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Electrical conductivity of bilayer-graphene double layers at finite temperature

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ABSTRACT

We calculate the dielectric function of a system composed of a pair of electrically isolated Bernal graphene bilayers separated by a spacer as a function of temperature T, interlayer distance d and spacer dielectric constant ε_2. Using the obtained results for dielectric function we calculate finite-temperature electrical conductivity of the first layer in presence of the second one due to the screened Coulomb scattering for different values of temperature, interlayer distance and dielectric constants ε_2, ε_3.

1. Introduction

Since discovered in 2004 graphene has attracted tremendous research interest because of its salient features like high mobility, atomic thinness and large surface area. There has been intensive investigation on transport properties of gapless monolayer graphene (MLG) due to different scattering mechanisms, especially the charged impurity scattering [1–9]. Similar investigations have been extended to gapped [10,11] and bilayer graphene (BLG) [12–17].

Recently double-layer structures composed of two atomically thin materials such as MLG-MLG [18–21], MLG-GaAs [22–25], BLG-GaAs [25,26], BLG-MLG [27,28], BLG-BLG [29–32] heterostructures have been proposed, realized and studied both experimentally and theoretically since these systems may serve as new types of electronic devices. Transport properties, which are key benchmark of device performance, have been investigated by several authors for double-layer structures [20,27,29,33]. Especially, Hosono and Wakabayashi have studied the dielectric environment effect on carrier mobility of MLG-MLG heterostructure at $T = 0$ K [33], while Parhizgar and Asgari have calculated the zero-temperature longitudinal resistivity and magnetoresistance of first graphene layer under effect of the second one [20]. To our knowledge, up to now no similar calculations have been done for BLG-BLG (hereafter referred to as 2BLG) systems at both zero and finite temperatures. Therefore, in this paper, we calculate the dielectric function of bilayer graphene double layers consisting of two layers of doped bilayer graphene separated by a spacer. Based on obtained dielectric functions, we calculate finite-temperature electrical conductivity of the first layer in presence of the second one due to the screened Coulomb scattering for different values of temperature, interlayer distance and dielectric constants ε_2, ε_3. Following Parhizgar and Asgari we assume that the charged impurities are located only in the first layer.

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2. Theory

We consider the double-layer system, shown in Fig. 1, consisting of a doped BLG (layer I) placed above another doped BLG (layer II) deposited on an insulating substrate. Two layers have equal carrier density ($n_1 = n_2 = n$) and are electrically isolated via an insulating spacer of thickness d.

We assume each layer is of zero thickness and neglect the tunneling of electrons between the layers.

To calculate the conductivity of layer I in presence of layer II, we use the Boltzmann approach which is based on the relaxation time approximation and consider only charged impurity scattering. In this approach, the conductivity is given by Ref. [12]:

$$\sigma = \frac{N_0 e^2}{m^*} \int_0^\infty dE \left(-\frac{\partial f}{\partial E}\right) \tau(E,T) \tag{1}$$

where $N_0 = \frac{2m^*}{\pi\hbar^2}$ is density of states in BLG, with m^* being the effective mass of electron. $f(E_{\overrightarrow{k}}) = \frac{1}{e^{\frac{E-\mu}{k_B T}}+1}$ is the Fermi − Dirac distribution function, $\mu = E_F = \frac{\hbar^2 k_F^2}{2m^*}$ is the BLG chemical potential, and $\tau(E,T)$ is the relaxation time of BLG given by Ref. [12]:

$$\frac{1}{\tau\left(E_{\overrightarrow{k}},T\right)} = \frac{n_i}{2\pi E_{\overrightarrow{k}}} \int_0^{2k} dq \frac{q^2\left[1-2\left(\frac{q}{2k}\right)^2\right]^2}{\sqrt{4k^2-q^2}} |W_{11}(q,T)|^2 \tag{2}$$

Here n_i is ionized impurity concentration, $E_F(k_F)$ is the Fermi energy (Fermi wave-vector) of BLG and $W_{11}(q,T)$ represents the effective interaction between impurities and electrons in layer I [20],

$$W_{11}(q,T) = \frac{V_{11}(q) + \left(V_{12}(q)^2 - V_{11}(q)V_{22}(q)\right)\Pi_2(q,T)}{\varepsilon(q,T)} \tag{3}$$

where $V_{ll'}(\overrightarrow{q})$ refers to the inter- and intralayer electron − electron Coulomb interactions that can be obtained by using electrostatic theory for a two parallel conducting systems. The intralayer interactions are given by Ref. [20]:

$$V_{11}(q) = \left(\frac{4\pi e^2}{q}\right)\left(\frac{\varepsilon_2 + \varepsilon_3 \tanh(qd)}{\varepsilon_2(\varepsilon_1+\varepsilon_3) + (\varepsilon_2^2 + \varepsilon_1\varepsilon_3)\tanh(qd)}\right) \tag{4}$$

$$V_{22}(q) = \left(\frac{4\pi e^2}{q}\right)\left(\frac{\varepsilon_2 + \varepsilon_1 \tanh(qd)}{\varepsilon_2(\varepsilon_1+\varepsilon_3) + (\varepsilon_2^2 + \varepsilon_1\varepsilon_3)\tanh(qd)}\right) \tag{5}$$

The interlayer interactions are given by Ref. [20]:

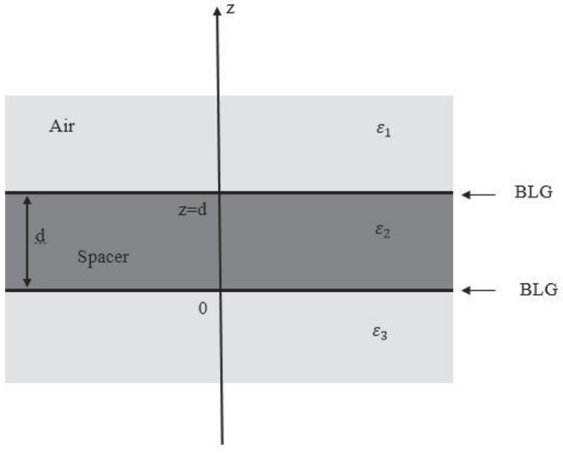

Fig. 1. A bilayer graphene double-layer system immersed in a three layered dielectric medium with the background dielectric constants $\varepsilon_1 = \varepsilon_{\text{Air}} = 1$, ε_2 and ε_3.

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