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The magnetic properties of optical Quantum transitions of electron-piezoelectric potential interacting systems in CdS and ZnO

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Abstract

We investigated theoretically the magnetic field dependence of the quantum optical transition of qusi 2-Dimensional Landau splitting system, in CdS and ZnO. In this study, we investigate electron confinement by square well confinement potential in magnetic field system using quantum transport theory(QTR). In this study, theoretical formulas for numerical analysis are derived using Liouville equation method and Equilibrium Average Projection Scheme (EAPS). In this study, the absorption power, P (B), and the Quantum Transition Line Widths (QTLWS) of the magnetic field in CdS and ZnO can be deduced from the numerical analysis of the theoretical equations, and the optical quantum transition line shape (QTLS) is found to increase. We also found that QTLW, $\gamma(B)_{total}$ of CdS < $\gamma(B)_{total}$ of ZnO in the magnetic field region B<25 Tesla.

Key words : CdS and ZnO, Quantum Transport Theory, EAPS, Electron Phonon Coupling System, QTLS, QTLW.

Ⅰ. Introduction

Studies on the transfer of electrons by magnetic field and optics have been very helpful in studying the electron transfer phenomenon in low dimensional electron system. Many theories have been proposed to solve quantum transport problems[1-14], among them we use the projected Liouville equation method with the Equilibrium Average Projection Scheme (EAPS)[12].

Using Equilibrium Average Projection Scheme(EAPS), quantum transfer theory can be extended to have the advantage of obtaining the quantum response function and the scatter factor formula in one step. In the previous work[12], we applied EAPS theory to Ge and Si. This is because Ge and Si have a lot of experimental data[13] and have a lot of data in non-confining potential systems. Using EAPS theory, we found that the numerical results of Ge and Si are in good agreement with experimental data known from previous studies. It can be seen that EAPS theory can help to study systems of many substances. However, in the case of the previous the extremely weak coupling(EWC) theory, the approximation method was used, which had a

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limitation in the material interpretation. The measured optical absorption spectrum of Ge and Si have a direct effect on the line width of the line shape function of the electric conductivity tensor by the optical absorption spectrum. Therefore, it is important to interpret the theoretical formula in a given confining potential system to represent it as the line-shape function. In recent studies like our references 13-15, we proposed a method to extend EAPS in low-dimensional electronic systems by applying the moderately weak coupling (MWC) approximation method[15-19]. The distribution factor in the MWC scheme shows an adequate explanation for thequantum transition processes. In a previous study of MWC scheme, the intermediate states of quantum transition processes did not appear.

Ⅱ. The absorption power formula and the scattering factor function

When the electronic system is supplied with a static magnetic field $\overrightarrow{B}=B_z\hat{Z}$, the single electron energy state becomes the Landau stage. We select a system of electrons confined in an infinite square well potential (SQWP) between $Z=0$ and $Z=L_z$ in the z-direction. We use the eigenvalue and eigenstate presented in Ref. 9 for a square well potential system. Assuming that the oscillating electric field $E(t)=E_0\exp(i\omega t)$ is applied along the Z axis, the absorption power transmitted to the system is like $P(\omega)=(E_0^2/2)Re\sigma(\omega)$. Where "Re" denotes the real component and $\sigma(\omega)$ is the optical conductivity tensor which is the coefficient of the current formula. Here, the QTLS can be used to know the absorbed power, and the optical QTLW can be known as the scatter factor function. When we examine the electron-phonon interaction system here, we can find the Hamiltonian of the system as Eq. (1).

$$H_s=H_e+H_p+V=\sum_{\beta}<\beta|h_0|\beta>\alpha_\beta^+\alpha_\beta + \sum_q \eta\omega_q b_q^+ b_q+\sum_q\sum_{\alpha,\mu}C_{\alpha,\mu}(q)a_q^+a_\mu(b_q+b_{-q}^+) \quad (1)$$

Here H_e is the electron Hamiltonian, h_0 is a single-electron Hamiltonian, H_P is the phonon Hamiltonian and V is the electron-phonon(or impurity) interaction Hamiltonian. The $b_1(b_2^+)$ are the annihilation operator(creation operator) of boson particle, and q is phonon(or impurity) wave vector. The interaction Hamiltonian of electron-phonon(or impurity) interacting system is $V\equiv\sum_q\sum_{\alpha,\mu}C_{\alpha,\mu}(q)a_\alpha^+a_\mu(b_q+b_{-q}^+)$ where the coupling matrix element of electron-phonon interaction $C_{\alpha,\mu}(q)$ is $C_{\alpha,\mu}(q)\equiv V_q<\alpha|\exp(i\check{q}\cdot\check{\gamma})|\mu>$, $\check{\gamma}$ is the position vector of electron and V_q is coupling coefficient of the materials.

We recently proposed a potential absorption power formula in a paper like our reference 16 in confining potential systems. Using the continuous approximation to the right circularly polarized external field, we can derive the absorption power formula (or the QTLS formula) as shown in Eq. (2).

$$P(\omega)\propto\left(\frac{e^2\omega_c^2}{\pi^2\eta\omega}\right)\frac{\gamma_{total}(\omega_c)\sum_{N_a}\int_{-\infty}^{\infty}dk_{za}(N_a+1)(f_a-f_{a+1})}{(\omega-\omega_c)^2+(\gamma_{total}(\omega_c))^2} \quad (2)$$

where the scattering factor function(or QTLW) is given by

$$\gamma_{total}(\omega)\equiv Re\Xi_{kl}(\omega)\equiv\sum_\mu\sum_{N_\alpha=0}\sum_{N_\beta=0}\gamma_{\alpha,\beta}^\mu \quad (3)$$

$$=\left(\frac{\Omega}{4\pi\eta^2v_s}\right)\left(\frac{\pi}{L_z}(2+\delta(n_\alpha,n_\beta))\right)\frac{\sum_\mu\sum_{N_\alpha=0}\sum_{N_\beta=0}\int_{-\infty}^{\infty}dk_{z\alpha}\int_{-\infty}^{\infty}dq_z Y_{\alpha,\beta}^\mu}{\sum_{N_\alpha=0}^{\infty}\int_{-\infty}^{\infty}dk_{z\alpha}(N_\alpha+1)(f_{\alpha+1}-f_\alpha)}$$

Recently, we suggested the final derivation of the integrand $Y_{\alpha,\beta}^\mu$ of the scattering factor in Ref.[16]. In this study, the results from Eqs. (18) to (23) of Ref. 16 were used.

In this work, in CdS and ZnO, we investigate the optical Quantum Transition Line Shapes(QTLSs) which show the absorption power and the Quantum Transition Line Widths(QTLWs), which show the scattering effect in the electron-piezoelectric potential phonon interacting system. The theory and experiment to analyze the magnetic field dependence of QTLWs is very difficult because the absorption power must be calculated or observed in various external fields. The QTR theory of EAPS is advantageous in this respect because QTLWs can be obtained directly through EAPS in various cases. Calculation of absorption power does not necessarily yield QTLWs. Through numerical analysis of the theoretical equations, we can obtain the results of QTLS and QTLWs, which can analyze the line width and absorption power of CdS and ZnO. To analyze the quantum transition line widths and the quantum transition line shapes, we use the material constants in table 1 and 2. We arrange the material constant at the table[1,2].

Table 1. Material constant of CdS

Symbol	Contents	Value
m^*	Effective mass of electron	$0.19m_0$
$\overline{m}$	Effective mass of hole	$0.7m_0$
ρ	Mass density	$4820kg/m^3$
k	Characteristic constant	$17.88\times10^{-4}eV/K$
$\wp$	Characteristic constant	235
$\overline{K}$	Electromechanical constant	$4.77\times10^{-3}m/s$
$\overline{v_s}$	Speed of sound	3045 m/s
$\widetilde{\epsilon_s}$	Energy gap	0.744 eV
L_z	Length of well of z direction	20×10^{-6} m

Table 2. Material constant of ZnO

Symbol	Contents	Value
m^*	Effective mass of electron	$0.28m_0$
$\overline{m}$	Effective mass of hole	$0.59m_0$
ρ	Mass density	$4090kg/m^3$
k	Characteristic constant	$17.88\times10^{-4}eV/K$
$\wp$	Characteristic constant	204
$\overline{K}$	Electromechanical constant	$6\times10^{-2}m/s$
$\overline{v_s}$	Speed of sound	4300.5 m/s
$\widetilde{\epsilon_s}$	Energy gap	1.219 eV
L_z	Length of well of z direction	20×10^{-6} m

III. The analysis and summary

In FIG. 1, Comparisons of the magnetic field dependence of QTLW, $\gamma(B)_{total}$ of CdS and $\gamma(B)_{total}$ of ZnO ,at T=50, 70, 90, 120 and 210K, is shown. Our results reveal that $\gamma(B)_{total}$ of ZnO < $\gamma(B)_{total}$ of CdS in the magnetic field region B<25 Tesla.

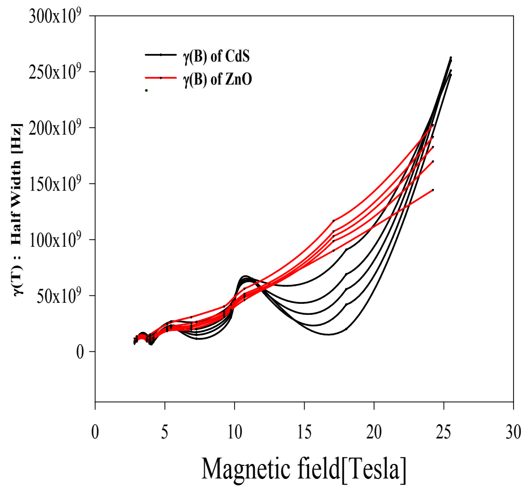
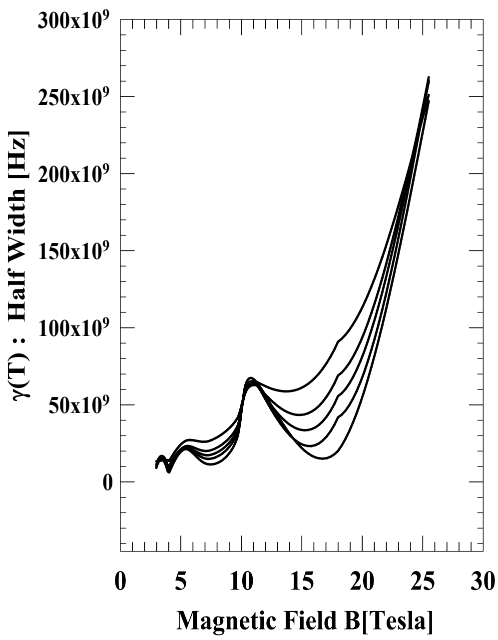
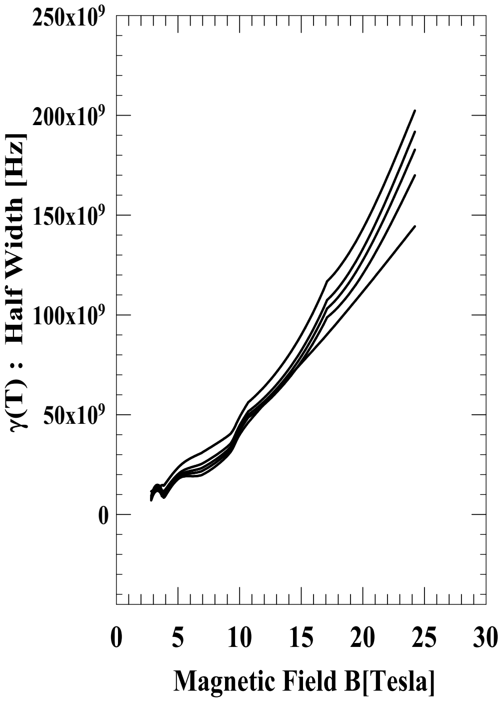


Fig. 1. Comparisons Magnetic field dependence of QTLW, $\gamma(B)_{total}$ of CdS and $\gamma(B)_{total}$ of ZnO at T=50,70,90,120 and 210K(from the bottom line to the top line).



(a) $\gamma(B)$ of CdS



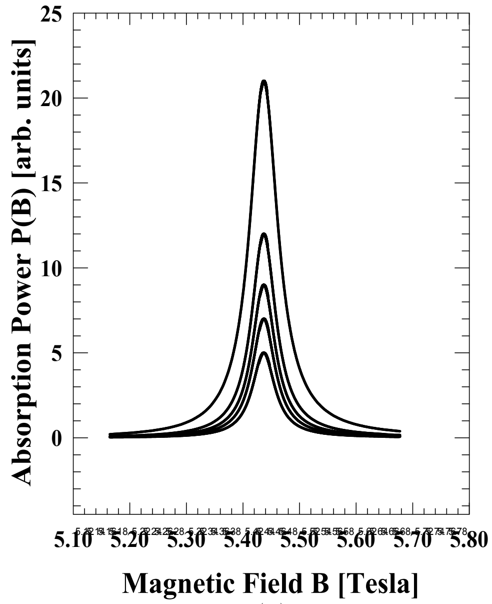
(b) $\gamma(B)$ of ZnO

Fig. 2. Magnetic field dependence of QTLW, at T=50, 70, 90, 120 and 210K (from the bottom line to the top line).

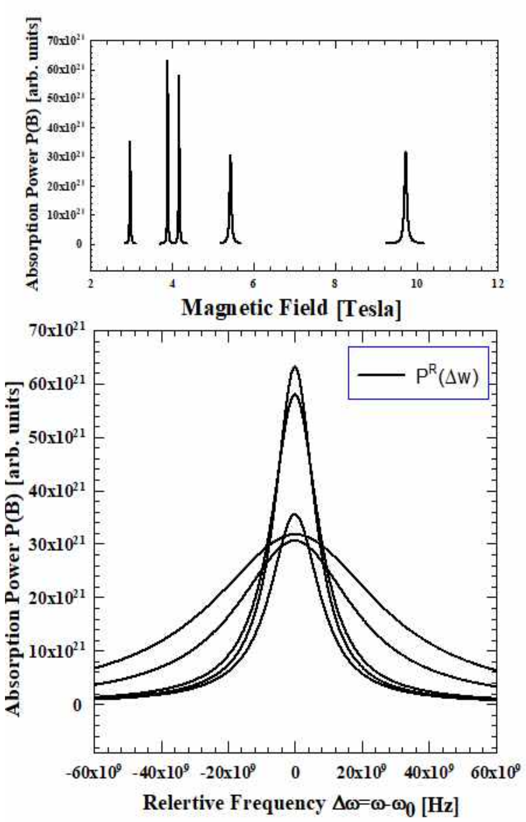
In FIG.2. the magnetic field dependence of QTLW, $\gamma(B)_{total}$ of CdS and $\gamma(B)_{total}$ of ZnO at T=50, 70, 90, 120 and 210K, is plotted separately in log scale.

As shown in FIG. 2, $\gamma(B)_{total}$ of CdS increase as the magnetic field increase and $\gamma(B)_{total}$ of ZnO increase as the magnetic field increase while decrease as the magnetic field in the high magnetic field lager than B=18 Tesla at T=50, 70, 90, 120 and 210K.

FIG. 3(a) represents the magnetic field dependence of the absorption power $P(B)$ of the QTLS of CdS for the external field wave length λ=393 μm at several temperatures, T=50, 70, 90, 120 and 210K. In order to compare the line of QTLS in the same graph, we plot the value of $P_{nr}(B) = \alpha P(B)$ as seen in FIG. 3(a), $P(B)$ increases as the temperature increases.



(a)



(b)

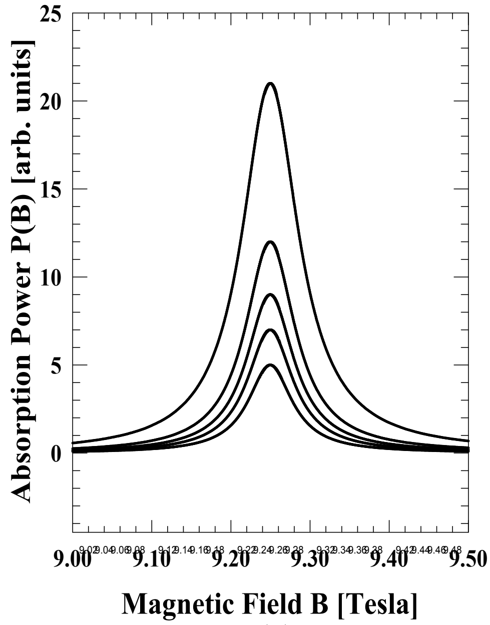
Fig. 3. (a) The Magnetic Field dependence of normalized P(B) (QTLS) with λ=394 μm the a t T=50, 70, 90, 120and 210K. (from the bottom line to top) (b) The relativity frequency dependence of P(Δω) (QTLS) with λ=220, 394,513,550 and 720 μm at T=50K.

Also, the linewidth increases with the increasing temperatures. In the FIG. 3(b), we can read the magnetic-field dependence of the maximum absorption power in upper figure. The bellow figure of FIG. 3(b) shows the relative frequency dependence of the absorption power(QTLS), $P(\Delta\omega)$ of CdS, with λ=220, 394, 513, 550 and 550 μm at T=50K. The relative frequency dependence analysis of the absorption power obtained through QTLS shows the magnetic field dependence of the absorption power at the external field wavelength and the system conditions.

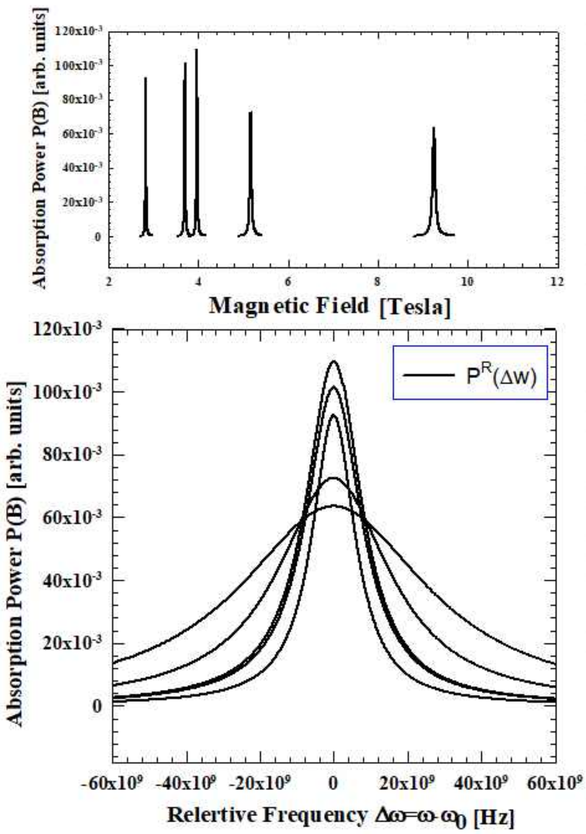
FIG. 4(a) represents the magnetic field dependence of the absorption power of the *P(B)* QTLS of ZnO for the external field wave length λ=393 μm at several temperatures, T=50, 70, 90, 120 and 210K. To compare the magnitude of the values of QTLS over the same figure, we plot the value of $P_{nr}(B)=\alpha P(B)$ here $\alpha \equiv ((T/10)/P_s(B))$. The $P_s(B)$ is the maximum value at T=30K. As seen in FIG. 4(a), normal absorption power, *P(B),* increases as the temperature increases. Also, as the temperature increases, the line width also increases. From these results, it can be concluded that the collision phenomenon of phonons due to the thermal lattice vibration becomes larger as the temperature increases. This can explain the resonance phenomenon of the electron-piezoelectric interaction system.

In the FIG. 4(b), shows the dependence of the maximum absorption power on the magnetic field in upper figure. The figure below in FIG 4(b) illustrates the relative frequency dependence of the absorption power(QTLS), P(Δω) of ZnO, with λ=220, 394, 513, 550 and 550 μm at T=50K. By analyzing the relative frequency dependence of QTLS, we can predict the magnetic field dependence and system of externally applied wavelengths.

In the summary, EAPS theory has an advantage in analyzing the magnetic field dependence of QTLS and QTLW.



(a)



(b)

Fig. 4. (a) The Magnetic Field dependence of normal absorption power(QTLS), P(B), with λ=394 μm the at T=50,70,90,120 and 210K.(from the bottom line to top) (b) The relativity frequency dependence of absorption power(QTLS) with λ =220,394,513,550 and 720 μm at T=50K.

The results of QTLS and QTLW are analyzed according to the magnetic field size of CdS and ZnO. As the magnetic field increases, QTLS and QTLW also increase. We also found that $\gamma(B)_{total}$ of CdS < $\gamma(B)_{total}$ of ZnO in the magnetic field region B<25T esla. This study showed reasonable results for QTLS. This study will theoretically analyze the scattering mechanism due to the interaction of electron-piezoelectric potential, and will be helpful for future experimental analysis.

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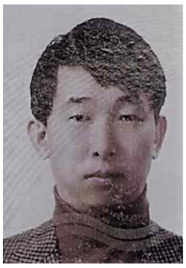

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