FREE -CARRIER ABSORPTION IN SIZE-CONFINED SYSTEMS IN A QUANTIZINQ MAQNETIC FIELD

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The theory of free-carrier absorption is developed for size-confined systems in a quantizing magnetic field for the case where the carriers are scattered by acoustic phonons via the deformation potential coupling and the radiation field is polarized perpendicular to the plane of the layer. The free-carrier absorption coefficient is found for the case nondegenerate electron gas. The free-carrier absorption is found to be an oscillatory function of the magnetic field. The obtained results are compared with those of the theory of free-carrier absorption in the absence magnetic field.

In the last years the size-confined systems in the presence of a magnetic field have been the subject of numerous experimental and theoretical investigations [1,2]. In quasi - two-dimensional systems magnetic field, which is perpendicular quantum well, transforms the continium electron and hole energetic spectrum to discrete spectrum. Appearance of discrete level should essentially influence on optical properties of quantum well structures. The theory for free-carrier absorption in size-confined systems is well developed, when the absence magnetic fields [3-6]. In these papers the case when the radiation field is polarized parallel to the layer plane is considered. The theory free-carrier absorption in n-type GaAs films has been investigated [7] for two special cases: the radiation field polarized parallel to the layer plane and the radiation field polarized perpendicular to the layer plane. The theory free-carrier absorption in semiconductors in the presence of a quantizing magnetic field has been studied [8] and it was found that the free-carrier absorption coefficient depends upon the polarization of the radiation field relative to the direction of the magnetic field. When the radiation field is polarized perpendicular to the applied magnetic field, then cyclotron-resonance absorption of the radiation occurs. We are interested here in extending the theory of free-carrier absorption in nondegenrate semiconductors in quantizing magnetic fields developed in [8] to the case of quasi-two-dimensional semiconducting systems.

In this paper, we will present a calculation of free-carrier absorption for longitudinally polarized radiation in size-confined systems in the presence of a guantizing magnetic field with acoustic phonon scattered via deformation potential coupling as the dominant scattering mechanism for the carriers.

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 (i.e., perpendicular to the interfaces). Adopting a single-band spherical effective mass model for electrons, the one electron eigenfunctions ψ_{nlk_y} and energy eigenvalues E_{nl} are given by

$$E_{nl}=\left(n+\frac{1}{2}\right)\hbar\omega_c+l^2E_0 \qquad E_0=\frac{\pi^2\hbar^2}{2m^*d^2}$$
$$\psi_{nlk_y}=\left(\frac{2}{L_yd}\right)^{1/2}\Phi_n(x-x_0)e^{ik_yy}\sin\left(\frac{l\pi z}{d}\right) \qquad (1)$$

where $n=0,1,2...,$ $l=1,2,3,...$ 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 $x_0=R^2k_y$ with $R=(\hbar c/eH)^{1/2}$ being the cyclotron radius, and $\omega=eH/m^*c$ the cyclotron frequency. n denotes the Landau level index and l denotes level quantization in the z direction.

The free-carrier absorption coefficient can be related to the quantum-mechanical transition probability for the absorption of photons [8]

$$\alpha=\frac{\varepsilon^{1/2}}{n_0c}\sum_i W_if_i \qquad (2)$$

Here ε is the dielectric constant of material, n_0 the number of photons in the radiation field, f_i is the free carrier distribution function and the sum goes over all the possible initial states of the system. The transition probabilities W_i can be calculated using the standard second-order Born golden rule approximation:

$$W_i=\frac{2\pi}{\hbar}\sum_f\left|\sum_\alpha\left(\frac{<f|H_R|\alpha><\alpha|V_s|i>}{E_i-E_\alpha-\hbar\omega_\alpha}+\frac{<f|H_R|i><f|V_s|\alpha>}{E_i-E_\alpha-\hbar\Omega}\right)\right|^2\times\delta\left(E_f-E_i-\hbar\Omega-\hbar\omega_q\right) \qquad (3)$$

Here E_i, E_α and E_f are the initial, intermediate and final state energies of the electron, H_R is the interaction Hamiltonian between the electrons and the radiation field, V_s is the scattering potential due to the electron-phonon interaction, and

$\hbar\Omega$ and $\hbar\omega_q$ are the energies of the photon and phonon, respectively.

The matrix elements of the electron-photon interaction Hamiltonian using the wave functions are

$$< k_y^{'} n' l' \left| H_R \right| k_y n l > = -\frac{ie\hbar}{m^*}\left(\frac{2\pi\hbar n_0}{\varepsilon\Omega\Omega_0}\right)^{1/2}\frac{l}{d}\left[\frac{1-\cos[\pi(l'-l)]}{l'-l}+\frac{1-\cos[\pi(l'+l)]}{l'+l}\right]\delta k_y^{'} k_y \delta nn' \qquad (4)$$

Here the radiation field is polarized perpendicular to the plane of the layer.

The electron-phonon scattering potential when deformation potential coupling is the dominant interaction mechanism is [8]

$$V_s = \left(\frac{k_\beta T}{2\rho\vartheta_s^2\Omega_0}\right)^{1/2}\varepsilon_d \exp\left(i\vec{q}\cdot\vec{r}\right) \qquad (5)$$

Here $\vec{q}$ is the phonon wave vector, ε_d is the deformation potential constant, ρ is the density of material, v is the sound velocity, T is the absolute temperature and Ω_0 is the volume of the crystal.

The matrix elements of the electron-phonon interaction Hamiltonian, using the wave function of E_g (1), are

$$< k_y^{'} n' l' \left| V_s \right| k_y n l > = \left(\frac{k_B T}{2\rho\vartheta_s^2\Omega_0}\right)^{1/2}\varepsilon_d \delta k_y^{'}, k_y + q_y J_{n'n}\left(q_x, q_y\right)\Lambda_{ll'}\left(q_z\right) \qquad (6)$$

Here

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

$$J_{n'n}\left(q_x q_y\right) = \int_{-\infty}^{\infty} dz \exp\left(iq_x x\right)\Phi_{n'}\left(x - R^2 k_y - R^2 q_y\right)\Phi_n\left(x - R^2 k_y\right)$$

using E_{gs}. (3)-(6) in (2) and also the following properties of the integrals [9]

$$\int_0^\infty \left|J_{nn'}\left(q_x, q_y\right)\right|^2 q_\perp dq_\perp = \frac{1}{R^2} \cdot$$

$$\int_0^\infty \left|\Lambda_{ll'}\left(q_z\right)\right|^2 dq_z = \frac{2\pi}{d}\left(1 + \frac{1}{2}\delta_{ll'}\right)$$

we obtain the following expression for the free-carrier absorption coefficient for acoustic phonon scattering

$$\alpha(H) = \frac{2k_B T\varepsilon_d^2 e^2 n_e \omega_c sh\left(\hbar\omega_c / 2k_B T\right)}{c\rho\vartheta_s^2 m^* \varepsilon^{1/2} d^3 \hbar\Omega^3 \gamma}\sum_{n_f l_f}\sum_{n_i l_i}\sum_{l''}\left(l''\right)^2 \exp\left\{-\frac{1}{k_B T}\left[\left(n_i + \frac{1}{2}\right)\hbar\omega_c + E_0 l_i^2\right]\right\}\cdot g_{l_f l_i l''} \times$$
$$\times \delta\left(\left(n_f^{'} - n_i\right)\hbar\omega_c + \left(l_f^2 - l_i^2\right)E_0 - \hbar\Omega\right)$$

(7)

where

$$g_{l_f l_i l''} = \left[\frac{\dfrac{1-\cos\pi(l_f - l'')}{l_f - l''} + \dfrac{1-\cos\pi(l_f + l'')}{l_f + l''}}{\left(l_f^2 - (l'')^2\right)E_0' - 1}\right]^2 \left(1 + \frac{1}{2}\delta l_e l''\right) +$$

$$+\left[\frac{\dfrac{1-\cos\pi(l''-l_i)}{l_i - l''} + \dfrac{1-\cos\pi(l''+l_i)}{l_i + l''}}{1 + \left(l_i^2 - (l'')^2\right)E_0'}\right]^2 \left(1 + \frac{1}{2}\delta l_f l''\right)$$

Where we have used distribution function for a quasi-two-dimensional nondegenerate electron gas in the presence of the magnetic field

$$f_{nl} = 2\pi n_e dR^2 sh(\hbar\omega_c / 2k_B T)\gamma^{-1} \exp\left\{-\frac{1}{k_B T}\left[\left(n + \frac{1}{2}\right)\hbar\omega_c + E_0 l^2\right]\right\}$$

Where $\gamma = \sum_l \exp\left(-E_0 l^2 / k_B T\right)$, n_e is the concentration of the electrons and $E_0' = E_0 / \hbar\Omega$

In the quantum limit, $\hbar$ free-carrier absorption coefficient takes the particularly simple form

$$\alpha(H) = \frac{k_B T \varepsilon_d^2 e^2 n_e \omega_c'}{c\rho\vartheta_s^2 m^* \in^{1/2} d^3 \hbar^2 \Omega^3} \sum_{n_f l_f} \sum_{l''} (l'')^2 g_{l_f 1 l''} \frac{\Gamma_s' / 2\pi}{\left[n_f \omega_c' + (l_f^2 - 1)E_0' - 1\right]^2 + \left(\Gamma_s' / 2\right)^2} \qquad (8)$$

where $\Gamma_s' = \dfrac{\Gamma_s}{\hbar\Omega}$, $\omega_c' = \dfrac{\omega_c}{\Omega}$

We replace the Dirac delta function in E_g (7) by a Lorentzian of width Γ_s.

From E_g (7) and E_g (8), it can also be seen that the free-carrier absorption coefficient decreases with increasing photon frequency and increases with increasing temperature. The free-carrier absorption coefficient show oscillatory behavior with magnetic field and decrease with increasing well width. The magnetic field dependence of the free-carrier absorption is From expression (8) and (9) we can express our results in terms of the dimensionless ratio of the free-carrier absorption

explained in terms of phonon assisted transitions between the various Landau levels of the carriers.

Using the zero-field expression for the free-carrier absorption coefficient longitudinally polarized radiation in n-type GaAs films for the carriers, which are scattered by acoustic phonons [7]

$$\alpha(0) = \frac{2\pi e^4 n_e k_B T \varepsilon_d^2}{\Omega^3 \in^{1/2} \rho\vartheta_3^2 m^* c d^3} \sum_{nn'} F_{nn'}(\Omega, T, E_0) \qquad (9)$$

coefficient in the presence of the magnetic field to that in the absence of the field

$$\frac{\alpha(H)}{\alpha(0)} = \frac{1}{(2\pi)^4}\omega_c' \frac{\sum\limits_{n_f l_f}\sum\limits_{l''}(l'')^2 g_{l_f 1 l''}\dfrac{\Gamma_s'/2\pi}{\left[n_f\omega_c' + \left(l_f^2-1\right)E_0' - 1\right]^2 + \left(\Gamma_s'/2\right)^2}}{\sum\limits_{nn'}F_{nn'}(\Omega, T, E_0)} \qquad (10)$$

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.

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MAQNİT SAHƏSİNDƏ MƏHDUD ÖLÇÜLÜ SİSTEMLƏRDƏ SƏRBƏST YÜ KDAŞIYICILARINDAN İŞIĞIN UDULMASI

Ölçülü kvantlanma istiqamətində yönələn maqnit sahəsində yerləşən məhdud ölçülü sistemlərdə qəfəsin akustik rəqslərindən səpilən halında sərbəst yükdaşıyıcılarından işığın udulması tədqiq edilmişdir. Elektronların cırlaşmamış halında belə sistemlərdə udulma əmsalı üçün ifadə alınmışdır. Müəyyən olunmuşdur ki, udulma əmsalının maqnit sahəsindən asılılığı ossillasiya xarakteri daşıyır. Alınmış nəticə maqnit sahəsi olmayan halda olan naticələrlə müqayisə olunmuşdur.

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ПОГЛОЩЕНИЕ СВЕТА СВОБОДНЫМИ НОСИТЕЛЯМИ В РАЗМЕРНО-ОГРАНИЧЕННЫХ СИСТЕМАХ В МАГНИТНОМ ПОЛЕ

Исследовано поглощение инфракрасного электромагнитного излучения свободным квазидвумерным электронным газом, рассеяние которых происходит на акустических колебаниях решетки в размерно-ограниченных системах в магнитном поле, направленном параллельно оси пространственного квантования. Получены выражения для коэффициента поглощения в такой системе в случае невырожденной статистики электронов. Найдено, что зависимость коэффициента поглощения света от магнитного поля носит осцилляционный характер. Проведено сравнение полученных результатов с имеющимися для случая без магнитного поля.

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