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INTERBAND SINGLE-PHOTON ABSORPTION OF POLARIZED LIGHT IN CRYSTALS WITH ALLOWANCE FOR THE EFFECT OF COHERENT SATURATION. 1-PART

Abstract. The spectral-temperature dependence of the coefficient of single-photon absorption of light in crystals of tetrahedral symmetry, due to optical transitions occurring from the subbands of light and heavy holes to the conduction band, is calculated. In this case, the contribution of the coherent saturation effect to the single-photon light absorption coefficient is taken into account.

Keywords: polarized light, spectral and temperature dependence of the single-photon light absorption coefficient, crystal of tetrahedral symmetry, coherent saturation effect.

As indicated in the first part of this work, the nonlinear absorption of light in a semiconductor with a degenerate valence band, which is due to direct optical transitions between the subbands of heavy and light holes and depends on the state of radiation polarization, was studied in [1–8]. In these papers, it is assumed that the nonlinearity in the intensity dependence of the single-photon absorption coefficient arises due to resonant absorption saturation. This saturation is due to the photoinduced change in the distribution functions of light and heavy holes in the region of momentum space near the surface corresponding $E_{hh}(\vec{k}) - E_{hl}(\vec{k}) - \hbar\omega = 0$ to the resonance condition. Here, $E_{hh}(\vec{k})\left(E_{hl}(\vec{k})\right)$ is the energy spectrum of heavy (light) holes, and ω is the frequency of light.

In [1–10], the spectral-temperature dependence of the single-photon light absorption coefficient was not calculated. This work is devoted to the solution of this issue. For this, we consider various variants of single-photon interband absorption of polarized light, which differ from each other by intermediate states. In particular, in the case of single-photon interband absorption of light, these intermediate states can be located both in the subbands of the valence band, and in the conduction band, or in the spin-orbital splitting band. And also, depending on the energy of photons, optical transitions can occur, which differ from each other by initial states. In particular, in the frequency range $E_g \le \hbar\omega \le E_g + \Delta_{SO}$, optical transitions are allowed between subbands of light or heavy holes, but in the frequency range $\hbar\omega \ge E_g + \Delta_{SO}$, optical transitions from the spin-orbit splitting zone to the conduction band are allowed. Therefore, we will consider them separately, where $\hbar\omega$ is the photon energy, E_g is the band gap, Δ_{SO} is the spin-orbit splitting energy.

Let us first consider the one-photon absorption of light between the subbands of the valence band and the conduction band (at $E_g \le \hbar\omega \le E_g + \Delta_{SO}$). Following [5–10], in further calculations of the spectral and temperature dependence of the single-photon light absorption coefficient, we neglect the light wave vector, i.e. we assume that the wave vector of current carriers in the final (initial and intermediate) state). Then

$$K^{(1)}_{C,\pm1/2;V,\pm3/2} = \frac{2\pi}{\hbar}\hbar\omega\frac{1}{I}\rho(\hbar\omega)F(\beta,1,\omega)\times$$
$$\times\left(\left\langle\frac{\left|M^{(1)}_{C,\pm1/2;V,\pm3/2}(\vec{k})\right|^2}{\sqrt{1+4\frac{\alpha_\omega}{\hbar^2\omega^2}\left|M^{(1)}_{C,\pm1/2;V,\pm3/2}(\vec{k})\right|^2}}\right\rangle+\left\langle\frac{\left|M^{(1)}_{C,\pm1/2;V,\mp3/2}(\vec{k})\right|^2}{\sqrt{1+4\frac{\alpha_\omega}{\hbar^2\omega^2}\left|M^{(1)}_{C,M1/2;V,\mp3/2}(\vec{k})\right|^2}}\right\rangle\right), \quad (1)$$

where $I,(\omega)$ is the intensity (frequency) of light, $\rho(\hbar\omega)$ is the density of states of current carriers involved in optical transitions, where the law of conservation of energy is taken into account, $F(\beta,1,\omega)$ is the distribution function of current carriers in the initial state, k_B is the Boltzmann constant, T is the sample temperature, $F(\beta,1,\omega)=\left[1-\exp\left(1\beta\hbar\omega\right)\right]\cdot$ $\exp\left[\beta\left(\mu-E_{L=hh}(k^{(\omega)}_{c,L=hh})\right)\right]$, $E_{L=hh}(k^{(\omega)}_{c,L=hh}) = =\frac{m_c}{m_c+m_{hh}}\left(\hbar\omega-E_g\right)$, $\rho(\hbar\omega)=\frac{\mu^* k_\omega}{(\pi^2\hbar^2)}$, μ^* is the reduced effective mass of current carriers, the form of which depends on the type of optical transitions. Now we need to calculate

$$\left\langle\frac{\left|M^{(1)}_{C,\pm1/2;V,\pm3/2}(\vec{k})\right|^2}{\sqrt{1+4\frac{\alpha_\omega}{\hbar^2\omega^2}\left|M^{(1)}_{C,\pm1/2;V,\pm3/2}(\vec{k})\right|^2}}\right\rangle = =\left(\frac{eA_0}{c\hbar}\right)^2 p^2\left[\Re_1(I)+\Re_2(I)\right], \quad (2)$$

(it is these integrals that determine the averaged values of the matrix elements of the considered optical transitions) where $\Re_1(\mathrm{I})=\left\langle\frac{|e'_\pm|^2}{\sqrt{1+\zeta_\omega|e'_\pm|^2}}\right\rangle$, $\Re_2(\mathrm{I})=\left\langle\frac{|e'_z|^2}{\sqrt{1+\zeta_\omega|e'_z|^2}}\right\rangle$, $I=\left|\vec{S}\right|=\frac{n_\omega\omega^2A_0^2}{2\pi c}$ is the light intensity, $\left\langle\left|M^{(N)}_{n'k',nk}\right|^2\right\rangle$ is the square of the absolute value of the matrix element $M^{(N)}_{n'\vec{k}',n\vec{k}}$ averaged over the solid angles of the vector $\vec{k}$, $\zeta_\omega=4\frac{\alpha_\omega}{\hbar^2\omega^2}\left(\frac{eA_0}{c\hbar}\right)^2 p^2$, the wave vector k_ω is determined from the energy conservation law. In particular, for the optical transition considered above $k_\omega=k_{c,L}=\sqrt{\frac{2\mu_+^{(c,L)}}{\hbar^2}\left(\hbar\omega-E_g\right)}$, $\mu_+^{(c,L)}=\frac{m_c m_L}{m_c+m_L}$, $E_c\left(\vec{k}\right)=\frac{\hbar^2k^2}{2m_c}+E_g$, $E_L\left(\vec{k}\right)=-\frac{\hbar^2k^2}{2m_L}$ $m_c(m_L)$ are the effective masses in the conduction band and in the valence band, $L=lh$ (hh) are for the subband of light (heavy) holes.

Calculation of single-photon absorption of polarized light due to optical transitions from the subband of light and heavy holes to the conduction band is performed by the formula

$$K^{(1)}=\frac{4\pi e^2}{c\omega m_0^2 n_\omega}\sum_{nn'\vec{k}}\left|\vec{e}\vec{p}_{nn'}\left(\vec{k}\right)\right|^2\left(f_{n\vec{k}}-f_{n'\vec{k}}\right)\delta\left(E_{n'}\left(\vec{k}\right)-E_n\left(\vec{k}\right)-\hbar\omega\right) \quad (3)$$

or

$$K_{c,SO}^{(1)}=\frac{4\pi e^2}{c\hbar n_\omega}\left\{\iiint\frac{1}{2}p_{cV}^2|e'_\pm|^2\left(f_{hh,\vec{k}}-f_{c,\vec{k}}\right)\delta\left(E_c\left(\vec{k}\right)-E_{hh}\left(\vec{k}\right)-\hbar\omega\right)+\right.$$
$$\left.+\left\{\iiint\left(\frac{2}{3}p_{cV}^2|e'_z|^2+\frac{1}{6}p_{cV}^2|e'_\pm|^2\right)\left(f_{lh,\vec{k}}-f_{c,\vec{k}}\right)\delta\left(E_c\left(\vec{k}\right)-E_{lh}\left(\vec{k}\right)-\hbar\omega\right)\right\}\right. \quad (4)$$

where $E_{c,\vec{k}}=\frac{\hbar^2k^2}{2m_c}+E_g$ is the energy spectrum of electrons in the conduction band, $E_{L,\vec{k}}=\frac{\hbar^2k^2}{2m_L}$ is the energy spectrum of holes in the subband of light $(L=lh)$ andheavy $(L=hh)$ holes, $E_{SO,\vec{k}}=\frac{\hbar^2k^2}{2m_c}+\Delta_{SO}$ $E_{SO,\vec{k}}=\frac{\hbar^2k^2}{2m_c}+\Delta_{SO}$ is the energy spectrum of holes in the spin-orbital splitting zone.

Then, from the energy conservation law, we have expressions for the wave vectors of photoexcited current carriers involved in interband optical transitions as $k_{c,lh}^{(1\omega)}=\sqrt{\frac{2\mu_+^{(c,lh)}}{\hbar^2}\left(\hbar\omega-E_g\right)}, k_{c,hh}^{(1\omega)}=\sqrt{\frac{2\mu_+^{(c,hh)}}{\hbar^2}\left(\hbar\omega-E_g\right)}$, where $\mu_+^{(c,lh)}=\frac{m_cm_{lh}}{m_c+m_{lh}}$, $\mu_+^{(c,hh)}=\frac{m_cm_{hh}}{m_c+m_{hh}}$ is the reduced effective mass of electrons and holes.

The spectral-temperature dependence of the coefficient of interband single-photon absorption of light, taking into account the latter relations, has the form

$$K_{c,V}^{(1)}=\frac{1}{3}p_{cV}^2\frac{e^2p_{cV}^2}{c\hbar^3n_\omega}\left\{\left(f_{hh,k_{c,hh}^{(1\omega)}}-f_{c,k_{c,hh}^{(1\omega)}}\right)\mu_+^{(c,hh)}k_{c,hh}^{(1\omega)}+\left(f_{lh,k_{c,lh}^{(1\omega)}}-f_{c,k_{c,lh}^{(1\omega)}}\right)\mu_+^{(c,lh)}k_{c,lh}^{(1\omega)}\right\} \tag{5}$$

or

$$K_{c,V}^{(1)}=\frac{1}{6}\frac{e^2p_{cV}^2}{c\hbar^3n_\omega}\left[f_{hh,k_{c,hh}^{(1\omega)}}k_{c,hh}^{(1\omega)}\mu_+^{(c,hh)}+f_{lh,k_{c,lh}^{(1\omega)}}\mu_+^{(c,lh)}k_{c,lh}^{(1\omega)}\right]\left\{1-\exp\left[\frac{E_g}{k_BT}(x-1)\right]\right\}, \tag{6}$$

where $x=\frac{\hbar\omega}{E_g}$, the distribution functions of photoexcited light and heavy holes are defined as

$$f_{lh,k_{c,lh}^{(1\omega)}}=\exp\left[\frac{E_F}{k_BT}\right]\cdot\exp\left[-\frac{1}{k_BT}\frac{\mu_+^{(c,lh)}}{m_{lh}}\left(\hbar\omega-E_g\right)\right], \tag{7}$$

$$f_{hh,k_{c,hh}^{(1\omega)}}=\exp\left[\frac{E_F}{k_BT}\right]\exp\left[-\frac{E_{hh}\left(k_{c,hh}^{(1\omega)}\right)}{k_BT}\right]=\exp\left[\frac{E_F}{k_BT}\right]\cdot\exp\left[-\frac{1}{k_BT}\frac{\mu_+^{(c,hh)}}{m_{hh}}\left(\hbar\omega-E_g\right)\right], \tag{8}$$

and the Fermi energy is determined by the relation

$$e^{\frac{\mu}{k_BT}}=\frac{1}{2}p\left(\frac{k_BT}{2\pi\hbar^2}\right)^{-3/2}\left(m_{hh}^{3/2}+m_{lh}^{3/2}\right)^{-1}. \tag{9}$$

Calculations show that the spectral and temperature dependences of the coefficient of single-photon absorption of polarized light in *GaA*s, due to optical transitions between the subbands of light $\left(K_{c,lh}^{(1)}\right)$ and heavy holes $\left(K_{c,hh}^{(1)}\right)$ and the conduction band, as well as the resulting single-photon absorption of light, first increases with increasing temperature and photon energy and reaches a maximum, then falls. This behavior $K_{c,lh}^{(1)}$ and $K_{c,hh}^{(1)}$ is due to the peculiarity of the temperature Fermi energy, as well as the temperature and spectral dependences of the distribution function of current carriers in the initial state. Above, the temperature dependence of the band gap is not taken into account, the inclusion of which will lead to a noticeable change in the spectral and temperature dependence of the single-photon absorption coefficient of polarized light.

Thus, we have received:

1. Spectral-temperature dependence of the coefficient of single-photon absorption of polarized light in *GaAs*, due to optical transitions between the subbands of light holes and the conduction band, where the contribution of the coherent saturation effect to the coefficient of single-photon light absorption is not taken into account.

2. Results are obtained both with and without allowance for the temperature dependence of the band gap.

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