GALAXY INTERNATIONAL INTERDISCIPLINARY RESEARCH JOURNAL (GIIRJ)
ISSN (E): 2347-6915
Vol. 10, Issue 12, Dec. (2022)

INTERACTION OF CURRENT CARRIERS WITH OPTICAL PIEZOELECTRIC GRATING VIBRATIONS GYROTROPIC CRYSTALS

И. М. Коканбаев
PhD, Docent. Kokand State Pedagogical Institute. Uzbekistan

ANNOTATION

This article presents scientific research on the interaction of current carriers with optical piezoelectric oscillations of gyrotropic crystal lattices

Keywords: Crystal, mechanical deformation, piezoelectric crystals, electron-phonon, pieelectric vibration

The temperature dependences of the momentum relaxation time and carrier mobility in semiconductors with a simple band are calculated taking into account the scattering of current carriers by pieoelectric vibrations of the crystal unit cell sublattices.

In a number of crystals without an inversion center, mechanical deformation is accompanied by their polarization and the appearance of a piezoelectric field. The latter leads to an additional mechanism of current carrier scattering in piezoelectric crystals ([1]). [1]To describe this type of scattering, we introduce the following electron–phonon interaction operator

$$H = e\varphi \quad , (1)$$

where e is the elementary charge ($e\rangle 0$ - for holes, $e\langle 0$ - for electrons), φ is the potential of the piezoelectric field . In what follows, we assume that the concentration of current carriers is sufficiently low, i.e., screening effects can be neglected, and using the Poisson equation and the linear relation between the components of the electrostatic induction and piezoelectric field vectors , it is not difficult to obtain the equations

$$\varepsilon_{\alpha\beta}\frac{\partial^2\varphi}{\partial x_\alpha \partial x_\beta}+4\pi\chi_{\lambda,\mu\nu}\frac{\partial u_{\mu\nu}}{\partial x_\lambda}=0 \quad (2)$$

$\varepsilon_{\alpha\beta}$ tensor of the permittivity of the crystal, $\chi_{\lambda,\mu\nu}$ is the piezoelectric tensor , $u_{\mu\nu}$ is the strain tensor [2], the indices $\alpha,\beta,\lambda,\mu,\nu$ take the values x,y,z , and the summation is implied by the repeated indices .

As is known [1-3], the relationship between the components of the long-wavelength part of the atomic displacement operator for optical piezoelectric oscillations

$$\vec{Q}=\sum_{\vec{q}<s,n}\left[\frac{\hbar}{2\rho\omega_{\vec{q},s}}\right]^{1/2}\left(\vec{\xi}^{(n)}b_{\vec{q},s}\,e^{i\vec{q}\vec{r}}+\text{э.с.}\right) \quad , (3)$$

and strain tensor $u_{\mu\nu}$ is described by the expression

$$u_{\mu\nu}=\frac{1}{2}\cdot\left(\frac{\partial Q_\mu}{\partial x_\nu}+\frac{\partial Q_\nu}{\partial x_\mu}\right), \quad (4)$$

where $1\langle n\langle\zeta$, ζ is the number of atoms in the elementary cell of the crystal, $\hat{b}_{\vec{q},s}$ and $\hbar\,\omega_{\vec{q},s}$ is the annihilation operator and the phonon energy of the piezoelectric sublattice vibration - relative to each other (branches s with momentum $\hbar\vec{q}$), $\vec{\xi}^{(n)}$ is the unit displacement vector of the atom with number n, ρ is the density of the crystal.

For convenience, we modify the potential φ as

$$\varphi=\sum_{\vec{q}<s,n}\left(\varphi_{\vec{q},s}\,e^{i\vec{q}\vec{r}}+\text{э.с.}\right), \quad (5)$$

Then substituting (3) into (4) and obtained in (2) taking into account (5)

$$\varphi_{\vec{q},n}=\frac{2\pi\chi_{\lambda,\mu\nu}}{\varepsilon_{\varepsilon\beta}q_\alpha q_\beta}q_\lambda\left[\frac{\hbar}{2\rho\omega_{\vec{q},n}}\right]^{1/2}\left(\xi_\mu^{(n)}q_\nu+\xi_\nu^{(n)}q_\mu\right), \quad (6)$$

Taking into account the last relation, we rewrite (1) in the form

$$H=\sum_{\vec{q}<s,n}\left(H_{\vec{q},s}\,b_{\vec{q},s}e^{i\vec{q}\vec{r}}+\text{э.с.}\right) \quad , (7)$$

where $$H_{\vec{q},s}=\sum_n\frac{2\pi\,e\chi_{\lambda,\mu\nu}}{\varepsilon_{\varepsilon\beta}q_\alpha q_\beta}q_\lambda\left[\frac{\hbar}{2\rho\omega_{\vec{q},n}}\right]^{1/2}\left(\xi_\mu^{(n)}q_\nu+\xi_\nu^{(n)}q_\mu\right), \text{ (eight)}$$

Note that for crystals of the type A_3B_5 (crystal symmetry) for which there is only one nonzero component of the piezotensor T_d $\chi_{\lambda,\mu\nu}$ ($\chi_{yzx}=\chi_{zxy}=\chi_{xyz}=\chi$), in the approximation linear with respect to $u_{\mu\nu}$ and with respect to the electric field strength, current carriers interact only with transverse optical piezoelectric phonons. For gyrotropic crystals of symmetry D_3 (for example, tellurium), the interaction of current carriers with longitudinal optical phonons also takes place. and for crystals , which have two atoms in the unit cell, we rewrite (8) as:

$$H_{\vec{q},s}^{(opt)}=\frac{2\pi e}{\varepsilon_{\alpha\beta}q_\alpha q_\beta}\beta_{\lambda,\mu\nu}\left(\xi_\mu^{(n)}q_\nu+\xi_\nu^{(n)}q_\mu\right)\frac{M_2-M_1}{\sqrt{M_1M_2}}\left[\frac{\hbar}{2\rho\omega_{\vec{q},n}}\right]^{1/2}, \quad (9)$$

The relaxation time of the momentum of the current carriers is determined by the formula

$$(\tau_{piezo}^{(opt)})^{-1}=\sum_{\vec{k}'}W_{\vec{k}',\vec{k}} \quad , (10)$$

where $W_{\vec{k}',\vec{k}}$ is the probability of transition from state $\vec{k}$ to $\vec{k}'$ with emission or absorption of an optical phonon, $\vec{q}=\vec{k}'-\vec{k}$ is the phonon wave vector.

In the spherical approximation of the energy spectrum of current carriers $\left(E(\vec{k})=\frac{\hbar^2k^2}{2m}\right)$ in crystals of the gallium arsenide type with a simple band, the temperature dependence of the pulse relaxation time is determined by the relation ;

$$\tau_{piezo}^{(opt)})^{-1} = \left(\frac{e\beta}{\varepsilon\hbar}\right)^2 \frac{m}{\rho\Omega}\sum_{t=\pm 1}\left(n_\Omega + \frac{1+t}{2}\right)\frac{(M_1 - M_2)^2}{M_1 M_2} \times k, \quad (11)$$

where $k = \int 2\,d\,\vec{k}'\,\delta\left(k'^2 - k^2 \pm k_\Omega^2\right) \times q^{-4}\left(\xi_x q_y q_z + \xi_y q_z q_x + \xi_z q_x q_y\right)^2$, $k_\Omega^2 = 2m\Omega\hbar^{-1}$, $\Omega = \omega_{\vec{q},s}(\vec{q}=0)$ is the average frequency of piezoelectric oscillations of the sublattices, n_Ω is the distribution function of optical phonons, and δ the -function describes the energy conservation law.

Note that the last integral cannot be solved analytically, and therefore we will analyze it in two limiting temperature regions: $\hbar\Omega \rangle\rangle k_B T$ and $\hbar\Omega \langle\langle k_B T$, k_B is the Boltzmann constant, T is the temperature. In these temperature ranges, we have: $\mathbf{k}_1 = {}^{4\pi k_\Omega}\!/_{3}$ и $k_2 = 104\pi k_\Omega / 15$ respectively, and the pulse relaxation time is determined by the expressions [A 6]:

$$\tau_{piezo}^{(opt)\,-1} = C_\Omega k_1^{-1} n_\Omega^{-1} \text{ и } \tau_{piezo}^{*(opt)\,-1} = C_\Omega^{-1} k_2^{-1} \text{th}\left(\frac{\hbar\Omega}{2k_B T}\right), \quad (12)$$

where $C_\Omega^{-1} = \left(\frac{e\beta}{\varepsilon\hbar}\right)^2 \frac{m}{\rho\Omega}\frac{(M_1 - M_2)^2}{M_1 M_2}$.

For completeness of the problem, we present below an expression for the temperature dependence of the mobility of current carriers in the temperature ranges considered by us: $\mu = \frac{e\tau}{m}$, where τ is determined by the relations for the quantities: $\tau_{piezo}^{(opt)}$ and , $\tau_{piezo}^{*(opt)}$ where it is necessary to replace $k_{1,2} \to k_T$ Here $k_T^2 = \frac{\pi m k_B T}{2\hbar^2}$.

Note here that the determination of the temperature dependence is τ и μ easily generalized for an isotropic crystal with a complex band. In this case, when calculating, one must keep in mind that the wave functions of current carriers also depend on the number of band branches. We also note that this case plays an important role in studies of both classical (for example, the Dember effect) and polarization photovoltaic effects, the latter of which depends on the polarization state of the exciting light [4].

LITERATURE

1.G. L. Beer , G.E. Picus . Symmetry and Depharmacological Effects in Semiconductors (Moscow, Nauka, 1972).
2.A. I. Anselm. Introduction to semiconductor physics. (Moscow, Nauka, 1978).
3. V.L. Bonch - Burevich , S.G. Kalashnikov. Physics of semiconductors. (Moscow, Nauka, 1977).
4 . Kokanbaev I.M. Influence of the shape effect on the spatial distribution of temperature in a thermoelement with internal heat release, taking into account the Thomson effect// PhD students and researchers (Moscow, Russian Academy of Sciences). -2003. -No. 6.- P.158-161 .

5. Kokanbaev I.M. _ On the theory of the drag effect in semiconductors with a complex valence band with nonlinear absorption of light // DAN RUz . -2005. -No . 1.- S.21-24 .
6. Kokanbaev I.M. On the theory of the photon drag effect of current carriers in gyrotropic crystals// Science and Education: Problems and Solutions. Scientific seminar dedicated to the 60th anniversary of the founding of the Academy of Sciences of the Republic of Uzbekistan : Materials of the seminar. -Tashkent. Fan. -2003. November. –S.45-46.
7. Kokanbaev I.M. On the theory of kinetic properties of semiconductor nanostructures // - International Scientific and Technical Conference. Aircraft monitoring: Materials of the conference . - Tashkent, -2005. May 27-28 -St. 158-163.
8. Kokanbaev I.M. Photon drag effect in semiconductors with exact allowance for the resonant saturation effect // International conference dedicated to the 90th anniversary of Academician S.A. Azimov . Fundamental and applied questions of physics: Proceedings of the conference. - Tashkent. -2004. November 18-19. -FROM. 278-279.
9. Rasulov, Vakhob Rustamovich, et al . "Two- and three- photon linear-circular dichroism in semiconductors of cubic symmetry." Semiconductor Physics and Engineering 54.11 (2020): 1181-1187.
10. Rasulov, R. Ya., et al . "POLARIZATION AND FREQUENCY-POLARIZATION DEPENDENCES OF THE THREE-PHOTON ABSORPTION OF LIGHT IN CRYSTALS." FUNDAMENTAL SCIENCE AND TECHNOLOGY. 2021.
11 . Rasulov , R. Ya , V. R. Rasulov , and I. M. Eshboltaev . "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 59.3 (2017): 463-468.
12 . Leksovsky A. _ _ M. , et al. "The damage zone of high-modulus materials under explosive loading of granite." Letters to JTF 28.16 (2002).
13 . Atakulov , Sh. B., and I. M. Kokanbaev . "Thermal and radiation-stimulated processes in polycrystalline films of lead chalcogenides ." Tashkent : Fan (1992).
14 . Rustamovich , Rasulov Voxob , et al. "Investigation of dimensional quantization in a semiconductor with a complex zone by the perturbation theory method." European science review 9-10-1 (2018): 253-255.
15.Soboleva, Elena V., et al. "Developing a personalised learning model based on interactive novels to improve the quality of mathematics education." Eurasia Journal of Mathematics, Science and Technology Education 18.2 (2022): em2078.
16 . Nasriddinov , KR, and AM Madaliyev . " Practical in training particles physics department appropriation efficiency increase ways ." Academic research in educational sciences 2.3 (2021): 42-46.