INFLUENCE OF SELF-CONSISTENT ELECTRON-DEFORMATION INTERACTION ON ELECTRON STATES LOCALIZED AT AN EDGE DISLOCATION

M.M. BARAN, R.M. PELESHCHAK

Ivan Franko Drohobych State Pedagogical University
(24, Ivan Franko Str., Drohobych 82100, Ukraine)

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In the framework of the model of self-consistent electron-deformation interaction in a single-band semiconductor, the influence of the conduction electron concentration n_0 on the energy levels of an electron localized at an edge dislocation has been investigated. The energy of the localized level in lightly doped semiconductors ($n_0 \leq 10^{17}$ cm^{-3}) has been shown to shift monotonously towards lower values as n_0 grows and to possess a nonmonotonous character in heavily doped semiconductors (10^{17} cm^{-3} $\leq n_0 \leq 10^{19}$ cm^{-3}). The probability for an electron to be near the edge dislocation nucleus has been found to increase by about 15% as the conduction electron concentration grows within the interval 10^{17} cm^{-3} $\leq n_0 \leq 10^{19}$ cm^{-3}.

Such parameters of the electron subsystem of semiconductor structures as the concentration of conduction electrons, the spectra of electrons localized at defects of various kinds (linear, dot, plane), the effective mass of current carriers, the cross-section of carrier capture, Coulomb interaction, and others, strongly depend on the lattice deformation induced by defects and impurities. For a long time, a traditional direction of researches has been based on studying the influence of impurities, defects (linear and dot) and strain effects connected to these defects, on electronic properties of semiconductors. In particular, in works [1–3], the problem concerning the influence of mechano-deformational effects on the energy of electron states localized at an edge dislocation has been solved.

Lately, inverse problems have been attracting more and more interest. One of such problems consists in studying the influence of an electronic subsystem, considered in the framework of self-consistent electron-deformation coupling, on the energy of electron states localized at defects of various kinds, because, owing to works [4, 5], it is known that the excitation of the electron subsystem affects the evolution of the defective structure of crystals. This work aims at studying, in the framework of the self-consistent electron-deformation interaction model, the influence of the conduction electron concentration on the energy of the ground state of an electron localized at an edge dislocation.

Consider a crystal with an edge dislocation in the YOZ plane with a Burgers vector $\vec{b} = (b, 0, 0)$ [6,7]. The edge dislocation (the axis of the dislocation coincides with the OZ axis) forms a mechanical deformation which is described in cylindrical coordinates by the relation [8]

$$U_{\text{mech}}(\rho, \theta) = -\frac{1-2\nu}{2\pi(1-\nu)} \frac{b}{\rho} \cos\theta, \quad \rho \geq \rho_0, \tag{1}$$

where $\nu = \frac{C_{12}}{C_{11}+C_{12}}$ is Poisson's ratio, C_{ij} are the elastic constants $(i, j = 1, 2)$, ρ and θ are the polar coordinates, $\rho_0 = (1 \div 2)a$ is the radius of the dislocation nucleus, a is the lattice constant, and the angle θ is reckoned from an excess dislocation plane to the radius-vector $\vec{\rho} = (x, y)$ in the crystal plane XOY. As is seen from Eq. (1), the crystal lattice undergoes the mechanical nonhomogeneous deformation of squeezing in the upper half of the XOY plane ($y > 0$ or $-\frac{\pi}{2} \leq \theta \leq \frac{\pi}{2}$), which includes this excess dislocation plane and that of stretching in the lower half plane ($y < 0$ or $\frac{\pi}{2} \leq \theta \leq \frac{3\pi}{2}$). Such a nonhomogeneous mechanical deformation of the lattice results in a local variation of the electron spectrum. Therefore, there occurs a spatial redistribution of electrons, which, due to the self-consistent electron-deformation interaction [6,9], renormalizes the initial mechanical strain of the lattice $U_{\text{mech}}(\rho, \theta)$. Then, the parameter of total deformation U will consist of two components, mechanical $U_{\text{mech}}(\rho, \theta)$ and electron-deformation $U_{\text{el-def}}$ ones. The electron-deformation component depends on the population level $\bar{n}$ of the conduction band $(0 \leq \bar{n} \leq 2)$, where $\bar{n} = n_0\Omega_0$, n_0 is the average concentration of conduction electrons, and Ω_0 is the initial volume of the elementary cell. The parameter $\bar{n}$ can be changed by doping the semiconductor (for example, CdTe:Cl, $n_0 \sim 5 \times 10^{18}$ cm^{-3}), varying its composition x (for example, $\text{Sm}_{1-x}\text{Cd}_x$ $(0 \leq x \leq 0.22)$ [11]) or undergoing photoillumination.

In this work, we calculated the energy of a localized state of an electron at an edge dislocation making use of

a dislocation potential V_d which takes into account the electron-deformation interaction self-consistently. Such a potential is obtained by solving the self-consistent system of the following five equations [9].

The equation of balance is

$$\left\langle \frac{\partial H}{\partial U} \right\rangle = \sigma_{\mathrm{mech}}\left(\rho,\theta\right) V, \tag{2}$$

where H is the Hamiltonian of a non-uniformly deformed (provided that there are dislocations) crystal taking into account the electron-deformation coupling, V is the crystal volume, and $\sigma_{\mathrm{mech}}\left(\rho,\theta\right)$ is the mechanical stress induced by the dislocation. The Hamiltonian has the form

$$\hat{H} = \sum_{i\sigma}\left[W + SU\left(\rho_i,\theta\right)\right] c_{i\sigma}^{+} c_{i\sigma} + \sum_{ij\sigma}{}' \lambda_{ij}^{0} v_{i\sigma}^{+} c_{j\sigma} +$$

$$+\frac{1}{2}\sum_{i} K\Omega_0 U^2\left(\rho_i,\theta\right) + H_c. \tag{3}$$

Here, the first term describes the energy of an electron at the i-th site with the coordinates (ρ,θ) and W is the energy in the middle of the conduction band, which was chosen as a reference mark, and S is the constant of the deformation potential of the conduction band. The conduction band is formed by the electron overlapping of the i-th and j-th sites in a non-deformed crystal. The quantity λ_{ij}^{0} in the second term is the energy width of the electron overlapping of the i-th and j-th sites in a non-deformed crystal. The third term describes the potential energy of the elastically deformed crystal, while the fourth one (H_c) corresponds to the Coulomb interaction. $c_{i\sigma}^{+}$ and $c_{i\sigma}$ are the Fermi operators of creation and annihilation, respectively, of an electron with the spin σ at the i-th site; $U(\rho,\theta) = \mathrm{Sp}\,\hat{U} = (\Omega(\rho,\theta) - \Omega_0)/\Omega_0$ is the strain parameter which describes the relative variation of the crystal volume in the presence of a dislocation; K is the elastic constant.

The equation

$$n\left(\rho,\theta\right) = \sum_{n} \frac{\psi_n^{*}\left(\rho,\theta\right)\,\psi_n\left(\rho,\theta\right)}{\exp\left[\beta\left(\lambda_n - \mu\right)\right] + 1} \tag{4}$$

defines the electron concentration. Here, $\psi_n\left(\rho,\theta\right)$ is a solution of the stationary Schrödinger equation

$$\left[\nabla_{\rho,\theta}^{2} - \frac{S}{\alpha^{*}} U\left(\rho,\theta\right) + \frac{e}{\alpha^{*}}\varphi\left(\rho,\theta\right)\right]\psi_n\left(\rho,\theta\right) =$$

$$= -\frac{1}{\alpha^{*}}\tilde{\lambda}_n \psi_n\left(\rho,\theta\right), \tag{5}$$

$\alpha^{*} = \hbar^2/2m^{*}$, $\tilde{\lambda}_n = \lambda_n - \lambda_0$, and λ_0 is the bottom energy of the conduction band in a non-deformed crystal. The last term in the brackets on the left-hand side of Eq. (5) is the electrostatic potential energy, which is connected to a charge redistribution induced by the electron-deformation interaction [9]. The potential $\varphi\left(\rho,\theta\right)$ can be determined from the Poisson equation

$$\nabla_{\rho,\theta}^{2}\varphi - g^2\varphi = \nabla_{\rho,\theta}^{2} SU_m \equiv \frac{2DS}{\rho_0^2}\delta\left(\rho - \rho_0\right)\cos\theta, \tag{6}$$

where $D = \frac{1-2\nu}{2\pi(1-\nu)}b$, $g^2 = \frac{e^2 R_S}{\varepsilon\varepsilon_0}$; g is the reciprocal effective radius of screening which is caused by the electron-deformation interaction and depends on the population level of the conduction band, elastic constants C_{ij}, the effective mass, and the constant of the deformation potential S;

$$R_S = \left(\frac{3}{8}\right)^{1/3} \frac{1}{\alpha^{*}\pi^{4/3}\Omega_0^{1/3}} \frac{n_0^{1/3}\left[1 + ln_0^{1/3}\right]^{1/2}}{1 - \frac{3}{2}ln_0^{1/3}\left[1 + ln_0^{1/3}\right]^{1/2}},$$

and

$$l = \frac{S^2}{\left(3\pi^2\right)^{2/3}\alpha^{*} K}.$$

At last, the equation for the definition of the electrochemical potential is

$$\frac{\Omega_0}{V}\int_{V_r} n\left(\rho,\theta\right)\partial\vec{r} = \bar{n}, \quad 0 < \bar{n} < 2, \quad \bar{n} = n_0\Omega_0. \tag{7}$$

The solution of Eq. (6) looks like

$$\varphi\left(\rho,\theta\right) = -\frac{2DS}{\rho_0 e}\times$$

$$\times\cos\theta\begin{cases} K_1\left(g\rho_0\right) I_1\left(g\rho\right), & \rho \in [0,\rho_0], \\ I_1\left(g\rho_0\right) K_1\left(g\rho\right), & \rho \in [\rho_0, +\infty), \end{cases} \tag{8}$$

where $I_1(x)$ and $K_1(x)$ are the modified Bessel functions of the first and second (the Macdonald function) kinds, respectively.

The solution of the self-consistent system of Eqs. (2), (4)–(7) was obtained under the condition that the electrostatic interaction energy and the deformation energy are of the same order ($|e\varphi| \sim |S\Delta U|$). Then, the wave function taken in the form of a plane wave is a good approximate solution of the Schrödinger equation. In this approximation, the variation of the conduction electron concentration $\Delta n(\rho,\theta)$ in the vicinity of the

edge dislocation is found in terms of a difference between the electrostatic and deformation energies [9] as

$$\Delta n\left(\rho,\theta\right)=R_S[e\varphi-SU_{\mathrm{mech}}]. \tag{9}$$

Substituting solution (8) into (9) and taking into account the deformation potential (1), the expression for $\Delta n(\rho,\theta)$ reads

$$\Delta n\left(\rho,\theta\right)=-SR_SD\cos\theta\left[\frac{2}{\rho_0}I_1\left(g\rho_0\right)K_1\left(g\rho\right)-\frac{1}{\rho}\right],$$

$$\rho\in[\rho_0,+\infty). \tag{10}$$

On the basis of the expressions obtained for $\Delta n(\rho,\theta)$ and $\varphi(\rho,\theta)$, as well as the expression

$$\Delta U\left(\rho,\theta\right)=-\frac{S}{K}\Delta n\left(\rho,\theta\right)+U_{\mathrm{mech}}\left(\rho,\theta\right), \tag{11}$$

one can define the energy of the bottom of the conduction band $E_c(\rho,\theta)$, dependent on the coordinates (ρ,θ), with respect to the bottom energy λ_0 of the conduction band in a non-deformed crystal, i.e. at a point far from the dislocation:

$$\mathrm{E_c}\left(\rho,\theta\right)=\lambda_0+S\Delta U\left(\rho,\theta\right)-e\varphi\left(\rho,\theta\right). \tag{12}$$

The condition $|e\varphi|\ll|S\Delta U|$ can hold true in lightly doped semiconductors ($n_0\le10^{17}$ cm^{-3}), because the redistribution of electrons induced by a shift of the conduction band, which, in its turn, is caused by a deformation, cannot give rise to a substantial accumulation of excess charges if the initial electron concentration is insignificant, so that the electrostatic interaction energy is not enough to compensate the contribution connected with the deformation [9].

The condition $|e\varphi|\sim|S\Delta U|$ may correspond to heavily doped and degenerate semiconductors (10^{17} cm^{-3} $\le n_0\le10^{19}$ cm^{-3}), in which the electrostatic interaction energy can be of the same order as the deformation component of the energy due to the high concentration of current carriers.

Substituting expression (11) for the parameter of the total deformation $\Delta U(\rho,\theta)$ into formula (12) and taking into account the redistribution of electron density (10), the analytical forms for the dislocation potential $V_d(\rho,\theta)=E_c-\lambda_0$ are as follows:

1) for lightly doped semiconductors ($|e\varphi|\ll|S\Delta U|$)

$$V_{1d}(\rho,\theta)=SD\cos\theta\left[\frac{S^2Rs}{K}\left(\frac{2}{\rho_0}I_1(g\rho_0)K_1(g\rho)-\right.\right.$$

$$\left.\left.-\frac{1}{\rho}\right)-\frac{1}{\rho}\right],\quad\rho\ge\rho_0, \tag{13}$$

2) for heavily doped and degenerate ones ($|e\varphi|\sim|S\Delta U|$)

$$V_{2d}(\rho,\theta)=\left(1+\frac{S^2Rs}{K}\right)\left[SD\cos\theta\left(\frac{2}{\rho_0}I_1(g\rho_0)\times\right.\right.$$

$$\left.\left.\times K_1(g\rho)-\frac{1}{\rho}\right)\right],\quad\rho\ge\rho_0. \tag{14}$$

For the field of elastic deformations at $\rho\gg\rho_0$,

$$K_1\left(g\rho\right)=\frac{\sqrt{\pi}}{2}\frac{1}{g\rho}+0\left(\frac{1}{(g\rho)^{\frac{3}{2}}}\right). \tag{15}$$

Taking this expansion into account, the dislocation potentials (13) and (14) can be written down as follows:

$$V_{1d}\left(\rho,\theta\right)=\frac{1}{\rho}SD[q_1\left(n_0\right)-1]\cos\theta \tag{16}$$

and

$$V_{2d}\left(\rho,\theta\right)=\frac{1}{\rho}SDq_2\left(n_0\right)\cos\theta, \tag{17}$$

where

$$q_1\left(n_0\right)=\frac{S^2R_S}{K}\left(\frac{\sqrt{\pi}}{g\rho_0}I_1\left(g\rho_0\right)-1\right) \tag{18}$$

and

$$q_2\left(n_0\right)=\left(1+\frac{S^2Rs}{K}\right)\left(\frac{\sqrt{\pi}}{g\rho_0}I_1\left(g\rho_0\right)-1\right) \tag{19}$$

are the parameters which describe how the electron-deformation interaction influences the localization degree of electron states at the dislocation at various values of the conduction electron concentration n_0 in lightly and heavily doped semiconductors, respectively.

As is seen from formulae (16)—(19), the dislocation attracts an electron in the range $-\frac{\pi}{2}\le\theta\le\frac{\pi}{2}$ (i.e. in the upper half-plane which includes the excess dislocation plane) and repulses it at $\frac{\pi}{2}\le\theta\le\frac{3\pi}{2}$ (i.e. in the lower half-plane, where the excess dislocation plane is absent) if the population level of the conduction band n_0 is such that either the inequalities $q_2\left(n_0\right)<0$, $q_1\left(n_0\right)<1$, and $S>0$ or the inequalities $q_2\left(n_0\right)>0$, $q_1\left(n_0\right)>1$, and $S<0$ are fulfilled. In the case $q_1\left(n_0\right)>1$ and $S>0$, the region $-\frac{\pi}{2}\le\theta\le\frac{\pi}{2}$, which includes the dislocation plane, becomes repulsive, and the region $\frac{\pi}{2}\le\theta\le\frac{3\pi}{2}$ does attractive.

We look for the wave function of an electron in the potential field (13) or (14) in the form

$$\psi\left(\vec{r}\right)=\left(2\pi\rho\right)^{-\frac{1}{2}}u\left(\rho,\theta\right)e^{-ik_zz}. \tag{20}$$

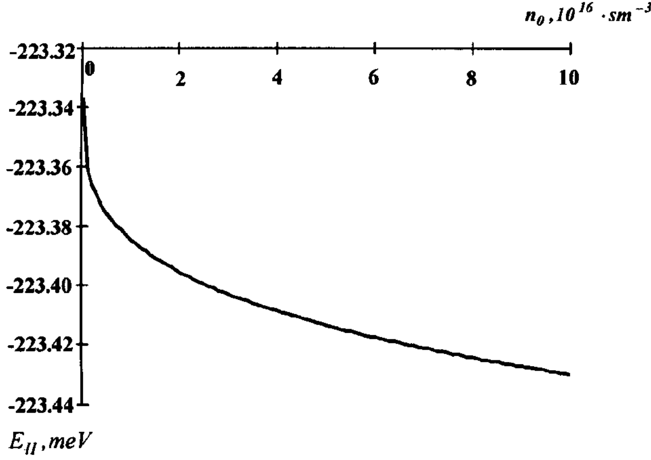

Fig. 1. Dependence of the ground state energy of an electron localized at an edge dislocation on the conduction electron concentration in lightly doped semiconductors ($|e\varphi| \ll |S\Delta U|$, $n_0 \leq 10^{17}$ cm^{-3})

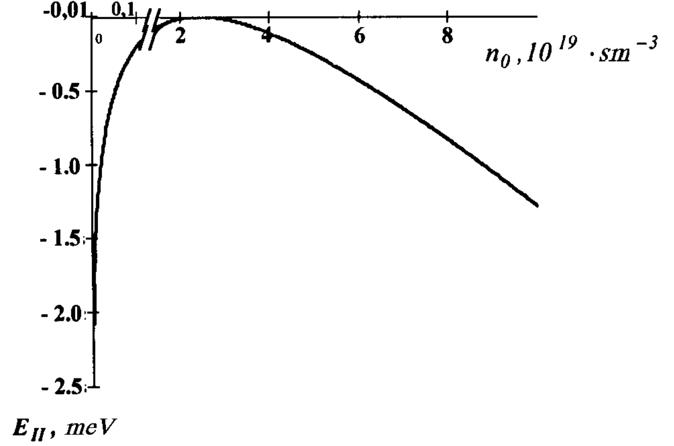

Fig. 2. The same as in Fig. 1 but in heavily doped semiconductors ($|e\varphi| \sim |S\Delta U|$, 10^{17} cm$^{-3} \leq n_0 \leq 10^{19}$ cm^{-3})

For potentials (13) and (14) which vary smoothly at distances of about the lattice parameter, the wave function $u(\rho, \theta)$ can be determined from the Schrödinger equation in the effective mass approximation [12]. We write down the Schrödinger equation in terms of dimensionless variables:

$$-\left(\frac{\partial^2 u}{\partial \eta^2} + \frac{u}{4\eta^2} + \frac{1}{\eta^2}\frac{\partial^2 u}{\partial \theta^2}\right) + \frac{\cos\theta}{\eta}u = \varepsilon u. \quad (21)$$

Here,

$$\eta = \frac{8\pi^2 p m^* \rho}{\hbar^2}$$

and

$$\varepsilon = \frac{\hbar^2}{8\pi^2 p^2 m^*}\left(E_c - \frac{\hbar^2 k_z^2}{8\pi^2 m^*}\right) \quad (22)$$

are the dimensionless coordinate and energy, respectively, of the "transverse motion"; $p = SD[q_1(n_0) - 1]$ or $p = SD[q_2(n_0) - 1]$ in cases 1) or 2), respectively; m^* is the electron effective mass; and $E_{II} = E_c - \frac{\hbar^2 k^2}{8\pi^2 m^*}$ is the energy of an electron that moves in a plane perpendicular to the dislocation line.

The variables in formula (21) are not separable. Therefore, our problem is expedient to be solved by a straightforward variational method [3]:

$$\delta\varepsilon = 0 \quad (23)$$

$$\varepsilon = \left[\left\langle \int_0^\infty d\eta u^2 \right\rangle\right]^{-1} \left\langle \int d\eta \left[\left(\frac{\partial u}{\partial \eta}\right)^2 + \frac{1}{\eta^2}\left(\frac{\partial u}{\partial \theta}\right)^2 - \right.\right.$$

$$\left.\left. - \frac{u^2}{4\eta^2} + \frac{\cos\theta}{\eta}u^2\right]\right\rangle, \quad (24)$$

where $\langle \ldots \rangle = (2\pi)^{-1} \int_0^{2\pi} d\theta \ldots$.

Consider a simple trial function

$$u(\eta, \theta) = u_0 \eta e^{-\eta\gamma(\theta)/2}, \quad (25)$$

where $\gamma(\theta) = \alpha + \beta\cos\theta$ and α, β are variational parameters. This form was selected for the trial function, because it should not differ very much from that of the wave functions for axially symmetric potential η^{-1}. On the other hand, it must decay anisotropically when tending to infinity, which reflects the anisotropy of potentials (13) and (14).

Substituting Eq. (25) into Eq. (24) and calculating the integrals, we obtain the following expression:

$$\varepsilon = \frac{1}{4}\frac{(\alpha^2 - \beta^2)(\alpha^2 - 4\beta)}{2\alpha^2 + \beta^2}. \quad (26)$$

Minimizing (26) over α and β brings us to $\varepsilon_0 = -0.10102$ at $\alpha = 1.34088$, $\beta = 0.89898$ and to

$$u_0 = \left(\frac{(\alpha^2 - \beta^2)^{5/2}}{2(2\alpha^2 + \beta^2)\pi}\right)^{1/2} = 0.16853.$$

Then, the energy E_{II} of the ground state of an electron localized at the edge dislocation, when taking into account Eqs. (22) and (26), reads

$$E_{II} = \varepsilon\left[\frac{\hbar^2}{8\pi^2 p^2 m^*}\right]^{-1}. \quad (27)$$

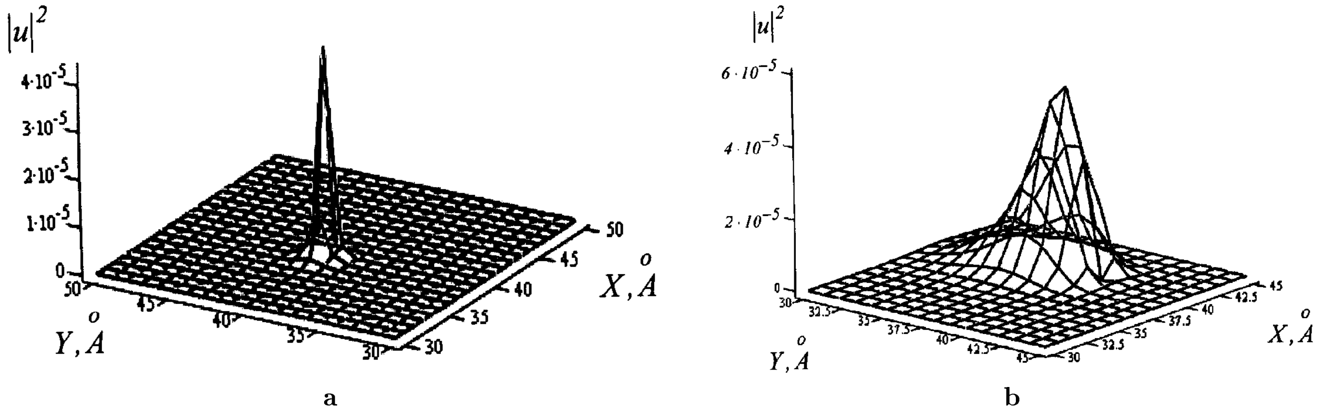

Fig. 3. Probability for an electron to be localized in the vicinity of the nucleus of an edge dislocation at the electron concentration $n_0 = 10^{17}$ (a) and 10^{19} cm^{-3} (b)

Figures 1 and 2 show the results of numerical calculations of the energy $E_{II}(n_0)$ of the two-dimentional bound state of an electron at the edge dislocation. The parameter values are typical of semiconductor CdTe doped by chlorine [13], namely, $S = 4.51$ eV, $K = 0.198$ eV/Å^3, $D = 0.31$ Å, and $\rho_0 = 6.477$ Å.

As is seen from Fig. 1, the energy of the localized electron states monotonously decreases as the population level of the conduction band grows ($n_0 \geq 10^{16}$ cm^{-3}). Such a behavior is typical of lightly doped semiconductors ($|e\varphi| \ll |S\Delta U|$).

As the population level of the conduction band grows within the interval 10^{17} cm^{-3} $\leq n_0 \leq 10^{19}$ cm^{-3}, the localized states become shallower, and, at $n_c = 2.5 \times 10^{19}$ cm^{-3} (the value, at which the localized electron states become delocalized, i.e. they find themselves in the conduction band), the energy of the electron ground state is zeroed (Fig. 2). Such a variation should influence the electron density of states in the conduction band, which must manifest itself in experiment [14, 15]. As is seen from Fig. 2, the electron states become localized again at $n_0 > 2.5 \times 10^{19}$ cm^{-3}, and, as the conduction electron concentration grows further, deepen. The results obtained can be qualitatively explained basing on the idea of self-consistent electron-deformation coupling in a crystal with a dislocation. In particular, if the band is populated much less than to a half, e.g. $0 \leq \bar{n} < 0.02$ (10^{17} cm^{-3} $\leq n_0 \leq 2 \times 10^{19}$ cm^{-3}), the expansion of the electron energy band caused by squeezing the lattice leads to a diminishing of the electron energy. It results in a shortening of the distance between the localized states and the bottom of the conduction band, so that the electron and mechanical components of the potential energy of a lattice deformation become equal at $n_0 = n_c$ and the electron energy is zeroed. Within the interval 2.5×10^{19} cm^{-3} $\leq n_0 \leq 10^{20}$ cm^{-3}, the crystal lattice undergoes the additional deformation of stretching, with the bottom energy of the conduction band being shifted towards higher values so that the energy of electron localized levels turn out beneath the bottom energy of the conduction band, i.e. the local levels deepen.

In Fig. 3, the results of numerical calculation of the probability for an electron to be in the vicinity of the edge dislocation nucleus (the XOY plane) are presented for the conduction electron concentrations $n_0 = 10^{17}$ (a) and 10^{19} cm^{-3} (b). As the concentration of current carriers increases within the interval $10^{17} - 10^{19}$ cm^{-3}, the probability for an electron to occupy the ground localized state with the energy E_{II} enhances by about 15%. The radius ($\rho_0 = \sqrt{x_0^2 + y_0^2}$) of the region of the electron localization with the probability $|u|^2 = 8.5 \times 10^{-6}$ around the dislocation amounts to about 5 Å at $n_0 = 10^{17}$ cm^{-3} and to about 10 Å at $n_0 = 10^{19}$ cm^{-3}. This means that the degree of localization of current carriers becomes lower as their concentration increases. The probability $|u|^2$ of electron localization decreases exponentially depending on the distance from the dislocation line (see formula (25)).

The variation of the energy of the ground state of an electron localized at an edge dislocation can reveal itself in either the spectra of low-temperature dislocation photoluminescence [16, 17] or the current-voltage characteristics of the dislocation $n^+ - n$ junction, depending on the conduction electron concentration.

Thus, from the results of the presented research, the following conclusions may be drawn:

— in the framework of the self-consistent electron-deformation interaction model of semiconductor, analytical expressions for the dislocation potential in the cases of lightly and heavily doped wide-gap semiconductors have been obtained;
— in lightly doped semiconductors ($n_0 \leq 10^{17}$ cm^{-3}), the energy of the ground state of an electron localized at an edge dislocation decreases monotonously with the growth of the conduction electron concentration;
— in heavily doped wide-gap semiconductors of the n-type (10^{17} cm^{-3} $\leq n_0 \leq 10^{19}$ cm^{-3}), the electron dislocation level becomes delocalized at a certain value of the conduction electron concentration from the indicated interval, i.e. this level becomes included into the conduction band;
— the probability of localization of an electron in the vicinity of the edge dislocation decreases as the conduction electron concentration rises.

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ВПЛИВ САМОУЗГОДЖЕНОЇ ЕЛЕКТРОН-ДЕФОРМАЦІЙНОЇ ВЗАЄМОДІЇ НА ЕЛЕКТРОННІ СТАНИ, ЛОКАЛІЗОВАНІ НА КРАЙОВІЙ ДИСЛОКАЦІЇ

М.М. Баран, Р.М. Пелещак

Р е з ю м е

У рамках однозонної самоузгодженої електрон-деформаційної моделі досліджено вплив концентрації електронів провідності на енергетичне положення локалізованих рівнів на крайовій дислокації. Показано, що з ростом концентрації електронів провідності у слаболегованих напівпровідниках ($n_0 \leq 10^{17}$ см$^{-3}$) локалізований рівень монотонно зсувається в бік менших енергій, а у сильнолегованих ($10^{17} \leq n_0 \leq 10^{19}$ см$^{-3}$) — має немонотонний характер. Встановлено, що з ростом концентрації електронів провідності ($10^{17} \leq n_0 \leq 10^{19}$ см$^{-3}$) ймовірність перебування електрона поблизу ядра крайової дислокації збільшується приблизно на 15 %.