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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

THE ROLE OF RASHBA SPIN ORBITAL INTERACTION TO THE LIGHT ABSORPTION AND CHARGE CARRIER SCATTERING PROCESS IN LOW DIMENSIONAL SYSTEMS

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GENERAL DESCRIPTION OF WORK

The actuality of work. Among the achievements of modern science and technology, artificial semiconductor structures have a special place. With the emergence of quantum effects, these semiconductor structures have unique physical properties. The most intensive of these is the quantization effect by size. This effect occurs when the characteristic dimensions of the system can be compared with the de Broglie wave value of the particles, resulting in restrictions on the motion of those particles. There are many types of low-dimensional systems: quantum holes, ultra-cages, quantum wire, quantum dots, quantum rings, quantum disks, and so on.

Advances in modern technology, such as computer-controlled molecular beam epitaxy, make it possible to obtain dimensional-limited semiconductor systems with any configuration, including parabolic potential. In systems with parabolic potential, the dimensional quantization effect occurs in sufficiently large quantum holes (greater than 1000Å), and the quantization of the energy spectrum at T ~ 100 K significantly affects the properties of the system. The quadratic dependence of the potential allows to obtain an analytical expression of many characteristics of the system, which is convenient for the analysis of the physical cases under consideration.

New effects are observed when electric and magnetic fields affect optical radiation in semiconductor structures, leading to more sophisticated devices. The study of the effect of the magnetic field and the geometric shape of nanostructures on the optical and kinetic properties is one of the current directions of nanoelectronics. One of the main methods of studying the spectral properties of electron gas in various low-dimensional structures is the study of intra-zone electron transitions under the influence of electromagnetic radiation. In the study of the spectral properties of nanostructures, the study of resonance absorption is superior to kinetic measurements because it does not require contact with contact systems that may affect the physical properties of the system.

In recent decades, spin phenomena in semiconductors and nanostructures have been extensively studied: the characteristics of spin-orbital interactions, the spin dynamics of electrons and holes, the angular momentum transfer of a photon in an electronic system. These effects were determined by a joint study of load and spin degrees of freedom. This branch of science is called spintronics. In addition, low-dimensional structures have a longer relaxation time than bulky materials. Here, the study of spin-dependent tunneling through semiconductor barriers and the study of the spin state of electrons in low-dimensional structures of various configurations are relevant.

In low-dimensional systems, the retaining lateral (longitudinal) potential of electrons leads to the absorption of resonance due to dimensional quantization. In the presence of a quantizing magnetic field, the resonance at the hybrid frequency causes an electronic transition, ie a hybrid-phonon resonance. The main aspect of the study of intra-zone absorption of high-frequency electromagnetic radiation is that in the case of a discrete energy spectrum, the absorption curve has a resonance peak at certain points, and the frequency of radiation at these points is equal to the distance between energy levels. In this case, it allows to obtain information about the resonant frequency determined by experience, the lateral configuration in nanostructures and the parameters of the electronic energy spectrum.

Intra-zone absorption in a number of semiconductor structures, the absorption of electrons by phonons, the absorption of light by free charge carriers, and the Rashba spin orbital interaction with charge scattering in this absorption have not been sufficiently studied.

Purposes and tasks of research: The main purpose of the dissertation - to determine the role of absorption of light and scattering of charge carriers in different nanostructures (extreme cells, extreme cells of quantum dots, quantum holes, quantum holes). To achieve this goal, the following problems were solved:

- Study of the absorption of light by carriers during the scattering of electrons on phonons in extreme cells in the magnetic field.
- Study of light absorption by charge carriers during the scattering of electrons on phonons in cells with quantum dots.
- Study of intrizonal absorption of light in extreme cells of quantum dots
- Study of light absorption by carriers during scattering of electrons on phonons in a cylindrical quantum wire.
- Study of light absorption in anisotropic parabolic quantum wire
- Study of interzonal optical absorption of light in quantum compression
- Study of electronic phonon interactions with account of spin-orbital interactions in low-dimensional systems.
- Study of light absorption by charge carriers when scattering electrons on phonons with accounting for spin-orbital interactions in low-dimensional systems in the magnetic field.

Research methods: From the method of studying intra-zone electron transitions under the influence of electromagnetic radiation to study the spectral properties of electron gas in various low-dimensional structures, from the method of radial wave function in determining the exact shape of the matrix element, from the method of second-order excitation theory methods, computing software packages and other computing technologies were used.

Basic provisions of protection:

- When the magnetic field is directed perpendicular to the surface of the semiconductor cage, scattering from polar and non-polar phonons shows that the absorption coefficient of light with free charge oscillates depending on both the intensity of the magnetic field and the frequency of the incident light, and resonans condition is $N\omega_c = \Omega + \omega_0$.

- The scattering of polar and non-polar phonons in quantum dots bounded by anisotropic parabolic potential oscillates the absorption coefficient of electromagnetic radiation with free charge carriers depending on the frequency of light, and the resonance state of absorption coefficient is given by $N\omega_x + P\omega_y \pm \omega_0 = \Omega$.

  In a quantum point extreme cage with a parabolic potential, the intra-zone optical absorption occurs between adjacent sub-levels when the limiting potential axis of the polarization vector of the electromagnetic wave is directed.
- The interzonal absorption coefficient of light in quantum narrowing under the influence of a longitudinal magnetic field has been determined.
- In quantum wires with asymmetric parabolic potential, the dependence of the intra-zone optical absorption coefficient peaks on the characteristic frequency $N\omega_x + P\omega_y \pm \omega_0 = \Omega$ is determined.
- In quantum holes, the absorption of light by free carriers increases as the scattering speed increases, taking into account the Rashba spin orbital interaction.

Scientific novelty of the research:

For the first time, the following was done

- An analytical expression was obtained for the coefficient of light absorption by free charge carriers in the case of scattering from polar and non-polar phonons when the magnetic field is directed perpendicular to the surface of the semiconductor ultra-lattice.
- An analytical expression was obtained for the absorption coefficient of electromagnetic radiation with free charge carriers scattered from polar and non-polar phonons in

extreme cells consisting of quantum dots limited by anisotropic parabolic potential.

- Expression for intra-zone optical absorption coefficient in quantum point extreme cage with parabolic potential
- The interzonal absorption coefficient of light in quantum contraction under the influence of a longitudinal magnetic field has been determined.
- Expression for intra-zone optical absorption coefficient in quantum wires with asymmetric parabolic potential
- In a cylindrical quantum wire, the coefficient of light absorption is calculated by free charge carriers when electrons are scattered from acoustic phonons.
- In quantum holes, the expression for the light absorption coefficient with free charge carriers was obtained, taking into account the Rashba spin orbital interaction.

Theoretical and practical significance of the research: The research of the dissertation was carried out in the field of nanostructure: two-dimensional structure of the electron gas with quantum holes, ultracellular, extreme cells with quantum dots, quantum dots. It is expected that quantum cascade lasers based on quantum dot ultra-cells will be more efficient than quantum cascade lasers based on quantum holes. It should be noted that the study of intra-zone optical transitions provides important information about the parameters of the farm surface and energy spectrum of electrons. Intra-zone absorption can be used in the manufacture of infrared detectors. The study focused on systems with parabolic potential. In systems with parabolic potential, the dimensional quantization effect occurs in quantum holes with a fairly large width. The quadratic dependence of the potential is suitable for theoretical calculations. Thus, many characteristics of the system can be obtained analytically, which is appropriate for the analysis of the physical conditions under consideration.

In small-sized structures, relaxation time is greater than in bulk materials. Here it is important to study the spin-dependent tunneling through semiconductor barriers and to study the spin position of electrons in low-dimensional structures of different configurations.

Approbation and application: The main results of the dissertation work were presented at the following international and republican scientific conferences - "International Conference on Physics, Mathematics and Technical Sciences" (Nakhchivan, 2009), 2009, Baku. , "ANAS - Scientific Conference of Postgraduate Students" (Baku, 2010), "Nanotechnology and their application in technology" I International Conference, Azerbaijan Technical University (Baku, 2010), VIII National Conference on X-ray, synchronized radiations, Neutrons and electrons for the study of nanosystems and materials. Nano-bio-info-cognitive technologies "(Moscow, 2011), IX International Scientific-Practical Conference, 8th, 2013) International Scientific Conference "Applied Sciences and Technologies in the USA and Europe: General Challenges and Scientific Solutions" (New York, 2014), "BSU Institute of Physical Problems, VIII Republican Conference" (Baku, 2014), Academician GB Abdullaeva, International Conference and School of Modern Trends in Physics Condensed Environment MTCMP (Baku-2018), "Current issues of personnel training in energy specialties. Proceedings of the Republican Scientific Conference of Sumgayit State University "(Sumgayit, 2019) and the International Scientific-Practical Conference. conference on the prospects of application in the military industry ", Az.MIU (Baku, 2019), XIV International Scientific Conference" Advanced Sciences ce "(Russia, 2020) - communicates.

The list of articles published at the end of the dissertation on the topic of the dissertation was published in the following journals:

Azerbaijan Physical Journal, 2010, 2018; National Academy of Sciences of Azerbaijan, Labor, Physics and Astronomy, 2013; Baku University News, 2014; Azerbaijan Technical University, Scientific works, 2018; European Sciences, 2019; News of the Azerbaijan

National Academy of Sciences, 2014, 2019; Technical Bulletin Don, 2020; Journal of Neoxide Glass, 2020.

Name of the organization where the dissertation work is carried out: The dissertation work was carried out in the laboratory "Transfer events in semiconductors and semiconductor nanostructures" of the Institute of Physics named after H.M.Abdullayev of the Azerbaijan National Academy of Sciences.

The structure and scope of the dissertation. The dissertation contains an introduction, 4 chapters, main results and a list of 172 references, covering 120 pages printed on a computer.

CONTENT OF THE WORK

In the introduction, the research object of the dissertation work have been chosen, the relevance was substantiated, the purpose of the research and the main questions that need to be solved were formulated, the practical significance of the work was indicated, scientific novelty were given and the summary of the dissertation have been commented.

Information on nanoscale systems and the Rashba spin orbital interaction is given in the **first chapter**.

In the second chapter, we examined the intraband optical transition in semiconductor ultracells. Under the action of a longitudinal magnetic field ($H = H_z$) the energy spectrum and wave function of an electron in the potential perforated extreme cages with d_{SL} periodic along the z axis can be expressed as follows:

$$E_n(k_z) = (n + 1/2)\hbar\omega_c + \frac{\Delta}{2}(1 - \cos k_z d_{SL}) \tag{1}$$

$$\Psi_{nk_xk_z} = \frac{1}{L_y}\exp(ik_x x)\chi_{nk_x}(y)\xi(k_z) \tag{2}$$

where L_x, L_y and L_z are the sizes of the extreme cage sample, Δ is the width of minizone, $H_n(x)$ - n-*s Hermit* function and $\xi_k(z)$ – Bloch function along the *z.*

When the magnetic field is directed perpendicular to the surface of the extreme lattice, Landau quantization occurs and the energy is divided into discrete levels. At the same time, the minizons which are the result of the movement of electrons and holes in the z direction remain uninterrupted.

When calculating the matrix elements of the H_R operator, the high-frequency field is considered homogeneous. The square of the H_R matrix element will be expressed as:

$$\left|\left\langle nk_x k_z \right| H_R \left| n' k'_x k'_z \right\rangle\right|^2 = \left(\frac{2\pi\hbar n_0}{\in(\omega)\omega}\right)\left(e\Delta d_{SL}\sin\left(k_z d_{SL}\right)/2\hbar\right)^2 \delta_{nn'}\delta_{k_x k'_x}\delta_{k_z k'_z} \quad (3)$$

Here $\vec{\varepsilon}$ - polarization vector of radiation field, $\in$ - dielectric constant, *ω* and *c* are the frequency and velocity of the light wave.

The expression of the $f_0(E_n(k_z))$ electron distribution function for a semiconductor extreme lattice that does not shrink in a magnetic field is:

$$f_0\left(E_n\left(k_z\right)\right) = \frac{4\pi\hbar n_e d_{SL}\sinh\left(\hbar\omega_c/2k_B T\right)}{m^*\omega_c I_0\left(\Delta/2k_B T\right)} e^{-\left(n+\frac{1}{2}\right)\frac{\hbar\omega_c}{k_B T}} e^{\frac{\Delta}{2k_B T}\cos k_z d_{sl}}$$

Due to the possibility of a quantum mechanical transition, at the same time as the charge carriers scatter from the phonons, the charge carriers either absorb or emit a photon, while the light charge absorption coefficient with free charge is calculated as

$$\alpha = \frac{\in^{1/2}}{n_0 c}\sum_i W_i f_i \qquad (4)$$

Here n_0 - is the number of photons in the radiation field, f_i - is the distribution function of the free charge carriers, and W_i - is the transition probability determined by the following expression:

$$W_i = \frac{2\pi}{\hbar}\sum_{fq}\left[\left|\left\langle f\right|M_+\left|i\right\rangle\right|^2\delta\left(E_f - E_i - \hbar\omega - \hbar\omega_q\right) + \left|\left\langle f\right|M_-\left|i\right\rangle\right|^2\delta\left(E_f - E_i - \hbar\omega + \hbar\omega_q\right)\right] \quad (5)$$

where E_i *and* E_f are the energies of the electrons at the initial and final states, respectively, $\hbar\omega_q$ is the energy of the phonon, and $\langle f|M_+|i\rangle$ are the matrix elements of the transition from the initial to the final state for the interaction between electrons, phonons and photons.

Modern nanotechnology allows the production of quantum dots of various shapes. It is expected that quantum cascade lasers based on quantum dot lattices should be more efficient than quantum cascade lasers based on quantum hole lattices. This chapter also examines the absorption of electromagnetic radiation by free electron gas in extreme cages consisting of quantum dots. It is assumed that the electron gas in quantum point extremes is limited by anisotropic parabolic potential:

The normalized specific function of the electron and the specific energy values in the conduction band are found in this way, respectively[1].

$$\Psi_{n,l,k_z}(r) = \frac{1}{\sqrt{L_z}}\Psi_n(x)\Psi_l(y)\xi_{k_z}(z) \quad , \tag{6}$$

$$E_{n,l}(k_z) = (n+\frac{1}{2})\hbar\omega_x + (l+\frac{1}{2})\hbar\omega_y + \frac{\Delta}{2}(1-\cos k_z d) = \varepsilon_{n,l} + \varepsilon(k_z) \ , \tag{7}$$

where m * - is the effective mass, ω_x and ω_y are the frequencies of the configuration in the x and y directions, respectively. $n(=0,1,2,...)$ and $l(=0,1,2,....)$ are the indices of the electron subzones level, k_z is the component of the wave vector in the z direction, Ψ_n (x) and Ψ_n (y) are the special functions of a simple harmonic oscillator. Using the wave function given by expression (6), the matrix element of the electron-photon interaction is obtained by substituting the $\delta_{k_x k_x}$ symbol for the $\delta_{ll'}$ symbol in expression (3).

The expression for the matrix element of the electron-phonon interaction is written as follows:

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[1]Sang Chil Lee_ Electrophonon Resonance in Quantum-Dot Superlattices Journal of the Korean Physical Society, Vol. 52, No. 4, April 2008, pp. 1081-1085

$$\left|\langle k_z' n' l' | V_s | k_z n l \rangle\right| = C_j' \; J_{nn'}(x) J_{ll'}(y) I(q_z) \quad (8)$$

V_S - is an electron interaction operator with a phonon. $C_j^{'} C_j$ is a function that characterizes the interaction between electrons and phonons[2]:

$$J_{nn'}(q_x) = \int_{-\infty}^{\infty} e^{iq_x x} dx \Psi_n(x) \Psi_{n'}(x)$$

$$J_{ll'}(q_y) = \int_{-\infty}^{\infty} e^{iq_y y} dy \Psi_l(y) \Psi_{l'}(y)$$

$$I(q_z) = \int_0^d \xi_{k_z}(z) \xi_{k_k'}(z) e^{iq_z z} dz \qquad\qquad C_j^{'2} = C_j^{\,2} F_j(q)$$

C_j and $F_j(q)$ depends on the type of phonons.

For the absorption coefficient for scattering by polar and non-polar optical phonons, we obtain:

$$\alpha_{pol} = \frac{4\pi e^4 \Delta d \omega_0 L_z}{c\Omega^3 \in^{1/2} \hbar^3} \left(\frac{1}{\varepsilon_\infty} - \frac{1}{\varepsilon_0} \right) \sum_{n'e'} \sum_{ne} \sum_{\pm} \int_{-\pi/d}^{\pi/d} dk_z f_{nek_z} \left(N_0 + \frac{1}{2} \pm \frac{1}{2} \right) \frac{\sqrt{1 - \frac{4}{\Delta^2}\theta_\pm^2} - \sin k_z d}{\sqrt{1 - \frac{4}{\Delta^2}\theta_\pm^2}} \times$$

$$\times \int_0^\infty \int_0^\infty \frac{\left|I_{nn'}(q_x)\right|^2 \left|I_{ee'}(q_y)\right|^2}{\left(q_x^{\,2} + q_y^{\,2}\right) + a_\pm^{\,2}} dq_x dq_y \qquad (9)$$

[2]İbrahimov H.B. Nanoölçülü sistemlərdə elektron prosesləri / -Bakı, 2012. -s.255.

$$\alpha_{n.pol} = \frac{D^2 e^2 \Delta d}{\pi c \rho \omega_0 \Omega^3 L_x L_y \in^{1/2}} \sum_{n'e'} \sum_{ne} \sum_{\pm} \int_{-\pi/d}^{\pi/d} dk_z f_{nek_z} \left(N_0 + \frac{1}{2} \pm \frac{1}{2} \right) \frac{\sqrt{1 - \frac{4}{\Delta^2}\Theta_\pm^2} - \sin k_z d}{\sqrt{1 - \frac{4}{\Delta^2}\Theta_\pm^2}} \times$$

$$\times \frac{1}{n'-n} \cdot \frac{1}{l'-l} \qquad (10)$$

where

$$\Theta_\pm (k_z d) = (n' - n)\hbar\omega_x + (l' - l)\hbar\omega_y \pm \hbar\omega_0 + \hbar\Omega + \frac{\Delta}{2}\cos k_z d$$

When deriving formula (10), it was taken into account that $\int_0^\infty \frac{|I_{nn'}(u)|^2 du}{u} = \frac{1}{n'-n}$

From expression (10) it is seen that the absorption coefficient diverges whenever the condition $1 - 4\Theta_i^2 / \Delta^2 = 0$ is satisfied. In addition, from the fact that $1 - 4\Theta_i^2 / \Delta^2$ are real and positive, we can obtain an energy range in which the absorption coefficient are allowed.

As follows from equations (9) and (10), peaks are observed at certain frequencies of the incident photon. The resonance behavior of the absorption coefficient for electron-phonon scattering appears for frequencies satisfying the relation

$$N\hbar\omega_x + P\hbar\omega_y \pm \hbar\omega_0 = \hbar\Omega \qquad (11)$$

here $N = n' - n = 1,2,3,...$ and $P = l' - l = 1,2,3,...$.

From Eq. (11) , in the course of scattering events, the electrons in the subband levels specified by the level index $n(l)$ can make transitions to one of the subband levels $n'(l')$ by absorbing and/or emitting a photon of energy $\hbar\Omega$ during the absorption of a LO phonon of energy $\hbar\omega_0$.

Eq. (11) is the basic equation for the absorption coefficient spectral lineshape, which enable us to analyze resonant effects in semiconductors.

It should be noted that the summations of Eq. (19) over the size subband levels contain three types of contributions: (i) $n' \neq n, l' = l$, (ii) $n' = n, l' \neq l$ and (iii) $n' \neq n, l \neq l'$. From the selection rules, we can expect three possible transitions in the absorption coefficient for electron- polar phonon scattering : (1) a transition due to the size subband levels for only the x direction, (2) a transition due to the size subband levels for only the y direction and (3) a transition due to the size subband levels for both the x direction and the y direction. From the Eq. (16) we can expect only one possible transitions in the, the absorption coefficient for electron-nonpolar phonon scattering : a transition due to the size subband levels for both the x direction and the y direction.

This chapter also examines intra-zone optical absorption in quantum point extremes with parabolic potentials. Note that the study of intra-zone optical transitions provides important information about the parameters of the Fermi surface and energy spectrum of electrons. Since we look at a parabolic potential configuration, electron-electron interactions are not taken into account. It is assumed that in quantum point cages, the electron gas is limited by the anisotropic parabolic potential.

The special function of the electron $\Psi_{n,e,k_z}(r)$ and the specific values in the conduction band $E_{n,l}(k_z)$ are given by (6) and (7), respectively

$$\alpha = \frac{2\pi\sqrt{\in(\Omega)}}{c\hbar N_f} \sum_{nlk_z} \sum_{n'l'k'_z} f_0\left(E_{nlk_z}\right) \left| < nlk_z \left| H_R \right| n'l'k'_z > \right|^2 \delta\left(E_{nlk_z} - E_{n'l'k'_z} + \hbar\Omega\right)$$

When the polarization vector of an electromagnetic wave is directed along the x-axis, the matrix element of the electron photon-interaction operator is as follows:

$$< n,l,k_z \left| H_R \right| n',l',k_z' >= ie\frac{\sqrt{\hbar m*\Omega}}{m*}\sqrt{\frac{2\pi\hbar N_f}{\in(\omega)\Omega}}\delta_{l_y,l'}\delta_{k_z,k_z'} \times$$

$$\left(\sqrt{\frac{n}{2}}\delta_{n',n-1} - \sqrt{\frac{n+1}{2}}\delta_{n'n+1} \right) \quad (12)$$

Note that when the polarization vector of an electromagnetic wave is directed in the y-axis direction, it is obtained by changing the position of the electron photon-interaction operator in the expression of the matrix element (12) n and l its quantities.

Thus, we obtain that when the polarization vector of an electromagnetic wave is directed in the x-axis direction, the transition occurs only between adjacent ($n' = n \pm 1$) levels, and when the polarization vector of an electromagnetic wave is directed in the y-axis direction, the transition occurs only between adjacent ($l' = l \pm 1$) levels.

In the third chapter, we examined the theory of the absorption of free charge carriers when the radiation field is polarized along the length of the wire for a quasi-one-dimensional electron gas in a cylindrical quantum wire when the carriers are scattered by acoustic phonons.

Assume that the motion of the electrons is limited by a cylindrical wire of radius R and moves freely along the length L of the wire. In this case, the wave function of the electron in the quantum wire within the effective mass approximation will be as follows:

$$\Psi_{nlK}(r) = \frac{\exp(iKz)\exp(il\vartheta)}{(\pi R^2 L)^{1/2}} \cdot \frac{J_{nl}(k_{nl}\rho)}{J_{l+1}(k_{nl}R)},$$

$$l = 0,1,2,3,....,n = 1,2,3,....., \quad (13)$$

where r is (ρ,ϑ,z), ϑ is the azimuthal angle of the wire, K is the wave vector of the electron along z selected along the axis of the cylindrical wire, $J_l(x)$ is the first-order Bessel function.

Using the wave function, the matrix element of the electron-photon interaction can be written as follows:

$$\left\langle n^{'}l^{'}K^{'}\left|H_R\right|nlK\right\rangle = -\frac{e\hbar}{m^*}\left(\frac{2\pi\hbar n_0}{V\Omega \in}\right)^{1/2}(\varepsilon K)\delta_{KK^{'}}\delta_{ll^{'}}G_{nl,n^{'}l^{'}}(R) , \qquad (14)$$

The radiation field is polarized along the y-direction.

For an acoustic phonon, the matrix elements of the electron-phonon interaction depend on the scattering mechanism

$$\left\langle f\left|V_s\right|\alpha\right\rangle = C_{nl}(q_z)I_{n^{'}l^{'},n^{''}l^{''}}(q_{nl})\delta_{K^{'},K^{''}+q_z} \qquad (15)$$

We consider the interaction of the deformed potential with the width-limited acoustic phonons in the nanowire. In this case, the expression for $C_{nl}(q_z)$ included in expression (14) is given as follows[3]:

$$\left|C_{nl,q_z}^{LA}\right|^2 = \frac{D^2\hbar\sqrt{k_{nl}^2R^2 + R^2q_z^2}}{2\pi RL\mu c_s J_{n+1}^2(k_{nl}R)} \qquad (16)$$

where c_s is the sound frequency, μ is the density of the material, and D is the deformation potential of the strip. Using expressions (4) - (5) and (14) - (16), it was found that the absorption coefficient of light decreases as the radius of the wire increases with the scattering of free charge carriers on acoustic phonons in a cylindrical quantum wire.

This chapter also examines the simultaneous absorption and scattering of electromagnetic radiation by electrons in a quantum wire, which describes the potential of a parabolic configuration.

It is assumed that the electron gas in a quantum wire is limited by the anisotropic parabolic potential of frequencies ω_x and ω_z, respectively, in the *x* and *z* directions.

[3]Hong-Jing, X. Bound polaron in a cylindrical quantum wire of polar crystal / Ch.-Y. Chen, K. M. Ben // Physical Review B, 2000. 61, 7, - p.4827-4834.

In quantum wires with asymmetric parabolic potential, the specific function $\Psi_{n,m,P_y}(r)$ and specific energy $E_{n,m}(p_y)$ of the electron in the conduction band are calculated by the following formulas:

$$\Psi_{n,m,p_y}(r) = \frac{1}{\sqrt{2\pi\hbar}}\Psi_n(x)\Psi_m(z)\exp(ip_y y) \quad , \tag{17}$$

$$E_{n,m}(p_y) = (n+\frac{1}{2})\hbar\omega_x + (m+\frac{1}{2})\hbar\omega_z + \frac{p_y^2}{2m}, \tag{18}$$

Here $n(=0,1,2,...)$ and $m(=0,1,2,...)$ are the indices the electron subzones levels, p_y is the impulse component of the electron in the y direction (y axis direction corresponds to the axis of the wire), $\Psi_n(x)$ and $\Psi_m(z)$ are special functions of a simple harmonic oscillator. The system is aggregated according to the "i" initial state. The probability of transition W_i from mnP_y to $m'n'P_y'$ is determined by the expression (5).

Using the expression for the wave function (17), the matrix element of the electron-photon interaction can be written as follows:

$$\langle n'l'K'|H_R|nlK\rangle = -\frac{e}{m^*}\left(\frac{2\pi\hbar n_0}{V\Omega \in}\right)^{1/2}(\varepsilon P_y)\delta_{P_yP_y}\delta_{mm'}\delta_{nn'} \tag{19}$$

In this case, the distribution function $f_0(E_{nmP_y})$ is subject to the following normalization condition:

$$\frac{L_Y}{2\pi\hbar}\sum_{m=-\infty}^{\infty}\sum_{n=0}^{\infty}\int_{-\infty}^{\infty} f_0(E_{mnP_y})dP_y = N \tag{20}$$

Here N -is the number of electrons in a unit volume, L_y - is the length of the wire along the y axis.

Thus, taking into account expression (10), the electron distribution function is found for an uncharged electron gas.

The matrix elements of electron-phonon interaction can be expressed as follows:

$$\left\langle n''m''P_y{}'' \middle| V_s \middle| nmP_y \right\rangle = D_q \sqrt{N_q + \frac{1}{2} \pm \frac{1}{2}} \left\langle n''m''P_y{}'' \middle| e^{\pm iqr} \middle| nmP_y \right\rangle \quad (21)$$

For deformation (DO-phonons) and polar optical (PO-phonons) phonons, the electron-phonon contact constant can be calculated as follows[4]:

$$\left|D_q\right|^2 = \frac{2\pi\hbar^2\alpha_l\omega_0}{m*} \begin{cases} \sqrt{2m^*\hbar\omega_0} \big/ q^2 - PO \\ 4\hbar^2 \big/ \sqrt{2m^*\hbar\omega_0} - DO \end{cases} \quad (22)$$

Here α_L - is the dimensionless contact constant.

The matrix elements of the electron-phonon interaction have been calculated using the $\exp(\pm aP_x x/\hbar)\Phi(x) = \Phi(x \pm a)$ shift operator and the following known expressions.

Expressions for α (19) are evaluated using matrix elements, electron-photon interaction matrix elements (20) and the distribution function of the unbroken electron gas. The scattering of polar and non-polar phonons in quantum dots bounded by anisotropic parabolic potential oscillates the absorption coefficient of electromagnetic radiation with free charge carriers depending on the frequency of light, and the resonance state of absorption coefficient is given by $N\omega_x + P\omega_y \pm \omega_0 = \Omega$.

This chapter also examines the absorption of light in quantum contraction under the influence of a longitudinal magnetic field.

Changes in the shape and size of nanostructures have a significant effect on spectral properties. Modern nanotechnology does not exclude the existence of a random field in quantum wires associated with the fluctuation of their thickness. The heterogeneity

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[4]Басс Ф. Г., Левинсон И. Б. Циклотронно-фононный резонанс в полупроводниках // Журнал Экспериментальной и Теоретической Физики, - 1965. 49, -с. 924.

of thickness leads to the formation of micro-narrowing. The characteristics of the geometric shape of this micro-narrowing are reflected in the cardinal modification of the electron spectrum in the "quantum wire-micro-narrowing" transition.

The magnetic field *H* applied along the axis of the quantum wire, as is well known, amplifies the lateral geometric configuration.

Absorption of direct interzonal light in microcontraction in the longitudinal magnetic field has been studied. The "soft wall" potential is taken as a potential model of the micro-shrinkage configuration:

$$V(x,y,z) = m^* (\omega_0^2x^2 + \omega_0^2y^2 - \omega_z^2z^2) / 2 \quad (23)$$

where z - is the coordinate in the direction of the microcontraction axis; the frequency ω_z is determined by the effective length of the microarray $\omega_z = \sqrt{\hbar/\left(m * L_z^2\right)}$; $\omega_0 -$ is the characteristic frequency of a two-dimensional harmonic oscillator. The vector potential of a homogeneous magnetic field *A*, directed along the axis of microcontraction, was selected in a symmetrical calibration $\vec{\mathrm{A}} = \left(-y\mathrm{B}/2, x\mathrm{B}/2, 0\right)$.

For a single-electron case, Hamilton H_H can be written as follows

$$H_H = H_{\rho,\varphi} + H_z \quad (24)$$

where

$$\mathrm{H}_{\rho,\varphi} = -\frac{\hbar^2}{2m^*}\left(\frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial}{\partial\rho}\right) + \frac{1}{\rho^2}\frac{\partial^2}{\partial\varphi^2} - \frac{i\hbar\omega_H}{2}\frac{\partial}{\partial\varphi} + \frac{m^*}{8}\Omega^2\rho^2\right),$$

$$\mathrm{H}_z = -\frac{\hbar^2}{2m^*}\frac{\partial^2}{\partial z^2} - \frac{m^*}{2}\omega_z^2z^2$$

$\Omega = \sqrt{4\omega_0^2 + \omega_C^2}$ - is the hybrid frequency.

The corresponding special function and special values of Hamiltonian are given by the following well-known expression:

$$\mathrm{E}_{n,m,\lambda} = \frac{\hbar\omega_B m}{2} + \frac{\hbar\Omega}{2}\left(2n + |m| + 1\right) + \hbar\omega_z\lambda,$$
$$\Psi_{n,m,\lambda}(\rho,\varphi,z) = \Psi_{n,m}(\rho,\varphi)\Psi_\lambda(z), \quad (25)$$

Here $\Psi_{n,m}(\rho,\varphi)$ and $\Psi_\lambda(z)$ are the special functions of the operators $H_{\rho,\varphi}$ and H_z, respectively:

Where $n = 0,1,2,...m$ are quantum numbers corresponding to Landau levels; $m = 0,\pm1,\pm2,...$, are the magnetic quantum numbers;

In microcontraction, we look at the absorption of light between straight zones. The known formula of *A. L. Ephros* was used to calculate this absorption coefficient[5] :

$$\alpha = A\sum_{\nu,\nu'}\left|\int \psi_\nu^e \psi_{\nu'}^h dr\right|^2 \times \delta\left(\Delta - E_\nu^e - E_{\nu'}^h\right) \quad (26)$$

here $\Delta = \hbar\Omega - E_g$ is the the width of the E_g forbidden zone of massive semiconductors, A – is the quantity proportional to the square of the matrix element taken from the Block function; ν and ν' - are quantum numbers corresponding to electrons and heavy holes. Here, the function through δ satisfies the law of conservation of energy for the corresponding transitions.

The Hille-Hardy formula and the Weber integral were used for the double derivative function when calculating the light absorption coefficient between straight zones.

The dependence of the light absorption coefficient on the quantity of the external magnetic field was studied in microcontraction. The "micro-shrinkage quantum wire" transition is considered.

In the fourth chapter, the intra-zone magnetic absorption of the linear polarization of two-dimensional electron gas, taking into account the spin-orbital interaction of Rashba, is studied. The Hamilton operator, which describes the quantum-mechanical motion

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[5]Efros A. L. , Efros A. L. Interband absorption of light in a semiconductor sphere // Semiconductors, - 1982. 16, -p.772–775.

of an electron in a two-dimensional system in a fixed homogeneous perpendicular magnetic field, taking into account the Zeeman decay and the Rashba spin-orbital interaction, is as follows:

$$H = \frac{P^2}{2m^*} + \frac{a}{\hbar}\left(\sigma_x P_y - \sigma_y P_x\right) + \frac{1}{2} g\mu_B B\sigma_z \qquad (27)$$

P - is the impulse operator, σ - is the Pauli matrix, μ_B - is the Bohr magneton, α is the spinorbital interaction constant of Rushba, g - is the Lande factor, ħ- is the Planck constant. As the vector potential of the magnetic field, Landau (caliber) takes ***A=(0, H·x,0)***. It is known that in this case the electronic spectrum describes discrete levels, combined pairs:

$$E_n^{\pm} = \hbar\omega_c n \pm \frac{1}{2}\sqrt{\left(\hbar\omega_c + 2g\mu_B H\right)^2 + \frac{8\alpha^2}{l_H^2} n} \qquad (28)$$

$$n = 1,2,3,...E_0^+ = \left(\hbar\omega_c / 2 + g\mu_B B\right),$$

If we take the direction of photon polarization along the oX axis, the electron-photon interaction operator can be written as follows:

$$H_R = -\frac{e}{m^* c}\left(P - \frac{eA}{c}\right)A_0 + \frac{ea}{c\hbar}\sigma_y A_0 \qquad (29)$$

here A_0 – is the amplitude of the electromagnetic wave associated with the volume concentration of the photons. The matrix element of electron- photon interaction is as follows:

$$\left|\left\langle k'_y n' l' \left| V_s \right| k_y n l \right\rangle\right|^2 = C'^2_j \delta_{k'_y, k_y \pm q_y} F^{\pm}_{nn'}\left(q_x q_y\right) \Lambda_{ll'}\left(q_z\right) \qquad (30)$$

V_s – energy operator of the electron-phonon interaction, C_j – is the function that charcaterizes an elektron-fonon interaction,

$$F^{\pm}_{nn'}\left(q_n\right) = \left| < \Psi_n(x,y) \right| e^{i\left(q_x x + q_y y\right)} \left| \Psi_{n'}(x,y) \right|^2 \qquad (31)$$

Here

$$A_{II}\ (q_z) = \left| \frac{2}{d} \int_0^d dz \exp(iq_z z) \sin\left(\frac{l' \pi z}{d}\right) \sin\left(\frac{l \pi z}{d}\right) \right|^2$$

$$\int_0^\infty A_{II'}(q_z) dq_z = \frac{2\pi}{d}\left(1 + \frac{1}{2}\delta_{II'}\right)$$

Using the expressions of the matrix element of the electron photon interaction and the matrix element of the electron-phonon interaction, the light absorption coefficient with free charge carriers was calculated, taking into account the Rashba spin orbital interaction in quantum holes. It has been found that in quantum holes, the absorption coefficient of light with free charge carriers increases as the scattering speed increases, taking into account the Rashba spin orbital interaction.

THE MAIN RESULTS:

1. When the magnetic field is directed perpendicular to the surface of the semiconductor cage, scattering from polar and non-polar phonons shows that the absorption coefficient of light with free charge oscillates depending on both the intensity of the magnetic field and the frequency of the incident light, and resonans condition is $N\omega_c = \Omega + \omega_0$.
2. The scattering of polar and non-polar phonons in quantum dots bounded by anisotropic parabolic potential oscillates the absorption coefficient of electromagnetic radiation with free charge carriers depending on the frequency of light, and the resonance state of absorption coefficient is given by $N\omega_x + P\omega_y \pm \omega_0 = \Omega$.

3. It has been found that in the case of an unbroken electron gas in quantum point extremes with anisotropic parabolic potential, the intra-zone absorption is between neighboring sub-levels within the first-order excitation theory of electron-photon interaction when the polarization vector of an electromagnetic wave is directed in the direction of the limiting potential axis.
4. It was found that the absorption coefficient of light decreases with increasing cross-section of the wire by scattering free charge carriers from acoustic phonons in a cylindrical quantum wire.
5. The interdisciplinary absorption coefficient of light in quantum shrinkage under the influence of a longitudinal magnetic field depends on the intensity of the external magnetic field and the length of the micro-shrinkage.
6. In quantum wires with asymmetric parabolic potential, the dependence of the intra-zone optical absorption coefficient peaks on the characteristic frequency $N\omega_x + P\omega_y \pm \omega_0 = \Omega$ is determined.
7. An analytical expression for the light absorption coefficient with free charge carriers was obtained, taking into account the Rasba spin orbital interactions in quantum holes. It has been found that the light absorption by free charge carriers increases in quantum holes as the scattering speed increases, taking into account the Rashba spin orbital interaction.

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