

An review analysis of Intraband and Interband Transition and Absorption in Quantum Well

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ABSTRACT

The system changes its energy exclusively as a result of an interaction with electromagnetic waves (photons). Among the different processes of interaction of electromagnetic fields and matter, the three major processes are absorption, spontaneous emission and stimulated emission. In low dimensional systems, e.g., quantum wells, wires and dots electrons can be excited by photons and jump from one confined energy level to another. Electrons excited from one bound state to another bound state in the conduction band of a quantum well and the transition is called *Intersubband transition*. When a defect is introduced into a perfect lattice the normal modes are changed and absorption will now take place by excitation of single phonons in all modes of appropriate point symmetry over a wide spectral range. It is widely known that the lattice anharmonicity and defects play an important role in the optical absorption in crystals. We have studied the problem of transition and absorption due to defects and anharmonicity in the quantum well using various Green's function formalisms of the many-body theory. It was observed from the present model that optical absorption in quantum wells can be successfully carried out with the help of the present formulation taking into account the influence of the anharmonic effects, isotopic point impurities, and electron phonon interactions. The results presented in the entire are however taken for a general quantum well structure but the can be successfully applied to the specific material model quantum wells.

Keywords- Intraband, Interband, Many body theory, Quantum well.

I. INTRODUCTION

According to quantum theory, the system changes its energy exclusively as a result of an interaction with electromagnetic waves (photons). Among the different processes of interaction of electromagnetic fields and matter, the three major processes are absorption, spontaneous emission and stimulated emission. The properties of photo transitions depend on the wave functions and the energies of the electron states involved in the process. The electron occupancies of the states are also important. The initial and the final states can belong to different electron bands, or to impurities and a band, or to the same band. Depending on these factors, different mechanisms of absorption and emission of light are possible. Among them, the most important are (i) Interband phototransitions (ii) Impurity to band transitions (iii) Intraband transitions (iv) Excitonic transitions (v) Phonon transitions, etc. All these phototransitions contribute to the overall absorption in a wide spectral region from far-infrared up to ultraviolet spectra. Absorption of light by a perfect crystal due to the creation of single phonon only takes place

under very restrictive selection rules[1-5]. Electrons in semiconductor material can absorb photons and be excited from valence band to conduction band. This is called Interband transition.

The inverse of this process occurs when electrons decay from higher energy level, such as conduction band, to lower energy level, such as valence band and photons are emitted. Electrons can absorb photons and be excited from one state to another within a particular band such as conduction band. This transition is called an Intraband transition. In low dimensional systems, e.g., quantum wells, wires and dots electrons can be excited by photons and jump from one confined energy level to another. Electrons excited from one bound state to another bound state in the conduction band of a quantum well (say) the transition is called Intersubband transition. When absorption does occur in ionic crystals, the interaction is very strong and perform phenomena results [6, 7]. Only a restricted amount of information about the vibration spectrum of crystals can, therefore, be obtained in this way. Optical absorption arising from the simultaneous creation of two phonons can give

much more information [6]. When a defect is introduced into a perfect lattice the normal modes are changed and absorption will now take place by excitation of single phonons in all modes of appropriate point symmetry over a wide spectral range, provided, of course, that charged ions are present [8].

It is widely known that the lattice anharmonicity and defects play an important role in the optical absorption in crystals. In the harmonic approximation, the linear terms in the dipole moment expansion in terms of nuclear displacements give rise to a set of temperature independent delta-function peaks at long wavelength transverse optical mode frequencies [3, 6-9]. Recent developments in the solid state theory indicate that the discrepancies between theory and experiments can be understood by considering two higher-order effects, namely, anharmonic term in the expansion of the potential energy. It is generally shown that anharmonic terms in the potential energy expansion cause the broadening of the lattice absorption lines in the immediate vicinity of the peak. The presence of defects in the crystals greatly modifies their optical and dynamical properties [10-14].

During the last few years, a number of published papers have been devoted to the theoretical analysis of the infrared absorption in ionic crystals. Many workers [15-25] have studied the effects of anharmonicity in this problem using different models and approaches. In their monograph, Born and Huang proposed a quantum mechanical theory of infrared dispersion in ionic crystals. The theory of Born and Huang has also been revised in a paper by Maradudin and Wallis [19]. The energy spectrum of a confined system is different from that of a bulk material because of additional quantization of both electrons and holes. There has been considerable interest in studying the behavior of impurity atoms with respect to their influence on the lattice dynamics and optical absorption. A huge amount of literature [13-25] is available, on infrared absorption in both pure and doped crystals. Contrary to other investigations [26, 27] Semwal and Sharma [3] showed that there are not only two side bands equally spaced from the central maximum but also a large number of equally spaced side bands exhibit their presence on the either side of the maximum with temperature dependence. This is due to neglecting anharmonic terms but taking into account the defect parameters in Hamiltonian. In studying the optical properties of solids

containing randomly distributed substitutional impurities, both defect and anharmonic parameters lead to some interesting features [28, 29].

In the present investigation, we adopted the many body quantum dynamical approach to reported the effects of anharmonicities on the transition and absorption within quantum well systems. And the obtained results make good sense with the phenomenological theory.

Theory

There are different physical factors that affect the interband optical spectra and cause them to differ from the ideal step like shape. One of them is the broadening of the spectra due to intraband scattering processes. Indeed, intraband-scattering processes lead to uncertainties of the electron and the hole energies. The energy uncertainties or in other words, the broadening of the energy levels result in the broadening of the optical spectra. Thus the spectral shape of the intensities of interband transitions becomes smooth and broad in spite of the sharp step like density of states [30].

The optical absorption coefficient [2], related to the displacement-displacement Green's function can be written in the form,

$$\alpha(\varepsilon) = \left(\frac{4\pi\varepsilon}{\eta c}\right) \text{Im} \left[\sum_{\alpha,\beta} \sum_{l,l'} e_{\alpha}(l) e_{\beta}(l') t_{\alpha} t_{\beta} G_{\alpha\beta}(l', \varepsilon) \right] \quad (1)$$

Where

$$G_{\alpha\beta}(l', \varepsilon) = \left(2\pi/\hbar\right) \langle\langle U_{\alpha}(l); U_{\beta}(l') \rangle\rangle_{\varepsilon} \quad (2)$$

Where ε is the refractive index, c is the velocity of electromagnetic radiation of frequency ε . $U_{\alpha}(l)$, $e_{\alpha}(l)$ and t_{α} are the displacement, effective charge on the α^{th} atom in the l^{th} unit cell and the polarization vector of the incident radiation respectively, and $\langle\langle \dots \rangle\rangle_{\varepsilon}$ stands for the Fourier transform of the thermodynamic double-time temperature- dependent retarded Green's function. For a diatomic crystal with reduced mass

$$\mu^{-1} = \frac{M_1 M_2}{M_1 + M_2}$$

M_1 and M_2 are the masses of two atoms. The above Equation (1) can be arranged as,

$$\alpha(\varepsilon) = \left(\frac{4\pi N e^2 \mu}{\eta c}\right) \left(\frac{\pi \mu \varepsilon}{\varepsilon_0}\right) \text{Im} G(k, \varepsilon) \quad (3)$$

Where N describes the number of cells in the crystal and ε_0 is the transverse optical mode energy (frequency) at $\mathbf{k}=0$ for the host lattice. The linear

infrared absorption coefficient $\alpha(s)$ can easily be obtained on substitution of imaginary part of Green's function into Eq. (3).

It is known that the absorption coefficient of a harmonic crystal is independent of temperature which is not in compliance to the experimental observations that the temperature play an important role in the absorption spectra, which can only be explained by considering the higher-order phonon processes arising from the anharmonic terms in the potential energy or nonlinear terms in the dipole moment or both.

II. RESULTS AND DISCUSSION

In the case of quantum wells, an absorbed photon can transfer its energy to an electron or a hole, thereby increasing its energy within the same band. Free carrier transitions require the participation of a third particle (another carrier, defect, phonon etc.). Inverse processes such as emission of infrared photons, also occur. In contrast, to bulk materials, intra-band photo transitions occur in semiconductor hetero structures. In an ideal bulk crystal, intra band photo-transitions are impossible because of the energy and momentum conservation laws. Intraband transitions can be induced only by phonons, impurities and other crystal imperfections [30].

If one starts with transitions between single particle states one finds that as a result of confinement in the k_z - direction leads to the formation of subbands starting at discrete energies and having free dispersion in the k_x and k_y -directions. We concentrate on the behavior near the optical threshold since in this energy range the differences with quantum confined systems are

extremely important. The conduction and the valence bands may be described by the parabolic bands of the effective masses m_e^* and m_h^* (e for electron and h for hole), respectively. In the present work if we neglect the intricate anisotropic dispersion in the valence band, the absorption coefficient may be described in the following form,

$$\alpha(\epsilon) = \frac{\hbar}{\epsilon} |M_{cv}(k)|^2 \delta\left(\epsilon_c - \epsilon_v - \epsilon + \frac{\hbar k^2}{2m_e^*} + \frac{\hbar k^2}{2m_h^*}\right)$$

Where s and s_v are conduction and valence band energies with band gap energy $s_g = s_c - s_v$ and $M_{cv}(k)$ stand for the optical matrix elements. After some algebraic simplifications and introducing the concept of reduced (effective) mass this expression then reduces to

$$\alpha(\epsilon) = \frac{\hbar}{\epsilon} |M_{cv}(k)|^2 \frac{2m^*}{\pi \hbar^2} \sum_{m,n} \theta(\epsilon_g + \epsilon_m + \epsilon_n + \epsilon_{||})$$

The absorption coefficient for a quantum well obviously has a staircase like shape. Using appropriate simplification the expressions for the various contributions of absorption coefficient for a quantum well can be easily obtained.

It is worth mentioning that marked absorption takes place at

$$\epsilon'' = \pm(\epsilon n + \epsilon \bar{q}), \pm(\epsilon + \epsilon n), \pm \epsilon q$$

where the delta function peaks may be prominently seen. Additionally the effect of anharmonicities can be explored in the form of temperature dependent bands and subbands in the quantum wells. This becomes more obvious if one studies the influence of $S_{\pm\alpha}$ and $S_{\pm\beta}$ which are temperature dependent distribution functions. These variations are depicted in figures 1 and 2.

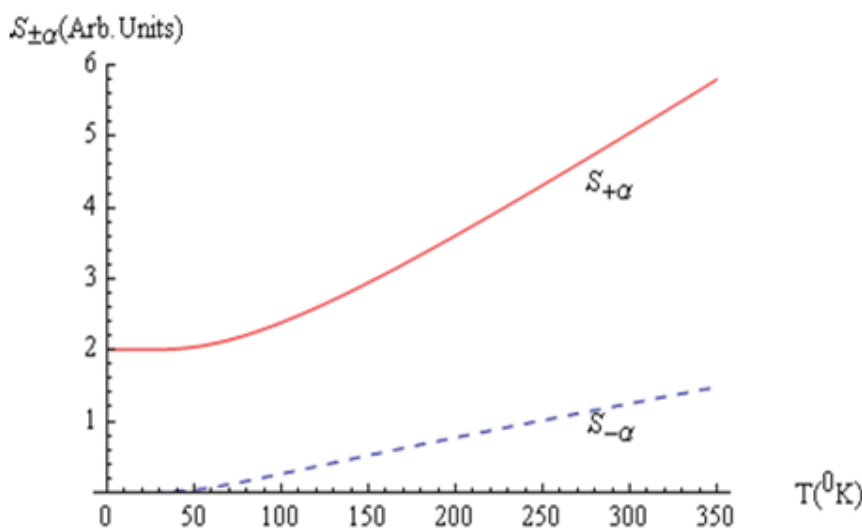


Figure 1: variation of $S_{\pm\alpha}$ and $S_{\pm\beta}$ with temperature T.

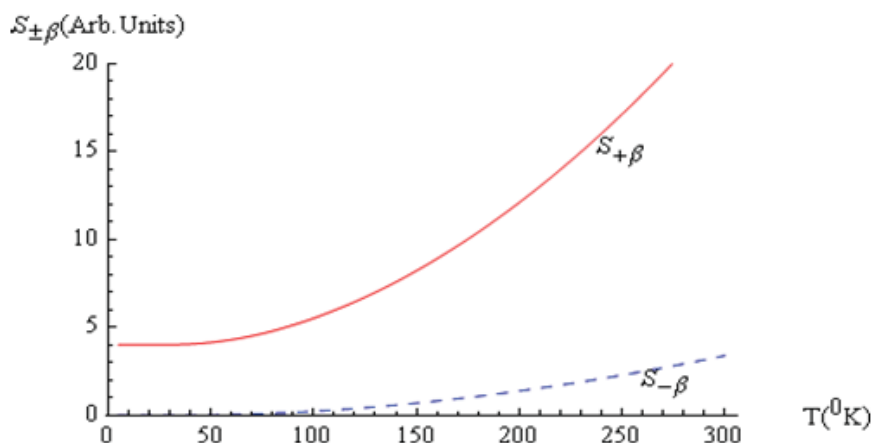


Figure 2: variation of $S_{\pm\alpha}$ and $S_{\pm\beta}$ with temperature T.

Adopting the in plane wave vector conservation rule with kz -confinement two situations for the optical absorption depending on the polarization of light may be possible, namely; along k_x - and k_y - polarizations. This problem then becomes the two dimensional analogue of a three dimensional problem. For direct transitions the phonons act as mediators. With a k_z - polarization the direct transitions are allowed between different subbands (Intraband transitions). If only one subband $n = 1$ is populated in the initial state then the delta function in the absorption coefficient is replaced by $\delta(s_m - s_1 + s)$ with adequate description of $s_{||}$.

III. CONCLUSION

It emerges from the present study that the study of optical absorption in the low dimensional systems (especially in quantum wells) can be successfully carried out with the help of the present formulation taking into account the influence of the anharmonic effects, isotopic point impurities, and electron phonon interactions. The results presented in the entire are however taken for a general quantum well structure but the can be successfully applied to the specific material model quantum wells.

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