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INTERBAND ONE-PHOTON LINEAR-CIRCULAR DICHROISM IN NARROW-GaP CRYSTALS PART 2

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Abstract

In this work, the spectral dependence of the one-photon light absorption coefficient in semiconductors with cubic symmetry is calculated, taking into account the degree of polarization and the contribution of the coherent saturation effect within the framework of the Kane approximation. The optical transitions from the subbands of the valence band to the spin–orbit split-off band are considered. It is shown that the one-photon absorption coefficient for both linearly and circularly polarized light initially increases with frequency, then decreases after passing through a minimum. Such spectral behavior of the one-photon light absorption coefficient is explained by the corresponding behavior of the hole distribution function.

Keywords: *one-photon absorption; linear–circular dichroism; coherent saturation; Kane approximation; cubic semiconductors; interband transitions; spin–orbit split-off band; polarization degree; intensity-dependent absorption; spectral dependence*

Introduction

At present, in the field of photoelectronics, the nonlinear intensity-dependent absorption of polarized radiation in semiconductors is being extensively studied (Rostami A., 2006; Pattanaik H. S., Reichert M., Hagan D. J., and Van Stryland E. W.; Yu J. H., Kwon S.-H., Petrášek Z., Park O. K., Jun S. W., Shin K., Choi M., Park Y. I., Park K., Na H. B., Lee N., Lee D. W., Kim J. H., Schwille P., and Hyeon T., 2013).

Before studies were conducted taking into account the coherent saturation effect in the considered optical transitions, it was generally assumed that one-photon light absorption should not exhibit linear-circular dichroism, regardless of the type of optical transitions.

The one- and multiphoton absorption of linearly and circularly polarized light in crystals, caused by intraband optical transitions, has been investigated in (Ivchenko E. L., 1972;

Rasulov R. Ya., 1993; Ganichev S. D., Ivchenko E. L., Rasulov R. Ya., Yaroshetsky I. D., and Averbukh B. Ya., 1993; Parshin D. A. and Shabaev A. R., 1987; Rasulov R. Ya., 1988; Rasulov R. Ya., Khoshimov G. Kh., and Kholitdinov Kh., 1996; Rasulov R. Ya., 1993). However, the contribution of the coherent saturation effect (Ganichev S. D., Ivchenko E. L., Rasulov R. Ya., Yaroshetsky I. D., and Averbukh B. Ya., 1993; Parshin D. A. and Shabaev A. R., 1987), to interband one-photon light absorption-arising from the finite lifetime of photoexcited charge carriers in the final state-has not been considered. This phenomenon constitutes the main focus of the present work.

IInterband One-Photon Light Absorption Coefficient: Quantitative Theory

It should be noted that if the coherent saturation effect ($\zeta_\omega = 0$) is not taken into account, then $K^{(1)}(\omega,T)$ does not depend on the aforementioned quantities - in particular, on the degree of light polarization - and therefore represents a constant value $\Im(\zeta_\omega = 0) = \frac{4}{3}$. In this case, one-photon linear-circular dichroism is not observed. However, if the coherent saturation effect is considered, then $\zeta_\omega \neq 0$, which indicates that one-photon linear-circular dichroism arises. This occurs because for linearly polarized light

$$\Im_{lin} = \int_{-1}^{+1} d\mu \frac{1-\mu^2}{\sqrt{1+\zeta_\omega\left(1-\mu^2\right)}}; \qquad (12)$$

for circularly polarized light

$$\Im_{circ} = \int_{-1}^{+1} d\mu' \frac{\frac{1}{2}\left(1+\mu'^2\right) \mp P_{circ}\mu'}{\sqrt{1+\zeta_\omega\left[\frac{1}{2}\left(1+\mu'^2\right) \mp P_{circ}\mu'\right]}}, \qquad (13)$$

where P_{circ} is the degree of circular polarization of light, the sign "±" corresponds to $\sigma_\pm$ polarized light, $\phi(\phi')-$ is the angle between the vectors $\vec{e}$ and $\vec{q}$, $\mu' = \cos\phi'$, $\mu = \cos\phi$, and $\vec{q}$ is the photon wave vector.

For example, in the case of $P_{circ} = 1$, for linearly polarized light

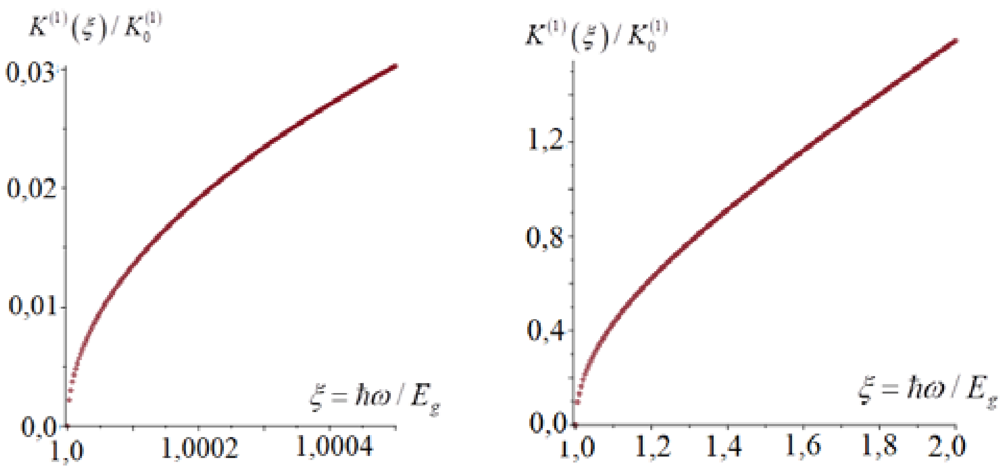
$$\Im_{lin} = \zeta_\omega^{-5/2}\left\{\zeta_\omega^{3/2} + \zeta_\omega^2 \cdot \arcsin\left(\frac{\zeta_\omega}{1+\zeta_\omega}\right)^{1/2} - \zeta_\omega \cdot \arcsin\left(\frac{\zeta_\omega}{1+\zeta_\omega}\right)^{1/2}\right\}, \qquad (14)$$

for circularly polarized light

$$\Im_{circ} = \frac{2\left(\zeta_\omega^{3/2}\sqrt{\zeta_\omega+1} - \zeta_\omega \arcsin\sqrt{\zeta_\omega}\right)}{\zeta_\omega^{5/2}}. \qquad (15)$$

Figure 1 shows the graphs of the functions $\Im_{lin}(\zeta_\omega)$ and $\Im_{circ}(\zeta_\omega)$ as a function of the parameter $\zeta_\omega \propto \left(\frac{eA_0}{c\hbar}\right)^2 \propto I$. The calculations demonstrate that as the light intensity increases, the coefficient of interband one-photon linear-circular

Figure 1.



a) b)

Figure 1. Spectral dependence of the one-photon interband light absorption coefficient in a narrow-band-gap crystal without taking into account the coherent saturation effect: (a) low-frequency region; (b) high-frequency region, where

$$\xi = \hbar\omega / E_g \, , \; K_0^{(1)} = e^2 \frac{\sqrt{2m^* E_g}}{\hbar^2 c n_\omega} .$$

dichroism $\eta = \Im_{lin}\left(\zeta_\omega\right) / \Im_{circ}\left(\zeta_\omega\right)$ also increases and tends toward saturation; that is, at very high intensity values, $\zeta_\omega >> 1$ becomes independent of both the intensity and $\eta \approx 1.1$. The quantitative calculations were performed using the data from (Leppenen N. V., Ivchenko E. L., and Golub L. E.)

Conclusion

Thus, the one-photon linear-circular dichroism caused by interband optical transitions in a narrow-band-gap crystal arises when the coherent saturation effect is taken into account. However, in the case of interband multiphoton absorption of polarized light, linear-circular dichroism is observed regardless of whether the coherent saturation effect is considered or not. This issue requires separate and more detailed consideration.

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