Theoretical Study of the Influence of Confined Phonons and a Strong Electromagnetic Wave on the Hall Effect in an One-Dimensional Cylindrical Quantum Wire GaAs/GaAsAl

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The Hall effect in an one-dimensional cylindrical quantum wire (CQW) with an infinite potential is studied by using the quantum kinetic equation under the influence a strong electromagnetic wave within the mechanising of scattering on confined acoustic phonons. We consider a case where an one-dimensional CQW is placed in a magnetic field $\vec{B} = (B, 0, 0)$, a constant-electric field $\vec{E}_1 = (0, 0, E_1)$ and a strong electromagnetic wave $\vec{E} = \vec{E}_0 \sin \Omega t$ (where E_0 and Ω are the amplitude and the frequency of the strong electromagnetic wave, respectively). Analytical expressions for the Hall conductivity tensors and the Hall coefficient (HC) are obtained. It is found that the Hall conductivity tensors and the Hall coefficient depend on the frequency Ω and the amplitude E_0 of the strong electromagnetic wave, the magnetic field B , the temperature T the system, the radius of CQW, and the quantum indices m_1 and m_2 characterizing the phonon confinement. These are different from the case of normal bulk semiconductor and from the case of cylindrical quantum wire with electron-unconfined acoustic phonons scattering mechanism. Numerical calculations are performed using parameters of a GaAs/GaAsAl one-dimensional cylindrical quantum wire. The phonon confinement increase of Hall coefficient by 2.3 times in comparison with the case of unconfined acoustic phonons. When the quantum numbers m_1 and m_2 go to zero, the result is the same as in the case of unconfined phonons. The Hall conductivity tensors (The Shubnikov-de Haas magnetoresistance oscillations) in the case of confined acoustic phonon scattering mechanism and in the presence of a strong electromagnetic wave have more resonance peaks. [doi:10.2320/matertrans.MT-MN2019017]

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1. Introduction

We know that when electromagnetic waves propagate in a material, the electrical properties of the material will change. If the amplitude of a strong electromagnetic wave can cause nonlinear effects. In particular, when electromagnetic waves are high-frequency so that the photon energy is at the energy level of the electron and the phonon, the electromagnetic waves will significantly alter the electron mobility of the states compared to the absence of the electromagnetic waves.^{1-5,8,9)} In recent years, the study of low-dimensional semiconductor systems has seen increased interest this includes the electrical, the magnetic and the acoustic properties. In these systems, the motion of carriers are restricted, leading to new properties under the action of external fields, for example: the absorption coefficient of the Hall effect of an electromagnetic wave,^{6,7,11-13)} the radioelectric effect, and the acoustoelectric effect.¹⁷⁾ The Hall effect—the effect of drag of charge carriers caused by the external magnetic field has been studied extensively.¹⁻¹¹⁾ There have been study of the Hall effect in bulk semiconductor in the presence of electromagnetic waves, in which classical theory of Hall effect in bulk semiconductor when placed in electricity, the magnetic field is perpendicular to the presence of an electromagnetic wave is built on the basis of Boltzman's classical kinetic equation, while quantum theory is built on bases on quantum-kinetic equation.

Influence of confined phonons^{14,16)} on the Hall effect in two-dimensional systems have been studied in Ref. 15). In one-dimensional semiconductor system, there have been studies on the Hall effect with the confined electronics—unconfined acoustic phonons. But the influence of the

confined acoustic phonons on the HC in one-dimensional semiconductor system is not studied. In this work, we study new properties of the HC under scattering mechanising confined acoustic phonons. We consider a case where an one-dimensional CQW is placed in a magnetic field, $\vec{B} = (B, 0, 0)$, a constant-electric field, $\vec{E}_1 = (0, 0, E_1)$, and a strong electromagnetic wave, $\vec{E} = \vec{E}_0 \sin \Omega t$ (where E_0 and Ω are the amplitude and the frequency of the strong electromagnetic wave).

The paper is organized as follows: in section 2 we present the confinement of electron and phonons in a CQW. By using the quantum kinetic equation method, we obtained analytical expressions for the Hall coefficient. Numerical results and discussions for the GaAs/GaAsAl cylindrical quantum wire are given in section 3. Finally, we conclude in section 4.

2. Calculation Procedure

2.1 A cylindrical quantum wire with an infinite potential

Consider a cylindrical quantum wire with an infinite potential placed in a perpendicular magnetic field, $\vec{B} = (B, 0, 0)$, and a constant-electric field $\vec{E}_1 = (0, 0, E_1)$ and a strong electromagnetic wave $\vec{E} = \vec{E}_0 \sin \Omega t$. Under the influence of the material confinement potential, the motion of carriers is restricted in x, y direction and free in the z direction. So, the wave function of an electron and its energy spectrum becomes: (we use the unit system where $\hbar = 1$)

$$\Psi_{n,l,\vec{k}}(r, \Phi, z) = \frac{1}{\sqrt{V_0}} e^{im\Phi} e^{ik_z z} \varphi_{n,l}(r),$$

$$\text{where } \varphi_{n,l}(r) = \frac{1}{J_{n+1}(B_{n,l})} J_n\left(B_{n,l} \frac{r}{R}\right) \quad (1)$$

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$$\varepsilon_{n,l}(\vec{k}_z) = \left(N + \frac{n}{2} + \frac{l}{2} + \frac{1}{2} \right) \hbar \omega_c + \frac{k_z^2}{2m} - \frac{1}{2m} \left(\frac{eE1}{\omega_c} \right)^2 \quad (2)$$

where k, m is the wave vector and the effective mass of an electron, R is the radius of the CQW, $n = 1, 2, 3, \dots$ and $l = 0, \pm 1, \pm 2, \dots$, are the quantum numbers characterizing the electron confinement, $N = 0, 1, 2, \dots$ is the Landau level, $\omega_c = \frac{eB}{m}$ is the cyclotron frequency, and $J_n(x)$ is the Bessel function of argument x . It has been seen that the electron's wave function and its discrete energy is now different from that in two-dimensional semiconductor systems.¹⁰⁾ This is caused by the new confinement potential in CQW, which leads to new phenomena (including the Hall effect) in one-dimensional systems. Thus, the Hall effect in the CQW could have new behaviours under the impact of the confined phonons and should be studied in details.

2.2 Expressions for Hall coefficient in a cylindrical quantum wire with an infinite potential

The Hamiltonian of the confined electron–confined phonon system in a cylindrical quantum wire under the influence of magnetic field, constant electric field and laser radiation field are:

$$\begin{aligned} H = & \sum_{n,l,\vec{k}_z} \varepsilon_{n,l} \left(\vec{k}_z - \frac{e}{\hbar c} \vec{A}(t) \right) a_{n,l,\vec{k}_z}^+ a_{n,l,\vec{k}_z} \\ & + \sum_{m_1,m_1,\vec{q}_z} \hbar \omega_{m_1,m_1,\vec{q}_z} b_{m_1,m_1,\vec{q}_z}^+ b_{m_1,m_1,\vec{q}_z} \\ & + \sum_{n,l,n',l',m_1,m_1,\vec{q}_z,\vec{q}_z} |C_q^{m_1,m_1}|^2 |I_{n,l,n',l'}^{m_1,m_1}|^2 \\ & \times a_{n,l,\vec{k}_z+\vec{q}_z}^+ a_{n,l,\vec{k}_z} (b_{m_1,m_1,\vec{q}_z}^+ b_{m_1,m_1,-\vec{q}_z}) \\ & + \sum_{n,l,\vec{k}_z,\vec{q}} \varphi(\vec{q}) a_{n,l,\vec{k}_z}^+ a_{n,l,\vec{k}_z} \end{aligned} \quad (3)$$

here $a_{n,l,\vec{k}_z}^+$ and $a_{n,l,\vec{k}_z}$ ($b_{m_1,m_1,\vec{q}_z}^+$ and $b_{m_1,m_1,\vec{q}_z}$) are the creation and annihilation operators of the electrons (phonons). $\vec{A}(t)$ the vector potential of the electromagnetic field is determined from $\vec{E} = \vec{E}_0 \cos(\Omega t)$; we have $-\frac{1}{c} \frac{\partial \vec{A}}{\partial t} = \vec{E}_0 \sin(\Omega t)$, $\hbar \omega_{m_1,m_1,\vec{q}_z}$ is the energy of phonon; $\vec{q}_z$ is the wave vector of the phonon, $\varphi(\vec{q}) = (2\pi i)^3 (e\vec{E}_1 + \omega_c [\vec{q}, \vec{h}]) \frac{\partial}{\partial \vec{q}} \delta(\vec{q})$ is the scalar potential.

$m_1, m_2 = 1, 2, 3, \dots$ are the quantum numbers characterizing phonon confinement. Also, the matrix element for confined electron–confined acoustic phonon interaction in the CQW now becomes

$$D_{n,l,n',l'}^{m_1,m_2} = C_{\vec{q}}^{m_1,m_2} \cdot I_{n,l,n',l'}^{m_1,m_2} \quad (4)$$

where $|C_{\vec{q}}^{m_1,m_2}|^2 = \frac{\xi^2}{2\rho v_s V} \sqrt{q_{\perp}^2 + q_z^2}$; $q = \sqrt{q_{\perp}^2 + q_z^2}$; $q_{\perp}^2 = (\frac{m_1\pi}{a_x})^2 + (\frac{m_2\pi}{a_y})^2$; a_x (a_y) is the length of confined potential in the x (y) direction (q is the phonon wave vector; v_s , ξ , ρ , V are the sound velocity, the acoustic deformation potential, the mass density and the normalization volume of specimen, respectively)

$$I_{n,l,n',l'}^{m_1,m_2} = \frac{2}{R^2} \int_0^R J_{n-n'}(q, R) \varphi_{n',l'}^*(r) \varphi_{n,l}(r) r dr. \quad (5)$$

It has been seen that the Hamiltonian has the similar form as in Ref. 10), but contains new elements. The Hamiltonian is now different than that in Ref. 10) due to the contribution of

confined acoustic phonons which is shown by the quantum phonon frequency $\omega_{m_1,m_2,\vec{q}_z}$ and the factor $I_{n,l,n',l'}^{m_1,m_2}$ has the quantum indices m_1 and m_2 characterizing the phonon confinement. This enhances the probability of electron scattering. As to result, the electron distribution function, the current density and the physical quantities characterizing the Hall effect have new analytical expressions. Therefore, the Hall coefficient, the magnetoresistance as well as the SdH oscillations in the CQW will have new properties under the influence of confined phonon and the laser radiation.

Using the Hamiltonian of the confined electrons—confined acoustic phonons in a CQW and the quantum kinetic equation for electron distribution function: $f_{n,l,\vec{k}_z}(t) = \langle a_{n,l,\vec{k}_z}^+ a_{n,l,\vec{k}_z} \rangle_t$ in the quantum wire, we have

$$i\hbar \frac{\partial f_{n,l,\vec{k}_z}(t)}{\partial t} = \langle [a_{n,l,\vec{k}_z}^+ a_{n,l,\vec{k}_z}, H] \rangle_t. \quad (6)$$

The current density vector can be calculated from

$$\vec{J} = \sum_{n,l,\vec{k}_z} \frac{e\hbar}{m_e} \vec{k}_z f_{n,l,\vec{k}_z}.$$

On the other hand, we have a formula for the relationship between current density J_i and conductivity tensor σ_{ip} :

$$J_i = \sigma_{ip} E_{ip} \quad (7)$$

$$\begin{aligned} J_i = & \frac{\tau}{1 + \omega_c^2 \tau^2} \{ \delta_{ik} - \omega_c \tau \varepsilon_{ijk} h_j + \omega_c^2 \tau^2 h_i h_k \} \{ a(T, B) \delta_{kp} \\ & + b(T, B, m_1, m_2) (\delta_{kp} - \omega_c \tau \varepsilon_{klp} h_l + \omega_c^2 \tau^2 h_k h_p) \} E_{ip}. \end{aligned} \quad (8)$$

Compared eq. (8) with the eq. (7), we derive the expression of the conductivity tensor J_i we establish the quantum kinetic equation for electron distribution function. After some manipulations, the expression for the conductivity tensor is obtained:

$$\begin{aligned} \sigma_{ip}(T, B, m_1, m_2) = & \frac{\tau}{1 + \omega_c^2 \tau^2} \{ \delta_{ik} - \omega_c \tau \varepsilon_{ijk} h_j + \omega_c^2 \tau^2 h_i h_k \} \{ a(T, B) \delta_{kp} \\ & + b(T, B, m_1, m_2) (\delta_{kp} - \omega_c \tau \varepsilon_{klp} h_l + \omega_c^2 \tau^2 h_k h_p) \} \end{aligned} \quad (9)$$

here δ_{ip} is the Kronecker delta; ε_{ijk} is the antisymmetric Levi-Civita tensor the symbols i, j, k, l, p correspond the components x, y, z of the Cartesian coordinates.

From (9) we find the components σ_{xx} and σ_{yx} of the conductivity tensor as

$$\begin{aligned} \sigma_{zz}(T, B, m_1, m_2) = & \frac{\tau}{1 + \omega_c^2 \tau^2} \{ a(T, B) + b(T, B, m_1, m_2) [1 - \omega_c^2 \tau^2] \} \end{aligned} \quad (10.A)$$

$$\begin{aligned} \sigma_{xz}(T, B, m_1, m_2) = & \frac{-\tau}{1 + \omega_c^2 \tau^2} (a(T, B) + b(T, B, m_1, m_2)) \omega_c \tau \end{aligned} \quad (10.B)$$

$$\begin{aligned} a(T, B) = & \frac{L_z}{2\pi} \sqrt{\pi} \frac{e\beta}{m^2} \frac{\tau_0}{1 + \omega_c^2 \tau_0^2} \\ & \times \exp \left\{ \beta \left[\varepsilon_F - \hbar \omega_c \left(N + \frac{n}{2} + \frac{l}{2} + \frac{1}{2} \right) + \frac{e^2 E_1^2}{2m\omega_c^2} \right] \right\} \\ & \times \left(\frac{2m}{\beta} \right)^{3/2} \frac{\sqrt{\pi}}{2} \end{aligned} \quad (11)$$

with $\beta = 1/k_B T$, k_B and ε_F are the Boltzman constant and the Fermi level, L_z is the length of the CQW in the z direction, τ is the momentum relaxation time of the electron.

$$b(T, B, m_1, m_2) = \frac{2\pi e^2}{m^2} \frac{\tau}{1 + \omega_c^2 \tau^2} b_0;$$

$$b_0(T, B, m_1, m_2) = S_1(T, B, m_1, m_2) + S_2(T, B, m_1, m_2) + S_3(T, B, m_1, m_2) + S_4(T, B, m_1, m_2) \\ + S_5(T, B, m_1, m_2) + S_6(T, B, m_1, m_2) + S_7(T, B, m_1, m_2) + S_8(T, B, m_1, m_2) \quad (12)$$

$$S_1(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{L_z \beta}{2\pi} \frac{m \xi^2}{2\rho v_s V} \frac{k_B T}{\omega_c} \exp \left\{ \beta \left[\varepsilon_F - \hbar \omega_c \left(N_1 + \frac{n}{2} + \frac{l}{2} + \frac{1}{2} \right) + \frac{1}{2} \left(\frac{e E_1}{\omega_c} \right)^2 \right] \right\} \\ \times \frac{1}{2\pi} \left[-\frac{1}{2} \exp \left(-\frac{\beta B_1}{2} \right) (4m^2 B_1^2)^{1/2} K_{3/2} \left(\frac{\beta B_1}{2} \right) - B_1 m \times \exp \left(-\frac{\beta B_1}{2} \right) (4m^2 B_1^2)^{1/4} K_{1/2} \left(\frac{\beta B_1}{2} \right) \right] \quad (13)$$

$$S_2(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{L_z \beta}{16\pi^2} \frac{\xi^2}{\rho v_s V} \frac{k_B T}{\omega_0} \frac{e^2 E_0}{m^2 \Omega^2} e^{\beta(\varepsilon_F - \varepsilon_{\gamma_1} - B_1/2)m^2} \\ \times \left[-\frac{5}{2} B_1^{5/2} m^{3/2} K_{3/2} \left(\frac{\beta B_1}{2} \right) - \frac{5}{2} B_1^{5/2} m^{3/2} K_{5/2} \left(\frac{\beta B_1}{2} \right) \right] \quad (14)$$

$$S_3(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{\xi^2 k_B \beta T L_z}{32\rho v_s V \pi^2 \omega_0} \frac{e^2 E_0^2}{\Omega^3} e^{\beta(\varepsilon_F - \varepsilon_{\gamma_1})} \times \left\{ \begin{aligned} & \left[-\frac{1}{2} (2m B_1 - 2m\Omega)^{5/2} K_{5/2} \left(\frac{\beta B_1}{2} - \frac{\beta \Omega}{2} \right) \right] - \\ & \left[B_1 (2m B_1 - 2m\Omega)^{3/2} K_{3/2} \left(\frac{\beta B_1}{2} - \frac{\beta \Omega}{2} \right) \right] - \\ & \left[\Omega (2m B_1 - 2m\Omega)^{3/2} K_{3/2} \left(\frac{\beta B_1}{2} - \frac{\beta \Omega}{2} \right) \right] \end{aligned} \right\} \quad (15)$$

$$S_4(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{\xi^2 k_B T \beta}{32\rho v_s V \omega_0} \frac{e^2 E_0^2}{\Omega^3} \frac{L_z}{\pi^2} e^{\beta(\varepsilon_F - \varepsilon_{\gamma_1} - B_1^2/4 - \Omega/2)} \times \left\{ \begin{aligned} & -\frac{1}{2m} (2B_1 m - 2\Omega m)^{5/2} K_{5/2} \left(\frac{\beta B_1}{2} - \frac{\beta \Omega}{2} \right) - \\ & -(2B_1 m + 2\Omega m)^{3/2} K_1 \left(\frac{\beta B_1}{2} - \frac{\beta \Omega}{2} \right) - \\ & -(2B_1 m + 2\Omega m)^{3/2} K_{3/2} \left(\frac{\beta B_1}{2} - \frac{\beta \Omega}{2} \right) \end{aligned} \right\} \quad (16)$$

$$S_5(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{\xi^2 m^2 k_B T \beta}{8\rho v_s V \omega_0} \frac{L_z}{\pi^2} e^{\beta(\varepsilon_F - \varepsilon_{\gamma_1})} \times \left\{ -\frac{\beta B_1}{2} (2m B_1)^{3/2} K_{3/2} \left(\frac{\beta B_1}{2} \right) + B_1 (2m B_1^{3/2}) K_{1/2} \left(\frac{\beta B_1}{2} \right) \right\} \quad (17)$$

$$S_6(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{\xi^2 k_B T \beta}{16\rho v_s V} \frac{e^2 E_0^2}{\Omega^4} \frac{L_z}{\pi^2} e^{\beta(\varepsilon_F - \varepsilon_{\gamma_1} - B_1/2)} \times \left\{ \frac{1}{2m} (4B_1^2 m^2)^{5/4} K_{5/2} (8\beta B_2) + B_1 (4B_1^2 m^2)^{1/4} K_{1/2} (8\beta B_2) \right\} \quad (18)$$

$$S_7(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{\xi^2 k_B T \beta}{32\rho v_s V \omega_0} \frac{e^2 E_0^2}{\Omega^2} \frac{L_z}{\pi^2} e^{\beta(\varepsilon_{\gamma_2} - \varepsilon_{\gamma_1})} \\ \times \left\{ -\frac{1}{2m} (\Omega m - B_1 m)^{5/2} K_5(|\beta \Omega - \beta B_1|) - (B_1 - \Omega) |\Omega m - B_1 m|^{3/4} K_{3/2}(2|\beta \Omega - \beta B_1|) \right\} \quad (19)$$

$$S_8(T, B, m_1, m_2) = \sum_{\gamma_1, \gamma_2, m_1, m_2} \frac{\xi^2 k_B T \beta}{32\rho v_s V \omega_0} \frac{e^2 E_0^2}{\Omega^2} \frac{L_z}{\pi^2} e^{\beta(\varepsilon_F - \varepsilon_{\gamma_1})} \\ \times \left\{ -\frac{\beta m}{2} (\Omega + B_1) K_1(\beta \Omega + \beta B_1) - (\beta B_1 \Omega m^2) K_0(\beta \Omega + \beta B_1) \right\} \quad (20)$$

$$B_1 = \varepsilon_{\gamma_2} - \varepsilon_{\gamma_1} + \omega_{m_1, m_2}; \quad B_2 = \varepsilon_{\gamma_2} - \varepsilon_{\gamma_1} - \omega_{m_1, m_2}. \quad (21)$$

With $K_n(x)$ is the Bessel function of type 2, γ_1 and γ_2 are the quantum numbers (n, l) and (n', l') .

From (10)–(21), we obtain the expression for Hall coefficient

$$R_H = -\frac{1}{B} \frac{\sigma_{xz}(T, B, m_1, m_2)}{\sigma_{xx}^2(T, B, m_1, m_2) + \sigma_{zz}^2(T, B, m_1, m_2)}. \quad (22)$$

The expression (22) is the analytics expression of the Hall coefficient in CQW with an infinite potential for electron–confined phonons scattering mechanism. From this ex-

pression, we see the HC dependent on the magnetic field B , the frequency Ω and amplitude E_0 of laser radiation, the temperature T of system and specially the quantum numbers m_1, m_2 characterizing the phonon confinement effect. When m_1, m_2 go to zero, we obtain same results as in the case of unconfined phonons.

3. Results and Discussions

In this section, we present the numerical evaluation of the Hall conductivity and the HC for the GaAs/GaAsAl quantum wire. The parameters, which used in this numerical

Table 1 Parameters used in this according to the result.

Quantities	Symbol	Value	Unit
The free mass of an electron	m_0	$9.1 \cdot 10^{-31}$	kilogram
The mass of an electron	m_e	$0.067 m_0$	kilogram
The Fermi level	ε_F	$8 \cdot 10^{-21}$	J
The sound velocity	v	8.73×10^4	$m \cdot s^{-1}$
The momentum relaxation time of electron	τ	10^{-12}	s
The Plank constant	h	$6,625 \cdot 10^{-34}$	J.s
The Boltzman constant	k_B	$1,38 \cdot 10^{-23}$	$J \cdot K^{-1}$
The length of the CQW in the z direction	L_z	30	nm
Radius of the wire	r	8.77	nm
The amplitude E_0 of laser radiation	E_0	10^5	$V \cdot m^{-1}$
The amplitude E_1 of laser radiation	E_1	$5 \cdot 10^5$	$V \cdot m^{-1}$
The acoustic deformation potential	ξ	$2,2 \cdot 10^{-18}$	J
The mass density	ρ	5320	$kg \cdot m^{-3}$
The normalization volume of specimen	V	1	m^3
The length of wire	$a_x(a_y)$	7	nm
The speed of light	c	$3 \cdot 10^8$	$m \cdot s^{-1}$

Fig. 1 The dependence of the conductivity tensor σ_{xy} on the magnetic field B for confined acoustic phonons ($m_1 = m_2 = 0$; 1) and bulk phonons at different values of B in the GaAs/GaAsAl CQW.

calculation has given in the Table 1.

In Fig. 1, we can see clearly the appearance of oscillations are controlled by the ratio of the Fermi energy and cyclotron frequency. First, in the quantum wires, phonons are confined in two dimensions x, y , only move free in the z direction. Therefore, the power spectrum of the external phonon depends on the normal effects of free movement, depending

Fig. 2 The dependence of the Hall coefficient on the Temperature.

on the confined indices of phonon m_1, m_2 corresponding to the x and y directions. In the case of confined acoustic phonons get more resonance peaks (The Shubnikov–de Haas magnetoresistance oscillations), it gets bigger and the condition of resonance is different comparing with than that in the case of unconfined phonons. When phonons are confined, specially the confined acoustic phonon frequencies are now modified to $\omega_{m_1, m_2} = v \cdot q_{m_1, m_2}$. Hence, confined acoustic phonons make remarkable changes to the resonance condition. Looking the Fig. 2, we see that the dependences of the Hall coefficient on

Fig. 3 The dependence of the Hall coefficient on the radius of wire R (m) of the CQW.

the temperature in the confined and unconfined phonon cases are different. This difference is due to the phonons and electrons in semiconductor moving in three dimensions. In the case of confined phonons, the Hall coefficient is further dependent on the confinement indices m_1 and m_2 . When the phonon is confined, in the temperature range of 20 K–40 K, the Hall coefficient increases by about 4.95 times. Looking Fig. 3, we see the dependence of the Hall coefficient on the radius of wire R of the CQW. When the radius of the wire is greater 0.5×10^{-9} (m) the Hall coefficient is strong reduced. It is the same as the unconfined acoustic phonon.

The confinement of acoustic phonons and the laser radiation make new properties of the Hall effect in a CQW. That is, the new analytical expressions of the Hall conductivity tensor, the HC, the magnetoresistance; the increasing of the HC and the stronger SdH oscillations in comparison with that in two-dimensional systems.¹⁰⁾ These new behaviours of the Hall effect could be explained by the increasing of the electron's scattering probability due to the confined acoustic phonons, the laser radiation and the new confinement potential in the CQW.

This is a new theoretical result built on the basis of quantum kinetic equations for quantum Hall effect in GaAs/GaAsAl one-dimensional cylindrical quantum wire under the influence of strong electromagnetic fields and including the confinement of electrons and phonons. Our results would give predictive results and potential insight in possible future experiment.

4. Conclusion

In this article, the influence of confined acoustic phonons on the Hall coefficient in a quantum wires with infinite potential has been theoretically studied base on quantum kinetic equation method. We obtained the analytical expression of the Hall conductivity and the Hall coefficient in the CQW under the influence of confined acoustic phonons. The Hall conductivity and the HC depends on the temperature T , the frequency Ω and amplitude E_0 of laser radiation, the radius of CQW and especially quantum indices m_1 and m_2 characterizing the phonon confinement. When m_1 and m_2 go to zero, the results for the case of unconfined acoustic phonon could be obtained. Numerical calculations are using parameters of GaAs/GaAsAl cylindrical quantum wire. We see the Hall conductivity depends on magnetic field B in the case of confined acoustic phonon get more resonance peaks (the Shubnikov–de Haas oscillations) than that in case of unconfined phonons. When $B \geq 0.15$ T, the Shubnikov–de Haas oscillations gets bigger and the condition of resonance is different from that in case of unconfined phonons. This phenomenon is due to the appearance quantum indices m_1 and m_2 . The confined acoustic phonons lead to an increase of the Hall coefficient by 2.3 times in comparison with the case of unconfined phonons.

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