Terahertz and infrared surface plasmon-polaritons in double-graphene layer structures

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Abstract. Spectra and damping of surface plasmon-polaritons (SPPs) in double graphene layer structures are studied theoretically. The SPPs in those structures exhibit a remarkable voltage tunability of velocity and damping, inherent to gated graphene. The spatial dispersion of conductivity significantly augments the free path and cutoff frequency of SPPs. It is also pointed out to the effect of photon-assisted interlayer tunneling, which leads to a substantial decrease in SPP damping.

1. Device model and main equations

The structures consisting of two graphene layers separated by a thin dielectric (figure 1) look promising for practical applications in nano- and optoelectronics. A bias voltage applied between graphene layers (GLs) controls over carrier densities in them, which boosts a functionality of double-graphene optical modulators [1]. The bias can also operate on interlayer tunneling in transistor-like structures [2].

Here we study the propagation of plasma waves in double graphene layers. The spectra and damping are obtained from a general dispersion relation for surface plasmon-polaritons

$$\frac{\varepsilon}{\sqrt{\mathbf{k}^2 - \varepsilon\omega^2 / c^2}} = -\frac{4\pi i}{\omega}\sigma_{\mathbf{k},\omega}$$

where ω is a SPP frequency and $\mathbf{k}$ is a SPP wave vector, ε is a permittivity of environment, c is a speed of light, and $\sigma_{\mathbf{k},\omega}$ is graphene conductivity. The latter depends both on frequency and wave vector and incorporates interband and intraband transitions. At small separation between GLs the interlayer tunneling also contributes to conductivity; the latter contribution is estimated via Fermi golden rule and second-order perturbation theory.

2. Results

It is shown that the bias voltage shifts the Fermi energies ε_F in GLs thus changing the interband conductivity and the propagation length of SPPs. Particularly, SPPs with frequencies $\omega > 2\varepsilon_F / \hbar$ are strongly damped due to interband electron transitions [3]. SPPs with lower frequencies exhibit propagation lengths up to 1 μm if the graphene conductivity is determined by electron-phonon scattering (figure 2).

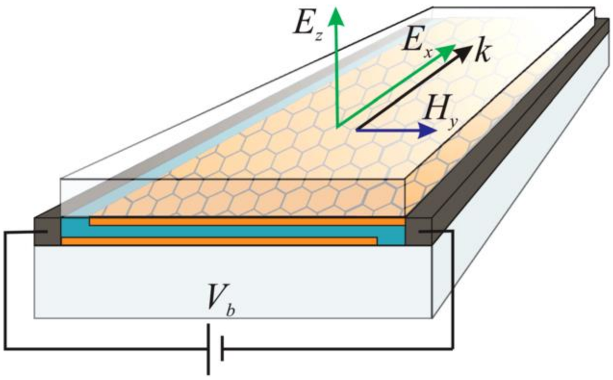

Figure 1. Schematic view of double-graphene layer structure with directions of wave-vector k, electric E and magnetic H fields in SPP.

In present calculations we rigorously treat the spatial dispersion of graphene conductivity omitted in the previous studies of plasmons in graphene. It turned out to be crucial and leads to much longer SPP free paths (up to 100 times) compared to that in preceding evaluations.

Finally, we emphasize that in double-graphene layer structures with steady bias between GLs the interlayer tunneling accompanied by photon emission is feasible. In the case the Fermi energies in layers differ resulting in a population inversion which can lead to negative dynamic tunnel conductivity. The latter effect causes an increase in SPP propagation length.

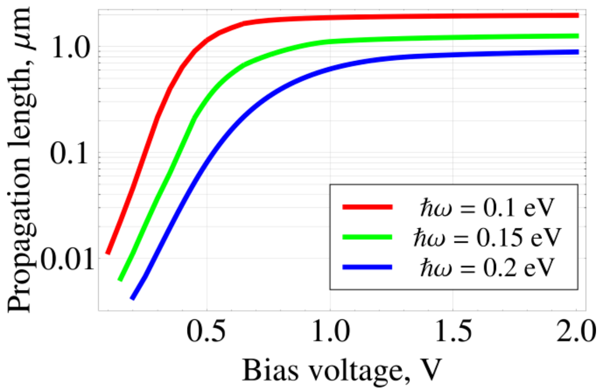

Figure 2. SPP propagation length in double GL structure vs. bias voltage.

References

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