Nanoscale physics

Dynamic conductivity of doped graphene in a high electric field

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The two-dimensional crystals such as graphene and related materials [1] have attracted much attention for a wide variety of devices in nanoelectronics and optoelectronics (transistors, THz lasers, photodetectors, etc.) The fundamental characteristic for all of these ultrahigh speed applications is the response of the free carriers to a weak ac perturbation such as an electromagnetic wave, which is described by the dynamic conductivity σ. In the most general case when the electric field of the wave in the material is space and time dependent, the dynamic conductivity tensor (DCT) depends on both the frequency ω and the wave vector **k**, that is $\sigma = \sigma(\mathbf{k}, \omega)$. In previous works, the DCT was considered in the collisionless regime [2] and in the relaxation-time approximation [3] for a weak electric field, which did not break the equilibrium distribution of Dirac quasiparticles over energy in the bands.

In this work, we present a theoretical study of the complex DCT of doped graphene, which takes into account spatial dispersion effects at high (THz) frequencies and in the presence of a strong (heating) dc electric field. The high-field transport is described on the base of the Boltzmann kinetic equation, assuming the steady-state distribution function in the form of the Fermi-Dirac distribution displaced in the momentum space. Then the corresponding ac counterpart is found from the kinetic equation in the collisionless regime, which allows us to analytically derive and analyze the DCT expression. We revealed new features in the behavior of the real and imaginary parts of the complex DCT $\sigma(\mathbf{k}, \omega)$, including the vicinity of the resonance $\omega = \mathbf{k}\cdot\mathbf{v}$ at which the phase velocity of the wave in the direction of propagation ω/k is equal to the carrier velocity v. The effects of deviation from the linear energy spectrum and screening by the charge carriers on the DCT are taken into account and analyzed in detail.

1. *Castro Neto A. H.,Guinea F., Peres N. M. R., Novoselov K. S., Geim A. K.* The electronic properties of graphene // Rev Mod Phys.-2009.**-81.-**P. 109-162.
2. *Falkovsky L. A.,Varlamov A. A.* Space-time dispersion of graphene conductivity // Eur Phys J B.-2007.**-56**.-P. 281-284.
3. *Lovat G., Hauson G. W., Araneo R., Burghignoli P.* Semiclassically spatially dispersive intraband conductivity tensor and quantum capacitance of graphene // Phys Rev B.-2013.**-87**.-P. 115429-1-11.