frac{d}{L}} \quad , \tag{5}$$

Then, introducing the electron fraction in the total current density at $x = d$ (d *is* the base length), i.e. we get the expression for

$$\frac{j_n}{j} = \frac{b\delta\theta}{b\delta\theta + 1} + \frac{(m_1 + 1)b\delta\theta + m_1}{(b\delta\theta + 1)sh\frac{d}{L}}sh\frac{d - x}{L} + \frac{(m_2 + 1)b\delta\theta + m_2}{(b\delta\theta + 1)sh\frac{d}{L}}sh\frac{x}{L} \quad , \tag{6}$$

Then, in the diffusion approximation, the electron distribution along the length of the base of the structure has the form

$$n = \frac{j L_n\ sh^{-1}\frac{d}{L}}{e D_n\sqrt{2(1 + b\delta\theta)}}\left\{\left[(m_2 - 1)b\delta\theta + m_2\right]sh\frac{x}{L} - \left[(m_1 - 1)b\delta\theta + m_1\right]sh\frac{d - x}{L}\right\}, \tag{7}$$

whence the electron concentrations in the contacts are determined by the relations (see table 1)

$$n(0) = \frac{j L_n}{e D_n\sqrt{2(1 + b\delta\theta)}\ sh\frac{d}{L}}\left\{\left[(m_2 - 1)b\delta\theta + m_2\right]\tilde{n}h\frac{d}{L} - \left[(m_1 - 1)b\delta\theta + m_1\right]\right\}, \tag{8}$$

$$n(d)=\frac{\left[(m_2-1)b\delta\theta+m_2\right]\tilde{n}h\frac{d}{L}-\left[(m_1-1)b\delta\theta+m_1\right]}{(m_2-1)b\delta\theta+m_2-\left[(m_1-1)b\delta\theta+m_1\right]\tilde{n}h\frac{d}{L}}n(0)$$

Hence the distribution of electrons over the thickness of the base for structures of the type, p^+-n-n^+, n^+-n-p^+ and n^+-n-n^+ is written in the form

$$n(x)=\frac{jL_n}{eD_n\sqrt{2(1+b\delta\theta)sh\frac{d}{L}}}\left[ch\frac{x}{L}+b\delta\theta ch\frac{d-x}{L}\right]$$

$$n(x)=\frac{jL_n\left[ch\frac{d-x}{L}-b\delta\theta ch\frac{x}{L}\right]}{eD_n\sqrt{2(1+b\delta\theta)}sh\frac{d}{L}} \quad (9)$$

$$n(x)=\frac{jL_n\left[ch\frac{x}{L}+ch\frac{d-x}{L}\right]}{eD_n\sqrt{2(1+b\delta\theta)}sh\frac{d}{L}}$$

The current – voltage characteristic of a three-layer semiconductor structure, determined by the voltage drop at the base of the structure, in the diffusion approximation has the form

$$V=\int_0^d Edx=V_1+V_2 \quad (10)$$

$$V_1=-\frac{kT}{e}\cdot\frac{b\delta\theta-1}{b\delta\theta+1}\cdot\ln\left|\frac{ch\frac{d}{L}-\aleph_1}{1-ch\frac{d}{L}\cdot\aleph_1}\right|,\quad \aleph_1=\frac{(m_1-1)b\delta\theta-m_1}{(m_2-1)b\delta\theta+m_2},$$

$$V_1=\frac{\varphi_{T1}}{\left\{\left(1-\aleph\cdot\exp\frac{d}{L}\right)\left[1-\aleph\cdot\exp\left(-\frac{d}{L}\right)\right]\right\}}\left\{arctg\left[\sqrt{\frac{1-\aleph\cdot\exp\left(-\frac{d}{L}\right)}{1-\aleph\cdot\exp\frac{d}{L}}}\cdot e^{d/L}\right]-arctg\sqrt{\frac{1-\aleph\cdot\exp\left(-\frac{d}{L}\right)}{1-\aleph\cdot\exp\frac{d}{L}}}\right\} \quad (11)$$

$$\aleph=\frac{(m_1-1)b\delta\theta-m_1}{(m_2-1)b\delta\theta+m_2},\quad \varphi_{T1}=\frac{kT}{e}\cdot\frac{4\cdot sh\,d/L}{\alpha(1+b\delta\theta)}.$$

For example, for the structure n^+-n-p^+ we have

$$V_1 = \frac{kT}{e} \cdot \frac{4 \cdot sh\, {}^{d}\!/_{L}}{1 + b\delta\theta} \cdot \frac{\eta_1 \cdot b\delta\theta}{\left\{ \left[1 + b\delta\theta \exp\frac{d}{L} \right] \cdot \left[1 + b\delta\theta \exp\left(-\frac{d}{L} \right) \right] \right\}^{\frac{1}{2}}}, \qquad (12)$$

$$\text{where } \eta_1 = arctg \left\{ \frac{\left[\left(b\delta\theta + e^{d/L} \right)\left(b\delta\theta + e^{-d/L} \right) \right]^{1/2}}{1 + b\delta\theta} th \frac{d}{2L} \right\}.$$

Then the electric field strength in the structure has the form

$$E = \frac{j \cdot L_n}{e D_n} \cdot \frac{(m_2 - 1)b + m_2}{\sqrt{2(1 + b) ch \frac{d}{L}}} \left[ch\frac{x}{L} - \aleph \cdot ch\frac{d - x}{L} \right], \qquad (13)$$

and for the minimum value of the voltage drop at the base

$$V_{\min} = \frac{kT}{e} \frac{\frac{4b}{b+1} \cdot sh\frac{d}{L} \cdot \left[arctg \left\{ \frac{\left[\left(1 - \aleph^1 \cdot e^{d/L} \right)\left(1 - \aleph \cdot e^{-d/L} \right) \right]^{1/2}}{(1 - \aleph)\, cth\, {}^{d}\!/_{L}} \right\} \right] \eta_i}{\left[\left(1 - \aleph \cdot e^{d/L} \right)\left(1 - \aleph \cdot e^{-d/L} \right) \right]^{1/2} \cdot \left((m_2 - 1)b + m_1 \right)} + \frac{b - 1}{b + 1} \cdot \frac{kT}{e} \ln \frac{1 - \aleph \cdot ch\frac{d}{L}}{ch\frac{d}{L} - \aleph}. \qquad (14)$$

In conclusion, we note that the discussion of our theoretical results on specific three-layer semiconductor structures in a diode inclusion requires a separate consideration.

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ИЗМЕНЕНИЕ КОЛИЧЕСТВА ВЕЩЕСТВА (NACL) В СОСТАВЕ БИОЛОГИЧЕСКОЙ ЖИДКОСТИ МОЖЕТ ПРИВЕСТИ К ИЗМЕНЕНИЯМ В ЕЁ КОАГУЛЯЦИИ (СГУЩЕНИЮ) И КРИСТАЛЛИЗАЦИИ.

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Аннотация. Многочисленные данные, полученные в области науки, позволяют прийти к выводу, что биологическая жидкость (слюна) является уникальным веществом с огромным потенциалом для использования в основных исследованиях и медицинской диагностике. Биологическая жидкость (слюна) может служить источником для изучения ДНК человека и проведения клинических анализов, так как состав определенных молекул в слюне отражает их концентрацию в крови.

Ключевые слова. биологическая жидкость, испарение, кристаллизация, организм.

Актуальность исследования. Биологическая жидкость является сложным средством, отражающим динамическое равновесие внутренней среды организма. При этом слюна под воздействием различных факторов может