The Austrian Journal of Technical and Natural Sciences, No 11–12
ISSN 2310-5607

PREMIER Publishing
ppublishing.org

DOI:10.29013/AJT-23-11.12-39-44

INTERZONE ONE-PHOTON ABSORPTION OF POLARIZED LIGHT WITH ACCOUNT OF THE COHERENT SATURATION EFFECT IN A_3B_5 SEMICONDUCTORS

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Cite: *Rasulov R.Y., Kasimov, F.K., Isomiddinova, U.M., Urinova, K.K. (2023). Interzone One-Photon Absorption of Polarized Light With Account of the Coherent Saturation Effect in A_3B_5 Semiconductors. Austrian Journal of Technical and Natural Sciences 2023, No 11-12.* https://doi.org/10.29013/AJT-23-11.12-39-44

Abstract

The polarization, spectral, and temperature dependences of the one-photon absorption coefficient of polarized radiation are calculated, and its linear-circular dichroism in crystals of tetrahedral symmetry is studied. In this case, the contribution to the coefficients of one-photon absorption of light from the effect of coherent saturation of optical transitions is taken into account.

Keywords: *polarization, spectral, and temperature dependences of the one-photon light absorption coefficient, linear-circular dichroism, crystal of tetrahedral symmetry, coherent saturation effect*

Intraduction

Nonlinear absorption of light in a semiconductor with a degenerate valence band, which is due to direct optical transitions between heavy and light hole subbands and depends on the state of radiation polarization, was studied in (Ivchenko, 1972; Rasulov, 1993; Ganichev, 1983; Parshin D.A., 1987; Rasulov, 2017; Rasulov, 1996; Rasulov, 1988; Rasulov, 1993). In these papers, it is assumed that the nonlinearity in the intensity dependence of the one-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.

Due to the smallness of the photon wave vector compared to the wave vector of the electron (hole) formed as a result of absorption, when calculating the light absorption

coefficient, we can assume $|\vec{q}| << |\vec{k}|$ and put $|\vec{q}| = 0$, where $\vec{q}(\vec{k})$ is the wave vector of the photon (holes).

In case $\hbar\omega \geq E_g$, $E_g + \Delta_{SO}$, there are two types of interband optical transitions, the first of which satisfies the condition $E_g \leq \hbar\omega \langle E_g + \Delta_{SO}$, and in the second case the condition $\hbar\omega \geq E_g + \Delta_{SO}$ is satisfied. Therefore, in the first case, optical transitions occur between the subbands of light and heavy holes in the valence band and the conduction band, and in the second case, optical transitions occur between the spin-orbit splitting and conduction bands, which we will analyze separately.

Interband one-photon absorption of polarized light with allowance for the effect of coherent saturation

Next, we investigate various variants of one-photon interband absorption of polarized light, where we take into account the contribution of the coherent saturation effect (Parshin, 1987; Rasulov, 2017; Rasulov, 1996) to the light absorption coefficient. Then the spectral – temperature dependence of the coefficient of one-photon absorption of light $K^{(1)}$ is determined by the formula (Parshin, 1987; Rasulov, 2017; (Rasulov, 1996)

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

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 energy conservation law is taken into account, $F(\beta,1,\omega)$ is the distribution function of current carriers in the initial state, $\beta^{-1} = k_B T$, k_B, – is Boltzmann's constant, T is the sample temperature: $F(\beta,1,\omega) = \left[1-\exp(1\beta\hbar\omega)\right]\exp\left[\beta\left(\mu - E_{L=hh}(k^{(\omega)}_{c,L=hh})\right)\right]$, $E_{L=hh}(k^{(\omega)}_{c,L=hh}) = \frac{m_c}{m_c+m_{hh}}\left(\hbar\omega - E_g\right)$, $\rho(\hbar\omega) = \mu^* k_\omega/(\pi^2\hbar^2)$, μ^* is the reduced effective mass of current carriers, the form of which depends on the type of optical transitions.

It can be seen from (1) that it is necessary to perform angular averaging of the squares of the composite matrix elements over the solid angles of the wave vector of the current carriers, i.e. we need to perform an integration of the type

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

where

$$\Re_1(I) = \left\langle\frac{|e'_\pm|^2}{\sqrt{1+\zeta_\omega|e'_\pm|^2}}\right\rangle, \quad I = |\vec{S}| = \frac{n_\omega\omega^2A_0^2}{2\pi c}$$
$$\Re_2(I) = \left\langle\frac{|e'_z|^2}{\sqrt{1+\zeta_\omega|e'_z|^2}}\right\rangle,$$

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 $\vec{k}$, $\zeta_\omega = 4\frac{\alpha_\omega}{\hbar^2\omega^2}\left(\frac{eA_0}{c\hbar}\right)^2 p^2_{cV}$, the wave vector k_ω is determined from the energy conservation law. In particular, for the optical transition considered above $k_\omega = k_{c,L} = \sqrt{\frac{2\mu^{(c,L)}_+}{\hbar^2}\left(\hbar\omega - E_g\right)}$, $\mu^{(c,L)}_+ = \frac{m_c m_L}{m_c+m_L}$.

The calculation of one-photon absorption of polarized light due to optical transitions from the subband of light and heavy holes to the conduction band is performed using the formula (Rasulov, 1996; Rasulov, 1988; Rasulov, 1993; Rasulov, 2016; Rasulov, 2015)

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

whence, in the Luttinger-Kohn approximation and in the three-band Kane model (Ivchenko E. L., 1989; Bir G. L., 1972), the spectral-temperature dependence of the coefficient of interband one-photon absorption of light takes the form

$$K_{c,V}^{(1)} = \frac{1}{3} p_{cV}^2 \frac{e^2 p_{cV}^2}{c\hbar^3 n_\omega} \left\{ \left(f_{hh,k_{c,hh}^{(1\omega)}} - f_{c,k_{c,hh}^{(1\omega)}} \right) \mu_+^{(c,hh)} k_{c,hh}^{(1\omega)} + \left(f_{lh,k_{c,lh}^{(1\omega)}} - f_{c,k_{c,lh}^{(1\omega)}} \right) \mu_+^{(c,lh)} k_{c,lh}^{(1\omega)} \right\} \quad (4)$$

where the distribution functions of photoexcited light and heavy holes are defined as

$$f_{lh,k_{c,lh}^{(1\omega)}} = \exp\left[\frac{E_F}{k_B T}\right] \cdot \exp\left[-\frac{1}{k_B T} \frac{\mu_+^{(c,lh)}}{m_{lh}} \left(\hbar\omega - E_g\right)\right], \quad (6)$$

$$f_{hh,k_{c,hh}^{(1\omega)}} = \exp\left[\frac{E_F}{k_B T}\right] \exp\left[-\frac{E_{hh}\left(k_{c,hh}^{(1\omega)}\right)}{k_B T}\right] = \exp\left[\frac{E_F}{k_B T}\right] \cdot \exp\left[-\frac{1}{k_B T} \frac{\mu_+^{(c,hh)}}{m_{hh}} \left(\hbar\omega - E_g\right)\right], \quad (7)$$

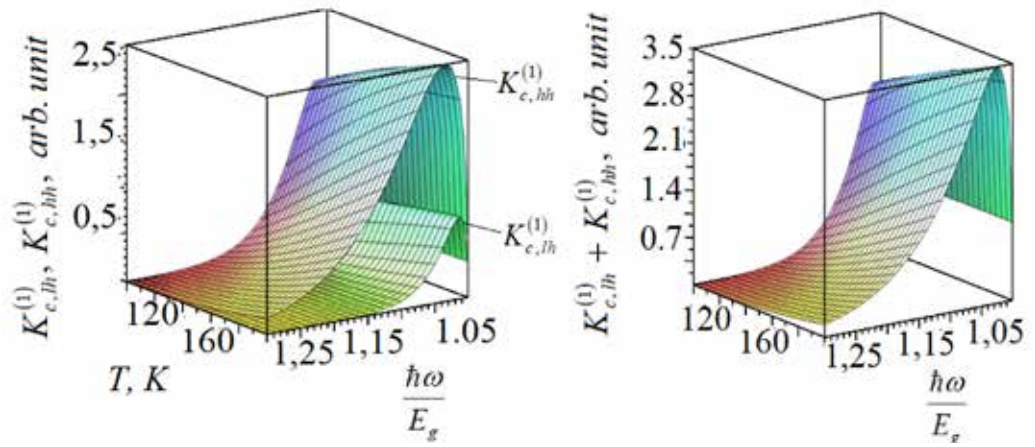
and the Fermi energy is determined by the relation

$$e^{\frac{\mu}{k_B T}} = \frac{1}{2} p \left(\frac{k_B T}{2\pi\hbar^2}\right)^{-3/2} \left(m_{hh}^{3/2} + m_{lh}^{3/2}\right)^{-1}. \quad (8)$$

Figure 1 shows the spectral and temperature dependences of the coefficient of one-photon absorption of polarized light in *GaAs*, due to optical transitions between the subbands of light $\left(K_{c,lh}^{(1)}\right)$ and heavy $\left(K_{c,hh}^{(1)}\right)$ holes (fig. 1 a) and the conduction band, as well as the resulting one-photon absorption of light (fig. 116 b), where the contribution of the coherent saturation effect to the one-photon light absorption coefficient is not taken into account. In quantitative calculations, the maximum value of $K_{c,lh}^{(1)}$ is chosen as one.

Figure 1. *Spectral – temperature dependence of the coefficient of one-photon absorption of polarized light in GaAs, due to optical transitions between the subbands of light* $\left(K_{c,lh}^{(1)}\right)$ *and heavy* $\left(K_{c,hh}^{(1)}\right)$ *holes (a) and the conduction band and their sum (b)*

a) b)

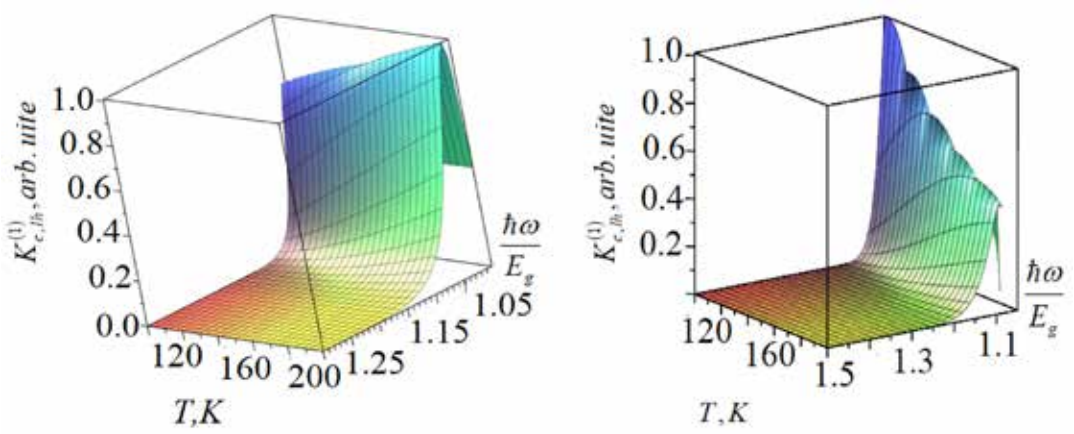


From fig. 2 a and 2 b, it can be seen that the spectral (temperature) dependence of the one-photon light absorption coefficient in GaAs, due to optical transitions between subbands of the valence band and the conduction band, first increases with increasing frequency (temperature) and, passing through a maximum, decreases. This is explained by the fact that the spectral dependence of the coefficient of one-photon absorption of light by the product of the density of states, with increasing frequency, which increases as a power function of frequency, and the distribution function of current carriers in the initial state, with increasing frequency, which decreases exponentially. The product of these quantities gives the graph shown in fig. 6. We note that here the temperature dependence

of the band gap is not taken into account, taking into account which will lead to a noticeable change in the spectral and temperature dependence of the one-photon absorption coefficient of polarized light, and it is shown in fig. 2 for *GaAs*. It can be seen from fig. 2 that, when the temperature dependence of the band gap is taken into account, the amplitude value of $K_{c,lh}^{(1)} + K_{c,hh}^{(1)}$ oscillates with increasing temperature in the region of low frequencies, while in the region of high frequencies, this value remains almost unchanged. In calculations, the temperature dependence of the band gap was chosen as: $E_g(T) = E_g(0) + \gamma_g T$, where $\gamma_g = 0{,}5405\ meV/K$ for *GaAs* (Vurgaftman, 2001).

Figure 2. *Spectral – temperature dependence of the coefficient of one-photon absorption of polarized light in GaAs, due to optical transitions between the subbands of light holes and the conduction band* $\left(K_{c,lh}^{(1)}\right)$ *without taking into account (a) and taking into account (b) the temperature dependence of the band gap on temperature*

a) b)



One-photon absorption of light between the spin-orbit splitting zone and the conduction band

The spectral-temperature dependence of the one-photon light absorption coefficient due to optical transitions between the spin-orbital splitting zone and the conduction band is defined as

$$K_{c,SO}^{(1)} = \frac{4\pi e^2}{c\hbar n_\omega}\frac{1}{3}p_{cV}^2 \iiint \left(|e_z'|^2 + |e_+'|^2\right)\left(f_{SO,\vec{k}} - f_{c,\vec{k}}\right)\delta\left(\frac{\hbar^2k^2}{2m_c} + E_g + \Delta_{SO} - \left(-\frac{\hbar^2k^2}{2m_{SO}}\right) - \hbar\omega\right)$$

or

$$K_{c,SO}^{(1)} = \frac{1}{3}\frac{e^2}{c\hbar n_\omega}\frac{p_{cV}^2}{\hbar^2}\mu_+^{(c,SO)}k_{c,SO}^{(1\omega)}f_{SO,k_{c,SO}^{(1\omega)}}\left\{1 - \exp\left[\frac{E_g}{k_BT}\left(x - 1 - \frac{E_{SO}}{E_g}\right)\right]\right\}, \quad (10)$$

where $\mu_+^{(c,SO)} = \frac{m_c m_{SO}}{m_c + m_{SO}}$ is the reduced effective mass, $k_{c,SO}^{(1\omega)} = \sqrt{\frac{2\mu_+^{(c,SO)}}{\hbar^2}\left(\hbar\omega - E_g\right)}$ is the wave vector of current carriers,

$$f_{SO,k_{c,SO}^{(1\omega)}} = \exp\left[\frac{E_F}{k_BT}\right]\cdot\exp\left[-\frac{1}{k_BT}\frac{\mu_+^{(c,SO)}}{m_{SO}}\left(\hbar\omega - E_g - E_{SO}\right)\right] \quad (11)$$

is the distribution function of current carriers in the spin-orbit splitting zone involved in optical transitions between the spin-orbit splitting zone and the conduction band.

Figure 3. *Spectral and temperature dependence of the coefficient of one-photon absorption of polarized light due to optical transitions between the spin-orbital splitting subband and the conduction band in InSb without (a) and with (b) the temperature dependence of the band gap and their ratio (c), where not the contribution of the coherent saturation effect to the one-photon light absorption coefficient is taken into account*

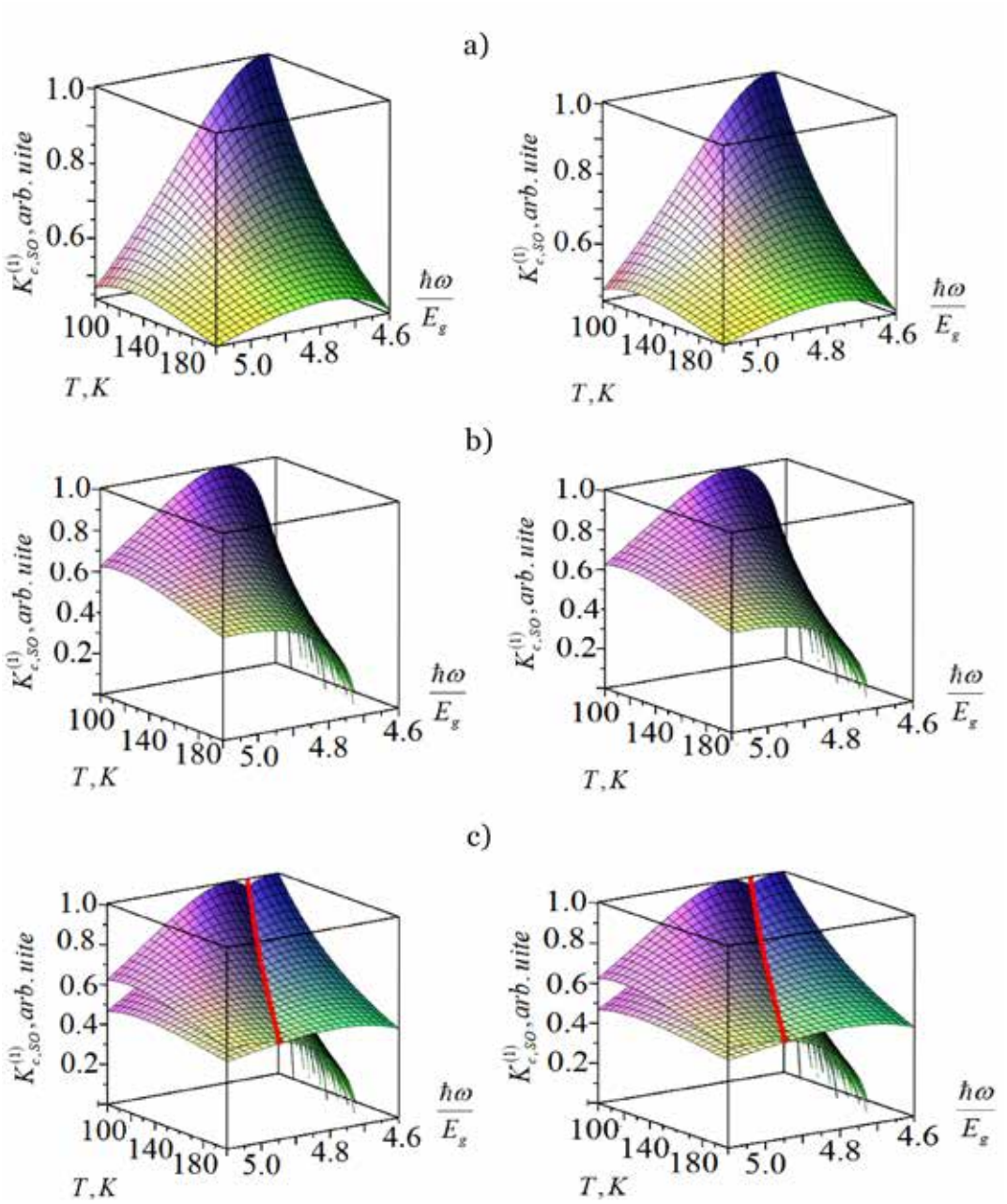


Figure 3 shows the spectral-temperature dependence of the one-photon absorption coefficient of polarized light, due to optical transitions between the spin-orbital splitting subband and the conduction band in *InSb* without taking into account (a) and taking into account (b) the temperature dependence of the band gap and their ratio (c), where not the contribution of the coherent saturation effect to the one-photon light absorption coefficient is taken into account. The red line marks the intersection of the spectral and temperature dependences of the one-photon absorption coefficient of polarized light, shown in figs. 3 a and 3 b. From fig. 3 it is seen that the spectral (temperature) dependence of the coefficient of one-photon interband absorption of light in *InSb*, both without taking into account and taking into account the temperature dependence of the band gap with increasing

frequency (temperature), first increases and reaches a maximum, and then decreases.

Conclusion

Thus, we have defined the following:

1. Spectral-temperature dependence of the one-photon absorption coefficient of polarized light in GaAs, caused by optical transitions between subbands of light holes and the conduction band, without and taking into account the temperature dependence of the band gap on temperature.

2. Spectral and temperature dependences of the one-photon absorption coefficient of polarized light, caused by optical transitions between the spin-orbital splitting subband and the conduction band in InSb without taking into account and taking into account the temperature dependence of the band gap and their ratio, where the contribution of the coherent saturation effect to the one-photon absorption coefficient is not taken into account.

References

Ivchenko E. L. (1972). Two-photon absorption and optical orientation of free carriers in cubic crystals *Semiconductors*.– Vol. 14.– Issue 12.– P. 3489–3485. (In Russian).

Rasulov R. Ya. (1993). Polarization optical and photovoltaic effects in semiconductors with linear and nonlinear absorption of light. Dissertation for thesis. of doctor's degree phys.-math. sciences.– St. Petersburg.– 206 p. (In Russian).

Ganichev S. D., Ivchenko E. L., Rasulov R. Ya., Yaroshetskii I. D. and Averbukh B. Ya. (1983). Linear and circular dichroism of drag current due to nonlinear inter subband absorption of light in p-type Ge *Phys. Solidi State*.– Vol. 35.– No. 1.– P. 104–108.

Parshin D. A., Shabaev A. R. (1987). Theory of nonlinear absorption of infrared radiation in semiconductors with degenerate bands. *ZhETF*.– Vol. 92.– Issue. 4.– P. 1471–1484. (In Russian).

Rasulov V. R. Rasulov R. Ya., Eshboltaev I. (2017). Linearly and circular dichroism in a semiconductor with a complex valence band with allowance for four-photon absorption of light *Physics of the Solid State*.– Vol. 59.– No. 3.– P. 463–468.

Rasulov R. Ya., Khoshimov G. Kh., Kholitdinov Kh. (1996). Linear-circular dichroism of the nonlinear absorption of light in n-GaP. *FTP*.– Vol. 30.– No. 2.– P. 274–277. (In Russian).

Rasulov, R. Ya. (1988). Drag effect at three-photon absorption of light in semiconductors of the Ge type, *FTP*.– Vol. 22.– No. 11.– P. 2077–2080.

Rasulov R. Ya. (1993). Linear circular dichroism in multiphoton interband absorption in semiconductors. *Semiconductors*.– Vol. 35.– No. 6.– P. 1674–1678. (in Russian).

Rasulov R. Ya., Rasulov V. R., Eshboltaev I. (2016). The theory of the four photon of polarized radiation in a semiconductor with complex band structure. *American Scientific journal*.– No. 2.– P. 93–96.

Rasulov V. R., Rasulov R. Ya., Eshboltaev I. (2015). Linear-Circular Dichroism of Four-Photon Absorption of Light in Semiconductors with a Complex Valence Band. *Russian Physics Journal*.– Vol. 58.– No. 12.– P. 1681–1686.

Ivchenko E. L., Rasulov R. Ya. (1989). Symmetry and real band structure of semiconductors. -Tashkent. Fan.– 126 p.

Bir G. L., Pikus G. E. (1972). Symmetry and strain effects in semiconductors.– M.: Science.– 584 p.

Vurgaftman I., Meyer J. R.M., Ram-Moha J.R. (2001). Band parameters for III–V compound semiconductors and their alloys. *J. Appl. Phys*.– Vol. 89.– P. 5815–5821.

submitted 20.12.2023;
accepted for publication 26.12.2023;
published 24.01.2024

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