ISSN 0021-3640, JETP Letters, 2019, Vol. 109, No. 11, p. 770. © Pleiades Publishing, Inc., 2019.
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DISCUSSION

Reply to Comment on "Plasmons in Waveguide Structures Formed by Two Graphene Layers" (JETP Letters 97, 535 (2013))

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Received April 10, 2019; revised April 10, 2019; accepted April 10, 2019

DOI: 10.1134/S0021364019110067

We are grateful to M.V. Davidovich for the comment on our work "Plasmons in Waveguide Structures Formed by Two Graphene Layers" [1]. We agree with the author that the conductivity of graphene is a tensor. Furthermore, the conductivity is a function of not only the frequency but also the electromagnetic wave vector projection on the graphene plane. Nevertheless, the wave-vector dependence of the conductivity of graphene, as well as anisotropy, can be neglected for small in-plane wave-vector projections. The locality and isotropy approximations are applicable when $\beta c/(2\mu) < c/v_{\mathrm{F}} = 300$ [2]. This condition is no longer satisfied only at very high wave vectors at which losses in the system that are characterized by the parameter γ make a significant contribution. We agree with Davidovich that it was necessary to discuss in more detail the conditions of applicability of the local isotropic model.

Solutions of the dispersion equation for a system with losses can be states with a real frequency and a complex wave vector and states with a complex frequency and a real wave vector. We seek solutions with the real frequency and the complex wave vector (as far as we understand, Davidovich too). Further, we require that an eigenmode be damped at propagation. This means that the signs of the real and imaginary parts of the wave vector in the structure plane should be the same. The component of the wave vector perpendicular to the plane is always chosen such that the field is damped from the boundary of the structure. This means that the wave vector across the structure for the waveguide number $k_x = k_x' + ik_x''$ is

$$q = \sqrt{k_x'^2 - k_0^2 - k_x''^2 + 2ik_x'k_x''} = |q|e^{i\varphi_q};$$
$$\varphi_q \in [0, \pi/2].$$

The equation for the waveguide number for transverse magnetic (TM) polarization in this case can be written in the form

$$1 - \frac{4\pi}{c}|\sigma||q|\exp\left[i\left(\varphi_q - \arctan\left(\frac{\mathrm{Re}(\sigma)}{\mathrm{Im}(\sigma)}\right)\right)\right].$$

In view of the exponent, it is easy to see that the equation has solutions only if the imaginary part of the conductivity is positive (the real part is always positive). Conditions for transverse electric (TE) polarization are obtained similarly. It should be emphasized that we initially required that the field be damped along the direction of propagation of the structure and from the boundary of the structure. Davidovich possibly uses another definition of the eigenmodes of the system. In particular, the damping condition is obviously optional for "inflowing" waves, i.e., waves in which the energy is continuously supplied from the outside. However, we think that such waves are not eigenmodes of the system.

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Translated by R. Tyapaev