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INTERSUBBAND OPTICAL ABSORPTION IN SEMICONDUCTING QUANTUM WIRES

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Intersubband optical transitions is investigated for quasi-one dimensional semiconducting structures (ultrathin wires). The absorption coefficient is calculated in degenerate and nondegenerate states of electrons.

In the last few years in the semiconductor electronics the composition materials with more complex structure are used. The achievements of semiconductor technology allow to grow semiconducting heterostructure of various dimension: two-dimensional (quantum wells, superlattices), one-dimensional (quantum filaments or wires), zero-dimensional (quantum disrs or pants). Properties of these heterostructures differ considerably from properties of homogeneous semiconductors [1].

In the ultra-thin semiconducting wires (submicron dimensions) usually called quantum well, wires carriers are quantised in two transverse directions and are moved only along the length of the wire and they behave as a quasi-one-dimensional electron gas. Size quantization of levels of electrons and holes brings about the splitting of conduction band and valence band into the subbands separated by energies of the size quantization. Due to such splitting a number of physical properties of a quasi-one-dimensional electron gas (in particular optical properties) differ from the property of its three-dimensional analog. Petroff et. all [2] have fabricated a thin wire structure and some optical properties were studied. Free carrier absorption [3] and interband optical absorption [4] has been studied theoretically in semiconducting thin wires.

The purpose of this paper in the theoretical treatment of the intersubband optical transitions in such system. First of all it is cross-over transition from one subband to another one. In such process electron and photon take place only.

Wave functions and energy eigenvalues of electrons, limited by motion along the length of quantum wire depend on the geometry. In the thin wire with rectangular cross section the electron wave functions and energy eigenvalues have the form [5]:

$$\psi_{n1k}(x,y,z) = \left[2/(abL)^{1/2}\right] exp(ikz)\, sin\left(\frac{n\pi x}{a}\right) \cdot sin\left(\frac{1\pi y}{b}\right) \quad (1)$$

and $$E_{n1k} = n^2 E_a + 1^2 E_b + E_k$$

where $$E_a = \frac{h^2}{8m^* a^2},\quad E_b = \frac{h^2}{8m^* b^2},\quad E_k = \frac{hk^2}{8\pi^2 m^*}$$

Here k-the wave vector of electron along z direction and L-the length of the wire, a и b are the cross-sectional dimensions of the rectangular wire in direction x and y respectively.

Matrix element of electron-phonon interaction has the form

$$< \psi_{n'1'k'} | H | \psi_{n1k} > = -\frac{1h}{2\pi m^*} \left(\frac{n_0 h}{\in \omega \Omega_0}\right)^{1/2} \vec{\varepsilon} \vec{k}\, \delta_{nn'} \delta_{11'} \delta_{kk'} \quad (2)$$

where $\in$ -the dielectric constant, $\Omega_0 = abL$ -the volume of the wire, $h\omega / 2\pi$ -the photon energy, $\vec{\varepsilon}$ -the field polarization vector which is directed along the wire (in the z direction), n_0 -the photon concentrations in the radiation field, and H is interaction Hamiltonian between electrons and radiation field, which is given by

$$H = -\left(\frac{1}{m^*}\right)\left(\frac{n_0 h}{\in \omega \Omega_0}\right)^{1/2} \vec{\varepsilon} \cdot \vec{p}$$

Transition probability between the occupied state with the wave function ψ_{n1k} and unoccupied one with the wave function $\psi_{n'1'k'}$, followed by photon absorptions of the radiation field, with frequency ω, is equal to

$$S = \frac{(2\pi)^2}{h} \left| < \psi_{n'1'k'} | H | \psi_{n1k} > \right|^2 8\,(E_{n'1'k'} - E_{n1k} - h\omega / 2\pi) \quad (3)$$

Taking into account width of around state we use this following relation [6]

$$\left| \frac{1}{\varepsilon + \frac{1}{2} i\Gamma} \right|^2 = \frac{2\pi}{\Gamma} \delta(\varepsilon)$$

In this case we obtain the following generalized expression for S [6]:

$$S = \frac{(2\pi)^2}{h}\left|< \psi_{n'l'k'}|H|\psi_{nlk} >\right|^2 \frac{\Gamma / 2\pi}{(E_{n'l'k'} - E_{nlk} - h\omega / 2\pi)^2 + \Gamma^2 / 4} \qquad (4)$$

where Γ -the broadening energy parameter which related to the scattering rate $\Gamma = h / 2\pi\tau$.

Number of transitions W causing by light of frequency ω in a time unit, in unit volume is obtained as a result of summation of (4) for all initial and final states of all electrons from both subbands. Introducing the factor $f(E)\ (1-f(E))$ in expression (4), where $f(E)$-the probability of occupation of the state with energies E, we obtain for W

$$W = \frac{1}{ab}\sum_{nlk}\sum_{n'l'k'} S f_{nlk}(E)\ (1 - f_{n'l'k'}(E))\ \qquad (5)$$

Using the expression W we calculate the absorption coefficient. The absorption coefficient by definition is the ratio of energy, absorbed in the unit volume in a time unit to the magnitude of energy flow [4]

$$\alpha = \frac{h\omega W}{n_0 h\omega (c / \in)}$$

Here $h\omega W$ -the absorbed energy density in a time unit and the product of the energy density into the light velocity in the substance gives the energy flow $n_0 h\omega(c/\in)$. Let us assume that the second subband is completely free $f_{n'l'k'}(E) = 0$. In the expression W passing from the sum to k to the integration and taking into account the law of conservation of the momentum we obtain for the absorption coefficient

$$\alpha = \frac{e^2 h^2}{2\pi^2 \omega c a^2 b^2 m^*}\sum_{if}\frac{\Gamma}{(\varepsilon_f - \varepsilon_i - h\omega / 2\pi)^2 + \Gamma^2 / 4}\int k^2 f(k)\, dk, \qquad (6)$$

where indexes i and f denote the initial and final states of the electron and include the quantum numbers n and l.

It should be noted that the maximum of the absorption is observed at the frequencies $\omega = \omega_0 = \frac{2\pi}{h}(\varepsilon_f - \varepsilon_i)$ and for α_{max} one can obtain the following expression

$$\alpha_{max} = \frac{4}{\pi\omega_0 c\Gamma}\frac{eh}{a^2 b^2 m^{*2}}\int k^2 f(k)\,dk \qquad (7)$$

The electron distribution function $f(k)$ for non-degenerate electron gas with energy E_{n1k} (1) can be written as [5]

$$f = \frac{hn_1 ab}{(2\pi)^{1/2}\gamma\delta(m^* k_B T)^{1/2}} exp\,(\varepsilon_i / k_B T)\, exp\left(-\frac{h^2 k^2}{8\pi^2 m^* k_B T}\right) \qquad (8)$$

where $\gamma = \sum_n exp\,(-n^2 E_a / k_B T)$, $\delta = \sum_l exp\,(-l^2 E_B / k_B T)$ and n_1 is concentration of the free carriers.

Substituting (8) in expression (6) we find

$$\alpha = \frac{l^2 k_B T h n_1}{\gamma\delta abc\omega m^*}\sum_{il}\frac{\Gamma exp\,(-\varepsilon_i / k_B T)}{(\varepsilon_f - \varepsilon_i - h\omega / 2\pi)^2 + \Gamma^2 / 4} \qquad (9)$$

In the case of Fermi statistics at the low temperatures the absorption coefficient has the form

$$\alpha = \frac{8\sqrt{2}\,l^2}{3a^2 b^2 m^{*1/2} h}\sum_i \frac{(\xi_i - \varepsilon_i)^{3/2}}{(\varepsilon_f - \varepsilon_i - h\omega / 2\pi)^2 + \Gamma^2 / 4}$$

where ξ_i - Fermi energy. The coefficient of the intersubband absorption rises with uncreasing of the concentration of charge carrier.

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NAZİK YARIMKEÇİRİCİ KVANT MƏFTİLLƏRİNDƏ ALT ZONALAR ARASINDA OPTİK UDULMA

Nazik yarımkeçirici kvant məftillərində alt zonalar arasında optik udulma tədqiq edilmişdir. Elektronların cırlaşmış və cırlaşmamış hallarında bu sistemdə udulma əmsalı üçün ümumi ifadə alınmışdır.

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МЕЖПОДЗОННОЕ ОПТИЧЕСКОЕ ПОГЛОЩЕНИЕ В ПОЛУПРОВОДНИКОВОЙ КВАНТОВОЙ ПРОВОЛОКЕ

Получено общее выражение для коэффициента межподзонного оптического поглощения в полупроводниковой квантовой проволоке в невырожденном и вырожденном состояниях электронов.