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THEORETICAL STUDIES OF THE INFLUENCE OF THE INTERFACES ON THE RADIATION INTENSITY OF OPTICAL TRANSITIONS AND LIFETIMES OF ELECTRONIC EXCITATIONS IN GERMANIUM/SILICON NANOSYSTEMS WITH GERMANIUM QUANTUM DOTS

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In mini-review, theoretical studies of some optical properties of heteronanosystems of the second type are considered. These nanosystems are germanium/silicon with germanium quantum dots (QDs). The influence of the interfaces on the radiation intensity of optical transitions and lifetimes of electronic excitations in germanium/silicon nanosystems with germanium in the germanium/silicon nanosystems with germanium QDs is studied. Dipole-allowed optical transitions between quasi-stationary and stationary states, which occur over the spherical surface of a single germanium QD embedded in a silicon matrix, are theoretically investigated. A mechanism is proposed for a significant increase (four times) in the intensities of optical interband and intraband transitions between quasi-stationary and stationary SIE-states arising above a spherical surface of a single germanium QD placed in a silicon matrix. These optical electronic transitions occur in the real space of the silicon matrix. Such a mechanism, apparently, will apparently solve the problem of a significant increase in the radiative intensity in germanium/silicon heterostructures with germanium QDs. This will provide an opportunity to develop fundamental and applied foundations, allowing to create a new generation of effective light-emitting and photodetector devices based on germanium/silicon heterostructures with germanium quantum dots. The theoretically predicted long-lived SIE-states, apparently, will make it possible to realize high-temperature quantum Bose-gases SIE-states in the nanosystem under study.

***Keywords**: electron transitions, quasi-stationary exciton states, radiation intensity, quantum dots.*

INTRODUCTION

The germanium/silicon nanosystems with germanium quantum dots (QDs) belonged to the second type of heterostructures. Elastic stresses that occur as a result of the mist match between the germanium and silicon lattice constants caused shifts in the conduction and valence bands in the Ge/Si heterostructure. A significant displacement of the top of the valence band ($\Delta E_{v(Ge)} = 610$ meV) of the QD germanium (relative to the top of the silicon matrix valence band) caused the localization of the holes to the QD volume. The hole was at the energy level $E_h(a)$ in the valence band of the germanium QD. A significant displacement of the bottom of the conduction band ($\Delta E_{c(Si)} = 340$ meV) of the silicon matrix (relative to the bottom of the conduction band of the germanium QD) in the heterostructure acts as the potential barrier for electrons. The electron was at the energy level $E_{eh}(a)$ in the conduction band of the silicon matrix. In these nanosystems, the spatial separation of electrons and holes was experimentally discovered [1 – 6]. In this case, holes located in the QD and electrons localized above the QD surface were attracted to each other due to the Coulomb interaction. As a result, spatially indirect

excitons (SIE) appeared in the nanosystem [7 – 10]. SIE was localized at the energy level $E_{ex}(a)$ in the bandgap of the silicon matrix.

In germanium/silicon heterostructures with double layers of vertically oriented germanium QDs, experimental conditions [7 – 10] revealed a seven-fold increase in the photoluminescence intensity compared to semiconductor structures. This intensity increase effect was due to electron tunneling into the germanium QDs. In this case, the overlap integral of the wave functions of the electron and the hole substantially increased [8]. In linear germanium QD chains with average radii not exceeding 30 nm photoluminescence was experimentally revealed in the infrared spectral region of the spectrum (0.20 – 1.14) eV at room temperatures [7 – 10].

In theoretical work [11], the possibility of tunneling a hole from a germanium QD into a silicon matrix was studied. Such tunneling caused a significant increase in the intensity of radiative recombination in the nanosystem.

The germanium/silicon nanosystems with germanium QDs, space-indirect interband transitions between the electron and hole states were observed [7 – 10]. In nanosystems consisting of single germanium QDs placed in a silicon matrix, a weak intensity of interband optical transitions was experimentally observed [8, 9]. Therefore, theoretical studies are needed that could suggest a mechanism for a significant increase in the intensity of optical transitions in a nanosystem. To create new optoelectronic devices on a single silicon substrate [8 – 21] it is necessary to propose mechanisms for a significant increase in the intensity of radiative recombination.

The theory of SIE, consisting of a hole moving in a germanium QD, and the electron is localized over the spherical interface (QD-silicon matrix), was developed in [12, 13]. The theory predicted a significant increase in the SIE-binding energy $E_{ex}\,(a)$ (where a is the QD radius) (by almost two orders of magnitude) in this nanosystem, compared with the exciton binding energy in a silicon single crystal. In this SIE, the electron and the hole were separated by centrifugal potential, as well as polarization interaction with the spherical interface (QD-matrix) [13] (see Figure).

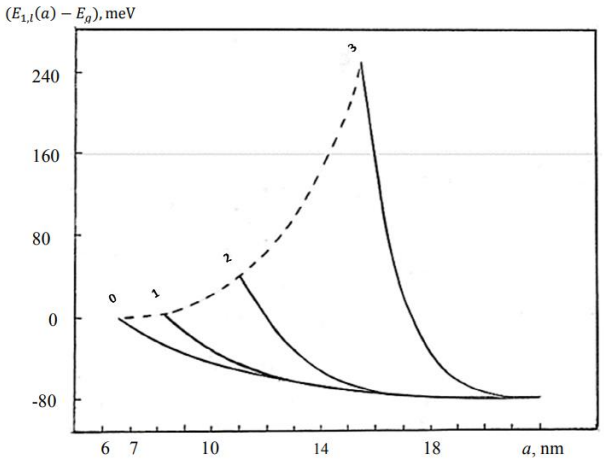

Figure 1. Dependence of the energy spectrum $(E_{1,l}(a) - E_g)$ of the exciton (with spatially separated electron and hole) (expressed by meV) in the state $n = 1$, $l = 0, 1, 2, 3$ (where n and l – are the principal and orbital quantum numbers of the electron) (solid line) on the the radius a of a germanium QD (expressed by nm) placed in the silicon matrix. Numbers at the curves indicate the value of l. The dotted line denotes the boundary of the spectrum of the quasistationary states $E_{1,l}^{max}(a)$ of the exciton (expressed by meV). Here, E_g – band gap width in the silicon matrix, $E_{ex}^{2D} = 82$ meV – binding energy of the two-dimensional exciton ground state with a spatially separated electron and hole

It was shown in [12, 13] that quasi-stationary SIE-states with energies $E_{1,l}(a) > 0$ (n =1, l =0, 1, 2, … were the main and orbital quantum numbers of an electron), as well as stationary SIE-states with energies $E_{1,l}(a) < 0$. These quasi-stationary SIE-states and stationary SIE-states arose above the spherical surface of a single germanium QD placed in a silicon matrix [12, 13] (see Fig.1).

At present, the optical properties of germanium/silicon heterostructures with germanium QDs have not been adequately studied. There are no reviews that study the effect of interfaces on the emission intensity of optical transitions and the lifetime of electronic excitations in germanium/silicon nanosystems with germanium QDs. In this mini-review, radiation intensities and lifetimes due to electronic transitions between quasi-stationary and stationary SIE-states are theoretically investigated. It is shown that the radiation intensities, as well as the lifetime due to electron transitions between quasi-stationary and stationary SIE-states, acquire significant values compared to similar values in nanosystems consisting of single germanium QDs placed in a silicon matrix.

THE INFLUENCE OF THE INTERFACES ON OPTICAL TRANSITIONS BETWEEN THE SIE-STATES

In [12, 13], a nanosystem model was used, which consisted of spherical germanium QD of radius a with dielectric permittivity ε_2 =16.3, placed in the silicon matrix with a permittivity $\varepsilon_1 = 11.7$. It was assumed that the hole h with the effective mass $(m_h/m_0) = 0.39$ was located in the center of the germanium QD, and the electron e with the effective mass $(m_e/m_0) = 0.98$ was localized along the spherical surface of the QD in the silicon matrix (m_0 is free electron mass). In the nanosystem, the ground electron level was in the silicon matrix, and the main hole level was in the germanium QD (see Fig.1). In this model of a nanosystem, a hole moves into a germanium QD (a_h =2.2 nm is the Bohr radius of a hole in a germanium QD) without penetrating into the silicon matrix. The electron also does not penetrate into germanium QD (see Fig.1).

The Hamiltonian SIE in [12,13] contained the energy of electron-hole Coulomb interaction, the energy of the polarization interaction of an electron and a hole with a QD surface, as well as the centrifugal energy of the SIE. In [9], the energy spectrum $E_{n=1,l}(a)$ of SIE-states (n = 1, l= 0.1,2, 3) was obtained by the variational method as a function of the radius a QD (see Fig.1). The variational the hydrogen-like radial wave functions were used [13]:

$$R_{1,l}(r) = A_l\,(r-a)^{\,l}\,exp\,(-j_l(r-a)/a),$$
$$A_{1,l}{}^2 = (2\,j_l/a)^{\,3+2l}\,(4(2l)!\,(\,j_l{}^2 + 4(2l+1)!\,j_l + (2l+2)!)^{\,-1} \qquad (1)$$

where r is distance of the electron e from the QD center, $j_l(a)$ − was a variational parameter.

It was shown that the inclusion of the centrifugal energy of the exciton in the Hamiltonian caused a positive potential barrier. Such a potential barrier has led to the fact that, in the zone of surface SIE- states in the nanosystem, starting from QD radius a, is higher than some critical QD radius $a_c^*(n=1,l)$ at first, quasi-stationary SIE-states with energies $E_{1,l}(a) > 0$ appeared. With increasing QD radius $a > a_c(1,l) > a_c^*(1,\ l)$, the quasi-stationary SIE-states were converted to stationary SIE-states with energies $E_{1,l}(a) < 0$ [13]. The critical QD radii for these states $(n=1, l \le 3)$ had corresponding values [13]: $a_c^*(1,l) = 8.04$ nm; 11.1 nm; 15.5 nm; $a_c(1,l) = 6.54$ nm; 8.35 nm; 11.95 nm; 17.34 nm. In [13] it was shown that in the range of QD radii $a \ge a_0 = 20.8$ nm, the quasistationary and stationary (n = 1, l) SIE-states were transferred into the states of two-dimensional SIE-states localized over the flat germanium/silicon interface. The binding energies $E_{1,l}(a)$ SIE-states asymptotically approached

the value E_{ex}^{2D}, which characterizes the binding energy of a two-dimensional SIE-states (see Fig.1).

In this case, quasi-stationary and stationary states formed a zone of surface SIE-states. The band of stationary SIE-states $E_{1,l}\,(a)$ with a width $\Delta E = E_{ex}^{2D} = 82$ meV was located in the bandgap of the silicon matrix (where E_{ex}^{2D} is the binding energy of the two-dimensional SIE). The band of quasi-stationary SIE-states $E_{n=1,l}\,(a)$ with a width $\Delta E = E_{1,l=3}^{max}\big(a = a_c^*(1, l=3)\big) \cong$ 248.4 meV was located in the conduction band of the silicon matrix. In this case, the zone of surface SIE-states contained a finite number of levels (n =1, $l \leq 3$) (see Fig. 1). It was found that the optical absorption in the nanosystem was caused by electron interband transitions between quasi-stationary and stationary SIE-states, as well as electron intraband transitions between stationary SIE-states [13].

For the emergence of stationary and quasi-stationary SIE-states with energies $E_{1,l}\,(a)$ in a nanosystem, it is necessary to absorption a light quantum with energy [12, 13]:

$$\hbar\omega_{ex(1,l)}(a) = E_{g(Ge)} - \Delta E_{c(Si)} + E_{1,l}(a) \tag{2}$$

In this case, a quasi-stationary SIE-state with energy $E_{1,l}\,(a) > 0$ appeared in the conduction band of the silicon matrix, and in the bandgap of the silicon matrix a stationary SIE-state appeared with energy $E_{1,l}\,(a) < 0$ (see Fig. 1). In formula (2), $\left|E_{1,l}\,(a)\right|$ is the SIE binding energy, and the value $(E_{g(Ge)} - \Delta E_{c(Si)}) = 330$ meV (where $E_{g(Ge)}$ is the bandgap energy of the germanium QD, $\Delta E_{c(Si)}$ is the shift of the bottom of the conduction band of the silicon matrix relative to the bottom of the conduction band of germanium QD).

The intensity $I_{1,l}^{1,l+1}(a)$ of the dipole-allowed optical transitions between the SIE-states (n = 1, l) and (n = 1, l + 1) in QD radius a is determined the square of the overlap integral of exciton wave functions $R_{1,l}(r)$ and $R_{1,l+1}(r)$ (1) [14]:

$$I_{1,l}^{1,l+1}(a) \approx \left|\int_a^\infty R_{1,l}(r)\, R_{1,l+1}(r)\, r^2 dr\right|^2 \delta\Big(\hbar\omega - \hbar\omega_{ex(1,l)}(a)\Big), \tag{3}$$

where the radiant energy $\hbar\omega_{ex(1,l)}(a)$ is defined using (2), ω is the frequency of the emitting light. The expression that determines the relative intensity () of optical transitions we find by integrating (3) taking into account (1)

$$I_{1,l}^{1,l+1}(a) \approx (2j_l)^{(2l+3)}(2j_{l+1})^{(2l+5)}(j_l + j_{l+1})^{-(4l+8)}\ [(2l+1)!\ (j_l + j_{l+1})^2\ + 2(2l+2)!\ (j_l + j_{l+1})\ +\ (2l+3)!\ ]^2\,[4(2l)!\ {j_l}^2\ + 4(2l+1)!\ j_l\ + (2l+2)!\ ]^{-1}\,[4(2l+2)!\ {j_{l+1}}^2\ + 4(2l+3)!\ j_{l+1} + (2l+4)!]^{-1} \tag{4}.$$

THE INFLUENCE OF THE INTERFACES ON LIFETIMES OF SIE-STATES IN A NANOSYSTEM

The lifetimes $\tau_{1,l}^{1,l+1}(a)$ of SIE-states caused by transitions between SIE-states (n =1, l) and (n=1, l+1) with energies $E_{1,l+1}(a) = \hbar\omega_{1,l+1}\,(a)$ and $E_{1,l}(a) = \hbar\omega_{1,l}\,(a)$, in the Ge/Si nanosystem with germanium QDs can be described by the expression:

$$\tau_{1,l}^{1,l+1}(a)\ /\tau_{ex} = (3/\tilde{\varepsilon}\ f_{1,l}^{1,l+1}(a))\ (c\ \mu_{ex}\ a_{ex}^{2D}\ \hbar^{-1})^3 (E_{ex}^{2D}/\Delta E_{1,l}^{1,l+1}(a))^2 \tag{5}$$

In formula (5), the exciton lifetime $\tau_{ex} = \hbar/E_{ex}^{2D}$ in the nanosystem (E_{ex}^{2D} $=2\hbar^2/\mu_{ex}\ (a_{ex}^{2D})^2$ is the 2D-SIE binding energy), $\tilde{\varepsilon}$ $=2\varepsilon_1\varepsilon_2/(\varepsilon_1 + \varepsilon_2)$ is the permittivity of the nanosystem, $(\mu_{ex}/m_0) = m_e m_h\ /(m_e + m_h)$ is the reduced SIE mass, $a_{ex}^{2D} = \tilde{\varepsilon}\ (m_0/\mu_{ex})\ (\hbar^2/m_0 e^2)$ is the 2D-

SIE Bohr radius, c is the speed of light, the value $\Delta E_{1,l}^{1,l+1}(a)$ is the distance between the SIE levels ($n = 1$, l) and ($n = 1$, $l + 1$), that is

$$\Delta E_{1,l}^{1,l+1}(a) = [E_{1,l+1}(a) - E_{1,l}(a)] \quad (6)$$

In this case, the oscillator strength $f_{1,l}^{1,l+1}(a)$ of the transition between the SIE-states (n=1, l) and (n=1, l+1) was described by the formula [15]:

$$f_{1,l}^{1,l+1}(a) = 4(\Delta E_{1,l}^{1,l+1}(a)/E_{ex}^{2D})(D_{1,l}^{1,l+1}(a)/e\, a_{ex}^{2D})^2 \quad (7)$$

Dipole moments $D_{1,l}^{1,l+1}(a)$ and oscillator strengths $f_{1,l}^{1,l+1}(a)$ of the transitions between SIE-states (n=1, l) and (n=1, l+1) were received in [15].

NUMERICAL RESULTS AND DISCUSSION

Let us estimate the intensity values $I_{1,l}^{1,l+1}(a)$ (4), as well as lifetimes $\tau_{1,l}^{1,l+1}(a)$ (5), depending on the radius a of germanium QDs caused by optical transitions between the SIE-states (n= 1, l) and (n= 1, $l + 1$) (see Fig.1). Intensity $I_{1,0}^{1,1}(a_1)$, as well as the lifetime $\tau_{1,0}^{1,1}(a_1)$, of the intraband transition in QDs with an average radius $a_1 = 10$ nm between stationary SIE-states (n= 1, l = 0) with energy $E_{1,0} = -42$ meV an (n= 1, l= 1) with energy $E_{1,1} = -26$ meV (with the nanosystem parameters $j_0 = 2.06$ and $j_1 = 2.22$ taken from [6]) took the valu $I_{1,0}^{1,1}(a_1) = 0.10$ and $\tau_{1,0}^{1,1}(a_1) = 7.9 \cdot 10^{-4}$ s (see Table).

Table. The calculated values of the normalized intensities $I_{1,l}^{1,l+1}(a)$ (4), as well as lifetimes $\tau_{1,l}^{1,l+1}$ (5) (expressed by seconds), caused by optical transitions between the SIE-states ($n = 1$, l) with the energy $E_{1,l}(a)$ (expressed by meV) and ($n = 1$, $l + 1$) (where $l = 0, 1, 2$) with energy $E_{1,l+1}(a)$ (expressed by meV) in a germanium quantum dot with an mean radius a (expressed by nm). $\Delta E_{1,l}^{1,l+1}(a) = E_{1,l+1}(a) - E_{1,l}(a)$ (expressed by meV) is the distance between the SIE levels (n =1, l) and (n =1, $l + 1$), energy $\hbar\omega_{ex(1,l)}(a)$ (2) of an electron transition (expressed by meV), oscillator strengths $f_{1,l}^{1,l+1}(a)$ (7).

a nm	(1,l)→(1,l+1)	$E_{1,l}$ meV	$E_{1,l+1}$ meV	$\Delta E_{1,l}^{1,l+1}$ meV	$\hbar\omega_{ex(1,l)}$ meV	$\hbar\omega_{ex(1,l+1)}$ meV	$f_{1,l}^{1,l+1}$	$I_{1,l}^{1,l+1}$	$\tau_{1,l}^{1,l+1}$ (10^{-6}) s
10.0	(1,0) → (1,1)	−42	−26	16	288	304	0.48	0.10	790
11.5	(1,1) → (1,2)	−45	28	73	285	358	0.49	0.15	37
16.0	(1,2) → (1,3)	−78	126	204	252	456	0.54	0.44	4.4

As a result of the interband transition in QDs with an average radius $a_2 = 11.5$ nm between the stationary SIE-state (n=1, l=1) with energy $E_{1,1} = -45$ meV and the quasi-stationary SIE-state (n=1, l=2) with energy $E_{1,2}$ =28 meV (with the nanosystem parameters $j_1 = 2.14$ and $j_2 = 2.26$ taken from [13]) the relative intensity $I_{1,1}^{1,2}(a_2)$ and lifetime $\tau_{1,1}^{1,2}(a_2)$ have taken the values $I_{1,1}^{1,2}(a_2)$= 0.15, and $\tau_{1,1}^{1,2}(a_2)$= $3.7 \cdot 10^{-5}$ s (see Table). Intensity $I_{1,2}^{1,3}(a_3)$ and lifetime $\tau_{1,2}^{1,3}(a_3)$ of the interband transition in quantum dots with an average radius a_3 =16 nm between the stationary SIE-state (n=1, l= 2) with energy $E_{1,2} = -78$ meV and the quasi-stationary SIE-state (n=1, l=3) with energy $E_{1,3}$ =126 meV (with the nanosystem parameters $j_2 = 2.24$ and $j_3 = 2.36$ taken from [13]) had such the value $I_{1,2}^{1,3}(a_3) = 0.44$ and $\tau_{1,2}^{1,3}(a_3) = 4.4 \cdot 10^{-6}$ s (see Table). Intensity $I_{1,2}^{1,3}(a_3)$ and lifetime $\tau_{1,2}^{1,3}(a_3)$ of the interband transition in

quantum dots with an average radius $a_3 = 16$ nm between the stationary state SIE (n= 1, $l = 2$) with energy $E_{1,2} = -78$ meV and the quasi-stationary state ($n = 1$, $l = 3$) with energy $E_{1,3}$ =126 meV had such the value $I_{1,2}^{1,3}(a_3) = 0.44$ and $\tau_{1,2}^{1,3}(a_3) = 4.4 \cdot 10^{-6}$ s (see Table) (see Fig. 2). It should be noted that transitions between the SIE-states ($n = 1$, $l = 2$) and ($n = 1$, $l = 3$) can occur at room temperature.

Quasi-stationary and stationary SIE-states (n =1, l) with large values of the orbital quantum number l (with $l \leq 3$) were included in the process of optical absorption in the zone of surface SIE-states with increasing QD radius a. With increasing l, SIE binding energies $\left|\boldsymbol{E_{1,l}}(\boldsymbol{a})\right|$ are growing (see Table) (see Fig. 2). In this case, the average distance between the electron and the hole decreases with increasing l. This leads to the fact that the overlap integral of the exciton wave functions $\boldsymbol{R_{1,l}(r)}$ (1) and $\boldsymbol{R_{1,l+1}(r)}$ (1) also increases with increasing l.

Therefore, the value of the intensity $\boldsymbol{I_{1,2}^{1,3}(a_3)} = 0.44$ (for l= 2) will be four times greater than the intensity $\boldsymbol{I_{1,0}^{1,1}(a_1)} = 0.10$ (for $l = 0$) (see Table). Such a significant increase in the intensity $\boldsymbol{I_{1,2}^{1,3}(a_3)}$ is due to the fact that the interband electron transition between the quasi-stationary SIE-state ($n = 1$, $l = 3$) and the stationary SIE-state ($n = 1$, $l = 2$) will be a direct transition in real space. In this case, the electron passes from the quasi-stationary SIE-state (n = 1, $l = 3$) located in the conduction band of the silicon matrix to the stationary SIE-state ($n = 1$, l =2), which is located in the bandgap of the silicon matrix.

For the appearance in the nanosystem with germanium QDs with radii $\boldsymbol{a_1} = 10$ nm of SIE levels $\left(\boldsymbol{E_{1,0} = -42\ meV}\right)$ and ($\boldsymbol{E_{1,1} = -26\ meV}$), according to (2), light quanta with following energies $\hbar\boldsymbol{\omega_{ex(1,0)}(a_1)} = 288$ meV and $\hbar\boldsymbol{\omega_{ex(1,1)}(a_1)} = 304$ meV are required (see Fig.1). As a result of the absorption of light quanta with energies $\hbar\boldsymbol{\omega_{ex(1,1)}(a_2)} = 285$ meV and $\hbar\boldsymbol{\omega_{ex(1,2)}(a_2)} = 358$ meV in the nanosystem with germanium QDs with radii $\boldsymbol{a_2} = 11.5$ nm, according to (2), the SIE levels ($\boldsymbol{E_{1,1} = -45\ meV}$) and ($\boldsymbol{E_{1,2} = 28\ meV}$) arise, respectively. In such a nanosystem containing germanium QDs with average radii $\boldsymbol{a_3}$ =16 nm, of SIE levels $\boldsymbol{E_{1,2} = -78\ meV}$) and ($\boldsymbol{E_{1,3} = 126\ meV}$), were formed upon absorption of a quantum of light, according to (2), with energies $\hbar\boldsymbol{\omega_{ex(1,2)}(a_3)} =$ 252 meV and $\hbar\boldsymbol{\omega_{ex(1,3)}(a_3)} =$ 456 meV, respectively (see Fig. 2). Such energies $\hbar\boldsymbol{\omega_{ex(1,l)}(a)}$ (2) were contained in the infrared spectral region (0.20 – 1.14) eV, which was observed under experimental conditions up to room temperature [7 – 10].

It follows from formula (5) that high lifetimes have SIE-states caused by optical transitions with the smallest distance $\Delta E_{1,l}^{1,l+1}(a)$ (6) between them (see Fig. 2). Therefore, the state that is due to optical transitions between the SIE-states (n =1, l) and (n =1, l + 1) has the longest lifetime $\tau_{1,0}^{1,1}(a_1) = 7.9 \cdot 10^{-4}$ s (see Table). The transition between the SIE-states (n =1, l =2) and (n =1, l =3), which occurs at room temperature, also determines the SIE- state with a high lifetime $\tau_{1,2}^{1,3}(a_3) = 4.4 \cdot 10^{-4}$ s (see Table). Such values of the lifetime $\tau_{1,2}^{1,3}$ exceed by four orders of magnitude the corresponding lifetimes of excitons in silicon [8, 9].

CONCLUSION

A mechanism is proposed for a significant increase (four times) in the intensities of optical interband and intraband transitions between quasi-stationary and stationary SIE-states arising above a spherical surface of a single germanium QD placed in a silicon matrix. These optical electronic transitions occur in the real space of the silicon matrix. Such a mechanism, apparently, will apparently solve the problem of a significant increase in the radiative intensity in germanium/silicon heterostructures with germanium QDs. This will provide an opportunity to develop fundamental and applied foundations, allowing to create a new generation of effective light-emitting and photodetector devices based on germanium/silicon heterostructures with

germanium quantum dots [11 – 21]. The theoretically predicted long-lived SIE-states, apparently, will make it possible to realize high-temperature quantum Bose-gases SIE-states in the nanosystem under study.

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ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ВПЛИВУ ПОВЕРХОНЬ ПОДІЛУ НА ІНТЕНСИВНОСТІ ВИПРОМІНЮВАННЯ ОПТИЧНИХ ПЕРЕХОДІВ ТА ЧАСІВ ЖИТТЯ ЕЛЕКТРОННИХ ЗБУДЖЕНЬ У НАНОСИСТЕМАХ ГЕРМАНІЙ/КРЕМНІЙ З КВАНТОВИМИ ТОЧКАМИ ГЕРМАНІЮ

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У цьому міні-огляді розглядаються теоретичні дослідження деяких оптичних властивостей гетеронаносистем другого типу. Ці наносистеми являють собою германій/кремній з германієвими квантовими точками (КТ). Досліджено вплив інтерфейсів на інтенсивність випромінювання оптичних переходів та часів життя електронних збуджень у наносистемах германій/кремній з германієм у наносистемах германій/кремній з КТ германію. Теоретично досліджено дипольно дозволені оптичні переходи між квазістаціонарним і стаціонарним станами, які відбуваються над сферичною поверхнею одиночної КТ германію, вбудованої в кремнієву матрицю. Запропоновано механізм значного збільшення (у чотири рази) інтенсивності оптичних міжзонних і внутрішньозонних переходів між квазістаціонарними та стаціонарними СІЕ-станами, що виникають над сферичною поверхнею одиночної КТ германію, розміщеної в кремнієвій матриці. Ці оптичні електронні переходи відбуваються в реальному просторі кремнієвої матриці. Такий механізм, мабуть, вирішить проблему значного збільшення інтенсивності випромінювання в гетероструктурах германій/кремній з КТ германію. Це дасть можливість розробити фундаментальні та прикладні основи, що дозволять створити нове покоління ефективних світловипромінюючих і фотоприймальних пристроїв на основі германієвих/кремнієвих гетероструктур з германієвими квантовими точками. Теоретично передбачені довгоживучі СІЕ-стани, мабуть, дозволять реалізувати високотемпературні квантові СІЕ-стани бозе-газів у досліджуваних наносистемах.

Ключові слова: *електронні переходи, квазістаціонарні електронні стани, інтенсивність випромінення, квантові точки.*