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PHONON ASSISTED FREE CARRIER MAGNETO-ABSORPTION IN QUANTUM WELL STRUCTURES.

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The theory of free-carrier absorption (FCA) is developed for quasi-two-dimensional quantum well in a quantizing magnetic field for the case where the carriers are scattered by polar optical phonons, piezoelectric phonons, and nonpolar optical phonons and the radiation field is polarized perpendicular to the plane of the layer. The FCA coefficients found for the case nondegenrate electron gas. For polar and nonpolar optical phonons the FCA coefficient oscillates as a functions of the magnetic field and photon frequency with resonance's occurring when $P\omega_c = \Omega \pm \omega_0$,where ω_c, Ω and ω_0 are the cyclotron, photon and phonon frequency, respectively, and where P is an integer. For elastic scattering with piezoelectric phonons resonance's are expected when $P\omega_c = \Omega$ .The obtained results are compared with those of the theory of FCA in the absence magnetic field.

1.INTRODUCTION

Intraband absorption of light must involve electron momentum transfer, because energy and momentum must be conserved simultaneously. Intraband absorption is dominated by transition via intermediate states in the same band. The role of a third particle that transfers momentum to an electron can be a static defect, an acoustic or optical phonon, or another electron.

In quantum well structures, intraband absorption can ve attributed to both indirect intrasubband optical transitions and direct intersubband transitions between size-quantized subbands (if photon energy corresponds to energy separation between subbands)A quantum theory of the FCA in size-confined systems is well developed, when the absence magnetic fields [1-8]. In this papers have dealt with FCA of electromagnetic radiation which is polarized parallel to the layer plane. The theory FCA n-type GaAs films have investigated [4] two special cases: the radiation field polarized parallel to the layer plane and the radiation field polarized perpendicular to the layer plane. The theory FCA in semiconductors in the presence of a quantizing magnetic field has been studied [9]. In work [10] we have extended the theory of FCA in quasi-two-dimensional systems to take into account the presence of quantizing magnetic fields. The theory was then applied to calculate the FCA of radiation polarized parallel to the magnetic field when acoustic phonon scattering is important. The purpose of this paper is to evaluate the FCA coefficient in a quasi-two-dimensional quantum well in the presence of a magnetic field perpendicular to quantum-well layer. We consider only the scattering of electrons by phonons in the deformation potential model. We will present a calculation of FCA coefficient for electromagnetic radiation polarized parallel to the applied magnetic field.

2.GENERAL RELATIONS

For the size-confined systems we assume quantum well-like structure with an infinite quantum well in the z-direction. The magnetic field H is applied in a direction perpendicular to quantum-well layer. Adopting a single-band spherical effective mass model for electrons, the one electron eigenfunctions ψ_{nlk_y} and energy eigenvalues E_{nl} are

$$E_{nl} = \left(n + \frac{1}{2}\right)\hbar\omega_c + l^2 E_0 \qquad E_0 = \frac{\pi^2\hbar^2}{2m^* d^2}$$

$$\psi_{nlk_y} = \left(\frac{2}{L_y d}\right)^{1/2} \Phi_n(x - x_0) e^{ik_y y} \sin\left(\frac{l\pi z}{d}\right) \qquad (1)$$

respectively. Here $n=0,1,2\ldots$, $l=1,2,3,\ldots$ d is the thickness of the layer and m^* is the effective mass of the electron. Φ_n represents the harmonic oscillator wave function centered at $x_0 = R^2 k_y$ with $R = (\hbar c/eH)^{1/2}$ being the cyclotron radius, and $\omega_c = eH/m^*c$ the cyclotron frequency. n denotes the Landau level index and l denotes level quantization in the z direction.

The FCA coefficient α, which is related to the quantum- mechanical transition probabilities in which the carriers absorb or emit a photon with the simultaneous scattering of the carriers from phonons, is given by [1-4,9]

$$\alpha = \frac{\varepsilon^{1/2}}{n_0 c}\sum_i \left(W_i^{ab} - W_i^{em}\right) f_i \tag{2}$$

Here ε is the dielectric constant of material, n_0 is the number of photons in the radiation field and f_i is the free- carrier distribution function. W_i^{ab} and W_i^{em} represent the transition probabilities for the absorption and emission of photons with simultaneous scattering of carriers by phonons, and can be calculated using the standard second-order Born rule approximation. The sum is over all the possible initial states *'i'* of the system.

We shall use three different scattering processes: polar-optical scattering, piezoelectric scattering and nonpolar-optical scattering. The matrix elements $\langle k'_y n' l' | V_s | k_y n l\rangle$ of electron-phonon interaction corresponding to the above three processes are equal to

$$\langle k'_y\; n' l | V_s | k_y n l\rangle = C'_j \delta_{k'_y, k_y \pm q_y} J_{nn'}\left(q_x q_y\right)\Lambda_{ll'}(q_z)$$

where $J_{n',n}(q_x, q_y)$ is the overlap integral of the harmonic wave functions:

$$J_{n',n}(q_x q_y) = \int_{-\infty}^{\infty} dx \exp(i q_x x)\Phi_{n'}\left(x - R^2 k_y - R^2 q_y\right)\Phi_n\left(x - R^2 k_y\right) \tag{4}$$

$$\Lambda_{ll'}(q_z) = \frac{2}{d}\int_0^{\infty} dz \exp(i q_z z)\sin\left(\frac{l'\pi z}{d}\right)\sin\left(\frac{l\pi z}{d}\right) \tag{5}$$

$$C_j'^2 = C_j^2 F_j(q)$$

Where C_j^2 and $F_j(q)$ depends on the kind of phonons considered. In the case of bulk materials and at extremely strong magnetic fields, the electronic wave functions have small absolute values of momentum components parallel to the applied magnetic field. Therefore we can neglect the q_z dependence in the interaction potential given by C_j'.

3. THE ABSORPTION COEFFICIENT FOR DIFFERENT SCATTERING MECHANISMS

Using Eq. (2) and straightforward calculation of transition probabilities $W_i^{ab.em}$ (10) we obtain the following expression for the FCA for polar, nonpolar and piezoelectric phonon scattering

$$\begin{aligned}
\alpha_{POL}(H) = {} & \frac{2\pi^2 e^4 \hbar\omega_0 n_e sh(\hbar\omega_c/2K_BT)}{\in' m^{*2}\varepsilon^{1/2}\Omega^3 V d^3 c\gamma}\times \\
& \times \sum_{n_f n_i}\frac{1}{n_f - n_i}\sum_{l_f l_i}\sum_{l''}(l'')^2 g_{l_f l_i l''}\times \\
& \times \exp\left\{-\frac{1}{K_BT}\left[\left(n_i + \frac{1}{2}\right)\hbar\omega_c + E_0 l_i^2\right]\right\}\times \\
& \times\left\{N_0\delta\left((n_f - n_i)\hbar\omega_c + \left(l_f^2 - l_i^2\right)E_0 - \right.\right. \\
& - (\hbar\Omega + \hbar\omega_0)) + (N_0 + 1)\delta\left((n_f - n_i)\hbar\omega_c + \right. \\
& \left.\left. + \left(l_f^2 - l_i^2\right)E_0 - \hbar\Omega - \hbar\omega_0\right)\right\}
\end{aligned} \tag{6}$$

where $g_{l_f l_i l''}$ are functions of l_i, l_f, l'', E_0 and $\hbar\Omega$.

Here we assumed $q_\perp >> q_z$ for transport in the (x,y) plane [11].

$$\begin{aligned}
\alpha_{np} = {} & \frac{2\pi e^2 D^2 n_e \omega_c sh(\hbar\omega_c/2K_BT)}{\varepsilon^{1/2} m^* c\rho\omega_0 d^3\Omega^3\gamma}\times \\
& \times\sum_{n_f n_i}\sum_{l_f l_i}\sum_{l''}(l'')^2 g_{l_f l_i l''}\times \\
& \times\exp\left\{-\frac{1}{K_BT}\left[\left(n_i + \frac{1}{2}\right)\hbar\omega_c + E_0 l_i^2\right]\right\} \\
& \left\{N_0\delta\left((n_f - n_i)\hbar\omega_c + \left(l_f^2 - l_i^2\right)E_0 - \hbar\Omega + \hbar\omega_0\right)\right. \\
& \left. + (N_0 + 1)\delta\left((n_f - n_i)\hbar\omega_c - \hbar\Omega - \hbar\omega_0\right)\right\}
\end{aligned} \tag{7}$$

$$\begin{aligned}
\alpha_{PE} = {} & \frac{2\pi K_B T e^4\beta_P^2\hbar^2 n_e sh(\hbar\omega_c/2K_BT)}{\rho\upsilon_s^2\varepsilon^{5/2} m^{*2}\Omega^3 d^3 c\gamma}\times \\
& \times\sum_{n_f n_i}\frac{1}{n_f - n_i}\sum_{l_f l_i}\sum_{l''}(l'')^2 g_{l_f l_i l''}\times \\
& \times\exp\left\{-\frac{1}{K_BT}\left[\left(n_i + \frac{1}{2}\right)\hbar\omega_c + E_0 l_i^2\right]\right\}\times \\
& \times\delta\left((n_f - n_i)\hbar\omega_c + \left(l_f^2 - l_i^2\right)E_0 - \hbar\Omega\right)
\end{aligned} \tag{8}$$

In the case of the two-dimensional system, in quantizing magnetic field FCA coefficient given by Eqs.(11)-(13) diverges under resonance condition through the delta function which reflects the singularities of the density of the states .

4. DISCUSSION

Thus we fund from the above three equations that the FCA coefficient is inversely proportional to the thickness of the well and photon frequency. Our results show that the FCA varies as d^{-3}. This dependence of the FCA coefficients on the thickness of the well has been obtained when the radiation field is polarized perpendicular to the layer plane in the absence of the magnetic field as well[4].

Using the zero-field expression for the FCA coefficient longitudinally polarized radiation in n-type GaAs films for the case carrier a scattered by piezoelectric phonons [4] and (13) we can express our results in terms of the dimensionless ratio of the FCA coefficient in the presence of the magnetic field to that in the absence of the field

$$\alpha_{PE}(H)/\alpha_{PE}(0) = F(T,\omega_c,\Omega) \qquad (9)$$

In this form, the ratio depends only upon the magnetic field, absolute temperature and photon frequency and does not depend upon such material parameters as the values of the deformation potential, sound velocity, or density of the material, although, of course, the absolute value of the absorption coefficient does depend upon the numerical values of these parameters.

In Fig 1 the FCA coefficient due to nonpolar optic phonon is plotted as a function of magnetic field in the range 3-8 T at $\hbar\Omega$=.0.1eV. The resonances in α vs H are noted. It is shown with increase of magnetic field, FCA coefficient increases. Since we introduced broadening in the delta function, the divergence at the resonance condition is removed.

In Fig.2 the FCA coefficient due to nonpolar optic phonon is plotted as a function of photon energy at H=5T. Similar to the magnetic field dependence, the resonances in α vs $\hbar\Omega$ are noted. It is shown with increase of magnetic field, FCA coefficient decreases.

For polar optic phonon and piezoelectric phonon scattering the oscillations in FCA coefficient as a function of magnetic field and photon energy should be similar to that of the nonpolar optical phonon scattering.

Therefore the FCA coefficient in quantizing magnetic fields due to nonpolar, polar optic and piezoelectric phonon as acoustic phonon [10] at resonance condition is directly proportional to the magnetic field. For optical and polar optical phonons the FCA coefficient oscillates as a functions of the magnetic field and photon frequency with resonances occurring when $P\omega_c = \Omega \pm \omega_0$. For elastic scattering with piezoelectrical

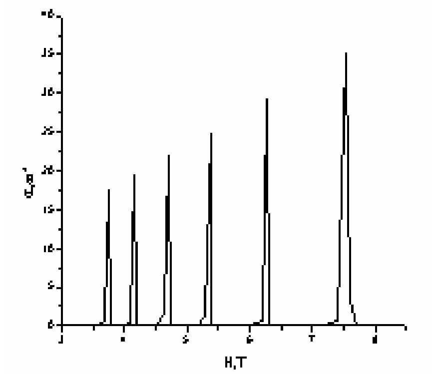

Fig.1 FCA coefficient in the presence of the magnetic field is shown as a function of the magnetic field at T=100K, due to the scattering of electrons by nonpolar optical phonons.

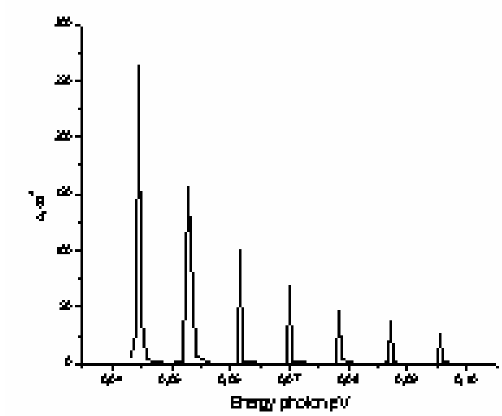

Fig.2 FCA coefficient in the presence of the magnetic field is plotted as a function of the photon energy at T=100K, due to the scattering of electrons by nonpolar optical phonons.

Phonons resonances are expected when $P\omega_c = \Omega$. The magnetic field dependence of the FCA is explained in terms of phonon assisted transitions between the various Landau levels of the carriers.

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