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LINEAR-CIRCULAR DICHROISM OF THE PHOTON DRAG EFFECT IN SEMICONDUCTOR SUPERSTRUCTURES

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ABSTRACT

This article analyzes the electric field strength resulting from the transfer of momentum from linearly and circularly polarized photons to current carriers in a semiconductor superlattice. The expressions for the electric field strength of the PhDE (photon drag effect) in the case of linear and circular polarization are obtained, revealing a nonlinear and oscillatory character. The analysis also suggests the presence of linear-circular PhDE dichroism in the energy spectrum of a semiconductor superlattice. Finally, the energy parameter of the superstructure is estimated based on the intensity magnitude.

Keywords: *Lorentz, consider, linear-circular, photon*

АННОТАЦИЯ

В данной статье анализируется напряженность электрического поля, возникающая в результате передачи импульса от линейно и циркулярно поляризованных фотонов носителям тока в полупроводниковой сверхрешетке. Получены выражения для напряженности электрического поля ФДЭ (эффект фотонного увлечения) в случае линейной и круговой поляризации, обнаруживающие нелинейный и колебательный характер. Анализ также свидетельствует о наличии линейно-кругового дихроизма ФДЭ в энергетическом спектре полупроводниковой сверхрешетки. Наконец, энергетический параметр надстройки оценивается на основе величины интенсивности.

Ключевые слова: *Лоренц, считать, линейно-круговой, фотон.*

INTRODUCTION

It is known [1,2] that an incident electromagnetic wave transmits an impulse to current carriers, as a result of which they participate in directed motion. Depending on the experimental conditions, this leads to the appearance of a direct current (in a closed sample) or a constant voltage (in an open sample). Below, the strength of a constant electric field is calculated, due to the transfer of a momentum of a linearly - and circularly polarized photon of an electromagnetic wave to current carriers.

It is explained as the result of the action of the Lorentz force arising from the movement of carriers in the electric field of the wave in the presence of the magnetic field of this wave. Consider a circularly polarized transverse electromagnetic wave with frequency ω propagating in a semiconductor superlattice along the *z* axis

$$\varepsilon_x = \varepsilon_0 \cos(\omega \cdot t - q \cdot z),\ \ \varepsilon_y = \varepsilon_0 \sin(\omega \cdot t - q \cdot z), \qquad (1)$$

$$H_x = H_0 \cos(\omega \cdot t - q \cdot z),\ H_y = -H_0 \sin(\omega \cdot t - q \cdot z),$$

where $\vec{q}$ is the wave vector of the electromagnetic wave. We assume that the *x* axis is directed along the superstructure axis, and we choose the energy spectrum $\mathrm{E}(\vec{p})$ of electrons in the form

$$\mathrm{E}(\vec{p}) = \left(p_x^2 + p_y^2\right) \Big/ 2m^* - W \cos\left(a\, p_x \big/ \hbar \right) \qquad (2)$$

Here m* is the effective mass of electrons, is the energy parameter of the superstructure (superlattice).

We write the equations of motion of current carriers neglecting diffusion and recombination in the form

$$\frac{dV_x}{dt} + \frac{V_x}{\tau} = \frac{e}{m^*}(\varepsilon_x - \frac{1}{c}V_z H_y),\ \ \frac{dV_y}{dt} + \frac{V_y}{\tau} = \frac{e}{m^*}(\varepsilon_y + \frac{1}{c}V_z H_x), \qquad (3)$$

$$\frac{dV_z}{dt} + \frac{V_z}{\tau} = \frac{e}{m^*}(\varepsilon_z + \frac{1}{c}(V_x H_y - V_y H_x),$$

where τ is the time of impulse relaxation, $\vec{V} = \hbar^{-1}\vec{\nabla}_{\vec{p}}\mathrm{E}(\vec{p})$ is the group velocity of the current carriers. The electric field strength of the photon drag effect ε_z is determined from the condition of the absence of an electron flow along the *z* axis, i.e. from the condition $V_z = 0$.

After simple transformations, it is easy to obtain useful expressions for further calculations

$$V_x = \frac{\mu\varepsilon_0}{1 + \omega^2\tau^2}(\cos\theta + \omega\tau\sin\theta), \qquad (4a)$$

$$V_y = \frac{\mu\varepsilon_0}{1 + \omega^2\tau^2}(-\omega t\cos\theta + \sin\theta), \qquad (4b)$$

where $\theta = \omega t - \vec{q}\vec{r}$. Solving the third equation (3), taking into account (4a, 4b), we have

$$V_y = A_0 + V_0 \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\left[A_m \sin(\alpha_m\theta + \psi) + B_m \sin(\alpha_{m-1}\theta - \psi) + \right.$$
$$\left. E_m \cos(\alpha_m\theta + \psi) + F_m \cos(\alpha_{m-1}\theta - \psi)\right] +$$
$$+ D_{mn}^{(\nu)} \cos(\alpha_{mn}^{(\nu)}\theta + (-1)^{\nu}\psi) + R_{mn}^{(\nu)} \sin(\alpha_{mn}^{(\nu)}\theta + (-1)^{\nu}\psi), \qquad (5)$$

where

$$A_0=\mu\varepsilon_z+\frac{\mu\varepsilon_0\mu H_0}{c(1+\omega^2\tau^2)}\left(\cos\psi-\omega\tau\sin\psi\right),\ V_0=\frac{\mu H_0\omega\tau}{2c\hbar},$$

$$A_m=\frac{(-1)^{m+1}\alpha_m\omega t\,J_0(x_1)J_{2m-1}(x)+J_0(x)J_{2m-1}(x_2)}{1+\alpha_m^2\omega^2\tau^2},$$

$$\mathrm{E}_m=-\frac{\left(\alpha_m\omega\tau I_0(x)I_{2m-1}(x_1)+(-1)^m I_0(x_1)I_{2m-1}(x)\right)}{1+\alpha_m^2\omega^2\tau^2}, \tag{6}$$

$$B_m=A_m(\alpha_m\to\alpha_{m-1}),\ \ F_m=A_m(\alpha_{m+1}\to\alpha_m),$$

$$D_{mn}^{(2)}=-\frac{\left((-1)^m\alpha_{mn}^{(2)}\omega\tau J_{2m-1}(x_1)+J_{2n}(x)-J_{2m-1}(x)J_{2n}(x_1)\right)}{1+\alpha_{mn}^{(2)^2}\omega^2\tau^2},$$

$$R_{mn}^{(2)}-\frac{\left(\alpha_{mn}^{(2)}\omega\tau J_{2m-1}(x)+J_{2n}(x_1)-J_{2m-1}(x_1)J_{2n}(x)\right)}{1+\alpha_{mn}^{(2)^2}\omega^2\tau^2}(-1)^m,,$$

$$D_{mn}^{(\nu)}=D_{mn}^{(2)}\left(\alpha_{mn}^{(2)}\to\alpha_{mn}^{(\nu)}\right),\ R_{mn}^{(\nu)}=R_{mn}^{(2)}\left(\alpha_{mn}^{(2)}\to\alpha_{mn}^{(\nu)}\right),\ \alpha_m=2\cdot m,\ \ \alpha_{mn}^{(1)}=2\cdot(m+n-1),$$

$$\alpha_{mn}^{(2)}=2\cdot(m+n),\ \ \alpha_{mn}^{(3)}=2\cdot(m-n-1),\ \ \alpha_{mn}^{(3)}=2\cdot(m-n-1),$$

$\alpha_{mn}^{(4)}=-2\cdot(m-n),\ x_1=\omega\tau x,\ x=\mu\varepsilon_0 a m^*\hbar^{-1}\left(1+\omega^2\tau^2\right)^{-1},\ J_n(x)-$ Bessel functions of the first kind of integer order *n*. In (1.5.5) underline are those expressions $m=1$ that in case $m=1$ do not depend on time for and contribute to the stationary component V_z. Separating the stationary component V_z in (1.5.5) and assuming that $V_z=0$ we get an expression for the electric field strength when illuminated by light of circular polarization:

$$\varepsilon_z^{(c)}=-\frac{\mu\varepsilon_0 H_0}{\tilde{n}(1+\omega^2\tau^2)}\left(\cos\psi-\omega\tau\sin\psi\right)-\frac{w\alpha H_0}{c\hbar}\left[J_0(x)J_1(x_1)\sin\psi+J_0(x_1)J_1(x)\cos\psi\right] \tag{7}$$

The expression for the electric field strength of the EUV in the case of linear polarization $\varepsilon_z^{(l)}$ can be obtained from (7), neglecting the first term in it, i.e.

$$\varepsilon_z^{(c)}-\varepsilon_z^{(l)}=-\frac{\mu\varepsilon_0 H_0}{c(1+\omega^2\tau^2)}\left(\cos\psi-\omega\tau\sin\psi\right), \tag{8}$$

As can be seen from (7) and (8), the dependence of the PhDE (photon drag effect) electric field strength on the intensity of the exciting light (1) is nonlinear and has an oscillatory character, i.e. $\varepsilon_z^{(c)}$ and $\varepsilon_z^{(l)}$ can take both positive and negative values. It can be seen from (8) that due to the presence of narrow allowed minibands in the energy spectrum of a semiconductor superlattice, it is possible to detect linear-circular dichroism of PhDE not only with nonlinear but also with linear absorption of light.

Finally, we note that it is possible to estimate the value of the -energy parameter of the superstructure (superlattice) knowing the magnitude of the intensity I_0. In the case $\varepsilon_z^{(c)} = 0$ we have

$$w = -\frac{\mu\varepsilon_0(I_0)\hbar^2}{\alpha(1+\omega^2\tau^2)}\frac{(\cos\psi - \omega\tau\sin\psi)}{J_0(x_0)J_1(x_{10})(\sin\psi) + J_0(x_{10})J_1(x_0)(\cos\psi)}\;, \qquad (9)$$

где $x_0 = x(I = I_0), x_{10} = x_1(I = I_0)$.

CONCLUSION

Calculations show that when CO_2 is illuminated by a laser with an intensity of I≅ 0.1 MW / cm^2, a wavelength of 10.6 μm (at which $\omega\tau\cong 32$) and for a semiconductor (with a mobility of $\mu\cong 10^4$cm^2/(Vs)) with a superlattice with a period of $=10^{-6}$ cm, we get the value $\varepsilon_z^{(L)} \cong 10^6$ V/cm, and the value $\varepsilon_z^{(L)} \cong 10^6$ V/cm.

From the latest analysis of the electric field strength, even in the semiclassical approximation, there is a linear-circular dichroism of the current of the photon drag effect in semiconductor superstructures.

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