Solitons in a system of coupled graphene waveguides

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We consider a propagation of ultra-short optical pulses, which can be represented as discrete solitons in the graphene waveguides. The effective equation, which has the form of an analog of the classical sine-Gordon equation was obtained. And the effects observed when changing the width of initial momentum were.

The unique properties of graphene [1-2], largely related to the periodical dispersion law, and also works on ultrashort optical pulses amplification in nanotubes and graphene [3] give additional incentive to study the problem of the propagation of electromagnetic pulses through a system consisting of several graphene sheets.

We consider Hamiltonian of the electron system in the Hubbard model. It should be noted taking into account the energy of the Coulomb repulsion between electrons located at one site leads to a change in the spectrum of elementary excitations of the model. Now we consider the propagation of electromagnetic pulse in geometry where the wave vector along a graphene layer and the polarization vector lies in a graphene plane.

Maxwell's equations taking into account dielectric and magnetic properties of the system [4] with Coulomb calibration can be written in the following form:

$$\frac{\partial^2 \vec{A}_k}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 \vec{A}_k}{\partial t^2} + \frac{4\pi}{c}\vec{j}_k - \frac{4\pi}{c}\frac{\partial \vec{P}_k}{\partial t} = 0$$

here $\vec{A}_k = (0,0,A_k(x,t))$ is the vector-potential which corresponds to electromagnetic field in the k-th layer of graphene. $\vec{j}_k$ is the current in k-th layer of graphene, and $\vec{P}_k$ is the polarization induced in the k-th layer of the electromagnetic field and currents of the neighboring graphene layers. Further we consider the simple model, where $\vec{P}_k = \alpha(\vec{E}_{k-1} + \vec{E}_{k+1})$, here α is the coupling coefficient, and $\vec{E}_{k\pm1}$ are the magnitudes of electric field in the neighboring graphene layers.

After the expansion rate of the carrier in a Fourier series, we obtain an effective equation which has the form of an analog of the classical sine-Gordon equation. The equations were solved numerically by using a direct difference scheme of the cross type. The initial condition was selected in the form of a Gauss curve:

$$R(t,N) = A \cdot e^{-(t-t_0)^2} \cdot e^{-\beta(N-N_c)^2}$$

where A is the pulse amplitude, N_c is the number of central waveguide (N_c=5), β is the parameter that determines the pulse wide, N is the number of waveguide, t_0 is the initial time.

Studying the dynamics of the momentum carried in the nine parallel graphene planes. The dependence of electric field on waveguide number is presented in Figure 1. The dependences suggest a significant effect of the pulse width β on the energy distribution between the waveguides. And the pulses evolution is shown in Figure 2. An inversion signal was observed starting from a certain time (t = 150), the amplitude of the inverted signal is almost identical to the amplitude of the original signal.

References

[1] Novoselov K. S., Geim A. K., Morozov S. V., Jiang D., Zhang Y., Dubonos S. V., Grigorieva I. V., Firsov A. A., Science, **306** (2004) 666.
[2] Novoselov K. S, Geim A. K., Morozov S. V., Jiang D., Katsnelson M. I., Grigorieva I. V., Firsov A. A., Nature, **438** (2005) 197.
[3] Yanyushkina N.N., Belonenko M.B., Lebedev N.G., Optics and Spectroscopy, **108** (2010) 618.
[4] Landau L.D., Lifshitz E.M., Theoretical physics. Theory of field. Moscow: Nauka, (1988) 512.

Figures

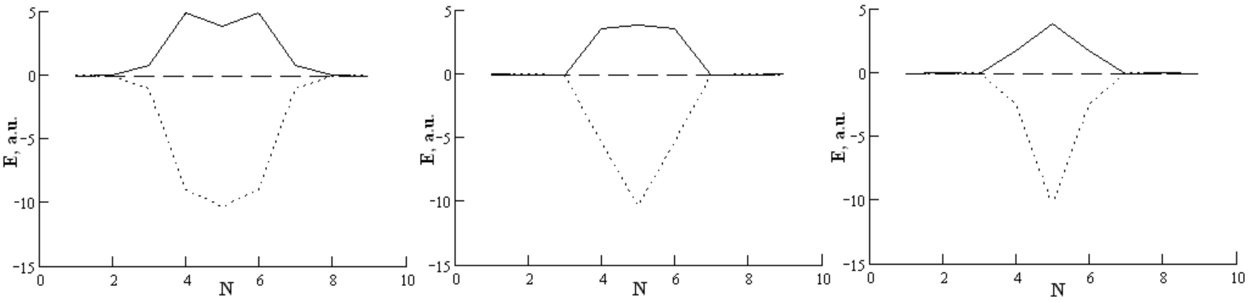

Figure 1. Dependence of the electric field on the waveguide number. All magnitudes are in the non-dimensionless units. For the solid curve the time is t=130, for the dotted curve t=200, for the dashed curve t=250: a) β=1; b) β=2; c) β=3.

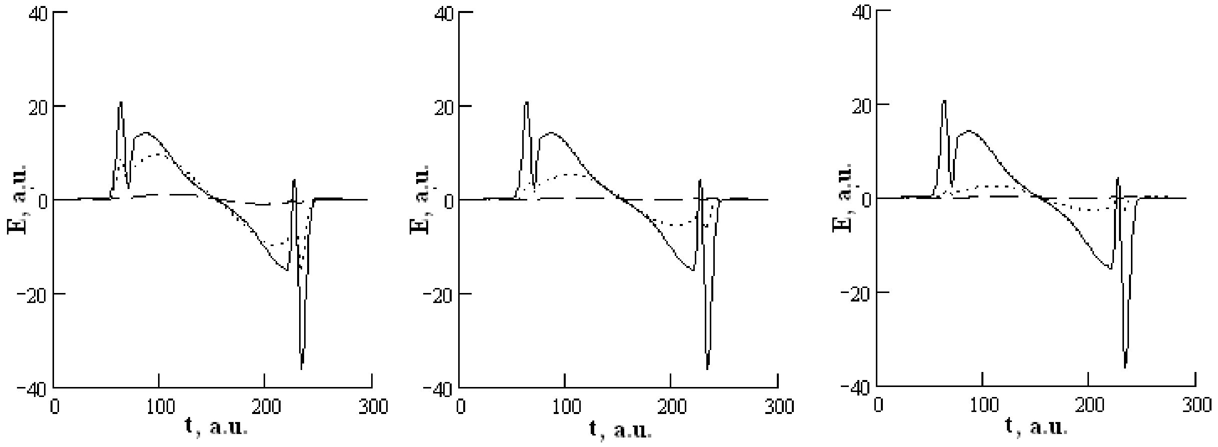

Figure 2. Dependence of the electric field on the time. All magnitudes are in the non-dimensionless units. For the solid curve the waveguide is N=5, for the dotted curve N=6, for the dashed curve N=7: a) β=1; b) β=2; c) β=3.

Acknowledgments

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