RESONANT INTERACTION OF ULTRASOUND WAVE WITH ELECTRONS IN QUANTUM WIRE

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The effects of possible resonance interaction ultrasound wave with electrons in the parabolic quantum well wires have been studied. The intersubband transition probability of electrons under the influence of the sound wave have been calculated.

In the ultra-thin semiconducting wires (submicron dimensions) usually called quantum well wires, carriers are quantized in two transverse directions and move only along the wire and they behave as a quasi-one-dimensional (Q1D) 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 dimensional quantization. Due to such splitting a number of physical properties of a Q1D electron gas differ from the property of its three-dimensional analog [1-7]. Magnetophonon resonances [2] and effects of resonant intersubband optical-phonon scattering [3] in Q1D systems is well developed.

In this communication we present the effects of possible of resonant interaction of ultrasound wave with electrons of a quantum wire with parabolic wells. We consider a Q1D electron gas confined in a wire of sizes $L_x=L$, L_y,L_z. The lateral restriction in the y direction is modeled by parabolic potential of frequency ω and that in the *Z* direction with a triangular well. We will consider electron densities such that only the lowest subband with energy E_z^0 is occupied in the *Z* direction. The corresponding wave function is denoted by $\Psi_0(z)$. The electrons are free in the wire direction.

Electron wavefunction depending on time in quantum wire in the presence of the sound field satisfies the Schrödinger equation

$$i\hbar\frac{\partial\psi(r,t)}{\partial t}=(H_0+H_1)\psi(r,t) \qquad (1)$$

with

$$H_0=\frac{p^2}{2m^*}+\frac{m^*\omega^2y^2}{2}+H(z),$$

$$H_1=\frac{1}{2}V_c\left[e^{iqx}e^{-i\omega t}+e^{-iqx}e^{i\omega t}\right],\quad V_c^2=\frac{2IE_c^2}{\rho_0\upsilon_s^3} \qquad (2)$$

Where H_0 is an unperturbed Hamiltonian of electron in the quantum wires, ω is a frequency of the parabolic potential, E_d is the deformation potential, *I* is sound wave intensity, ρ is a crystal density, $\omega_q=q\upsilon_s$, where *q*, υ_s are wave number and velocity of the sound wave, respectively.

We assume that, the sound wave can cause the transition of an electron between the first subband (*n*=1) and the second subband (*n*=2). Therefore, in the resonant approximation the eigenfunctions $\Psi(r,t)$ of Hamiltonian H_0+H_1 can be expressed as a superposition of wave function for *n*=1 and *n*=2 subband [8]

$$\psi(t)=\sum_k[a_2(k,t)\psi_2\exp(-\frac{iE_2t}{\hbar})+a_1(k,t)\psi_1\exp(-\frac{iE_1t}{\hbar})] \qquad (3)$$

where electron wave function Ψ_n and energy eigenvalue E_n in the case of parabolic quantum well wires are well-known [1]

$$E_n=\hbar\omega(n+\frac{1}{2})+\frac{\hbar^2k^2}{2m^*}+E_z^0,$$
$$\psi_n=\sqrt{1/L}H_n(y)e^{ikx}\psi_0(z), \qquad (4)$$
$$n=1,2,...,$$

$$\psi_0(z)=z(b_0^3/2)^{1/2}\exp(-b_0z/2),$$
$$\langle L_z\rangle=3/b_0$$

Here $|a_1|^2$ and $|a_2|^2$ are probability of finding electrons in *n*=1 and *n*=2 subbands, respectively, $H_n(y)$ is a Hermite polynomial. Inserting Eq.(3) into Eq.(1), we obtain the following equations for a_1 и a_2:

$$i\hbar\frac{\partial a_2}{\partial t}=\lambda a_1(k-q_x)\exp[\frac{i}{\hbar}2\xi(k)t]$$
$$i\hbar\frac{\partial a_1}{\partial t}=\lambda^* a_2(k+q_x)\exp[-\frac{i}{\hbar}2\xi(k+q_x)] \qquad (5)$$

with

$$2\xi(k)=\hbar(\omega-\omega_q)+\frac{\hbar^2k^2}{2m^*}-\frac{\hbar^2(k-q_x)^2}{2m^*} \qquad (6)$$

$$\lambda^2=\frac{u^{1/2}IE_c^2e^{-u}[L_1^1(u)]^2}{4\rho_0\upsilon_s^3}. \qquad (7)$$

where $u = q_y^2 l_\omega^2 / 2$, $l_\omega^2 = \hbar / m^* \omega$, L_n^p – Laguerra polynomial.

Passing in (5), to new variables α_1 and α_2 by the formulae.

$$a_2 = \alpha_2 \exp(\frac{i}{\hbar}\xi t)$$
$$a_1 = \alpha_1 \exp(-\frac{i}{\hbar}\xi t) \qquad (8)$$

we receive a system of he equations.

$$i\hbar \frac{\partial \alpha_1}{\partial t} + \alpha_1 \xi = \lambda^* \alpha_2$$
$$i\hbar \frac{\partial \alpha_2}{\partial t} - \alpha_2 \xi = \lambda \alpha_1 \qquad (9)$$

From (9) it follow [8], that if at t=0, electron was in n=1 subband, probability of the transition to the n=2 subband oscillates with time by the formula

$$|\alpha_2|^2 = \frac{|\lambda|^2}{|\varepsilon|^2} \sin^2 [\frac{\varepsilon t}{\hbar}] \qquad (10)$$

where $\varepsilon = \sqrt{\xi^2 + \lambda^2}$. Thus, $|a_2|^2$ is a periodic function of time varying from zero up to λ^2/ε^2 with frequency $\varepsilon/\hbar$. It means, that in a strong sound field electron makes the transition between the next subband with frequency $\varepsilon/\hbar$. Notice that the at ξ =0 (exact resonance) the transition probability

$$|\alpha_2|^2 = \sin^2 [\frac{\lambda t}{\hbar}] \qquad (11)$$

varies from zero up to unit with frequency $\lambda/\hbar$. Such character of transitions reflects coherency of interaction of electrons with a sound field, which shows itself under the condition that, if the frequency of transitions λ surpasses frequency of collisions electrons $1/\tau$, i.e. $\lambda\tau/\hbar$ >>1.

For a quantum wire such as GaAs/AlGaAs: E_c=7 eV, ρ_0=5.37 g/cm^3, υ_s=5.3·10^5 cm/c, q_x=10^{6}cm^{-1}, at I=1Вт/cm^2 (quite achievable meaning of sound energy flow [9]) we receive λ= 3·10^{-3} eV . Thus, coherency of interaction of electrons with a sound can expose itself at

$\tau \geq$ 10^{-12}c, that is quite real.

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ULTRASƏS DALĞALARI İLƏ KVANT NAQİLİN ELEKTRONLARININ REZONANS QARŞILIQLI TƏSİRİ

Ultrasəs dalğaları ilə parabolik çuxurlu kvant naqilin elektronlarının rezonans qarşılıqlı təsirinin mümkünlüyü göstərilmişdir. Güclü səs dalğaları sahəsində elektronların qonşu altzonalar arası keçidin ehtimalı hesablanmışdır.

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РЕЗОНАНСНОЕ ВЗАИМОДЕЙСТВИЕ УЛЬТРАЗВУКА С ЭЛЕКТРОНАМИ КВАНТОВОЙ ПРОВОЛОКИ

Показана возможность резонансного взаимодействия ультразвука с электронами квантовой проволоки с параболическими ямами. В сильном звуковом поле вычислена вероятность перехода электронов между соседними подзонами.

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