Proc. Natl. Conf. Theor. Phys. **36** (2011), pp. 121-124

THE AMPLIFICATION OF CONFINED SOUND (CONFINED ACOUSTIC PHONONS) BY ABSORPTION OF LASER RADIATION IN A CYLINDRICAL QUANTUM WIRE WITH AN INFINITE POTENTIAL

NGUYEN DINH NAM, NGUYEN QUANG BAU, NGUYEN THI QUYEN
Department of Physics, Hanoi University of Science, Hanoi, Vietnam
NGUYEN VU NHAN
Department of physics, Academy of Defence force-Air force, Hanoi, Vietnam
DINH QUOC VUONG
Quang Ninh Department of Education and Training, Quang Ninh, Vietnam

Abstract. *The amplification of confined sound (confined acoustic phonons) by absorption of laser radiation in a cylindrical quantum wire with an infinite potential is theoretically studied by using a set of quantum kinetic equations for the electron phonon system. The analytic expression of the amplification of confined sound G is obtained. Unlike the case of unconfined phonons, the formula of G contains a quantum number m characterizing confined phonons. Their dependence on the temperature T of the system, acoustic wave vector* $\overrightarrow{q}$*, the frequency of acoustic wave* $\omega_{\overrightarrow{q}}$ *and laser radiation* Ω *is studied. Numerical computations have been performed for GaAs/GaAsAl quantum wire. The results have been compared with the case of unconfined phonons which show that confined phonons cause some unusual effects.*

I. INTRODUCTION

It is well known that when a laser radiation is applied to a material, the number of acoustic phonons inside is varied with time. This studied phenomenon can lead to new knowledge about the electron phonon interaction mechanism, especially in low dimensional structures. There have been a lot of works on the amplification of acoustic phonons for bulk semiconductors [1-6] and for low dimensional semiconductors in the case of unconfined phonons [7-9]. However, the amplification of acoustic phonons by absorption of laser radiation in quantum wire in the case of confined phonons has not been studied yet. Therefore, in this paper, we have studied the amplification of confined sound (confined acoustic phonons) by absorption of laser radiation in a cylindrical quantum wire with an infinite potential. The comparison of the result of confined phonons to one of unconfined phonons shows that confined phonons cause some unusual effects. To demonstrate this, we estimate numerical values for a GaAs/GaAsAl quantum wire.

II. RATES OF ACOUSTIC PHONONS EXCITATION

Consider a cylindrical quantum wire with an confining infinite potential:

$$V(\overrightarrow{r}) = \begin{cases} 0 & \text{if r} < \text{R} \\ \infty & \text{if r} > \text{R} \end{cases} \tag{1}$$

Here R is the radius of the cylindrical quantum wire. Electron wave function and energy in this model have the form:

$$\psi_{n,l,k_z}(r,\Phi,z) = \begin{cases} 0 & \text{if r > R} \\ \frac{1}{\sqrt{V_0}} e^{im\Phi} e^{ik_z z} \psi_{n,l}(r) & \text{if r < R} \end{cases} \tag{2}$$

$$\varepsilon_{n,l}(k_z) = \frac{\hbar^2 k^2}{2m^*} + \frac{A_{n,l}^2 \hbar^2}{2m^* R^2} \tag{3}$$

where $\psi_{n,l}(r) = \dfrac{1}{J_{n+1}(A_{n,l})} J_n(A_{n,l}\dfrac{r}{R})$ is the radial wave function, m^* is the effective electron mass, $J_n(x)$ is the Bessel function of the first kind, $A_{n,l}$ is the lth test of the real argument Bessel function at level n: $J_n(A_{n,l}) = 0$.

With bulk phonon assumption, the Hamiltonian function for electron phonon system in a quantum wire can be written as: $H(t) = \sum\limits_{\alpha,k_z} \varepsilon_\alpha(k_z - \dfrac{e}{\hbar c}\overrightarrow{A}(t)) c^+_{\alpha,k_z} c_{\alpha,k_z} + \sum\limits_{m,n,q_z} \hbar\omega a^+{}_{m,n,q_z} a_{m,n,q_z} + \sum\limits_{\substack{\alpha,\alpha',k_z \\ m,n,q_z}} \gamma I_{1D}(q_z) c^+{}_{\alpha',k_z+q_z} c_{\alpha,k_z} (a_{m,n,q_z} + a^+{}_{n,m,-q_z})$, where c^+_{α,k_z} and c_{α,k_z} ($a^+{}_{m,n,q_z}$ and a_{m,n,q_z}) are the creation and annihilation operators of electron (phonon), k_z and q_z are the electron wave vector and the phonon wave vector (along the wires axis : z axis), γ is the interaction constant of electron acoustic phonon scattering, I_{1D} is the electron form factor, $A(t) = \frac{c}{\Omega} E_0 \cos(\Omega t)$ is the potential vector that depend on the external field.

From the quantum kinetic equation for particle number operator of phonon

$$N_{m,n,q_z}(t) = \left\langle a^+{}_{m,n,q_z} a_{m,n,q_z} \right\rangle_t \tag{4}$$

$$i\hbar \frac{\partial N_{m,n,q_z}(t)}{\partial t} = \left\langle \left[a^+_{m,n,q_z} a_{m,n,q_z}, H(t) \right] \right\rangle_t \tag{5}$$

and the electron gas is degenerated in this case, we use Bolztmann distribution function and use Hamiltonian in Eq (4), realizing calculations, we obtain quantum kinetic equation for confined phonon in CQW. Using properties of Bessel function, fourier transformation, some approximation methods and realizing calculations, we obtain the coefficient of the amplification of confined sound (confined acoustic phonons) by absorption of laser radiation in a cylindrical quantum wire with an infinite potential:

$$G = \frac{m^* L_z}{2\pi\hbar^3 q_z} \sum_{\alpha,\alpha'} \left|\gamma I_{1D}(q_z)\right|^2 \left\{ \frac{m^* L_z}{2\pi\hbar^2 q_z} \left[\exp\left[\beta \left(\varepsilon_F - \varepsilon_{\alpha'} - \frac{\hbar^2}{2m^*} (\frac{m^*}{\hbar^2 q_z}(A-\lambda) - q_z)^2 \right) \right] - \exp\left[\beta(\varepsilon_F - \varepsilon_\alpha - \frac{m^*}{2\hbar^2 q_z^2}(A-\lambda)^2 \right] + \frac{m^* L_z}{2\pi\hbar^2 q_z} \left[\exp\left[\beta \left(\varepsilon_F - \varepsilon_{\alpha'} - \frac{\hbar^2}{2m^*} (\frac{m^*}{\hbar^2 q_z}(A+\lambda) - q_z)^2 \right) \right] - \exp\left[\beta(\varepsilon_F - \varepsilon_\alpha - \frac{m^*}{2\hbar^2 q_z^2}(A+\lambda)^2 \right] \right\}. \tag{6}$$

where $\varepsilon_\alpha = \dfrac{\hbar^2 B_\alpha^2}{2m^* R^2}$, $\varepsilon_{\alpha'} = \dfrac{\hbar^2 B_{\alpha'^2}}{2m^* R^2}$, $\lambda = \dfrac{e\hbar q_z E_0}{m^* \Omega}$, $A = \dfrac{\hbar^2 B_{\alpha'}^2}{2m^* R^2} - \dfrac{\hbar^2 B_\alpha^2}{2m^* R^2} + \dfrac{\hbar^2 q_z^2}{2m^*}$, B_α and $B_{\alpha'}$ are the tests of the Bessel function of the first kind, is the length of the quantum wire.

The formula of the amplification of confined sound contains the quantum number m characterizing confined phonons and is easy to come back to the case of unconfined phonons.

III. NUMBERICAL RESULTS AND DISCUSSISONS

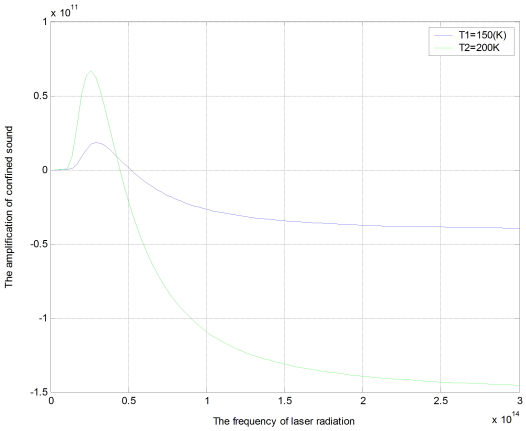

Fig. 1. The dependence of G on the frequency of laser radiation

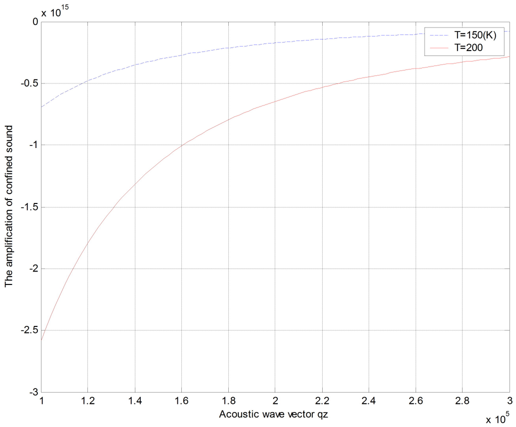

Fig. 2. The depence of G on the acoustic wave vector

The obtained results are much different from the previous work on bulk semiconductors [3-5] and in the case of unconfined phonons. From these results, using numberial data for GaAs/GaAsAl quantum wire: $V_s = 4078ms^{-1}$, L_z=100.10$^{-10}(m)$, R=5.10$^{-9}(m)$, $m^* = 0.066.m_0$,$\rho = 5.310^3 kgm^{-3}$, ε_F=0.05.16.10$^{-19}(J)$. We plot the dependence of the rate of confined acoustic phonon on acoustic wave vector and on the frequency of laser radiation. We see that the amplification of confined acoustic phonons also depends on the frequency of acoustic wave, temperature of system. These dependences are much more than in case of unconfined phonons, this is consistent with the theory that possible combinations increase in the case of confined phonons.

IV. CONCLUSION

In this paper, the amplification of confined acoustic phonons by absorption of laser radiation is investigated. We obtained a general dispersion equation for the amplification of confined acoustic phonons. However, an analytical solution to the equation can only be obtained within some limitations. Using these limitations for simplicity, similarly to the mechanism pointed out by several authors for bulk semiconductors [1-6] and for low dimensional semiconductors [7-9], we have numerically calculated and graphed the amplification of confined sound by absorption of laser radiation for GaAs/GaAsAl cylindrical quantum wire with an infinite potential clearly show the predicted mechanism. Unlike the case of unconfined phonons, the formula of the amplification of confined sound contains a quantum number m characterizing confined phonons. Their dependence on the temperature T of the system, acoustic wave vector $\overrightarrow{q}$, the frequency of acoustic wave $\omega_{\overrightarrow{q}}$ and laser radiation Ω is studied. The results have been compared with the case of unconfined phonons which show that confined phonons cause some unusual effects and is easy to come back to the case of unconfined phonons.

ACKNOWLEDGMENT

This work is completed with financial support from the Vietnam National Foundation for Science and Technology Development (NAFOSTED), Hanoi University of Sciences (TN 11-07).

REFERENCES

[1] E. M. Epstein, *Radio in Physics* **18** (1975) 785.
[2] E. M. Epstein, *Lett. JEPT* **13** (1971) 511.
[3] Peiji Zhao, *Phys. Rev. B* **49** (1994) 13589.
[4] V. A. Geyler, V. A. Margulis, *Phys. Rev. B* **61** (2000) 1716.
[5] L. Sholimal, *Tunnel effects in semiconductors and applications*, Moscow (1974).
[6] Nguyen Hong Son, G. M. Shmelev, E. M. Epstein, *Izv. VUZov USSR, Physics* **5** (1984) 19.
[7] Nguyen Quang Bau, Vu Thanh Tam, Nguyen Vu Nhan, *J. Science and Technical Investigations in Army* **3** (24) (1998) 38.
[8] Nguyen Quang Bau, Nguyen Vu Nhan, Chhoumm Navy, *VNU Journal of Science* **2** (1991) 1.
[9] Nguyen Quang Bau, Nguyen Vu Nhan, Nguyen Manh Trinh, *Proceedings of IWOMS99*, Hanoi (1999), p. 869.

Received 30-09-2011.