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Մ.Գ. ՀԱԿՈԲՅԱՆ, Ա.Մ. ՀԱԿՈԲՅԱՆ

ԷՄՈՒԼՍԱՅԻՆ ԴԻԷԼԵԿՏՐԻԿՆԵՐԻ ՎԱՐՔԸ ԳԵՐՁԱՅՆԱՅԻՆ ՏԱՏԱՆՈՒՄՆԵՐԻ ԱԶԴԵՑՈՒԹՅԱՄԲ

Ներկայացված են հեղուկ դիէլեկտրիկներում բևեռականացման պատճառների և դրա արտահայտման վերլուծությունը: Բերված են էմուլսային դիէլեկտրիկների տեսակարար դիմադրության չափման փորձարարական տվյալները և գերձայնային տատանումների ներգործությամբ էմուլսային դիէլեկտրիկների հնարավոր բևեռականացման հաստատումը գերձայնային տատանումների ազդեցության ընթացքում:

Առանցքային բառեր. բևեռականացում, հեղուկ, էմուլսային դիէլեկտրիկներ, գերձայնային տատանումներ:

M.G. HAKOBYAN, A.M. HAKOBYAN

THR BEHAVIOUR OF EMULSION DIELECTRICS AT ULTRASONIC VIBRATIONS

The overview of the polarization reasons and developments in liquid dielectrics is carried out. The experimental data on the specific resistance of emulsion dielectrics are presented. The influence of ultrasonic vibrations on the possible establishment of polarization of the emulsion dielectric at an ultrasonic impact is shown.

Keywords: polarization, liquid, emulsion dielectrics, ultrasonic vibrations.

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K.H. AHARONYAN, N.B. MARGARYAN

SCREENED EXCITONS IN A LEAD SALT QUANTUM WIRE

The binding energy of a screened exciton in the semiconductor quantum wire embedded in a barrier environment is calculated. The binding energy dependence on the physical parameters of the system is discussed.The results were compared with those of the unscreened case.

Keywords: quantum wire, screened exciton, binding energy.

1. Introduction

The energy spectrum and other physical characteristics of Coulomb centers (impurities and excitons) in quasi-one-dimensional (Q1D) semiconductor quantum wires (QWr) surrounded by the low dielectric constant barrier environment are under intensive investigations. These nanosystems are favorable because in addition to dimensional quantization effects, which make an exciton or impurity center Q1D, image potentials due to the large contrast between dielectric constants of the semiconductor and dielectric barrier environment also play an important role [1]. They notably intensify the attraction between the charges in the Coulomb pair (dielectric confinement effect (DC effect)), hence enhancing both the exciton binding energy and the interband transition oscillator strength [1, 2]. From this point of view, the lead salt binary compound semiconductor nanowire system inside the channels of mesoporous silica SBA-15 represents considerable interest owing to extremely distinguished QWR/barrier dielectric constant contrast ($\varepsilon_w \sim 17 \div 50$ and $\varepsilon_b \sim 1.4 \div 2.1$), as well as the highly ordered and uniform mesoporosity of the barrier media [3]. The most interesting experimental data of lead salt/mesoporous silica semiconductor quantum wire system are connected with the luminescence. For that, a massive blue shift is observed in the related spectra. The latter clearly shows the presence of the quantum size effects in these systems and, therefore, may be affected by excitons to a great extent [3].

Quasi-free carriers in these systems may screen the Coulomb interactions between charge carriers and, in turn, the influence of screening produced by free carriers in Q1D structure is considerably weaker than in 3D or 2D semiconductor systems [4,5]. In this paper, we investigate the screened excitonic bound state energy properties of semiconductor QWr enhanced due to the DC effect.

2. Theory

Let us consider infinitely long semiconductor cylindrical QWr of radius R filled by a semiconductor material with the dielectric constant ε_w and embedded in the dielectric barrier environment with the dielectric constant ε_b. A QWr contains a Q1D EG where the electrons are confined to move in a QWR and are free to move along the axis of the wire by the mean linear density n_L. Moreover, a strong confinement regime is accepted in the discussed case, assuming that the quantum wire radius R is small compared with the Bohr radius a_0 in the semiconductor bulk samples ($a_0 >> R$). For that case, the large asymptotic distances between the interacting particles along the wire axis $|z| >> R$ are essential. As shown in [6], the tunability of the Coulomb interaction in the QWr due to the DC effect enhances and modifies the Q1D screening potential. As a result, in the intermediate distance range for a cylindrical wire $3R \le |z| \sim q_L^{-1}$, the interaction potential depends exponentially on the interparticle distance z, and it is constatnt for $|z| < R$

$$V_S^{Q1D}(z) = \begin{cases} -\dfrac{e^2}{\varepsilon_w R}\dfrac{1}{q_L R}e^{-q_L|z|}, z \geq 3R \\ -\dfrac{e^2}{\varepsilon_w R}\dfrac{1}{q_L R}e^{-3q_L R}, z < 3R \end{cases} \tag{1}$$

In (1) $q_L = \sqrt{q_S^2 + q_d^2}$, $q_d = (1/R)\sqrt{2/\varepsilon_r \ln\varepsilon_r}$, $\varepsilon_r = \varepsilon_w / \varepsilon_b >> 1$ is the DC effect condition, $q_S^{-2} = R^2[(\pi^2/32r_S) + (K_1/16)\sqrt{\pi x} + (r_S x/4) + (K_2 x/4K_3)][(1/r_S) + (4/K_3)\sqrt{x/\pi}]^{-1}$ [4], $K_1 \approx 14.91$, $K_2 \approx -15.61$, $K_3 \approx -0.38$, $x = k_B T / R_0$, $k_B T$ is the thermal energy, R is the QWr radius, $R_0 = \hbar^2 / 2m_w a_0^2$ is the bulk effective Rydberg, $r_S = (2a_0 n_L)^{-1/2}$ is the 1D spacing of free carriers in the units of Bohr radius $a_0 = \varepsilon_w \hbar^2 / m_w e^2$.

Now we are interested to find the screened excitonic bound state energy levels in the potential (1), for that we shall solve the Schrödinger wave equation:

$$-\frac{\hbar^2}{2m_w}\frac{d^2\psi}{dz^2} + V_S^{Q1D}(z)\psi = E\psi \ . \tag{2}$$

As follows, Eq. (2) does not change under reflection $z \to -z$, therefore, in accordance with the standard treatment of the 1D problem [12], the solutions $\psi(z)$ must possess both even and odd parity. We look for bound state solutions of wave equation (2) and thus introduce proper substitutions for that case such as: $E = -\hbar^2\chi^2 / 2m_w$, $y = \xi \exp(-q_L|z|)$, $\xi = \sqrt{8m_w E_R / q_L^2 \hbar^2}$, $E_R = e^2 / \varepsilon_w R q_L R$, $\nu = 2\chi / q_L (\chi > 0)$. Afterwards Eq.(2) for $3R \leq |z| \sim q_L^{-1}$ takes the Bessel equation form:

$$\frac{d^2\psi}{dy^2} + \frac{1}{y}\frac{d\psi}{dy} + (1 - \frac{\nu^2}{y^2})\psi = 0 \ . \tag{3}$$

Because $\psi(x)$ decreases as $z \to \infty$ ($y \to 0$), we have the solution of Eq.(3)

$$\psi(z) = C\, J_\nu(z) = C\, J_\nu[\xi \exp(-0.5 q_L z)] \ .$$

For $|z| < 3R$, we introduce the substitution:

$$\omega^2 = \frac{2m_w}{\hbar^2}\left(E + E_R e^{-3q_L R}\right) \ .$$

After this substitution Eq.(2) takes the harmonic oscillator equation form:

$$\frac{d^2\psi}{dz^2}+\omega^2\psi=0. \tag{4}$$

For odd and even states Eq.(4) takes the solutions:

$$\psi\left(z\right)=C_1\sin\omega z\ , \tag{5}$$

$$\psi\left(z\right)=C_2\cos\omega z\,. \tag{6}$$

The eigenvalues of the system for even and odd states are defined from the conditions of continuity of the wave function and its derivative:

$$\frac{\left.\frac{d}{dz}J_\nu[\xi\exp(-0.5q_L z)]\right|_{z=3R}}{J_\nu[\xi\exp(-1.5q_L\,\mathrm{R})]}=-\omega tg\left[3\omega R\right], \tag{7}$$

$$\frac{\left.\frac{d}{dz}J_\nu[\xi\exp(-0.5q_L z)]\right|_{z=3R}}{J_\nu[\xi\exp(-1.5q_L z)]}=\omega ctg[3\omega R]\ . \tag{8}$$

Eqs. (7) and (8) give the screened exciton energy eigenvalues of the system for the given mean linear density n_L, permitted reduced temperature parameter x and QWr radius R, which we will get numerically in the next section. In particular, from Eq. (5), we calculate the enhanced ground-state energy, namely, the screened exciton binding energy graphical dependence versus R and compare with the unscreened exciton counterpart.

3. Numerical calculation

In order to numerically display the screened Coulomb properties, we refer to the model with the PbSe- based QWr embedded in the mesoporous silica SBA-15 barrier environment. Accordingly, the following material parameters are adopted: $m_w\approx 0.0355m_0$ (m_0 is the free electron mass) and $\varepsilon_w=23$ [2,3], which leads to $a_0\approx$ 34.45 nm and $R_0\approx$ 0.91 meV parameter values. With the ε_b = 2 [1], we have the dielectric constant ratio value ε_r = 11.5. For the numerical analysis of q_S^{-2} the moderately high linear density nL1 ≈1.5.106 cm-1 and the moderately low temperature T ≈32 K values are taken into consideration. In Fig. 1 we outline the graphical results of the screened exciton binding energy as a function of the QWr radius R for the fixed linear density and temperature. As it is shown in Fig.1, the exciton binding energy decreases when QWr radius increases.

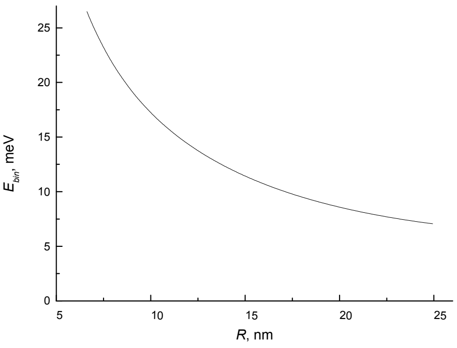

Fig. 1. The binding energy of the screened exciton as the function of QWr radius R for the fixed linear density ($n_L \approx 1.5.10^6$ cm^{-1}) and temperature ($T \approx 26K$)

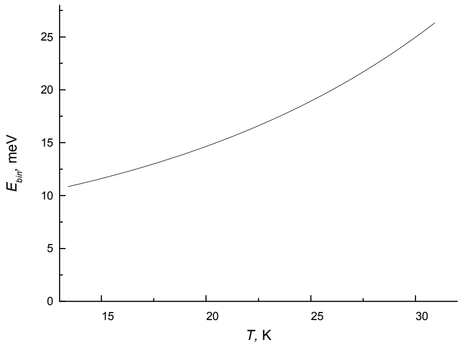

Fig. 2. The binding energy of the screened exciton as the function of temperature for the fixed linear density ($n_L \approx 1.5{\cdot}10^6$ cm^{-1}) and fixed QWr radius (R=6nm)

The dependence of the binding energy on the QWr radius becomes weaker when the radius increases. In Fig. 2 the dependence of the binding energy on temperature for the fixed QWr radius (R= 6 nm) and linear density (n_L=1.5.10^6 cm^{-1}) is shown. The binding energy value increases with increasing the temperature and the dependence of the binding energy on the temperature becomes stronger.

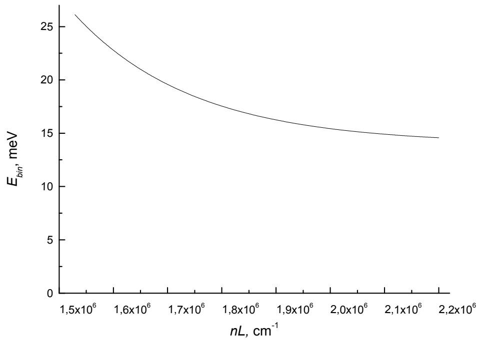

Fig. 3. The binding energy of the screened exciton as the function of linear density for the fixed temperature ($T \approx 26K$) and QWr radius (R=6nm).

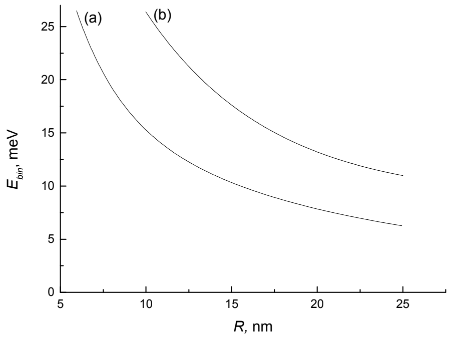

Fig. 4. Comparison of the binding energy values of screened (a) and unscreened (b) excitons.

In Fig. 3, we show the results of the screened exciton binding energy as a function of the linear density for the fixed QWr radius and temperature. In Fig. 4 the comparison of the binding energy values of screened and unscreened excitons is shown. The character of dependence on the QWr radius for both is the same but for unscreened excitons we have closely 1.5 times high value. The received graphical lines are shown in comparison with the QWr unscreened potential graphical curves ($q_S \to 0$).

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Կ.Հ. ԱՀԱՐՈՆՅԱՆ, Ն.Բ. ՄԱՐԳԱՐՅԱՆ

ԷԿՐԱՆԱՎՈՐՎԱԾ ԷՔՍԻՏՈՆՆԵՐԸ ՔՎԱՆՏԱՅԻՆ ԼԱՐՈՒՄ՝ ԿԱՊԱՐԻ ԱՂԵՐԻ ՀԵՆՔՈՎ

Հաշվարկված է էկրանավորված էքսիտոնի կապի էներգիան արգելքային միջավայր ներառված կիսահաղորդչային քվանտային լարերում: Քննարկված է կապի էներգիայի կախվածությունը համակարգի ֆիզիկական պարամետրերից: Ստացված արդյունքները համեմատված են չէկրանավորված դեպքում ստացված արդյունքների հետ:

Առանցքային բառեր. քվանտային լար, էկրանավորված էքսիտոն, կապի էներգիա:

К.Г. АГАРОНЯН, Н.Б. МАРГАРЯН

ЭКРАНИРОВАННЫЕ ЭКСИТОНЫ В КВАНТОВОЙ ПРОВОЛОКЕ НА БАЗЕ СОЛЕЙ СВИНЦА

Вычислена энергия связи экранированного экситона в полупроводниковой квантовой проволоке, вложенного в барьерную среду. Обсуждена зависимость энергии связи от физических параметров системы. Полученные результаты сопоставлены с результатами для неэкранированного случая.

Ключевые слова: квантовая проволока, экранированный экситон, энергия связи.