Dynamics of laser bullet propagation in carbon nanotube array with metal inhomogeneities

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In constructed model of ultra-short optical pulse propagation in a 2D array of CNTs we assume that the electric field vector $\mathbf{E}(x, y, t)$ is directed along the tube axis, and electromagnetic wave propagates in the transverse direction (Fig. 1). We also assume the CNTs being ideal, so they have a zigzag modification and all of them are oriented in the space along about the same direction. The inhomogeneities of two-dimensional array of carbon nanotubes is simulated by two small diameter metal wires (Δx,Δy ~ 32 nm), which is placed into the array of CNTs. The axis of the wire coincides with the axes of nanotubes. To determine the electric current within the region occupied by wires, we assume the Ohm's law, $j = \sigma E = -\sigma \partial A / c \partial t$, where σ is the complex conductivity, which generally depends on the applied field frequency.

The electromagnetic field is considered on the basis of Maxwell equations, and the electronic system of carbon nanotubes is treated by the Boltzmann equation in relaxation time approximation.

As a result of mathematical transformations we finally come to the following resulting equation for the vector potential:

$$\frac{\partial^2 A_x}{\partial x^2} + \frac{\partial^2 A_z}{\partial y^2} - \frac{1}{c^2}\frac{\partial^2 A_z}{\partial t^2} + \frac{q}{\pi\hbar}\sum_m c_m \sin\left(\frac{maq}{c} A_z(t)\right) = 0$$

$$c_m = \sum_s a_{ms} b_{ms} \qquad b_{ms} = \int_{-q_0}^{q_0} dp_z \cos(map_z) F_0(\mathbf{p})$$

As was established by numerical simulation, during this evolution, an ultrashort pulse separates into two components with different amplitudes. Figure 2 shows the result of the numerical simulation of a laser bullet propagating in a 2D array of CNTs with two closely spaced metal wires. Calculations were performed for the metal inclusions situated at a distance of 570 nm from the initial pulse position and displaced each by 60 nm from the axis.

The results of simulation reveal a principally new effect that takes place upon the laser pulse scattering on two closely spaced wires, namely, the periodic separation of the intensity maximum into two components and their subsequent merging back into a single maximum. We believe that this phenomenon is closely analogous to the dynamics of internal soliton modes [3, 4] and consists in the excitation of intrinsic oscillation modes in the laser bullet upon its scattering on the system of defects, which leads to the appearance of periodically separating and merging maxima as a result of the interference between the scattered and primary pulse. The observed behavior allows us to suggest that boomeron analogs are also possible in other strongly nonlinear 2D systems.

Thus, the results of this investigation can by formulated as follows:

1) A model is proposed and an effective equation for the vector potential is obtained that describes the dynamics of propagation of an ultrashort laser pulse in an array of CNTs. Assumptions used for the model construction are formulated.

2) The results of numerical calculations according to the model show that stable nonlinear waves localized in two directions, which are analogous to the laser (light) bullets, are possible in the 2D case.

3) The scattering of the ultrashort laser pulse on a pair of closely spaced metal defects is accompanied by a periodic separation of the pulse maximum into two components followed by their merging.

This study was supported in part by the Ministry of Science and Education of the Russian Federation (Federal Targeted Program "Scientific and Pedagogical Staff for Innovative Russia (2009–2013)" project no. NK16(3)) and the Russian Foundation for Basic Research (project no. 0802 00663).

References

[1] M. S. Dresselhaus, G. Dresselhaus, P. C. Eklund Science of Fullerenes and Carbon Nanotubes. Academic Press, Inc. (1996) 965 p.
[2] Belonenko M. B., Lebedev N. G., Popov A.S. // JETP. Vol. 91, **9** (2010) p. 506
[3] P. I. Krepostnov, V. O. Popov, and N. N. Rozanov // Opt. Spektrosk. **89**, (2000) 964
[4] A. B. Vittenberg P. I. Krepostnov, V. O. Popov, and N. N. Rozanov. // Opt. Spektrosk. **92**, (2002) 603

Figures

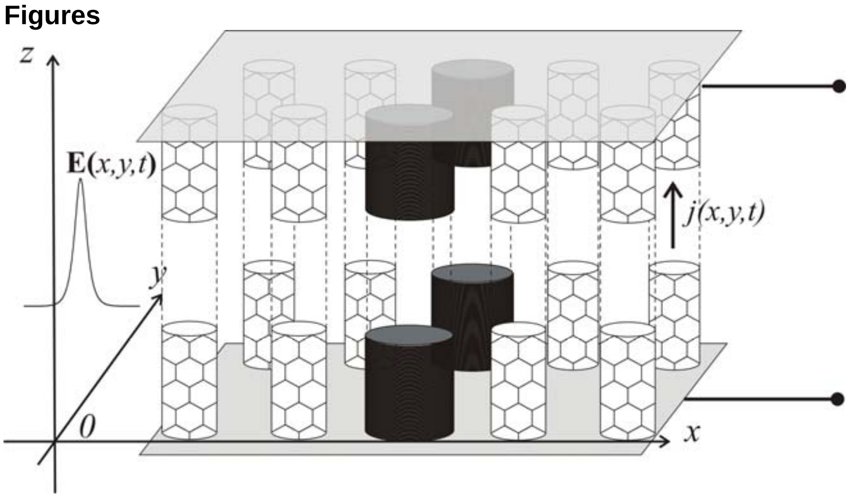

Fig. 1: Geometry of the problem.

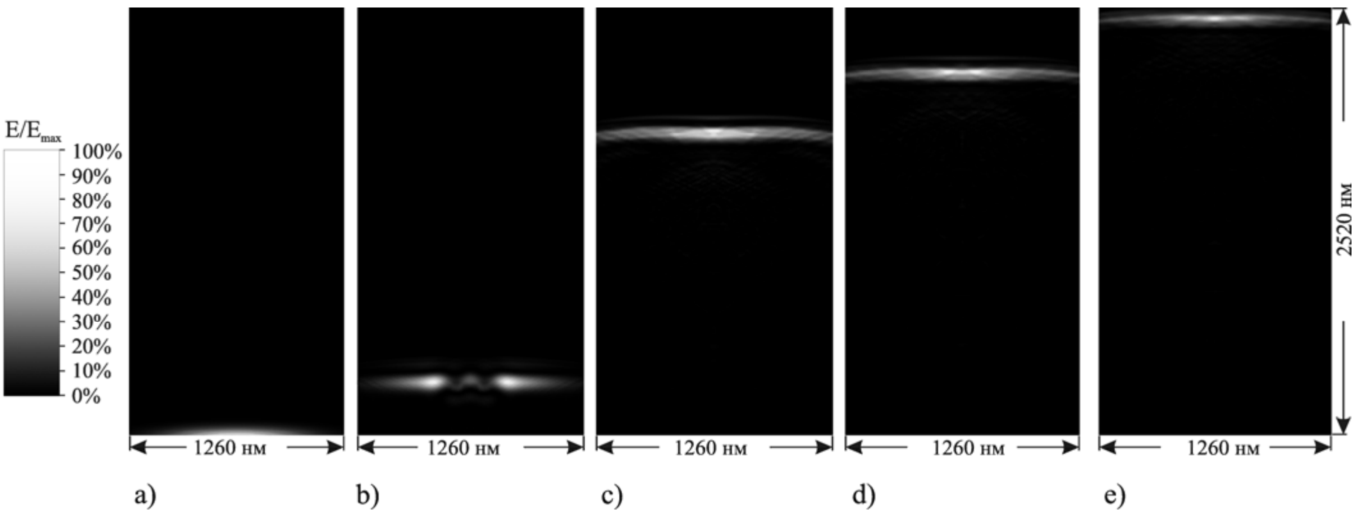

Fig. 2: Distribution of light bullet in an array of carbon nanotubes with two metallic irregularities for two-dimensional case. a) initial form of light bullet, b) $t=0.5\cdot10^{-12}$ s , c) $t=2.2\cdot10^{-12}$ s, d) $t=2.6\cdot10^{-12}$ s, e) $t=2.9\cdot10^{-12}$ s.