CIRCULAR PHOTOVOLTAIC EFFECT IN AN ANISOTROPIC GRAPHENE SUPERLATTICE IN THE PRESENCE OF A CONSTANT ELECTRIC FIELD

P. Badikova, D. Zav'yalov, D. Zharikov
Volgograd State Technical University, Volgograd, Russia

polin.badicova@gmail.com

I. INTRODUCTION

The unique electrical and optical properties of graphene-based materials and the development of techniques for fabricating low-dimensional structures motivate intensive efforts to implement graphene-based nano- and optoelectronics. However, the pseudo-relativistic behavior of charge carriers was found in the energy bands of not only graphene.

There is a certain class of two-dimensional (2D) materials, which includes graphene, silicene, germanene, phosphoric, etc. It is called Dirac materials or graphene-like materials. Currently, the possibility of creating an electronic band structure of graphene by using an additional periodic potential has aroused increased research interest in superlattices (SLs) based on graphene-like materials (GSL) [1]. In this paper, the influence of a constant electric field on the circular photovoltaic effect in an anisotropic GSL at normal incidence are investigated. The expression for the current density in such a superlattice is obtained.

II. MAIN FORMULAS

The energy spectrum of the structure in the low-energy approximation has the following form [2]

$$\varepsilon(\boldsymbol{p}) = \pm 2F\sqrt{sin^2\left(\frac{p_x}{2}\right) + \frac{1}{4}(p_y^2 + \Delta_{eff})^2} \tag{1}$$

where $\Delta_{eff} = \frac{\Delta_1 + n\Delta_2}{1+n}$, $F = \frac{Q}{shQ}$, $Q = \frac{n(\Delta_1 - \Delta_2)}{(1+n)^2}$, $n=b/a$, a is the height of the hole, b is the barrier width, $p_x=p_xd$, $p_y^2 = \alpha p_y^2 d/v_F$, $d=a+b$. Different signs are applicable the valence and conduction bands.

We will consider the response of the superlattice to the action of constant and alternating electric fields. $\vec{E} = (E_{0x}\cos(\omega t) + E_0; E_{0y}\cos(\omega t + \varphi))$ where E_0 is the modulus of the intensity of the constant electric field, $E_{0x,y}$, ω are the amplitude and frequency of the alternating electric field.

The current density j_y, along the Y-axis is determined by the formula:

$$j_y = \langle e\ \textstyle\sum_p v_y f(\boldsymbol{p}, t)\rangle_t \tag{2}$$

where e is the electron charge, $f(\mathbf{p},t)$ is the nonequilibrium carrier distribution function.

The distribution function will be found using the classical Boltzmann equation

$$\frac{\partial f(\boldsymbol{p},\boldsymbol{t})}{\partial t}+e\boldsymbol{E}\frac{\partial f(\boldsymbol{p},\boldsymbol{t})}{\partial p}=-\nu[f(\boldsymbol{p},t)-f_0(\boldsymbol{p})] \tag{3}$$

where $f_0(\mathbf{p})$ is the equilibrium distribution function.

The electron velocity along the Y-axis is given by

$$v_y=\frac{\partial\varepsilon(\boldsymbol{p})}{\partial p_y}=\frac{Fp_y(p_y^2+\Delta_{eff})}{\sqrt{sin^2\left(\frac{p_x}{2}\right)+\frac{1}{4}(p_y^2+\Delta_{eff})^2}} \tag{4}$$

After expanding the velocity in terms of p_y, we get the following expression

$$v_y\approx\frac{2F\Delta_{eff}p_y}{\sqrt{sin^2\left(\frac{p_x}{2}\right)+\Delta_{eff}{}^2}} \tag{5}$$

$$v_y'(x)=\frac{1}{\sqrt{sin^2\left(\frac{p_x}{2}\right)+\Delta_{eff}{}^2}} \tag{6}$$

Expand (6) into a complex Fourier series

$$v_y'(x)=\sum_{m=-\infty}^{+\infty}\hat{a}_m\,e^{imx} \tag{7}$$

where $\hat{a}_m=\frac{1}{2\pi}\int_{-\pi}^{\pi}\frac{e^{imx}dx}{\sqrt{sin^2\left(\frac{p_x}{2}\right)+\Delta_{eff}{}^2}}=\frac{{}_3\tilde{F}_2(\frac{1}{2}\frac{1}{2},1;1-m,m+1;4/(\Delta_{eff}{}^2+4))}{\sqrt{\Delta_{eff}{}^2+4}}$.

Solving equation (3) by the method of characteristics, substituting it and (4) in (2), an expression for the constant component of the current is obtained.

$$j_y=\frac{2ev}{(2\pi\hbar)^2}\left\langle\int_{-\pi}^{\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{t}e^{-\nu(t-t')}\,v_y(p_x;p_y)\times f_0(p_x-\frac{e}{c}\left(A_x(t)-A_x(t')\right);p_y-\frac{e}{c}\left(A_y(t)-A_y(t')\right))d^2\boldsymbol{p}dt'\right\rangle_t \tag{8}$$

We substitute (5) taking into account the expansion (7) into (8), integrate, and after some transformations, expression (8) takes the form:

$$j_y=j_0Re[\sum_{m=-\infty}^{+\infty}\hat{a}_mC_m\sum_{l=-\infty}^{\infty}\frac{\beta_{oy}J_lJ_{l+1}(\alpha_{0x})cos(\varphi)}{(\tilde{\alpha}_0-i\tilde{\nu}+l)(\tilde{\alpha}_0-i\tilde{\nu}+(l+1))}dxdy\,] \tag{9}$$

where $\tilde{\nu}=\nu/\omega$, $\alpha_{0x}=\frac{medE_{0x}}{\hbar\omega}$, $\alpha_0=\frac{medE_0}{\hbar}$, $\beta_{oy}=\sqrt{\frac{\alpha d}{v_F\hbar}\frac{e}{\omega}}E_{0y}$, $\tilde{\alpha}_0=\alpha_0/\omega$, $C_m=\frac{1}{I_0}\int_{-\pi}^{\pi}\int_{-\infty}^{\infty}e^{-\frac{\varepsilon(x,y)}{kT}}\mathrm{e}^{imx}$, $I_0=\int_{-\infty}^{\infty}\int_{-\pi}^{\pi}e^{-\frac{\varepsilon(x,y)}{kT}}dxdy$, $j_0=\frac{\hbar e\tilde{\nu}F\Delta_{eff}n_0}{d}\sqrt{\frac{v_F\hbar}{\alpha d}}$, $v_F=10^8$ cm / s, $J_l(z)$ is the Bessel function.

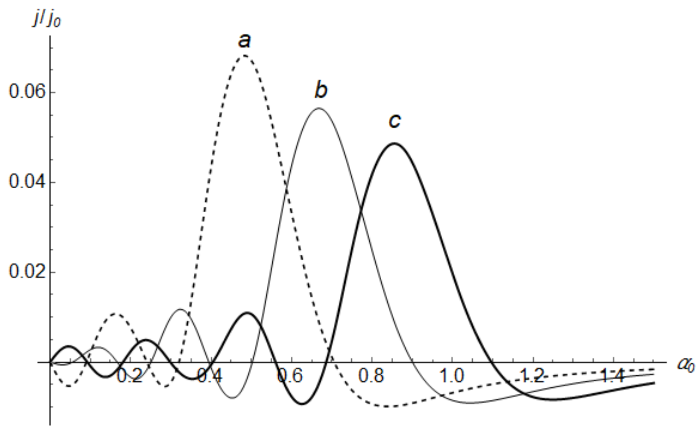

Figure 1. Dependence of the current density on the strength of a constant electric field applied along the X-axis at fixed values of $\beta_{oy}=1.0$ and $\varphi=\pi/4$ *a*) $\alpha_{ox}=0.6$ *b*) $\alpha_{ox}=0.8$ *c*) $\alpha_{ox}=1.0$

III. CONCLUSIONS

The influence of a constant electric field on the circular photovoltaic effect in an anisotropic graphene superlattice at normal incidence is investigated. An expression is obtained for the current density in such a superlattice. The features of the photovoltaic effect in such a structure are noted. The dependence of the current density on the strengths of the applied fields has a non-monotonic, oscillating, alternating character (Figure 1). The largest amplitude of oscillations is achieved in the region of low fields.

REFERENCES

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