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ABSORPTION OF LIGHT IN SEMICONDUCTORS OF CUBIC SYMMETRY DURING INTRABAND THREE-PHOTON OPTICAL TRANSITIONS

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Abstract

The polarization and frequency-polarization dependences of the linear-circular dichroism and light absorption coefficients in semiconductors of cubic symmetry, caused by vertical three-photon optical transitions between the states of the spin-orbit splitting and conduction bands, are calculated.

Keywords: *three-photon optical transitions, spin-orbit splitting band, conduction band, linear-circular dichroism, light absorption, semiconductor*

Introduction

Currently, the main research in the field of multiphoton absorption of light is carried out in wide-gap semiconductors, since a number of their physicochemical properties have been studied in depth and in more detail. In this respect, multiphoton effects occurring in narrow-gap crystals have been little studied both in theoretical and experimental aspects. The main reason for this is that the theoretical study of a number of photon-kinetic phenomena in narrow-gap crystals requires the use of not only the Luttinger-Kohn approximation, but also the multiband Kane approach. In the latter case, theoretical calculations are performed using matrices of at least 6×6 or 8×8 .

The first works on two-photon interband transitions in crystals were carried out in the early 1960 y., shortly after the appearance of lasers (Miller A., A. Johnston, J. Dempsey, J. Smith, C. R. Pidgeon, and G. D. Holah. 1978; Comparee C. R. Pidgeon, B. S. Wherrett, A. M. Johnston, J. Dempsey, and A. Miller. 1979; Braunstein R. and Ockman N., 1964). When calculating the matrix elements of two-photon transitions in crystals, perturbation theories were used in the field of an unpolarized electromagnetic wave (Comparee C. R. Pidgeon, B. S. Wherrett, A. M. Johnston, J. Dempsey, and A. Miller. 1979; Braunstein R. and Ockman N., 1964), where the two-band Kane model was used.

In (Rasulov R.Ya., 1993; Ivchenko E. L., 1972; Beregulin E. V., Dvornikov D. P., Ivchenko E. L., Yaroshetskiy I. D., 1975; Arifzhanov S. B., Ivchenko E. L., 1975; Rasulov R.Ya., 1993; Rasulov R.Ya., 1993; Rasulov V. R. Rasulov R.Ya., Eshboltaev I., 2017), both theoretically and experimentally, linear-circular dichroism (LCD) of two- and three-photon absorption of light in crystals of cubic symmetry was investigated. However, the question of the polarization and frequency-polarization study of three-photon interband absorption of light in crystals of cubic symmetry, caused between the states of the spin-orbit splitting band and the conduction band in the Kane approximation, remained open.

Three-photon linear-circular dichroism

In our previous works, three-photon optical transitions originating from the state of the spin-orbit splitting subband into the conduction bands were analyzed and it was shown that they are 10 different transitions (Rasulov V. R., Rasulov R. Ya., Eshboltaev I. M., Qo'chqorov M. X., 2021), which differ from each other by virtual states. As indicated in (Rasulov V. R., Rasulov R. Ya., Eshboltaev I. M., Qo'chqorov M. X., 2021), the multiphoton interband light absorption coefficient has two terms, one of which describes the sum of partial light absorption coefficients, and the second contribution to the multiphoton light absorption coefficient due to the interference terms of the matrix elements of the above optical transitions in crystals of cubic symmetry.

First, we will analyze the polarization dependences of interband optical transitions arising from the state of the spin-orbit splitting subband $|\text{SO}, \pm 1/2\rangle$ into $|\text{c}, \pm 1/2\rangle$ conduction bands (i.e., three-photon transitions of type $|\text{SO}, \pm 1/2\rangle \Rightarrow |\text{c}, \pm 1/2\rangle$), where we take into account that for linearly polarized light:

$|e'_z|^2 = \cos^2 \alpha$, $|e'_\pm|^2 = 1 - |e'_z|^2$, for circularly polarized light

$$|e'_z|^2 = \frac{1}{2} \sin^2 \beta,$$

$|e'_\pm|^2 = 1 - |e'_z|^2 \mp P_{\text{circ}} \cos \beta$, where α (β) is the angle between the polarization vectors \vec{e} (the wave vector of the photon \vec{q}) and the wave vector of current carriers (\vec{k}), e'_x, e'_y, e'_z are the projections of the polarization vector of

light along the axis x', y', z' , associated with the direction of the wave vector of electrons \vec{k} ($\vec{k} \parallel z'$), $e'_\pm = e'_x \pm ie'_y$, \vec{q} – is the wave vector of the photon, e'_\pm is the degree of circular polarization of light, and the sign of " $\pm 1/2$ " is describes the spin states of current carriers.

Calculations carried out according to the golden rule of quantum mechanics (Landau L.D., Lifshits E.M., 2004) for InSb show that in three-photon transitions of the type $|\text{SO}, \pm 1/2\rangle \Rightarrow |\text{c}, \pm 1/2\rangle$, the graph of the polarization dependence of the coefficient of three-photon linear-circular dichroism is described for two virtual states lie in the subbands of the valence band and both virtual states lie in the conduction band, and the initial virtual states lie in the conduction band, and the next ones, in the valence band (in the approximation quadratic in the wave vector in the effective carrier Hamiltonian, some of the optical transitions are forbidden, and the part is nonzero).

In quantitative calculations, the numerical values of the band parameters were taken from (Vurgaftman I. and R. Meyer J., Ram-Mohan L. R., 2001). Note here that in the first case, the polarization dependence of three-photon linear-circular dichroism is almost independent of the frequency of light. This means that linear-circular dichroism does not appear in this case, i.e. interband three-photon absorption of light does not depend on the degree of polarization of the light.

Note here that the energy spectra of current carriers in all bands are taken as parabolic, and when the three branches of the band structure of the semiconductor are nonparabolic, then the quadratic dependence of the energy on the wave vector is approximately restored only near the edges of the Brillouin zones.

That showed that the polarization dependence of the linear-circular dichroism of three-photon absorption of light on the type of optical transitions. Since the matrix elements of some optical transitions have in the numerator the difference in the energies of current carriers, which in a certain region of the frequency of light tends to zero, which leads to an anomalous increase in the spectral dependence of the three-photon absorption coefficient of light, but this phenomenon leads to a noticeable change in the spectral depen-

dence of linear-circular dichroism, since the coefficient of linear-circular dichroism is defined as the ratio of the probabilities of optical transitions occurring upon absorption of light with linear and circular polarization.

The three-photon light absorption coefficient

Let us now analyze the frequency-spectral dependence of the light absorption coefficient for InSb, caused by three-photon transitions of the type. Calculations for the semiconductor InSb show that in three-photon transitions of the type, the graph of the polarization dependence of the coefficient of three-photon linear-circular dichroism is described for two virtual states lie in the subbands of the valence band, and when both virtual states which lie in the conduc-

tion band (in the approximation quadratic in the wave vector in the effective carrier Hamiltonian, some of the optical transitions are forbidden, and some nonzero).

Conclusion

From the above results it can be seen that both the polarization and frequency-polarization dependences of the linear-circular dichroism and linear-circular dichroism coefficients have several extrema. This is due to the specificity of the Kane model used to study the band structure in narrow-gap crystals. In particular, in the Kane model, some off-diagonal matrix elements of the momentum operator do not depend on the wave vector of current carriers, which does not occur in the Luttinger-Kohn model.

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