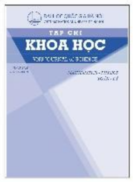
VNU Journal of Science: Mathematics – Physics, Vol. 40, No. 1 (2024) 41-50

VNU Journal of Science: Mathematics - Physics

Journal homepage: https://js.vnu.edu.vn/MaP



Original Article

Theoretical Study of the Nernst Effect in Compositional Superlattices in the Presence of Strong Electromagnetic Wave

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Received 17 July 2023
Revised 04 October 2023; Accepted 18 March 2024

Abstract: The Nernst effect has been theoretically studied in compositional superlattice in the presence of a strong electromagnetic wave. Using the quantum kinetic equation for electrons with two cases electrons-acoustic phonons scattering and electrons-optical phonons scattering, we obtained the analytic expression of the Nernst coefficient and kinetic tensors as a function of the magnetic field, temperature, frequency, and amplitude of the electromagnetic wave and parameters of the compositional superlattice. The dependence of the Nernst coefficient on the magnetic field and temperature is achieved by numerical calculations for AlGa/AlGaAs material. The result indicates that in the case of electron-acoustic phonon scattering, the Shubnikov-de Hass oscillation appears. Whereas, in the case of electrons-optical phonons scattering, the peak of magneto-photon-phonon resonance appears. In both cases, when temperature increases, the Nernst coefficient decreases rapidly, and for electrons-optical phonons scattering, the resonance peak has a movement.

Keyword: Nernst effect, compositional superlattice, quantum kinetic equation, electron-phonon scattering, Shubnikov-de Hass oscillaton.

1. Introduction

Nowadays, many modern electronic devices are made of semiconductors, so examining semiconductors is a fundamental problem. When examining the semiconductor, the researcher realized that the low dimensional semiconductor material has many special properties which is very different

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https//doi.org/10.25073/2588-1124/vnumap.4864

from bulk semiconductor material [1-26]. One special phenomenon is the Nernst effect. The Nernst effect was examined first by Albert Von Ettingshausen and his PhD student Walther Nernst when investigating Hall effect [1, 2]. The Nernst effect is a thermoelectric phenomenon observed when a sample allowing electrical conduction is subjected to a magnetic field and a temperature gradient normal (perpendicular) to each other; an electric field will be induced normal to both [1, 2]. In low-dimensional material, the difference of electron wave function and energy spectrum compared to bulk semiconductors cause the different properties [3-24]. There are some researches about Nernst effect in some low-dimensional material, f.i. the Nernst effect in cylindrical quantum wire [14]. Another low-dimensional material is compositional superlattice, which is not only interesting for basic research because of its unique structure but also provides an important application for future technology [25]. The superlattice is a multi-well structure. We can create multiple-quantum-well structures by changing the semiconductor layers order in the crystal formation process. The compositional superlattice is the material made of two different semiconductor materials with difference energy ban gap differences. The Nernst effect in compositional superlattice is not examined fully so we performed this research.

2. Calculation of the Quantum Nernst Coefficient and the Kinetic Tensor in A Two-dimensional Compositional Superlattice under the Influence of an EMW

2.1. Wave Function and Energy Spectrum of the Electron in A Two-dimensional Compositional Superlattice

We are examining a two-dimensional compositional superlattice subjected to a magnetic field. $\vec{B} = (0,0,B)$ and a static electric field $\overrightarrow{E_1} = (E_1, 0,0)$. So, the wave function and the energy spectrum of the electron are, respectively, given by [26]:

$$|\xi\rangle = |N, n, \overrightarrow{k_y}, \overrightarrow{k_z}\rangle = \frac{1}{\sqrt{L_y}} \exp\,(ik_y y)\phi_N(x = x_0) \otimes |n, \overrightarrow{k_z}\rangle \quad (1)$$

$$\varepsilon_\zeta\left(\overrightarrow{k_y}\right) = \varepsilon_{N,n,k_z}\left(\overrightarrow{k_y}\right) = \left(N + \frac{1}{2}\right)\hbar\omega_H + \varepsilon_{n,\overrightarrow{k_z}} - \hbar v_d k_y + \frac{1}{2} m_e v_d^2 \quad (2)$$

Where N is the Landau level index, n denotes level quantization and N, n=0,1,2,3,…, and $k_y(k_z)$ and L_y are the wave vector and normalization length in the y(z) direction. $\phi_N(x)$ represents harmonic oscillator wave function centered $x_0 = -\frac{\hbar}{m_e\omega_H}(k_y - \frac{m_e v_d}{\hbar})$, where ω_H is the cyclotron frequency, $v_d = \frac{E1}{B}$, m_e is the electron's effective mass, $\varepsilon_{n,k_z = \varepsilon_n - t_n \cos(k_z f)}$, $f = f_I + f_{II}$ is the superlattice period, $\varepsilon_n = \frac{\hbar^2\pi^2(n+1)^2}{2m_e f_I^2}$, and t_n is the half=width of the nth mini-band given by:

$$t_n = -4(-1)^n \frac{f_I}{f_I + f_{II}} \varepsilon_n \frac{\exp\,(-2\sqrt{\frac{2m_e(f - f_I)^2 W}{\hbar^2}}}{\sqrt{\frac{2m_e(f - f_I)^2 W}{\hbar^2}}} \quad (3)$$

2.2. Quantum Kinetic Equation for Electron

Electron-phonon Hamiltonian under the influence of an intense EMW with the electric field vector $\vec{E} = (0, E_0 sin\Omega t, 0)$ in a two-dimensional compositional superlattice is [26]

$$H = \sum_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}} \varepsilon_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}}(\overrightarrow{k_y} - \frac{e}{\hbar c}\vec{D}(t))a^+_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}} a_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}} + \sum_{\vec{q}} \hbar\overrightarrow{\omega_q}\, b^+_{\vec{q}} b_{\vec{q}} + \sum_{N,N',n,n',\overrightarrow{k_y},\overrightarrow{k_z},\vec{q}} K_{N,n,N',n'}(\vec{q}) a^+_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y},\overrightarrow{k_y}+\overrightarrow{q_z}} a_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}} (b^+_{-\vec{q}} + b_{\vec{q}}) \quad (4)$$

where $\hbar\omega_{\vec{q}}$ is the energy of a phonon with the ware vector $\vec{q} = (\overrightarrow{q_\perp}, q_z)$; $\vec{D}(t)$ is the vector potential of the laser field given by $-\frac{1}{c}\frac{\partial\vec{D}(t)}{\partial t} = \vec{F}\sin(\Omega t)$, with $\vec{F} = e\overrightarrow{E_1} - \frac{\varepsilon-\varepsilon_F}{T}\Delta T$, $a^+_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}}$ and $a_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}}$ ($b^+_{-\vec{q}}$ and $b_{\vec{q}}$) being the creation and the annihilation operators of a electron (a phonon), respectively;

$$|K_{N,n,N',n'}| = |V_{\vec{q}}||I_{n,n'}(k_z, k'_z)|^2 |J_{N,N'}(b)|^2 \quad (5)$$

With $V_{\vec{q}}$ being the electron-phonon interaction constant and

$$I_{n,n'}(k_z, k'_z, q_z) = 2^{-1}\sin\left\{\frac{[q_z \pm (k_{n'} \pm k_n)]f_I}{2}\right\}\left\{\frac{[q_z \pm (k_{n'} \pm k_n)]f_I}{2}\right\}^{-1}\exp\left\{\frac{[q_z \pm (k_{n'} \pm k_n)]f_I}{2}\right\} \quad (6)$$

Here $k_n = \left(\frac{2m_e\varepsilon_{n,k_z}}{\hbar^2}\right)^{\frac{1}{2}}$, $|J_{N,N'}(b)| = \frac{N_{min}!}{N_{max}!}e^{-u}b^{N_{max}-N_{min}}\left[L^{N_{max}-N_{min}}_{N_{min}}(b)\right]^2$, with $N_{min} = \min(N, N')$, $N_{max} = \max(N, N')$, $L^N_M(x)$ being the associated Laguerre polynomials, $b = \frac{\hbar}{m_e\omega_H}\frac{q_x^2+q_y^2}{2}$

The quantum kinetic equation for the average number of electrons $f_{N,n,\overrightarrow{k_y}} = \langle a^+_{N,n,\overrightarrow{k_y}} a_{N,n,\overrightarrow{k_y}}\rangle$ is:

$$\frac{\partial f_{N,n,\overrightarrow{k_y}}}{\partial t} + \left(\frac{e\overrightarrow{E_1}}{\hbar} + \frac{\omega_H}{\hbar}\left[\overrightarrow{k_x}, \vec{h}\right]\right)\frac{\partial f_{N,n,\overrightarrow{k_y}}}{\partial\overrightarrow{k_y}} = \frac{2\pi}{\hbar}\sum_{N',n',\vec{q}}|K_{N,N',n,n'}(\vec{q})|\left|\sum_{s=-\infty}^{+\infty}J_s^2\left(\frac{\lambda}{\Omega}\right)\times(2N_{\vec{q}}+1)\{\left(f_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}}(N_{\vec{q}}+1) - f_{N,n,\overrightarrow{k_y}}N_{\vec{q}}\right)\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}} - l\hbar\Omega\right) + \left(f_{N',n',\overrightarrow{k_y}-\overrightarrow{q_y}}N_{\vec{q}} - f_{N,n,\overrightarrow{k_y}}(N_{\vec{q}}+1)\right)\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}-\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} + \hbar\omega_{\vec{q}}l\hbar\Omega\right)\right. \quad (7)$$

2.3. Quantum Nernst Coefficient and Kinetic Tensor

In both sides of Eq. (1), multiplying $\frac{e}{m_e}\overrightarrow{k_y}\delta(\varepsilon - \varepsilon_{N,n,\overrightarrow{k_y}})$ then summing according to to $N, n, \overrightarrow{k_y}$ we obtained the equation for the specific current density $\vec{M}(\varepsilon)$

$$\frac{\vec{M}(\varepsilon)}{\tau(\varepsilon)} + \omega_H\left[\vec{h}, \vec{M}(\varepsilon)\right] = \vec{Y}(\varepsilon) + \vec{I}(\varepsilon) \quad (8)$$

where $\vec{Y}(\varepsilon) = -\frac{e}{m_e}\sum_{N,n,\overrightarrow{k_y}}\overrightarrow{k_y}(\vec{F}, \frac{\partial n_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}}}{\hbar\partial\overrightarrow{k_y}})\delta(\varepsilon - \varepsilon_{N,n,\overrightarrow{k_y},\overrightarrow{k_z}})$

$$\vec{I}(\varepsilon) = \frac{2\pi e}{m_e\hbar}\sum_{N,n,\overrightarrow{k_y}}|K_{N,N',n,n'}|^2 N_{\vec{q}}\overrightarrow{k_y}\Big\{\left(f_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}} - f_{N',n',\overrightarrow{k_y}}\right)\times\Big[\left(1 - \frac{\lambda^2}{e\Omega^2}\right)\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}}\right) + \frac{\lambda^2}{4\Omega^4}\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}} + \hbar\Omega\right) + \frac{\lambda^2}{4\Omega^4}\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}} - \hbar\Omega\right)\Big] + \left(f_{N',n',\overrightarrow{k_y}-\overrightarrow{q_y}} - f_{N',n',\overrightarrow{k_y}}\right)\Big[\left(1 - \frac{\lambda^2}{e\Omega^2}\right)\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}-\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}}\right) + \frac{\lambda^2}{4\Omega^4}\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}-\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}} + \hbar\Omega\right) + \frac{\lambda^2}{4\Omega^4}\delta\left(\varepsilon_{N',n',\overrightarrow{k_y}+\overrightarrow{q_y}} - \varepsilon_{N,n,\overrightarrow{k_y}} - \hbar\omega_{\vec{q}} - \hbar\Omega\right)\Big]\Big\}\delta(\varepsilon - \varepsilon_{N,n,\overrightarrow{k_y}})$$

2.3.1. Electron-acoustic Phonon Interaction

From the specific current density expression, we obtain the total current density expression $\vec{J}$ and the thermal flux density $\overrightarrow{q_e}$, respectively

$$\vec{J} = \int_0^\infty \vec{M}(\varepsilon) d\varepsilon = \sigma_{im}\overrightarrow{E_m} + \beta_{im}\nabla_m T \tag{8}$$

The quantum Nernst coefficient is given by:

$$NC = -\frac{1}{B}\frac{\sigma_{xx}\beta_{xy} - \alpha_{xy}\beta_{xx}}{\sigma_{xx}^2 + \sigma_{xy}^2} \tag{9}$$

where

$$\begin{aligned}\sigma_{im} = \alpha\frac{\tau(\epsilon_F)S}{1+\omega_H^2\tau(\epsilon_F)} &+ \frac{[A+N]e\tau^2(X_1 - eE1\overline{\Delta x})}{m_e\left(1+\omega_H^2\tau^2(X_1 - eE1\overline{\Delta x})\right)^2}T1_{ij}\delta_{jl}T1_{lm}\\ &+ L\frac{e\tau^2(X_1 - eE1\overline{\Delta x} - \hbar\Omega)}{m_e\left(1+\omega_H^2\tau^2(X_1 - eE1\overline{\Delta x} - \hbar\Omega)\right)^2}T2_{ij}\delta_{jl}T2_{lm}0\\ &+ Q\frac{e\tau^2(X_1 - eE1\overline{\Delta x} + \hbar\Omega)}{m_e\left(1+\omega_H^2\tau^2(X_1 - eE1\overline{\Delta x} + \hbar\Omega)\right)^2}T3_{ij}\delta_{jl}T3_{lm}\end{aligned} \tag{10}$$

$$\begin{aligned}\beta_{im} = -(X_1 - eE_1\overline{\Delta x} - \varepsilon_F)&\frac{[A+N]e\tau^2(X_1 - eE1\overline{\Delta x})}{m_eT\left(1+\omega_H^2\tau^2(X_1 - eE1\overline{\Delta x})\right)^2}T1_{ij}\delta_{jl}T1_{lm}\\ -L(X_1 - eE_1\overline{\Delta x} - \hbar\Omega - \varepsilon_F)&\frac{e\tau^2(X_1 - eE1\overline{\Delta x} - \hbar\Omega)}{m_eT\left(1+\omega_H^2\tau^2(X_1 - eE1\overline{\Delta x} - \hbar\Omega)\right)^2}T2_{ij}\delta_{jl}T2_{lm}\\ -Q(X_1 - eE_1\overline{\Delta x} + \hbar\Omega - \varepsilon_F)&\frac{e\tau^2(X_1 - eE1\overline{\Delta x} + \hbar\Omega)}{m_eT\left(1+\omega_H^2\tau^2(X_1 - eE1\overline{\Delta x} + \hbar\Omega)\right)^2}T3_{ij}\delta_{jl}T3_{lm}\end{aligned} \tag{11}$$

here τ is the electron relaxation time, δ_{jl} is the Kronecker delta, ε_{ijk} is the antisymmetric Levi – Civita tensor; the Latin symbols *i*, *j*, *k*, *m*, *p*, *l* stands for the *x*, *y*, *z* components of Cartesian coordinates, ε_F is the Fermi level, k_b is the Boltzmann constant

$$a = \frac{eL_y}{e\pi m_e\hbar^2 v}\left(\left(N+\frac{1}{2}\right)\hbar\omega_H + \left(n+\frac{1}{2}\right)\hbar\omega_p + \frac{1}{2}m_e v^2\right)$$

$$X_1 = (N' - N)\hbar\omega_H - \epsilon_{n',\frac{\pi}{f}} - \varepsilon_{n,0}$$

$$S = [\delta_{ij} - \omega_H\tau(\varepsilon_F)\varepsilon_{ijk}h_k + \omega_H^2\tau^2(\varepsilon_F)h_ih_j]$$

$$T1_{xy} = \left[\delta_{xy} - \omega_H\tau(X_1 - eE_1\overline{\Delta x})\varepsilon_{xyz}h_z + \omega_H^2\tau^2(X_1 - eE_1\overline{\Delta x})h_xh_y\right]$$

$$T2_{xy} = \left[\delta_{xy} - \omega_H\tau(X_1 - eE_1\overline{\Delta x} - \hbar\Omega)\varepsilon_{xyz}h_z + \omega_H^2\tau^2(X_1 - eE_1\overline{\Delta x} - \hbar\Omega)h_xh_y\right]$$

$$T3_{xy} = \left[\delta_{xy} - \omega_H\tau(X_1 - eE_1\overline{\Delta x} + \hbar\Omega)\varepsilon_{xyz}h_z + \omega_H^2\tau^2(X_1 - eE_1\overline{\Delta x} + \hbar\Omega)h_xh_y\right]$$

$$\overline{\Delta x} = \left(\sqrt{N+\frac{1}{2}} + \sqrt{N+1+\frac{1}{2}}\right)\frac{l_B}{2}$$

$$A = \gamma\left(\frac{eB\overline{\Delta x}}{\hbar}\right)\{1 + 2\sum_{s=1}^{+\infty}(-1)^s e^{-\frac{2\pi s\Gamma}{\hbar\omega_H}}\cos\left(2\pi s\overline{f_1}\right)\}$$

$$\overline{f_1} = \frac{\varepsilon_{n.0} - \varepsilon_{n',\frac{\pi}{f}} + eE1\overline{\Delta x}}{\hbar\omega_H}$$

$$N = -\frac{\gamma\theta}{2}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 \{1 + 2\sum_{s=1}^{+\infty}(-1)^s e^{-\frac{2\pi s\Gamma}{\hbar\omega_H}}\cos\left(2\pi l\overline{f_1}\right)\}$$

$$L = \frac{\gamma\theta}{4}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 \{1 + 2\sum_{s=1}^{+\infty}(-1)^s e^{-\frac{2\pi s\Gamma}{\hbar\omega_H}}\cos\left(2\pi s\overline{f_2}\right)\}$$

$$\overline{f_2} = \frac{\varepsilon_{n.0} - \varepsilon_{n',\frac{\pi}{f}} + eE1\overline{\Delta x} - \hbar\Omega}{\hbar\omega_H}$$

$$Q = \frac{\gamma\theta}{4}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 \{1 + 2\sum_{s=1}^{+\infty}(-1)^s e^{-\frac{2\pi s\Gamma}{\hbar\omega_H}}\cos\left(2\pi s\overline{f_3}\right)\}$$

$$\overline{f_3} = \frac{\varepsilon_{n.0} - \varepsilon_{n',\frac{\pi}{f}} + eE1\overline{\Delta x} + \hbar\Omega}{\hbar\omega_H}$$

$$\gamma = \frac{\zeta^2 L_y I_{n,n'}}{8\pi^3\beta\hbar^2\omega_H v_s\, l_B^2\alpha^2}\quad \left(\left(N + \frac{1}{2}\right)\hbar\omega_H + \left(\frac{\hbar^2\pi^2(n+1)^2}{2m_e f_I^2} + 4(-1)^n\frac{f_I}{f-f_I}\frac{\hbar^2\pi^2(n+1)^2}{2m_e d_I^2}\frac{\exp\left(-\sqrt{\frac{2m_e(f-f_I)^2W}{\hbar^2}}\right)}{\sqrt{\frac{2m_e(f-f_I)^2W}{\hbar^2}}}\cos(k_z d)\right) + \frac{1}{2}m_e v^2\right)$$

$$\theta = \frac{e^2E_0^2}{m^2\Omega^4}\ ;\ \Gamma = \frac{\hbar}{\tau}$$

2.3.2. Electron – optical phonon interaction

$$\begin{aligned}\sigma_{im} = {} & \alpha\frac{\tau(\epsilon_F)}{1+\omega_H^2\tau(\epsilon_F)}Q + [g_1+g_2]\frac{e\tau^2(C1 - eE1\overline{\Delta x})}{m_e\left(1+\omega_H^2\tau^2(C1 - eE1\overline{\Delta x})\right)^2}A1_{ij}\delta_{jl}A1_{lm} \\ & + g_3\frac{e\tau^2(C1 - eE1\overline{\Delta x} - \hbar\Omega)A2_{ij}\delta_{jl}A2_{lm}}{m_e\left(1+\omega_H^2\tau^2(C1 - eE1\overline{\Delta x} - \hbar\Omega)\right)^2} + g_4\frac{e\tau^2(C1 - eE1\overline{\Delta x} + \hbar\Omega)A3_{ij}\delta_{jl}A3_{lm}}{m_e\left(1+\omega_H^2\tau^2(C1 - eE1\overline{\Delta x} + \hbar\Omega)\right)^2} \\ & + [g_5+g_6]\frac{e\tau^2(C2 - eE1\overline{\Delta x})A4_{ij}\delta_{jl}A4_{lm}}{m_e\left(1+\omega_H^2\tau^2(C2 - eE1\overline{\Delta x})\right)^2} + g_7\frac{e\tau^2(C2 - eE1\overline{\Delta x} - \hbar\Omega)A5_{ij}\delta_{jl}A5_{lm}}{m_e\left(1+\omega_H^2\tau^2(C2 - eE1\overline{\Delta x} - \hbar\Omega)\right)^2} \\ & + g_8\frac{e\tau^2(C2 - eE1\overline{\Delta x} + \hbar\Omega)A6_{ij}\delta_{jl}A6_{lm}}{m_e\left(1+\omega_H^2\tau^2(C2 - eE1\overline{\Delta x} + \hbar\Omega)\right)^2}\end{aligned} \quad (12)$$

$$\begin{aligned}\beta_{im} = {} & -[g_1+g_2](C1 - eE1\overline{\Delta x} - \varepsilon_F)\frac{e\tau^2(C1 - eE1\overline{\Delta x})}{m_eT\left(1+\omega_H^2\tau^2(C1 - eE1\overline{\Delta x})\right)^2}A1_{ij}\delta_{jl}A1_{lm} \\ & - g_3(C1 - eE1\overline{\Delta x} - \hbar\Omega - \varepsilon_F)\frac{e\tau^2(C1 - eE1\overline{\Delta x} - \hbar\Omega)A2_{ij}\delta_{jl}A2_{lm}}{m_eT\left(1+\omega_H^2\tau^2(C1 - eE1\overline{\Delta x} - \hbar\Omega)\right)^2}\end{aligned}$$

$$-g_4(C1 - eE1\overline{\Delta x} + \hbar\Omega - \varepsilon_F)\frac{e\tau^2(C1 - eE1\overline{\Delta x} + \hbar\Omega)A3_{ij}\delta_{jl}A3_{lm}}{m_e T\big(1 + \omega_H^2\tau^2(C1 - eE1\overline{\Delta x} + \hbar\Omega)\big)^2}$$

$$-[g_5 + g_6](C2 - eE1\overline{\Delta x} - \varepsilon_F)\frac{e\tau^2(C2 - eE1\overline{\Delta x})A4_{ij}\delta_{jl}A4_{lm}}{m_e T\big(1 + \omega_H^2\tau^2(C2 - eE1\overline{\Delta x})\big)^2}$$

$$-g_7(C2 - eE1\overline{\Delta x} - \hbar\Omega - \varepsilon_F)\frac{e\tau^2(C2 - eE1\overline{\Delta x} - \hbar\Omega)A5_{ij}\delta_{jl}A5_{lm}}{m_e T\big(1 + \omega_H^2\tau^2(C2 - eE1\overline{\Delta x} - \hbar\Omega)\big)^2}$$

$$- g_8(C2 - eE1\overline{\Delta x} + \hbar\Omega - \varepsilon_F)\frac{e\tau^2(C2 - eE1\overline{\Delta x} + \hbar\Omega)A6_{ij}\delta_{jl}A6_{lm}}{m_e T\big(1 + \omega_H^2\tau^2(C2 - eE1\overline{\Delta x} + \hbar\Omega)\big)^2} \quad (13)$$

$$Q = [\delta_{ij} - \omega_H\tau(\varepsilon_F)\varepsilon_{ijk}h_k + \omega_H^2\tau^2(\varepsilon_F)h_i h_j]$$

$$A1_{xy} = \big[\delta_{xy} - \omega_H\tau(C_1 - eE_1\overline{\Delta x})\varepsilon_{xyz}h_z + \omega_H^2\tau^2(C_1 - eE_1\overline{\Delta x})h_x h_y\big]$$

$$A2_{xy} = \big[\delta_{xy} - \omega_H\tau(C_1 - eE_1\overline{\Delta x} - \hbar\Omega)\varepsilon_{xyz}h_z + \omega_H^2\tau^2(C_1 - eE_1\overline{\Delta x} - \hbar\Omega)h_x h_y\big]$$

$$A3_{xy} = \big[\delta_{xy} - \omega_H\tau(C_1 - eE_1\overline{\Delta x} + \hbar\Omega)\varepsilon_{xyz}h_z + \omega_H^2\tau^2(C_1 - eE_1\overline{\Delta x} + \hbar\Omega)h_x h_y\big]$$

$$A4_{xy} = \big[\delta_{xy} - \omega_H\tau(C_2 - eE_1\overline{\Delta x})\varepsilon_{xyz}h_z + \omega_H^2\tau^2(C_2 - eE_1\overline{\Delta x})h_x h_y\big]$$

$$A5_{xy} = \big[\delta_{xy} - \omega_H\tau(C_2 - eE_1\overline{\Delta x} - \hbar\Omega)\varepsilon_{xyz}h_z + \omega_H^2\tau^2(C_2 - eE_1\overline{\Delta x} - \hbar\Omega)h_x h_y\big]$$

$$A6_{xy} = \big[\delta_{xy} - \omega_H\tau(C_2 - eE_1\overline{\Delta x} + \hbar\Omega)\varepsilon_{xyz}h_z + \omega_H^2\tau^2(C_2 - eE_1\overline{\Delta x} + \hbar\Omega)h_x h_y\big]$$

$$C_1 = (N' - N)\hbar\omega_H - \epsilon_{n',\frac{\pi}{f}} - \varepsilon_{n,0} - \hbar\omega_0$$

$$C_2 = (N' - N)\hbar\omega_H - \epsilon_{n',\frac{\pi}{f}} - \varepsilon_{n,0} + \hbar\omega_0$$

$$g_1 = \left(\frac{eB\overline{\Delta x}}{M\hbar}\right)e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_1);\ M = |N - N'| = 1,2,3,\ldots$$

$$T_1 = (N' - N)\hbar\omega_H - \epsilon_{n',\frac{\pi}{f}} - \varepsilon_{n,0} - \hbar\omega_0 - eE1\overline{\Delta x}$$

$$g_2 = -\frac{\theta}{2}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^2 e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_1)$$

$$g_3 = \frac{\theta}{4M}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_1 + \hbar\Omega)$$

$$g_4 = \frac{\theta}{4M}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_1 - \hbar\Omega)$$

$$T_2 = (N' - N)\hbar\omega_H - \epsilon_{n',\frac{\pi}{f}} - \varepsilon_{n,0} - \hbar\omega_H + eE1\overline{\Delta x}$$

$$g_5 = \frac{1}{M}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_2)$$

$$g_6 = -\frac{\theta}{2}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^2 e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_2)$$

$$g_7 = \frac{\theta}{4M}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_2 + \hbar\Omega)$$

$$g_8 = \frac{\theta}{4M}\left(\frac{eB\overline{\Delta x}}{\hbar}\right)^3 e^{\beta(\varepsilon_F - \varepsilon_{N,n})}\left[\frac{(N+M)!}{N!}\right]^2\delta(T_2 - \hbar\Omega)$$

3. Numerical Results and Discussion for the Two-dimensional Compositional Superlattice GaAs/AlGaAs

In this section, we present the numerical calculations of the Nernst coefficient on temperature and magnetic field for the Compositional superlattice of GaAs/AlGaAs with a parameter used as $m* = 0.067\, m_0\ (m_0\ is\ the\ rest\ mass\ of\ electron)$, $n_0 = 3.10^{22}\, m^{-3}$, $X_\infty = 10.9$, $X_0 = 12.9$, $v_s = 6560\, ms^{-1}$ $L_x = L_y = 100\, nm$, $E_0 = 10^5\, V.m^{-1}$, $E_1 = 10^5\, V.m^{-1}$, $\Omega = 10^{14}\, Hz$, $\Delta Eg = 0.057\, eV$

3.1. Electron-acoustic Phonon Interaction

Figure 1 indicates the dependence of Nernst coefficient on the magnetic field with different temperatures. In general, the chart fluctuates strongly from 1T to 5T, and the amplitude of fluctuation decreases significantly. The amplitude of fluctuation falls slowly to 0 from 5T to 15T. We could also see that when the temperature increases, the Nernst coefficient decreases.

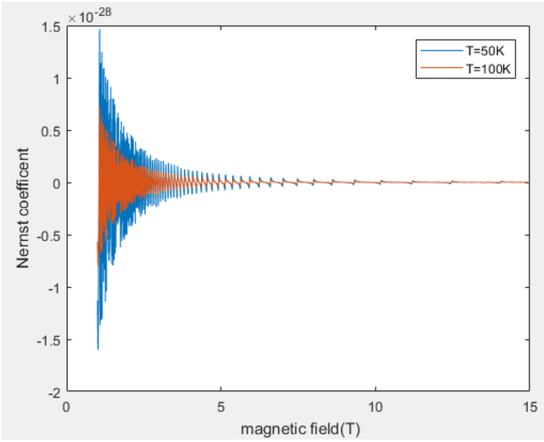

Figure 1. Dependence of Nernst coefficient on the magnetic field for different values of temperature.

According to Figure 2, the Nernst coefficient decreases sharply to 0 when the temperature increase.

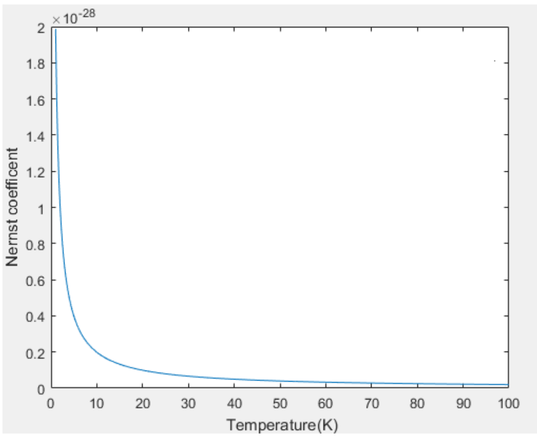

Figure 2. Dependence of Nernst coefficient on temperature.

3.2. Electron – optical Phonon Interaction

Figure 3 indicates the dependence of the Nernst coefficient on the magnetic field with different temperature. Over-all, we can see that the Nernst coefficient reaches a peak of around 2.7T at 50K, and when we decrease temperature, we obtain a higher peak.

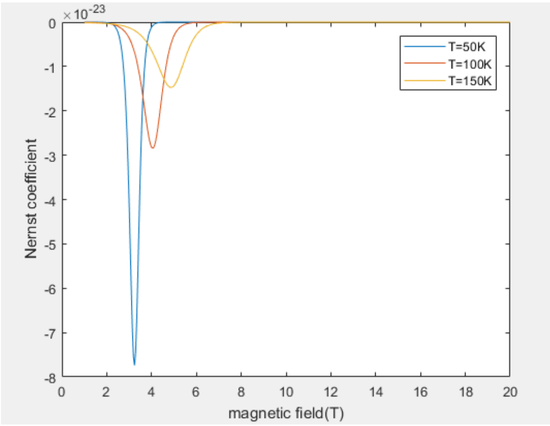

Figure 3. The Dependence of Nernst coefficient on magnetic field for different values of temperature.

Figure 4 shows that when temperature increases, the Nernst coefficient increases sharply and peaks at 180K. After that, the Nernst coefficient decreases and maintain the value from 1000K to higher.

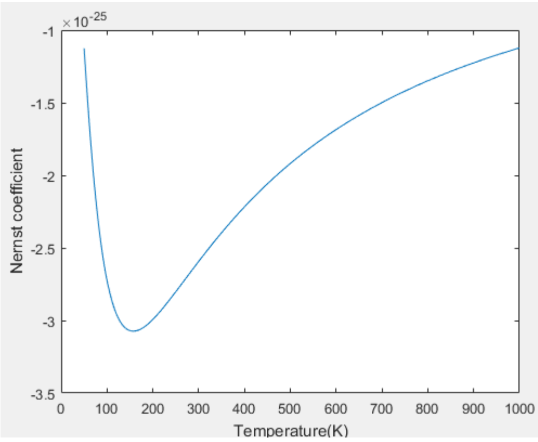

Figure 4. The dependence of the Nernst coefficient on temperature.

4. Conclusion

In summary, we studied the Nernst effect in two-dimensional compositional superlattice using the quantum kinetic equation. We obtain the kinetic tensor for two cases: electron-optical phonon interaction and electron-acoustic phonon interaction and the numerical result for both cases. We examined the dependence of Nernst coefficient on magnetic field and temperature. The result indicates that in first case (electron-acoustic phonon interaction), the Shubnikov-de Hass oscillation appears and the second case (electron-optical phonon), the photon – phonon resonance peak appears. The result also indicates that the Nernst coefficient depends on elements such as the temperature and magnetic field.

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