PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY

Physical and Mathematical Sciences 2011, № 2, p. 55–62

Physics

CONFINED AND INTERFACE POLARONS IN CYLINDRICAL NANOWIRES IN AN ELECTRIC FIELD

A. L. VARTANIAN*,

Chair of Solid State Physics YSU, Armenia

The effect of an electric field on the basic parameters of confined and interface polarons in cylindrical nanowires embedded in a non-polar matrix are studied theoretically for the first time. Analytical expressions for the quasi-one-dimensional Fröhlich polaron self-energy and effective mass are obtained as functions of wire radius and strength of the electric field applied perpendicular to the wire axis, which may be of use at the interpretation of optical phenomena related to polaron motion in cylindrical nanowire, when the effect of an applied electric field competes with the size quantization.

Keywords: quantum wire, electric field, polaron.

Introduction. While the electron-polar optical phonon interaction in semiconductor nanostructures has been extensively studied from the low-dimensional moving polaron perspective (see Ref. [1] and references therein), the studies of its combined effects with the external electric field have only recently been commenced [1–5]. The presence of an electric field in semiconductor quantum structures gives rise to a polarization of the carrier distribution and to an energy shift of the heterostructure quantum states. Chen et al. [2] have investigated the ground-state energy and effective mass of a polaron in the quantum well of a AlAs/GaAs double heterostructure as functions of the width of the well and the strength of electric field applied along the growth direction. It was shown that the electric field hardly has any influence on the polaron effects in QWs with $d < 50\,\AA$ width, but for $d > 50\,\AA$ the influence becomes much stronger. At the consideration of the strong built-in electric field, induced by the spontaneous and piezoelectric polarization, Zhu and Shi [3, 4] have investigated the intermediate-coupling polaron effects in GaN/AlN quantum wells by means of a coordinate-dependent Lee-Low-Pines variational approach [5]. Their results show that the polaron energy shifts due to the various optical-phonon modes greatly changed in comparison with the case of negligible built-in electric field. The effect of electric field on the free polaron energy levels in finite GaAs/$Al_xGa_{1-x}As$ parabolic quantum wells has been investigated by means of modified variational method, including the longitudinal optical phonons and the four branches of interface optical phonons and the effect of spatial dependent effective mass [6].

* E-mail: vardan@ysu.am

The properties of free moving polaron in rectangular quantum wire have been studied in detail in our previous work [1], where the external electric field was applied perpendicular to the cylindrical nanowire (CNW) axis, but the effect of phonon confinement was not included. In the present paper the influence of phonon confinement as well as of electric field on the energy-momentum relation for polaron quantum confined in CNW has been investigated for the first time. This allows us, in particular, to obtain in the closed form the basic parameters of the polaron state (self-energy and effective mass) as a function of the CNW radius and the electric field, including both the confined (CO) and interface (IO) polar optical phonon modes in our calculation.

Theory. We consider an electron moving in a CNW, which consists of a polar semiconductor material and surrounded by non-polar medium. An electric field is applied perpendicular to the CNW axis. In the approximation of isotropic effective mass the Hamiltonian of the system, consisting of an electron and the LO phonons, can be written as

$$H=\frac{p^2}{2m^*}+V(\rho,z)+|e|F\rho\cos\varphi+\sum_{npq_z}\hbar\omega_{CO}a^+_{np}(q_z)a_{np}(q_z)+\sum_{sq_z}\hbar\omega_{IO}a^+_s(q_z)a_s(q_z)-$$
$$-\sum_{npq_z}\left[\Gamma^{np}_{CO}(q_z)J_n\left(\frac{\kappa_{np}\rho}{R}\right)\exp(im\varphi)\exp(-iq_zz)a^+_{np}(q_z)+H.c.\right]- \quad (1)$$
$$-\sum_{sq_z}\left[\Gamma^{s}_{IO}(q_z)Q_s(\rho)\exp(is\varphi)\exp(-iq_zz)a^+_s(q_z)+H.c.\right],$$

where the first line of Eq. (1) is the electron Hamiltonian in a CNW in the presence of an electric field, the second line describes the non-interacting optical phonon system, and the third and the fourth lines represent the electron–CO phonon, electron–IO phonon interactions respectively [7, 8]. Here m^* is the electron's effective mass, $\boldsymbol{p}$ is the momentum operator and F is the value of the electric field applied perpendicular to the CNW axis, $a^+_{np}(q_z)$, $a_{np}(q_z)$ and $a^+_s(q_z)$ $a_s(q_z)$ are respectively the creation and annihilation operators of CO and IO phonons with frequency ω_{CO} and ω_{IO}, $\varepsilon_\infty(\varepsilon_0)$ is the optical (static) dielectric constant, $K_s(x)$ and $I_s(x)$ are the modified Bessel functions of the first and second kind respectively, $J_n(x)$ is the Bessel function of the nth order, κ_{np} is the pth zero of $J_n(x)$, ε_d is the dielectric constant of the embedding medium, R is the CNW radius and $V(\rho,z)$ is the infinite confining potential,

$$\omega_{CO}=\omega_{LO},\qquad \omega_{IO}=\sqrt{1+\frac{\varepsilon_0-\varepsilon_\infty}{\varepsilon_\infty-\varepsilon}}\,\omega_{TO}, \quad (2)$$

$$\varepsilon(\omega)=-\frac{I_s(q_zR)\left[K_{s-1}(q_zR)+K_{s+1}(q_zR)\right]}{K_s(q_zR)\left[I_{s-1}(q_zR)+I_{s+1}(q_zR)\right]}\varepsilon_d, \quad (3)$$

$$|\Gamma^{np}_{CO}(q_z)|^2=\frac{2e^2\hbar\omega_{CO}}{LJ^2_{n+1}(\kappa_{np})(\kappa^2_{np}+R^2q_z^2)}\left(\frac{1}{\varepsilon_\infty}-\frac{1}{\varepsilon_0}\right), \quad (4)$$

$$|\Gamma^{s}_{IO}(q_z)|^2=\frac{2e^2\hbar\omega_{IO}}{LK^2_s(q_zR)I_s(q_zR)q_zR(I_{s-1}(q_zR)+I_{s+1}(q_zR))}\left(\frac{1}{\varepsilon-\varepsilon_0}-\frac{1}{\varepsilon-\varepsilon_\infty}\right), \quad (5)$$

$$Q_s(\rho)=\begin{cases} K_s(q_zR)I_s(q_z\rho), & \rho\le R,\\ I_s(q_zR)K_s(q_z\rho), & \rho>R.\end{cases} \tag{6}$$

Since the Hamiltonian (1) is translational invariant along the z axis, the total linear momentum component parallel to the CNW axis $p_z+\sum\limits_{npq_z}\hbar q_z a^+_{np}(q_z)a_{np}(q_z)+$ $+\sum\limits_{npq_z}\hbar q_z a^+_s(q_z)a_s(q_z)$ commutes with the Hamiltonian (1). Therefore, we can define unitary transformations

$$S_1=\exp\left(-iz\sum_{npq_z}q_z a^+_{np}(q_z)a_{np}(q_z)\right),\quad S_2=\exp\left(-iz\sum_{sq_z}q_z a^+_s(q_z)a_s(q_z)\right), \tag{7}$$

which remove the electronic coordinate z [5]. Next, we also introduce unitary transformations

$$P_1=\exp\left(-i\varphi\sum_{npq_z}na^+_{np}(q_z)a_{np}(q_z)\right),\quad P_2=\exp\left(-i\varphi\sum_{sq_z}sa^+_s(q_z)a_s(q_z)\right) \tag{8}$$

as well as the second Lee-Low-Pines transformation [5]

$$U=\exp\left(\sum_{npq_z}(g_{npq_z}a^+_{np}(q_z)-g^*_{npq_z}a_{np}(q_z))+\sum_{sq_z}(h_{sq_z}a^+_s(q_z)-h^*_{sq_z}a_s(q_z))\right), \tag{9}$$

where g_{npq_z} and h_{sq_z} are the variational parameters, which will be subsequently determined by minimizing the energy of the system. Since we look for the system ground state the expectation value of the transformed Hamiltonian $H_{eff}=U^{-1}P_2^{-1}P_1^{-1}S_2^{-1}S_1^{-1}HS_1S_2P_1P_2U$ is evaluated by choosing the wave function $|\Psi\rangle$ as a product of an electron wave function $\Phi(x,y,z)$ and a coherent phonon vacuum state $|0\rangle$ leading to

$$\begin{aligned}
&\langle\Phi(\rho,\varphi,z)|\langle 0|H_{eff}|0\rangle|\Phi(\rho,\varphi,z)\rangle=\\
&=E(F,R)+\sum_{npq_z}\hbar\omega_{CO}|g_{npq_z}|^2+\sum_{sq_z}\hbar\omega_{IO}|h_{sq_z}|^2+\frac{\hbar^2}{2m^*}\left[k_z^2-2k_z\left(\sum_{npq_z}q_z|g_{npq_z}|^2+\sum_{sq_z}q_z|h_{sq_z}|^2\right)\right]+\\
&+\frac{\hbar^2}{2m^*}\Bigg[\sum_{npq_z}q_z^2|g_{npq_z}|^2+\sum_{\substack{npq_z\\ n'p'q'_z}}q_zq'_z|g_{npq_z}|^2|g_{n'p'q'_z}|^2+\sum_{sq_z}q_z^2|h_{sq_z}|^2+\sum_{\substack{sq_z\\ s'q'_z}}q_zq'_z|h_{sq_z}|^2|h_{s'q'_z}|^2+\\
&+2\sum_{\substack{npq_z\\ s'q'_z}}q_zq'_z|g_{npq_z}|^2|h_{s'q'_z}|^2\Bigg]+\frac{\hbar^2B}{m^*}\left(\sum_{npq_z}n|g_{npq_z}|^2+\sum_{sq_z}s|h_{sq_z}|^2\right)-\frac{\hbar^2A}{2m^*}\left(\sum_{npq_z}n^2|g_{npq_z}|^2+\sum_{sq_z}s^2|h_{sq_z}|^2\right)-\\
&-\frac{\hbar^2A}{2m^*}\left(\sum_{\substack{npq_z\\ n'p'q'_z}}nn'|g_{npq_z}|^2|g_{n'p'q'_z}|^2+\sum_{\substack{sq_z\\ s'q'_z}}ss'|h_{sq_z}|^2|h_{s'q'_z}|^2+2\sum_{\substack{npq_z\\ s'q'_z}}ns'|g_{npq_z}|^2|h_{s'q'_z}|^2\right)-\\
&-\sum_{npq_z}L_1(n,p,R)(\Gamma^{np}_{CO}(q_z)g_{npq_z}+\Gamma^{np*}_{CO}(q_z)g^*_{npq_z})-\sum_{sq_z}L_2(s,q_z,R)(\Gamma^s_{IO}(q_z)h_{sq_z}+\Gamma^{s*}_{IO}(q_z)h^*_{sq_z}),
\end{aligned} \tag{10}$$

where $\Phi(\rho,\varphi,z)=N_0 J_0\left(\frac{\kappa_{0p}\rho}{R}\right)\exp[-\beta\rho\cos\varphi]\exp(ik_z z)$ is the wave function of an electron, moving in a CNW along the wire axis with momentum $\hbar k_z$, N is the normalization constant, β is a dimensionless variational parameter that allows for the application of external electric field,

$$E(R,F)=\left\langle\Phi\right|-\frac{\hbar^2}{2m^*}\left(\frac{\partial^2}{\partial\rho^2}+\frac{1}{\rho}\cdot\frac{\partial}{\partial\rho}+\frac{1}{\rho^2}\frac{\partial^2}{\partial\varphi^2}\right)+V(\rho,z)+|e|F\rho\cos\varphi\left|\Phi\right\rangle, \quad (11)$$

$$A=\left\langle\Phi\right|\rho^{-2}\left|\Phi\right\rangle, \qquad B=\left\langle\Phi\right|i\rho^{-2}\frac{\partial}{\partial\varphi}\left|\Phi\right\rangle, \quad (12)$$

$$L_1(n,p,F,R)=\left\langle\Phi\right|J_n\left(\frac{\kappa_{np}\rho}{R}\right)\left|\Phi\right\rangle, \quad L_2(s,q,F,R)=\left\langle\Phi\right|K_s(q_z R)I_s(q_z r)\left|\Phi\right\rangle. \quad (13)$$

From the variational conditions

$$\frac{\delta\left\langle\Phi(\rho,\varphi,z)\right|\left\langle 0\right|H_{eff}\left|0\right\rangle\left|\Phi(\rho,\varphi,z)\right\rangle}{\delta g^*_{npq_z}}=\frac{\delta\left\langle\Phi(\rho,\varphi,z)\right|\left\langle 0\right|H_{eff}\left|0\right\rangle\left|\Phi(\rho,\varphi,z)\right\rangle}{\delta h^*_{sq_z}}=0 \quad (14)$$

we obtain

$$g_{npq_z}=\frac{L_1(n,p,F,R)}{\hbar\omega_{CO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}+\frac{\hbar^2q_z}{m^*}Q_1-\frac{\hbar^2n^2}{2m^*}A-\frac{\hbar^2n}{m^*}AQ_2+\frac{\hbar^2n}{m^*}B}, \quad (15)$$

$$h_{sq_z}=\frac{L_2(s,q_z,F,R)}{\hbar\omega_{IO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}+\frac{\hbar^2q_z}{m^*}Q_1-\frac{\hbar^2s^2}{2m^*}A-\frac{\hbar^2s}{m^*}AQ_2+\frac{\hbar^2s}{m^*}B}, \quad (16)$$

where

$$Q_1=\sum_{npq_z}q_z|g_{npq_z}|^2+\sum_{sq_z}q_z|h_{sq_z}|^2, \quad Q_2=\sum_{npq_z}n|g_{npq_z}|^2+\sum_{sq_z}s|h_{sq_z}|^2. \quad (17)$$

In this case it is quite acceptable to introduce the parameters η_{CO} and η_{IO} by expressions

$$\sum_{npq_z}q_z|g_{npq_z}|^2=\eta_{CO}k_z, \quad \sum_{sq_z}q_z|h_{sq_z}|^2=\eta_{IO}k_z, \quad (18)$$

where for small values of k_z the parameters η_{CO} and η_{IO} are independent on k_z and must be calculated self-consistently. The estimates of A and B demonstrate that $\hbar^2B/m^*\ll\min\{\hbar\omega_{CO},\hbar\omega_{IO}\}$ and $\hbar^2A/m^*\gg\max\{\hbar\omega_{CO},\hbar\omega_{IO},\hbar^2q_z^2/m^*,\hbar^2k_zq_z/m^*\}$ for a slow-moving electron. Therefore, $g_{0pq_z}\gg g_{n\neq 0pq_z}$ as $g_{n\neq 0pq_z}\sim(\hbar^2A/m^*)^{-1}$ and $g_{0pq_z}\sim(\hbar\omega_{CO}+\hbar^2q_z^2/2m^*-\hbar^2k_zq_z/m^*)^{-1}$. For the same reason, one can notice that $h_{0q_z}\gg h_{s\neq 0q_z}$. It is also not difficult to show that the dimensionless $Q_2\ll 1$. Taking into account the above-mentioned facts, after some algebraic transformations we obtain the total polaron energy $E_{pol}(k_z,F,R)=$ $=\left\langle\Phi(\rho,\varphi,z)\right|\left\langle 0\right|H_{eff}\left|0\right\rangle\left|\Phi(\rho,\varphi,z)\right\rangle$ in a closed form

$$E_{pol}(k_z,F,R)=E(F,R)+\frac{\hbar^2k_z^2}{2m^*}(1-\eta_{CO}-\eta_{IO})^2-$$
$$-\sum_{pq_z}\frac{\left|\Gamma_{CO}^{0p}(q_z)\right|^2\left|L_1(0,p,F,R)\right|^2}{\hbar\omega_{CO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})}\left(1-\frac{\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})}{\hbar\omega_{CO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})}\right)-\quad(19)$$
$$-\sum_{q_z}\frac{\left|\Gamma_{IO}^{0}(q_z)\right|^2\left|L_2(0,q_z,F,R)\right|^2}{\hbar\omega_{IO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})}\left(1-\frac{\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})}{\hbar\omega_{IO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})}\right).$$

The last two terms in Eq. (19) represent the polaron self-energy in terms of electron–CO and electron–IO interactions respectively. We can also obtain the following implicit equations for η_{CO} and η_{IO}:

$$\eta_{CO}=\sum_{pq_z}\frac{q_z\,|\Gamma_{CO}^{0p}(q_z)|^2|L_1(0,p,F,R)|^2}{k_z\left[\hbar\omega_{CO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})\right]},\quad(20)$$

$$\eta_{IO}=\sum_{q_z}\frac{q_z\,|\Gamma_{IO}^{0}(q_z)|^2|L_2(0,q_z,F,R)|^2}{k_z\left[\hbar\omega_{IO}+\frac{\hbar^2q_z^2}{2m^*}-\frac{\hbar^2k_zq_z}{m^*}(1-\eta_{CO}-\eta_{IO})\right]},\quad(21)$$

when $\hbar^2k_z^2/2m^*$ is sufficiently small in comparison with the phonon energy so that no spontaneous emission of phonons can occur, Eqs. (19)–(21) can be solved numerically for the given value of $\hbar^2k_z^2/2m^*$. The polaron self-energy $\varepsilon_{self}^0(F,R)$ and the effective mass m_{pol} are defined by expanding the right hand side of equation (19) into terms quadratic in k_z for the motion parallel to the CNW axis. As a result we obtain the following expression for the polaron energy:

$$E_{pol}(k_z,F,R)=E(F,R)+\varepsilon_{self}^0(F,R)+\frac{\hbar^2k_z^2}{2m^*_{pol}}+O\left(\frac{\hbar^2k_z^2}{2m^*\hbar\omega_{PO}}\right),\quad(22)$$

where

$$\varepsilon_{self}^0(F,R)=-\sum_{pq_z}\frac{|\Gamma_{CO}^{0p}(q_z)|^2|L_1(0,p,F,R)|^2}{\hbar\omega_{CO}+\frac{\hbar^2q_z^2}{2m^*}}-\sum_{q_z}\frac{|\Gamma_{IO}^{0}(q_z)|^2|L_2(0,q_z,F,R)|^2}{\hbar\omega_{IO}+\frac{\hbar^2q_z^2}{2m^*}},\quad(23)$$

$$m_{pol}=m^*\left(1+\sum_{pq_z}\frac{2\hbar^2q_z^2}{m^*}\cdot\frac{|\Gamma_{CO}^{0p}(q_z)|^2|L_1(0,p,F,R)|^2}{\left(\hbar\omega_{CO}+\frac{\hbar^2q_z^2}{2m^*}\right)^3}+\sum_{q_z}\frac{2\hbar^2q_z^2}{m^*}\cdot\frac{|\Gamma_{IO}^{0}(q_z)|^2|L_2(0,q_z,F,R)|^2}{\left(\hbar\omega_{IO}+\frac{\hbar^2q_z^2}{2m^*}\right)^3}\right).\quad(24)$$

Thus, we have obtained explicit analytic expressions for the polaron self-energy as well as the effective mass. Apparently, CO and IO phonon subsystems become independent and can be considered separately and, therefore, Eqs. (22)–(24) allow us to investigate electron–CO phonon and electron–IO phonon interactions and calculate the total contributions to the polaron self-energy and effective mass by simply adding up the two parts.

Numerical Results and Discussion. To calculate the self-energy and the effective mass of polaron in CNW in an electric field we have carried out the numerical integrations in Eq. (23) and Eq. (24). The results illustrate the competing effects of the spatial confinement, the confinement effects being to the applied electric field and the electron coupling with the polar-optical phonons. In calculations we have used the following parameter values for GaAs: $\varepsilon_0 = 12{,}83$, $\varepsilon_\infty = 10{,}9$, $\hbar\omega_{LO} = 36{,}25\ meV$, $\hbar\omega_{TO} = 33{,}29\ meV$, $m^* = 0{,}067 m_e$ [9]. The self-energy and the effective mass of the quasi-1D polaron in the electric field $F = 50\ kV/cm$ (see Fig. 1) as a function of CNW radius R.

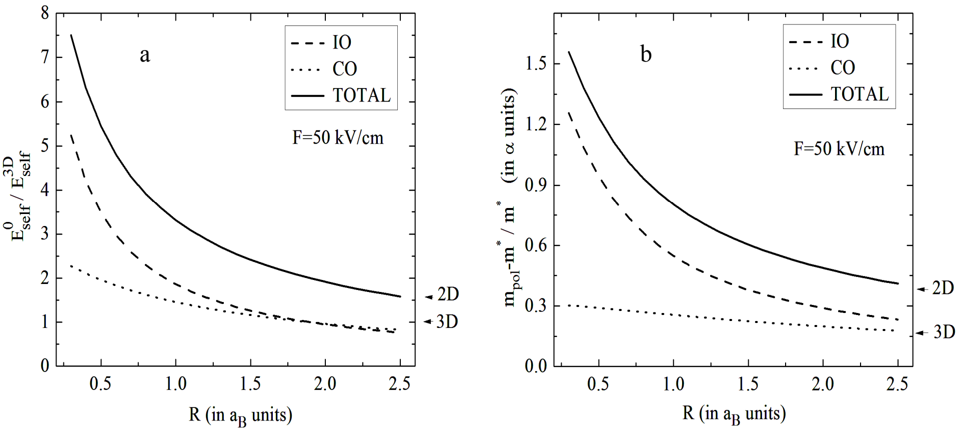

Fig. 1. The polaron self-energy (a) and the effective mass (b) as functions of GaAs wire radius R in electric field $F = 50\ kV/cm$. Dotted lines show the CO phonon contribution, dashed lines show the IO phonon contribution and the solid lines represent the total contribution.

It is clearly seen that the polaron self-energy monotonically decreases with increasing R due to electron coupling with IO and CO phonon modes. As a result the total polaron self-energy, which incorporates the contributions of electron interaction with both IO and CO phonons, also decreases. The same behavior is observed for the quasi-1D polaron effective mass (Fig. 1, b). For zero electric field the general features of these results are consistent with the results obtained by other authors [10, 11] for a quantum wire with a small radius. However, at large values of R the energy gaps between the electron subbands become smaller, and the inter-subband mixing increases the contribution of IO and CO terms [8] that will be taken into account later on. It should be noted that for small values of the wire radius the IO phonon contribution dominates over the contribution of CO phonons. Particularly, for $R = 0{,}7a_B$ ($a_B = \hbar^2\varepsilon_0 / m^* e^2$ is the hydrogen Bohr radius) the IO phonon contribution to the total polaron self-energy (effective mass) is more than 60% (64%) when $F = 50\ kV/cm$. A similar result in the absence of an electric field has been reported for narrow quantum wires in Ref. [12]. As is seen in Fig. 1, the contribution of the IO phonon modes both to the $\varepsilon^0_{self}(F,R)$ and m_{pol} strongly depends on the radius of quantum wire. The parts of the polaron self-energy as well as effective mass decrease rapidly due to the interaction with IO phonons, as a result, the contribution of CO phonons to the polaron self-energy (effective mass) becomes predominant when $R > 2a_B (R > 3a_B)$. In these figures the values of self-energy and effective mass of two- and three-dimensional polaron are indicated by arrows. In case of weak electron–LO phonon interaction, these values are: $E_S^{2D} = -\pi\alpha\hbar\omega_{LO}/2$, $m_p^{2D} = m^*(1+\pi\alpha/8)$ [13] and $E_S^{3D} = -\alpha\hbar\omega_{LO}$, $m_p^{3D} = m^*(1+\alpha/6)$ [5], where α is the electron–LO phonon coupling constant. Note that for small wire radius the total polaron self energy as well as the effective mass may be several times greater, than the 2D and 3D values of the quantities under consideration and the presented curves converge to the 3D limits, when R increases.

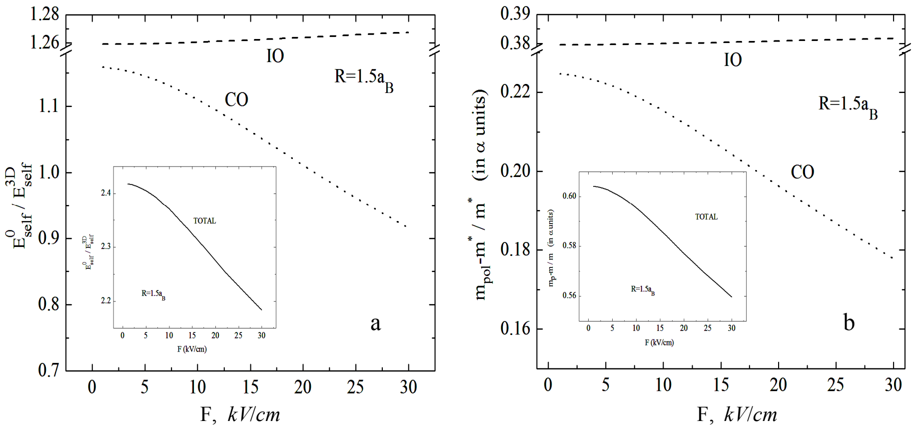

Fig. 2. The polaron self-energy (a) and the effective mass (b) as functions of electric field for GaAs wire with radius $R = 1{,}5a_B$. Dotted lines show the CO phonon contribution, dashed lines show the IO phonon contribution and inset shows the total contribution.

Fig. 2 shows the polaron self-energy and the effective mass as a function of the electric field, applied perpendicular to the quantum wire axis in case of wire radius $R = 1{,}5a_B$. It is noteworthy that in the region of electric field the polaron self-energy (effective mass) due to electron interaction with the IO phonons, increases slowly with increasing electric field under consideration, whereas the CO part of the self-energy (effective mass) is significantly reduced. Therefore, the total self-energy and the effective mass of the polaron decreases as is seen more clearly in the inset to Fig. 2, a and b. The electric field dependences of the IO as well as CO phonon caused polaron self-energy and effective mass can be explained by the fact that the maximum of the charge distribution of electrons with increasing electric field displaces from the wire axis towards the barrier region. As a result, the role of IO phonons increases, and the role of CO phonons decreases. The Fig. 2 shows that the change in polaron self-energy and effective mass is more, than 10%

and 7% respectively, when the electric field increases up to $30\ kV/cm$. Moreover, our calculation shows that the effect of electric field on the polaron basic parameters can be up to 20% at $F = 300\ kV/cm$ and can not be neglected.

Conclusions. We have first presented a systematic study of the polaron basic parameters in CNW in the presence of an external electric field, taking into account the confinement effect on the polar optical phonons. Analytical expressions for the polaron self-energy and the effective mass are obtained. The results for the basic parameters of polaron are obtained as functions of the applied electric field as well as of the CNW radius. We have shown that the polaron self-energy (effective mass) strongly depends on both the strengths of the electric field and on the nanowire radius. In particular, due to electric field effect, the correction to the polaron energy can reach values up to 20%. This aspect must be taken into account at the interpretation of optical phenomena related to polaron motion in CNW, when the effect of an applied electric field competes with the size quantization. Although to our knowledge, no experimental data to compare with our theoretical results is available, we believe that the present calculation may be relevant in establishing physical properties of synthesized semiconductor nanowire.

The author thanks Prof. A.A. Kirakosyan and Dr. L.A. Vardanyan for discussions and comments.

Received 21.03.2011

REFERENCES

1. **Vartanian A.L., Vardanyan L.A.** Physica E, 2009, v. 41, p. 1417.
2. **Chen C.Y., Liang S.D., Li M.** J. Phys.: Condensed Matter, 1994, v. 6, p.1903.
3. **Zhu Y.-H., Shi J.-J.** Physica E, 2009, v. 41, p. 746.
4. **Zhu Y.-H., Shi J.-J.** Phys. Status Solidi B, 2005, v. 242, p. 1010.
5. **Lee T.D., Low F.E., Pines D.** Phys. Rev., 1953, v. 90, p. 297.
6. **Zhao F.-Q., Guo Z.-Z.** International Journal of Modern Physics B, 2004, v. 18, p. 2991.
7. **Xie H.-J., Chen C.-Y. and Ma B.-K.** Phys. Rev. B61, 2000, p. 4827.
8. **Xie H.-J**. Physica E, 2004, v. 22, p. 906.
9. **Adachi S. J.** Appl. Phys., 1985, v. 58, R1.
10. **Li W.S., Gu S.W., Au-Yeung T.C., Yeung Y.Y.** Phys. Rev. B46, 1992, p. 4630.
11. **Buonocore F., Iadonisi G., Ninno D., Ventriglia F.** Phys. Rev. B65, 2002, p. 205415
12. **Maslov A.Yu., Proshina O.V.** Nanoscale Res. Lett., 2010, v. 5, p. 1744.
13. **Das Sarma S., Mason B.A.** Ann. of Phys., 1985, v. 163, p. 78.