EPJ Web of Conferences **220**, 03029 (2019) https://doi.org/10.1051/epjconf/201922003029
IWQO-2019

Two-dimensional ultra-short optical pulses in carbon nanotubes with acoustic field

Dmitry Skvortsov*, *Natalia* Konobeeva, *Irina* Zaporotskova, and *Mikhail* Belonenko

Volgograd State University, 400062 Volgograd, Russia

Abstract. We investigate the dynamics of ultra-short optical pulses in carbon nanotubes under the influence of an acoustic field in two-dimensional geometry. We obtain an effective equation for the vector potential of the electromagnetic field, taking into account the stress field described in the framework of the gauge theory. And, we study the effects, which observed with a change of the magnitude of the external strain.

Since the discovery of carbon nanotubes (CNTs) [1] and graphene [2], the interest of researchers in such materials has not decreased at all, due to the set of their unique properties and prospects for practical use. We note the possibility of using a medium with carbon nanotubes as a nonlinear waveguide in which ultra-short optical pulses can propagate [3] with the preservation of their shape over significant distances.

In this paper, we study the evolution of such pulses during propagation in a medium with CNTs, which mechanically stretch. In other words, they are under the influence of a strong acoustic field.

The electron spectrum for zigzag carbon nanotubes (n, 0) has the form:

$$\varepsilon\left(p,s\right)=\pm\gamma\sqrt{1+4\cos\left(ap\right)\cos\left(\pi s/n\right)+4\cos^{2}\left(\pi s/n\right)} \tag{1}$$

where $\gamma \approx 2.7$ eV, $a = 3b/2\hbar$, $b = 0.142$ nm is the distance between adjacent carbon atoms, with a quasi-momentum (p, s), where p is the momentum component along the CNT axis, $s = 0, .., n$. Different signs define the valence and conduction bands.

To taking into account for the acoustic field, we apply the gauge theory. External mechanical strain in CNTs cause the appearance of a stress field, which compensates for the effects of deformation. This field can be determined by the corresponding vector potential A′, which changes the momentum of electrons in an array of carbon nanotubes. The contribution of the electromagnetic field and the acoustic field (stress field) is reduced to the sum of the corresponding vector potentials [4]:

$$\begin{gathered}\frac{\varepsilon}{c^{2}}\frac{\partial^{2}A}{\partial t^{2}}=\frac{\partial^{2}A}{\partial x^{2}}+\frac{\partial^{2}A}{\partial y^{2}}+4\pi j\left(A+A'\right),\\ A'=\alpha\cdot u\end{gathered} \tag{2}$$

here ε is the dielectric constant of the medium, α=const and it is determined by the electronic Gruneisen parameter [5], the hopping integral, and the lattice constant; u is the strain tensor.

---

[*] Corresponding author: dmitry.skvortsov.mail@gmail.com

The equation (2) is solved numerically. The initial condition is chosen in the Gaussian form. We calculate the field intensity, which can be found as:

$$I = \frac{1}{c^2}\left(\frac{\partial A}{\partial t}\right)^2 \tag{3}$$

The evolution of the electromagnetic field for different values of the stress field is shown in Fig. 1. Two-dimensional solution of the equation (2) is presented in Fig. 2.

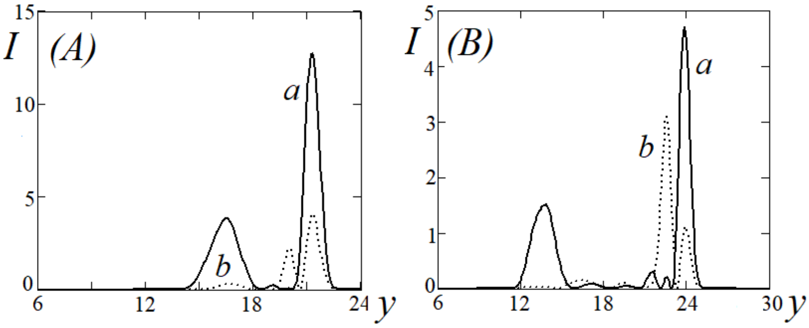

Fig. 1. The intensity of the electromagnetic pulse $I=|\boldsymbol{E}|^2$: (a) u=0.01; (b) u=0.1; (c) t=5.0. Fig. A – at the moment t=2.5, fig. B – at the moment t=5.0. Slice at x=15. All values in relatively units.

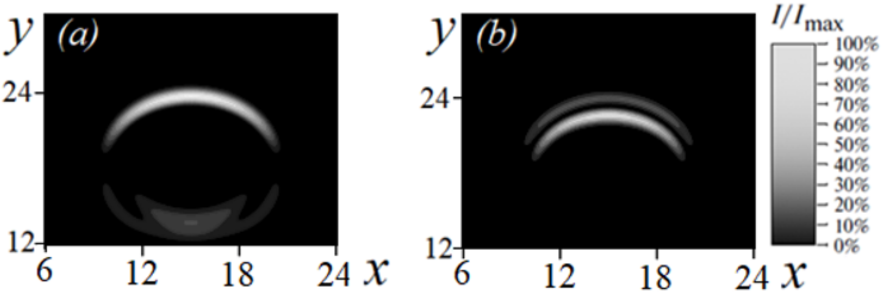

Fig. 2. $I=|\boldsymbol{E}|^2$ at t=5.0 (2D view): (a) u=0.01; (b) u=0.1. All values in relatively units.

It can be seen from figures that the deformation of CNTs substantially affects the propagation of ultra-short optical pulses. Moreover, an increase in the strain tensor leads to stabilization of the pulse and the bulk of the energy of which is contained in the main peak.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (government task project no. 2.852.2017/4.6; project no. 2019-0730 «Supercomputer simulation of continuum dynamics»).

References

1. S. Iijima, Nature, **354**, 56 (1991).
2. K.S. Novoselov, A.K. Geim, S.V. Morozov, D. Jiang, M.I. Katsnelson, I.V. Grigorieva, S.V. Dubonos, A.A. Firsov, Nature, **438**, 197 (2005).
3. M.B. Belonenko, N.G. Lebedev, A.S. Popov, JETP Letters, **91**, 461 (2010).
4. O.S. Lyapkosova, N.G. Lebedev, M.B. Belonenko, Phys. Solid State, **55**, 2602 (2013).
5. H. Suzuura, T. Ando, Phys. Rev. B., **65**, 235412 (2002).