Indirect electronic transitions in semiconductors occurring as a result of scattering of charge carriers by dislocations in a quantizing magnetic field

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The light absorption due to indirect electronic transitions in a semiconductor in a quantizing magnetic field is calculated under the assumption that an edge dislocation plays the role of a third body. The characteristic light frequency and magnetic field dependences of the absorption coefficient are determined for the mechanism considered. © *1998 American Institute of Physics.* [S1063-7826(98)01104-1]

Indirect interband transitions in a semiconductor with a dislocation mechanism for scattering of charge carriers (CCs) under certain conditions imposed on the temperature and dislocation density can compete with indirect transitions due to the phonon scattering mechanism.[1,2]

In the present paper we study indirect interband transitions of CCs in a semiconductor in a uniform magnetic field with edge dislocations playing the role of a third body.

The light absorption (AC) associated with indirect electronic transitions in an external magnetic field can be calculated in second-order perturbation theory as

$$\alpha(\omega,H)=\frac{2\pi\hbar c}{n_r\omega}\frac{n_D S}{|A_0|^2}\frac{2\pi}{\hbar V}\times\sum_{N,\mathbf{k}}\sum_{N'',\mathbf{k}''}\sum_{N',\mathbf{k}'}\frac{|M^{\mathrm{PHOT}}|^2|M^{\mathrm{DIS}}|^2}{[E_g^0+\varepsilon_{N'}^c(k_z')-\varepsilon_N^v(k_z)-\hbar\omega]^2}\times\delta(E_g+\varepsilon_{N''}^c(k_z'')-\varepsilon_N^v(k_z)-\hbar\omega),\tag{1}$$

where ω and A_0 are the frequency and amplitude of the incident light wave, n_r is the refractive index of the medium, n_D is the dislocation density on an area S, V is the volume of the sample, E_g is the band gap, and E_g^0 is the band gap at the center of the Brillouin zone ($\mathbf{k}=0$):[1)] Since the z axis of the coordinate system is chosen in the direction of the magnetic field $\mathbf{H}$, while the vector potential $\mathbf{A}=(0, Hx, 0)$, the state of an electron in the band l (c or v) is characterized by the set $\{N, k_y, k_z, l\}$.

In interactions of an edge dislocation with CCs the electrostatic part of the potential of the dislocation always predominates over the deformation part. In calculating the matrix element of the electron-dislocation interaction M^{DIS} we can therefore restrict the discussion to the electrostatic part. This potential in the dangling-bond approximation has the form[3]

$$V(\boldsymbol{\rho})=v_0K_0(\lambda\rho),\tag{2}$$

where $\boldsymbol{\rho}$ is the two-dimensional radius vector perpendicular to the line of the dislocation, $K_0(x)$ is the modified Bessel function of order 0, λ is the reciprocal of the Debye screening length, and

$$v_0=\frac{2e^2}{\varepsilon_S a}f.\tag{3}$$

Here a is the distance between the dangling bonds, f is the bond filling factor, and ε_S is the permittivity of the semiconductor.

Calculation of the matrix element M^{DIS} with the potential (2) shows that when the line of the dislocation is perpendicular to the magnetic field, we obtain[2)] the following expression for M^{DIS}:

$$M^{\mathrm{DIS}}=\frac{2\pi}{L_yL_z}\frac{v_0}{\lambda^2+|\mathbf{k}''-\mathbf{k}'|^2}\delta_{N',N''},\tag{4}$$

where L_y and L_z are the linear dimensions of the sample in the corresponding directions.

Using the expression (4) and the well-known expression for the optical matrix element M^{PHOT}, and switching in Eq. (1) from summation over $\mathbf{k}''$ and $\mathbf{k}$ to integration, we finally obtain the following expression for the AC:

$$\alpha(\omega,h)=\frac{2\pi^2n_D}{n_r\hbar\omega}\left(\frac{e}{m_0c}\right)^2(\mathbf{e}\mathbf{p}_{cv}(0))^2\times v_0^2\frac{(m_L^cm^V)^{1/2}}{\hbar^2}\frac{eH}{(\lambda^2+k^2)^{3/2}}\times\sum_N\frac{\Theta\left(\hbar\omega-E_g-\left(N+\frac{1}{2}\right)\hbar\omega_H^*\right)}{\left[E_g^0+\left(N+\frac{1}{2}\right)\hbar\omega_H-\hbar\omega\right]^2},\tag{5}$$

where m_L^c is the electron effective mass at the point $\mathbf{k}_L$ of the main minimum,

$$\omega_H=\frac{eH}{c}\left(\frac{1}{m^c}+\frac{1}{m^v}\right)\quad\text{and}\quad\omega_H^*=\frac{eH}{c}\left(\frac{1}{m_L^c}+\frac{1}{m^v}\right)$$

are reduced cyclotron frequencies.

As one can see from Eq. (5), the dependence of $\alpha(\omega, H)$ on $\hbar\omega-E_g$ for an indirect-gap conductor is of a step char-

acter at the fundamental absorption edge. The jumps correspond to values of $\hbar\omega$, for which transitions between energetically more distant levels are excited.

In contrast to the generally accepted phonon mechanism,[4] the main characteristic features of the light absorption mechanism, studied here, in a semiconductor in an external magnetic field are as follows:

1. $\alpha(\omega,H)\sim H$, i.e., the absorption coefficient for light is directly proportional to the magnetic field, in contrast to the phonon mechanism where the dependence is quadratic.

2. The absorption depends strongly on the momentum transfer $\hbar\mathbf{k}_L(\alpha\sim 1/k_L^3)$, which can give an additional possibility of determining experimentally the displacement of the conduction-band bottom relative to the valence-band top.

3. The absorption coefficient is proportional to the density n_D of scattering dislocations.

The numerical estimates presented here show that, for example, for GaP with density $n_D\simeq 3\times 10^7$ cm^{-2} and magnetic field $H\approx 10^2$ G, the dislocation mechanism can compete with the phonon mechanism even at temperature $T\approx 100$ K.

[1)]The expression (1) takes into account the fact that the valence band is completely filled, while the conduction band is empty.
[2)]It is easy to show that dislocations oriented parallel to **H** do not contribute to indirect transitions.

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