

PHONON-PHONON INTERACTION IN SPECTRAL DENSITY FUNCTION OF SEMICONDUCTOR CRYSTALS

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ABSTRACT

An electron Green's function has been taken to develop the theory. Fourier transformed electron Green's function has been evaluated with the help of equation of motion technique of quantum dynamics and Dyson equation approach. The response function has been provided the electron phonon linewidth and electron phonon shift from this technique. The perturbed mode energy has been dependent on electron band energy and electron phonon shift. The linewidth has been contributed by harmonic part, localized part, cubic, and quartic anharmonic parts. This study concludes that spectral density function has been contributed by harmonic part, electron part, defect part, cubic and quartic anharmonic parts. It has also been obtained that spectral density function shows a different delta function peaks which are affected by temperature and electron phonon coupling constant. It has been found that intensity of peaks have got sharper response when phonon frequency approaches to perturbed mode energy. The different excitations have been created in the form of exciton, polaron, combination, and difference bands. These have been responsible to broaden the delta function peaks. The different limiting cases of excitations have been undertaken, and their effect on intensity of spectral density function has been investigated in presence of impurity and anharmonicity. The effect of force constant change parameter and atomic force constants has been undertaken to investigate the present property.

Keywords: Electron, Phonon, Phonon - phonon interaction, Electron Green's function, Electron phonon coupling constant, Semiconductor, Spectral density function,

List of symbols used in equations:

1. π = pi
2. * = Star
3. α = alpha
4. β = beta
5. ε = epsilon
6. \hbar = hcross
7. \rightarrow = Arrow
8. ω = omega
9. Δ = delta
10. $\tilde{\varepsilon}_q$ = cap over ε_q
11. δ_{kk} = Kronecker delta function
12. $\delta(\)$ = Dirac delta function
13. \tilde{n}_k = cap over n_k
14. θ = theta
15. η = eta
16. Γ = gamma
17. $\overset{\approx}{n}_k$ = double cap over n_k
18. \sum = summation

1. Introduction

The dynamics of the crystal is known by their dynamical constituents. The work on monolayer IV-VI semiconductors and magnetic semiconductors EuO (Averyanov et al., 2015; Liu et al., 2015) has been done by the researchers to promote the semiconductor technology. The different types of semiconductors such as diamond structure, zinblende structure, wurtzite structure are being applied in many fields. Real semiconductor crystals contain electron, phonon, impurity, and anharmonicity. In harmonic approximation, normal mode of vibrations are independent to one another and forces between atoms is a linear function of displacements (Callaway,1974). But in real crystal, the harmonic nature is destroyed in presence of impurity and anharmonicity. The presence

of impurity creates localized mode (Indu,1990). An anharmonicity can not be neglected even at 0⁰K. An anharmonicity comes into an account by taking cubic and quartic terms beyond the quadratic term of Taylor series expansion of potential energy. This results in a formation of phonon-phonon interaction (Madelung,1978). In present case of semiconductor crystal, phonon-phonon interaction is taken to extract the information through excitations of electron. An electron moves in localized and anharmonic fields to create dynamical system in semiconductor crystals. An electron Green's function is taken to investigate the study of spectral density function through electron phonon linewidth. This property is well understood by obtaining Fourier transformed electron Green's function with the help of Hamiltonian. This type of Hamiltonian is contributed by harmonic part, electron part, electron phonon interaction part, defect part, and anharmonic part. This study is done on the basis of sections. These are formulation of the problem, evaluation of electron phonon linewidth, effect of phonon-phonon interaction on spectral density function, and conclusion of the work.

2. Formulation of the problem

Electron and phonon are the main constituents of semiconductor crystals. Spectral density function $J_{qq}(kqQ)$ is taken as (Zubarev, 1960: Pathak,1965)

$$J_{qq}(kqQ) = -2[\exp(\beta\hbar\varepsilon) + 1]^{-1} \text{Im}.G_{qq}(\varepsilon) \quad (1)$$

In eq.(1), $\text{Im}.G_{qq}(\varepsilon)$ indicates the imaginary part of Fourier transformed electron Green's function $G_{qq}(\varepsilon)$. This Fourier transformed electron Green's function $G_{qq}(\varepsilon)$ is to be obtained from equation of motion technique of quantum dynamics.

3. Evaluation of electron phonon linewidth

The Fourier transformed electron Green's function can be evaluated with the help of many body approach. This approach is processed by taking Hamiltonian. This Hamiltonian H contains harmonic part H_{op} , electron part H_{oe} , electron phonon interaction part H_{ep} , defect part H_D , and anharmonic part H_A as (Maradudin et al., 1971: Frohlich, 1966 : Fan, 1987 : Feinberg et al., 1990 : Mahanty and Behera, 1983 : Behera and Mishra, 1985 : Ziman, 1969 : Sharma and Bahadur, 1975 : Sahu and Sharma, 1983 : Pathak, 1965 : Indu, 1990).

$$H = H_{op} + H_{oe} + H_{ep} + H_D + H_A \quad (2)$$

Where,

$$H_{op} = \hbar/4 \sum_k \varepsilon_k [A_k^* A_k + B_k^* B_k] \quad (3a)$$

$$H_{oe} = \hbar \sum_q \varepsilon_q b_q^* b_q \quad (3b)$$

$$H_{ep} = g\hbar \sum_{k,q} b_Q^* b_q B_k \quad (3c)$$

$$H_D = \hbar \sum_{k_1, k_2} [D(\vec{k}_1, \vec{k}_2) A_{k_1} A_{k_2} - C(\vec{k}_1, \vec{k}_2) B_{k_1} B_{k_2}] \quad (3d)$$

$$H_A = \hbar \sum_{s \geq 3} \sum_{k_1, k_2, \dots, k_s} V^{(s)}(\vec{k}_1, \vec{k}_2, \dots, \vec{k}_s) A_{k_1} A_{k_2} \dots A_{k_s} \quad (3e)$$

where ,

$$A_k = a_k + a_{-k}^* = A_k^* ; B_k = a_k - a_{-k}^* = -B_{-k}^* ; \bar{Q} = \vec{k} + \vec{q} \quad (4)$$

The notations op, oe, ep, D, and A of eqs.(3a-3e) denote harmonic part, electron part, electron phonon interaction part, and anharmonic part of Hamiltonian respectively.

In eqs.(3a-3e), $b_q (b_q^*)$, $a_k (a_k^*)$, ε_q , ε_k , g , $D(\vec{k}_1, \vec{k}_2)$, $C(\vec{k}_1, \vec{k}_2)$, $V^{(s)}(\vec{k}_1, \vec{k}_2, \dots, \vec{k}_s)$ are electron annihilation (creation) operators, phonon annihilation (creation) operators, electron band energy, phonon frequency(in energy unit), electron phonon coupling constant, force constant change parameter, mass change parameter, and Fourier transforms of atomic force constants respectively which are defined in references (Maradudin et al., 1971: Frohlich, 1966 : Fan, 1987 : Feinberg et al., 1990 : Mahanty and Behera, 1983 : Behera and Mishra, 1985 : Ziman,1969 : Sharma and Bahadur, 1975 : Sahu and Sharma,1983 : Pathak 1965: Indu, 1990). The Fourier transformed electron Green's function $G_{qq}(\varepsilon)$ can be obtained with the help of Hamiltonian eqs.(3a-3e) by applying equation of motion technique of quantum dynamics, and Dyson equation approach as(Zubarev,1960 : Sharma and Bahadur, 1975 : Sahu and Sharma, 1983 : Indu,1990 : Painuli et al., 1993 : Srivastava et al. 1996)

$$G_{qq}(\varepsilon) = \left(\frac{\delta_{qq}}{\pi} \right) [(\varepsilon - \tilde{\varepsilon}_q) + i\Gamma_{ep}(kqQ, \varepsilon)]^{-1} \quad (5)$$

In eq.(5), perturbed mode energy $\tilde{\varepsilon}_q$ is given as

$$\tilde{\varepsilon}_q = \varepsilon_q + \Delta_{ep}(kqQ, \varepsilon) \quad (6)$$

An electron phonon linewidth $\Gamma_{ep}(kqQ, \varepsilon)$ and electron phonon shift $\Delta_{ep}(kqQ, \varepsilon)$

of eq.(5) and eq.(6) are related through response function $P_{ep}(kqQ, \omega)$ as

$$P_{ep}(kqQ, \omega) = \Delta_{ep}(kqQ, \varepsilon) - i\Gamma_{ep}(kqQ, \varepsilon), \quad \omega \rightarrow 0^+ \quad (7)$$

This technique gives electron phonon linewidth $\Gamma_{ep}(kqQ, \varepsilon)$ as

$$\Gamma_{ep}(kqQ, \varepsilon) = \Gamma_{oep}(kqQ, \varepsilon) + \Gamma_{oep'}(kqQ, \varepsilon) + \Gamma_{oe}(kqQ, \varepsilon) + \Gamma_D(kqQ, \varepsilon) + \Gamma_{De}(kqQ, \varepsilon) + \Gamma_{3A}(kqQ, \varepsilon) + \Gamma_{3Ae}(kqQ, \varepsilon) + \Gamma_{4A}(kq, \varepsilon) + \Gamma_{4Ae}(kq, \varepsilon) \quad (8)$$

Where,

$$\Gamma_{oep}(kqQ, \varepsilon) = 4\pi g^2 N_Q \left\{ \varepsilon_{+kq}^2 X_{kq}^2(+) \delta(\varepsilon + \varepsilon_k) - \varepsilon_{-kq}^2 X_{kq}^2(-) \delta(\varepsilon - \varepsilon_k) + 2\varepsilon_q \varepsilon_k (\varepsilon_k^2 - 3\varepsilon_q^2) (X_{kq}^2)^2 \delta(\varepsilon - \varepsilon_q) \right\} \quad (9a)$$

$$\Gamma_{oep'}(kqQ, \varepsilon) = -\pi g^4 \varepsilon_k \left(4\varepsilon_q^2 \tilde{n}_k + 4\varepsilon_q \varepsilon_k \tilde{n}_k + \varepsilon_k^2 n_k + 72 \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 n_{k_1} n_{k_2} + 384 \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 \times n_{k_1} n_{k_2} n_{k_3} + 16 \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 n_{k_1} \right) \left[4^{-1} \varepsilon_k^{-2} X_{Q4k}^2 \left\{ \frac{5}{3} X_{2kq}^2(+) \delta(\varepsilon + 2\varepsilon_k) - X_{2kq}^2(-) \delta(\varepsilon - 2\varepsilon_k) \right\} - 2^{-1} \varepsilon_k^{-2} X_{Qk}^2 \left\{ X_{kq}^2(+) \delta(\varepsilon + \varepsilon_k) - X_{kq}^2(-) \delta(\varepsilon - \varepsilon_k) \right\} \right] \quad (9b)$$

$$\Gamma_{oe}(kqQ, \varepsilon) = \pi g^2 \left(4\varepsilon_q^2 \tilde{n}_k + 4\varepsilon_q \varepsilon_k \tilde{n}_k + \varepsilon_k^2 n_k + 72 \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 n_{k_1} n_{k_2} + 384 \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 \times n_{k_1} n_{k_2} n_{k_3} + 16 \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 n_{k_1} \right) (\varepsilon_q + \varepsilon_Q)^{-2} [\delta(\varepsilon - \varepsilon_q) - \delta(\varepsilon + \varepsilon_Q)] \quad (9c)$$

$$\Gamma_D(kqQ, \varepsilon) = 16\pi g^2 N_Q \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 [X_{k_1q}^2(-) \delta(\varepsilon + \varepsilon_{k_1}) - X_{k_1q}^2(+) \delta(\varepsilon - \varepsilon_{k_1})] \quad (9d)$$

$$\Gamma_{De}(kqQ, \varepsilon) = 64\pi g^2 N_Q \varepsilon_q \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 \varepsilon_{k_1} (X_{k_1q}^2)^2 \delta(\varepsilon - \varepsilon_q) \quad (9e)$$

$$\Gamma_{3A}(kqQ, \varepsilon) = 36g^2 N_Q \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 \eta_1 [S_{+1} \{X_{+\alpha q}^2(+) \delta(\varepsilon + \varepsilon_{+\alpha}) - X_{+\alpha q}^2(-) \delta(\varepsilon - \varepsilon_{+\alpha})\} + S_{-1} \{X_{-\alpha q}^2(+) \delta(\varepsilon + \varepsilon_{-\alpha}) - X_{-\alpha q}^2(-) \delta(\varepsilon - \varepsilon_{-\alpha})\}] \quad (9f)$$

$$\Gamma_{3Ae}(kqQ, \varepsilon) = 144g^2 N_Q \varepsilon_q \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 \eta_1 (S_{+1} \varepsilon_{+\alpha} X_{+\alpha q}^2 + S_{-1} \varepsilon_{-\alpha} X_{-\alpha q}^2) \delta(\varepsilon - \varepsilon_q) \quad (9g)$$

$$\Gamma_{4A}(kqQ, \varepsilon) = 32g^2 N_Q \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 \eta_2 [S_{+2} \{X_{+\beta q}^2(+) \delta(\varepsilon + \varepsilon_{+\beta}) - X_{+\beta q}^2(-) \delta(\varepsilon - \varepsilon_{+\beta})\} - S_{-2} \{X_{-\beta q}^2(+) \delta(\varepsilon + \varepsilon_{-\beta}) - X_{-\beta q}^2(-) \delta(\varepsilon - \varepsilon_{-\beta})\}] \quad (9h)$$

$$\delta(\varepsilon - \varepsilon_{+\beta}) \} + 3S_{-2} \{ X_{-\beta q}^2(+) \delta(\varepsilon + \varepsilon_{-\beta}) - X_{-\beta q}^2(-) \delta(\varepsilon - \varepsilon_{-\beta}) \}] \quad (9h)$$

$$\Gamma_{4Ae}(kqQ, \varepsilon) = 128g^2 N_Q \varepsilon_q \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 \eta_2 (S_{+2} \varepsilon_{+\beta} X_{+\beta q}^2 + 3S_{-2} \varepsilon_{-\beta} X_{-\beta q}^2) \delta(\varepsilon - \varepsilon_q) \quad (9i)$$

The various symbols in above eqs.(9a-9i) are given in the following equations as

$$\tilde{n}_k = \langle A_k B_k \rangle ; \tilde{n}_k = \langle B_k^* B_k \rangle ; n_k = \langle A_k^* A_k \rangle ; \varepsilon_{\pm\alpha} = \tilde{\varepsilon}_{k_1} \pm \tilde{\varepsilon}_{k_2} ; \varepsilon_{\pm\beta} = \tilde{\varepsilon}_{k_1} \pm \tilde{\varepsilon}_{k_2} \pm \varepsilon_{k_3} ;$$

$$\varepsilon_{\pm kq}^2 = \varepsilon_k^2 - \varepsilon_q^2 \pm \varepsilon_q \varepsilon_k \quad (10a)$$

$$N_Q = \langle b_Q^* b_Q \rangle ; n_k = \left(\frac{\tilde{\varepsilon}_k}{\varepsilon_k} \right) \text{Coth} \left(\frac{\beta \hbar \varepsilon_k}{2} \right) \quad (10b)$$

$$S_{\pm 1} = n_{k_2} \pm n_{k_1} ; S_{\pm 2} = 1 \pm n_{k_1} n_{k_2} + n_{k_2} n_{k_3} \pm n_{k_3} n_{k_1} \quad (10c)$$

$$\eta_{i-1} = \frac{\varepsilon_{k_1} \varepsilon_{k_2} \dots \varepsilon_{k_i}}{\tilde{\varepsilon}_{k_1} \tilde{\varepsilon}_{k_2} \dots \tilde{\varepsilon}_{k_i}} ; X_{ij}^2(\pm) = \frac{1}{(\varepsilon_i \pm n_{\varepsilon_j})^2} ; n^{\cdot} = 1, 2 ; i = k, k_1, \pm\alpha, \pm\beta ; j = q ;$$

$$X_{lm}^2 = \frac{1}{(\varepsilon_l^2 - n^{\cdot} \varepsilon_m^2)} ; n^{\cdot} = 1, 4 ; l = k, k_1, \pm\alpha, \pm\beta, Q ; m = k, q \quad (10d)$$

An electron phonon linewidth of eq.(8) represented by (oep ,oep`), (D,De), (3A,3Ae), and (4A,4Ae) are contributed by interaction of electron with harmonic field, localized field, cubic anharmonic field and quartic anharmonic field respectively.

4. Effect of Phonon-phonon Interaction on Spectral Density Function

The spectral density function $J_{qq}(kqQ)$ can be obtained by substitution of imaginary part of eq.(5) into eq.(1) through eqs.(9a-9i) as(Painuli et al.,1993; Srivastava et al.,1996)

$$J_{qq}(kqQ) = J_{qq}^{oep}(kqQ) + J_{qq}^{oep'}(kqQ) + J_{qq}^{oe}(kqQ) + J_{qq}^D(kqQ) + J_{qq}^{De}(kqQ) + J_{qq}^{3A}(kqQ) + J_{qq}^{3Ae}(kqQ) + J_{qq}^{4A}(kqQ) + J_{qq}^{4Ae}(kqQ) \quad (11)$$

Each terms of eq.(11) are given as

$$J_{qq}^{oep}(kqQ) = 8g^2 k_B \hbar^{-1} N_Q T X_{eq} \{ \varepsilon_{+kq}^2 X_{kq}^2(+) \delta(\varepsilon + \varepsilon_k) - \varepsilon_{-kq}^2 X_{kq}^2(-) \delta(\varepsilon - \varepsilon_k) + 2\varepsilon_q \varepsilon_k (\varepsilon_k^2 - 3\varepsilon_q^2) X_{kq}^2 \} \delta(\varepsilon - \varepsilon_q) \quad (12a)$$

$$J_{qq}^{oep'}(kqQ) = -2g^4 k_B \hbar^{-1} T \varepsilon_k X_{eq} \left(4\varepsilon_q^2 \tilde{n}_k + 4\varepsilon_q \varepsilon_k \tilde{n}_k + \varepsilon_k^2 n_k + 72 \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 n_{k_1} n_{k_2} + 384 \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 \times n_{k_1} n_{k_2} n_{k_3} + 16 \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 n_{k_1} \right) \left[4^{-1} \varepsilon_k^{-2} X_{Q4k}^2 \{ \frac{5}{3} X_{2kq}^2(+) \delta(\varepsilon + 2\varepsilon_k) - X_{2kq}^2(-) \delta(\varepsilon - 2\varepsilon_k) \} - 2^{-1} \varepsilon_k^{-2} X_{Qk}^2 \right]$$

$$\left\{ X_{kq}^2(+)\delta(\varepsilon + \varepsilon_k) - X_{kq}^2(-)\delta(\varepsilon - \varepsilon_k) \right\} \quad (12b)$$

$$J_{qq}^{oe}(kqQ) = 2g^2 k_B \hbar^{-1} T \left(4\varepsilon_q^2 \tilde{n}_k + 4\varepsilon_q \varepsilon_k \tilde{n}_k + \varepsilon_k^2 n_k + 72 \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 n_{k_1} n_{k_2} + 384 \right. \\ \left. \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 n_{k_1} n_{k_2} n_{k_3} + 16 \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 n_{k_1} \right) (\varepsilon_q + \varepsilon_Q)^{-2} \\ X_{\alpha q} [\delta(\varepsilon - \varepsilon_q) - \delta(\varepsilon + \varepsilon_Q)] \quad (12c)$$

$$J_{qq}^D(kqQ) = 32g^2 k_B \hbar^{-1} T N_Q \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 X_{\alpha q} [X_{k_1 q}^2(-)\delta(\varepsilon + \varepsilon_{k_1}) - X_{k_1 q}^2(+)\delta(\varepsilon - \varepsilon_{k_1})] \quad (12d)$$

$$J_{qq}^{De}(kqQ) = 128g^2 k_B \hbar^{-1} T N_Q \varepsilon_q \sum_{k_1} |D(\vec{k}_1, -\vec{k})|^2 \varepsilon_{k_1} X_{\alpha q} (X_{k_1 q}^2)^2 \delta(\varepsilon - \varepsilon_q) \quad (12e)$$

$$J_{qq}^{3A}(kqQ) = 72g^2 N_Q \pi^{-1} \hbar^{-2} k_B^2 T^2 \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 (\varepsilon_{k_1}^{-1} + \varepsilon_{k_2}^{-1}) X_{\alpha q} \eta_1 [X_{+\alpha q}^2(+)\delta(\varepsilon + \varepsilon_{+\alpha}) - X_{+\alpha q}^2(-)\delta(\varepsilon - \varepsilon_{+\alpha})] \quad (12f)$$

$$J_{qq}^{3Ae}(kqQ) = 288g^2 \varepsilon_q N_Q \pi^{-1} \hbar^{-2} k_B^2 T^2 \sum_{k_1, k_2} |V^{(3)}(\vec{k}_1, \vec{k}_2, -\vec{k})|^2 \eta_1 \varepsilon_{+\alpha} X_{+\alpha q}^2 (\varepsilon_{k_1}^{-1} + \varepsilon_{k_2}^{-1}) X_{\alpha q} \delta(\varepsilon - \varepsilon_q) \quad (12g)$$

$$J_{qq}^{4A}(kqQ) = 64g^2 N_Q \pi^{-1} \hbar^{-3} k_B^3 T^3 \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 (\varepsilon_{k_1}^{-1} \varepsilon_{k_2}^{-1} + \varepsilon_{k_2}^{-1} \varepsilon_{k_3}^{-1} + \varepsilon_{k_3}^{-1} \varepsilon_{k_1}^{-1}) \\ X_{\alpha q} \eta_2 [X_{+\beta q}^2(+)\delta(\varepsilon + \varepsilon_{+\beta}) - X_{+\beta q}^2(-)\delta(\varepsilon - \varepsilon_{+\beta})] \quad (12h)$$

$$J_{qq}^{4Ae}(kqQ) = 256g^2 \varepsilon_q N_Q \pi^{-1} \hbar^{-3} k_B^3 T^3 \sum_{k_1, k_2, k_3} |V^{(4)}(\vec{k}_1, \vec{k}_2, \vec{k}_3, -\vec{k})|^2 \eta_2 \varepsilon_{+\beta} X_{+\beta q}^2 (\varepsilon_{k_1}^{-1} \varepsilon_{k_2}^{-1} + \varepsilon_{k_2}^{-1} \varepsilon_{k_3}^{-1} + \varepsilon_{k_3}^{-1} \varepsilon_{k_1}^{-1}) \\ X_{\alpha q} \delta(\varepsilon - \varepsilon_q) \quad (12i)$$

where,

$$X_{\alpha q} = \left\{ \varepsilon (\varepsilon^2 - \tilde{\varepsilon}_q^2) \right\}^{-1} \quad (13)$$

5. Conclusion

The present study is based on different interactions as of electron with harmonic, localized and anharmonic fields. This many body approach based on electron Green's function gives various contributions to spectral density function. It is found that cubic and quartic anharmonic parts are depended as T^2 and T^3 on temperature in comparison to T dependence on temperature due to harmonic part, electron part, and defect part. One phonon bound state, two phonon bound state, exciton state are found in harmonic field, exciton state, polaron state are found in electron electron field, two phonon combination and difference bands $\varepsilon_{\pm\alpha}$, exciton state are found in cubic anharmonic field, three phonon combination and difference bands $\varepsilon_{\pm\beta}$, exciton state are occurred

in quartic anharmonic field. When one phonon bound state, two phonon state, localized state, two and three phonon combination and difference bands are approached to the exciton state, the intensity of peaks of perturbed spectrum increases asymptotically. It is also known that three phonons and four phonons are participated to form a exciton. The presence of N_Q in each term is the birth of polaron besides electron electron interaction part. The non-linear dependence on electron phonon coupling constant, force constant change parameter, atomic force constants are the factors which greatly influenced this property. The non-linear dependence on electron phonon coupling constant of delta function peaks shows that in semiconductor crystal this type of response only due to electron phonon interaction. It is concluded that if creation of exciton state is due to destruction of polaron state, then electron electron interaction field contributes significantly for spectral density function. When frequency becomes identical with perturbed mode energy, spectral density function shows sharper peaks of excitations namely harmonic phonon, localized phonon, exciton, polaron, combination, and difference bands. The study of spectral density function will help in explaining the different physical properties of semiconductor crystal particularly optical related properties.

References

- A. A. Maradudin, E. W. Montroll, G. H. Weiss, and I. P. Ipatova, (1971), Solid State Physics, Supplement 3, Theory of Lattice Dynamics in the Harmonic Approximation 2nd edition, Academic Press, New York, London, ch.2, 56.
- Averyanov Dmitry V., Teterin Peter E., Sadofyev Yuri G., Likhachev Igor A., Primenko Alexey E., Tokma Chev Andrey M., and Storchak Vyachslav G., 2015, Epitaxial Growth of Magnetic Semiconductor EuO on Silicon By Molecular Beam Epitaxy, Crystal Research and Technology, 50(3), 268-275[DOI: 10.1002/crat201500005].
- Behera S. N., and Mishra S. G., 1985, Electron - Phonon Interaction in Charge – density - wave Superconductors, Physical Review B, 31(5), pp 2773-2775.
- Feinberg D., Ciuchi S., and dePasquale F., 1990, Squeezing Phenomena in Interacting Electron– Phonon Systems, International Journal of Modern Physics B, 4(7 & 8), pp 1317-1367.
- Frohlich H. (1966), New Perspectives In Modern Physics, Ed. R. E. Marshak, John Wiley & Sons, New York, 539.
- H. Y. Fan, (1987), Elements of Solid State Physics, John Wiley & Sons, New York, 183&184.
- Indu B. D., 1990, Theory of Lattice Specific Heat of an Isotopically Disordered Anharmonic Crystal, International Journal of Modern Physics B, 4(7 & 8), pp 1379-1393.

J. Callaway(1974), Quantum Theory of the Solid State (Part A), Academic Press, New York, London, ch.1,1.

J. M. Ziman, (1969), Elements of Advanced Quantum Theory, Cambridge University Press, Cambridge, ch. 2, 38 & 43.

Liu Junwei, Qian Xiaofeng, and Fu Liang, 2015, Crystal Field Effect Induced Topological Crystalline Insulators In Monolayer IV-VI Semiconductors, Nano Letters,15(4), 2657-2661 [10.1021/acs.nanolett.5b00308].

Mahanty G. C., and Behera S. N., 1983, Dispersion of Superconducting Gap Excitations in Layered Charge Density Wave Systems, Canadian Journal of Physics, 61(8), pp 1160-1168.

O. Madelung , (1978), Introduction to Solid-State theory, Springer Series in Solid-State Sciences ; Vol. 2 , Translated by B. C. Taylor ,Eds. Manuel Cardona , Peter Fulde , Hans-Joachim Queisser, Springer-Verlag Berlin Heidelberg, ch.3 and Ch. 7.

Painuli C.P., Chandra Jagdish, and Indu B.D., 1993, Infrared Absorption in Defect Induced Anharmonic Solids, Pramana Journal of Physics, 40(5), pp 345-356.

Pathak K. N., 1965, Theory of Anharmonic Crystals, Physical Review,139(5A), pp A1569-A1580.

Sahu D. N., and Sharma P. K., 1983, Thermal Conductivity of an Imperfect Anharmonic Crystal, Physical Review B, 28(6), pp 3200-3213.

Sharma P. K., and Bahadur R., 1975, Thermal Conductivity for Phonon Scattering by Substitutional Defects in Crystals, Physical Review B, 12(4), pp 1522-1530.

Srivastava S., Raiwani Y.P., Gairola S.C., and Indu B. D., 1996, Electrons in Anharmonic Phonon Fields of Low-dimensional High- T_c Superconductors, Physica B, 223 & 224, pp 538-540.

Zubarev D. N., 1960, Double-Time Green Functions in Statistical Physics, Usp. Fiz. Nauk, 71, pp 71-116 [Eng. Transl. Soviet Physics Uspekhi, 1960, 3(3), pp 320-345].