Influence of the vector order parameter on the evolution of electromagnetic pulses in an anisotropic optical medium with carbon nanotubes

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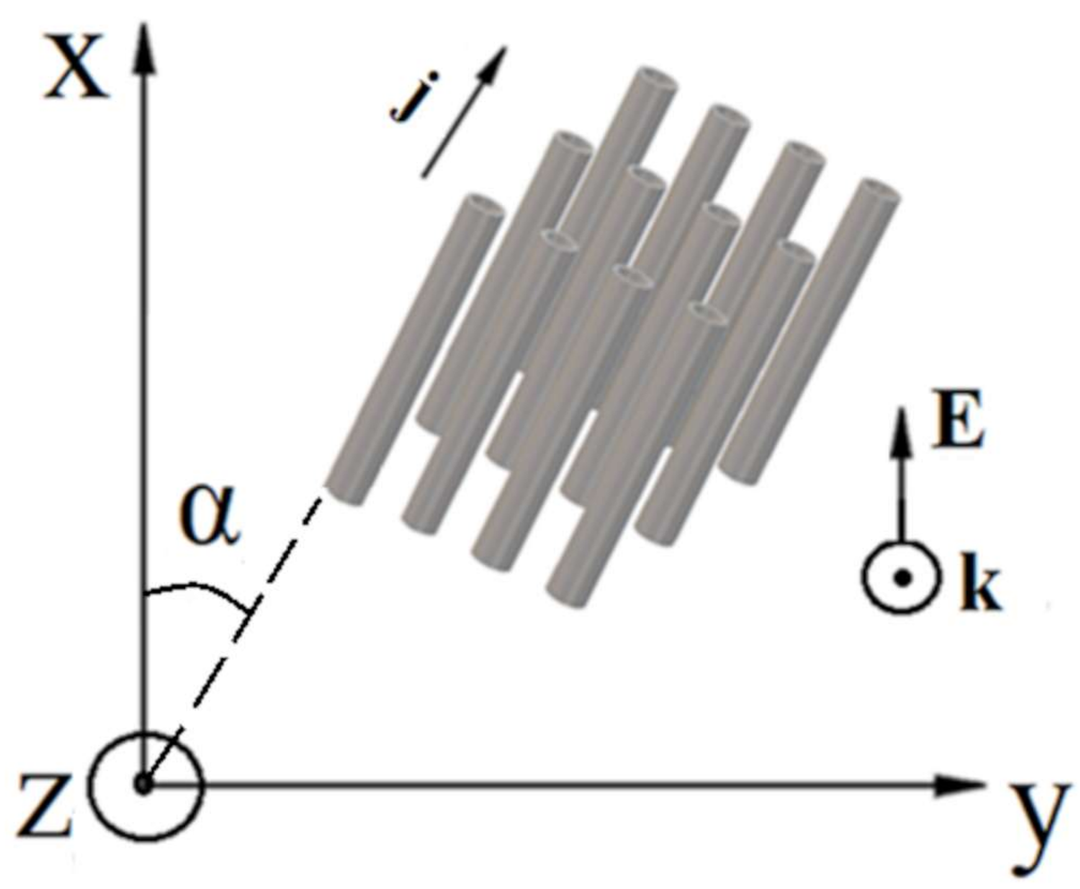

Figure 1 - The schematic representation of the geometry of the problem.

In this paper, we investigate the influence of a three-dimensional extremely short optical pulse in an anisotropic optical medium with carbon nanotubes on the vector order parameter of this medium. The dynamics of pulses as a function of the rate of relaxation of the order parameter, and on the parameter of the free energy in the Landau expansion, which characterizes the distance from the phase transition point is studied.

Model and basic equations

Using the phenomenological approach developed in [1, 2], the equation of motion can be written as:

$$\frac{d\mathbf{P}}{dt} = -\Gamma\frac{\delta\Phi}{\delta\mathbf{P}}, \qquad \Phi = \Phi_0 + a\cdot\mathbf{P}^2 + b\cdot\mathbf{P}^4 - \mathbf{E}\cdot\mathbf{P} \qquad (1)$$

here Γ is the kinetic coefficient, **P** is the order parameter, Φ is the density of the free energy functional. **P**=(Px(x,y,t), Py(x,y,t), 0), vector potential - **A**=(Ax(x,y,z,t), Ay(x,y,z,t), 0), a, b are the coefficients of the expansion of Φ in powers of P. We take into account that, in addition to the electromagnetic field of the pulse, the CNT electrons are affected by the field of the medium: Es=δΦ/δP.

$$j = 2e\sum_{s=1}^{m}\int v(p,s)\cdot F(p,s)\,dp \qquad (2)$$

j is the density of electric current, *e* is the electron charge, *p* is the quasi-momentum component of the conduction electron along the nanotube axis, v(*p*, *s*) is the electron speed in the CNT, *F*(*p*,*s*) is the Fermi distribution function.

$$\begin{cases} \Box A_x + \dfrac{4en_0\gamma_0 d\cdot\cos\alpha}{c}\displaystyle\sum_{q=1}^{\infty} b_q \sin\left(\dfrac{deq\left(A_x\cos\alpha + A_y\sin\alpha + A_x^s\cos\alpha + A_y^s\sin\alpha\right)}{c}\right) = 0 \\ \Box A_y + \dfrac{4en_0\gamma_0 d\cdot\sin\alpha}{c}\displaystyle\sum_{q=1}^{\infty} b_q \sin\left(\dfrac{deq\left(A_x\cos\alpha + A_y\sin\alpha + A_x^s\cos\alpha + A_y^s\sin\alpha\right)}{c}\right) = 0 \end{cases} \qquad (3)$$

$$\Box A_x = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial A_x}{\partial r}\right) + \frac{\partial^2 A_x}{\partial z^2} - \frac{1}{v_o^2}\frac{\partial^2 A_x}{\partial t^2},$$

$$\Box A_y = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial A_y}{\partial r}\right) + \frac{\partial^2 A_y}{\partial z^2} - \frac{1}{v_e^2}\frac{\partial^2 A_y}{\partial t^2},$$

$$v_o = c/n_x,\; v_e = c/n_y$$

n_x, n_y is the refractive indices in the x and y directions, *c* is the light speed, n_0 is the electron concentration, *d* is the distance between the adjacent carbon atoms, γ_0=2.7 eV, b_q are the coefficients in the expansion of the CNT electron dispersion law in a Fourier series.

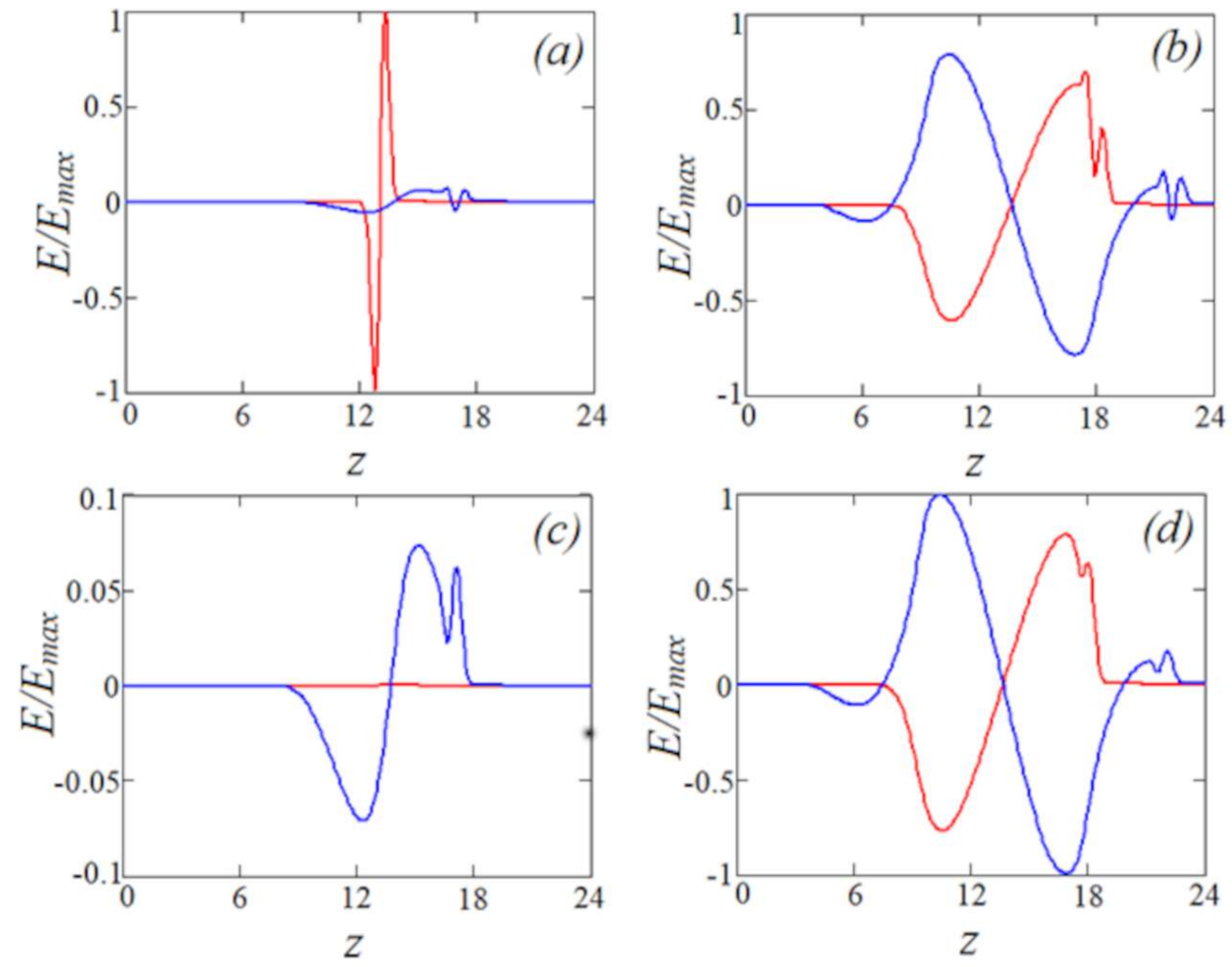

Figure 2 - Dependence of the pulse intensity on the z coordinate (longitudinal sections) at different times: (*a, c*) *t*=4; (*b, d*) *t*=9. The red line is without taking into account the order parameter, the blue line is with the order parameter. Figures (a, b) for the field component E_x; (c, d) for the field component E_y. The unit on the z-axis corresponds to 10^-5 m, E_{max} is the maximum of E for each time point.

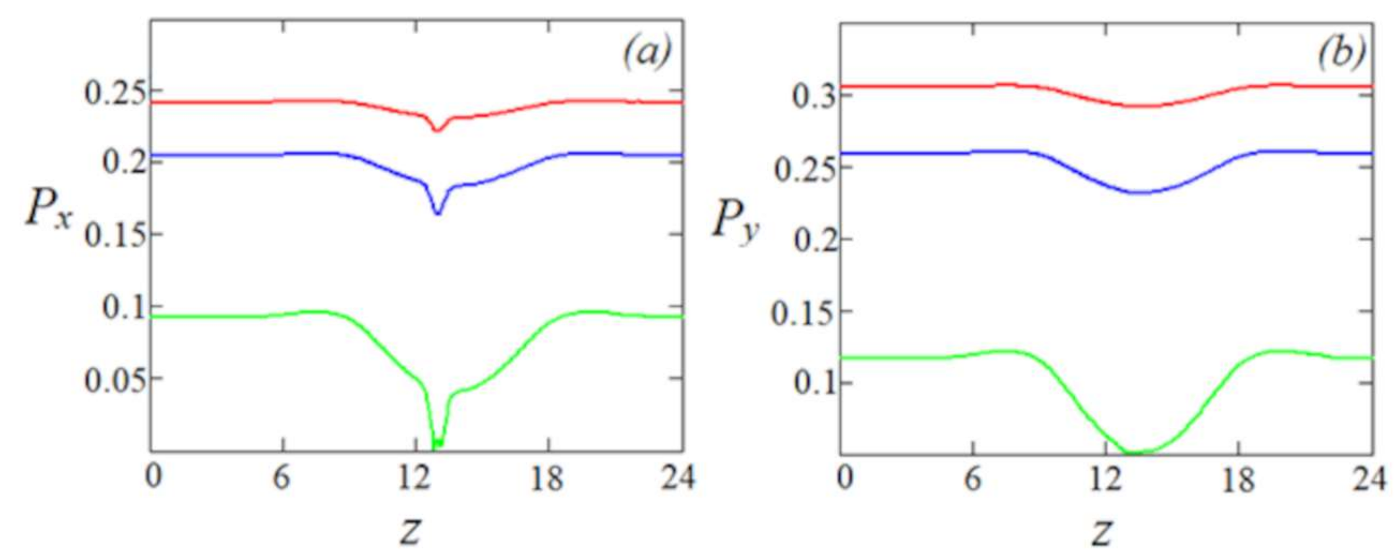

Figure 3 - Dependence of the order parameter on the coordinates for different values of the relaxation rate Γ (*t*=9, *a*=0.1, *b*=-1): (red) Γ=0.01; (blue) Γ=0.02; (green) Γ=0.05. (*a*) for the component P_x; (*b*) for the component P_y. The unit on the z-axis corresponds 10^-5 m, on the P – 10^-4 C/m2.

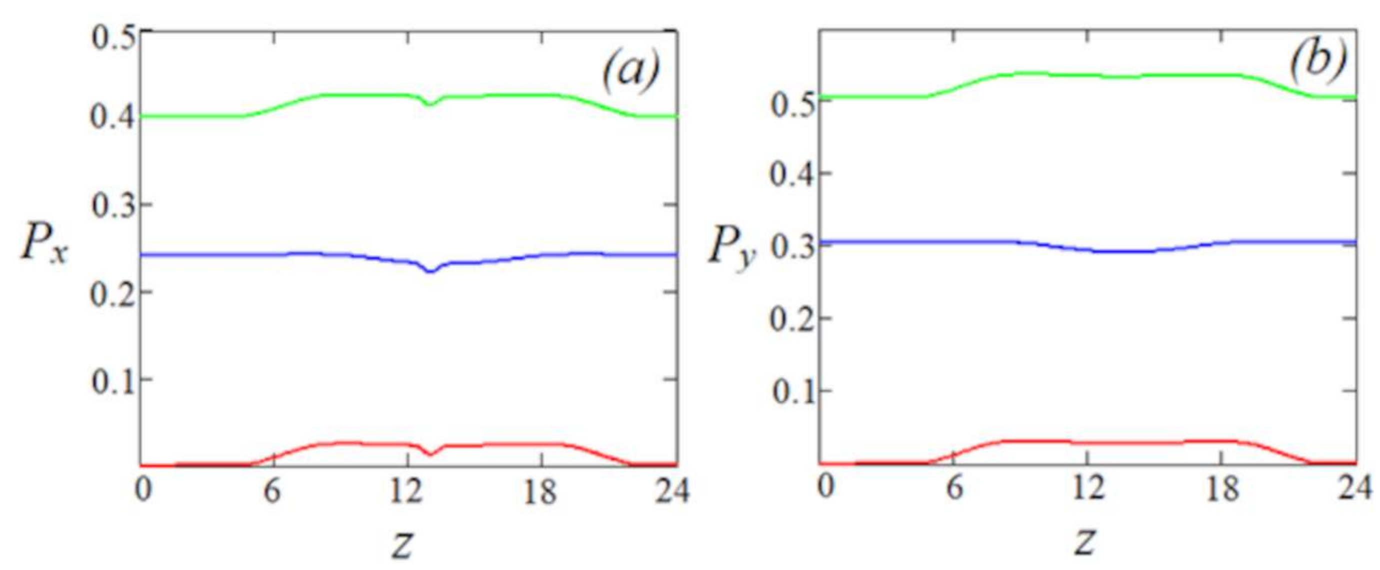

Figure 4 - Dependence of the value of the order parameter (longitudinal sections) on the z coordinate for different values of the parameter a (Γ=0.01, *t*=9): (*a*) *a*=0; (b) *a*=0.1; (c) a=0.2. (A) for the component Px; (B) for the component Py. The unit on the z-axis corresponds 10^-5 m, on the P – 10^-4 C/m2.

Conclusions:

1. The dynamics of the vector order parameter of an anisotropic optical medium with CNTs in the presence of an extremely short optical pulse has been simulated.
2. It is shown that taking into account the vector order parameter leads to an increase in the field component E_y, which causes significant changes in the pulse shape, from which the order parameter can be detected.

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References:

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