Localized States Influence Spin Transport in Epitaxial Graphene

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Published in:
Physical Review Letters

DOI:
10.1103/PhysRevLett.110.067209

Supplemental Material for "Localized states influence spin transport in epitaxial graphene"

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COUPLING RATE BETWEEN THE LOCALIZED STATES AND THE GRAPHENE CHANNEL

To estimate the coupling rate Γ between the localized states and the graphene channel, we can set up a simplified model based on the coupling between adjacent graphene layers in graphite, as these layers have the same or similar physical distance as the buffer layer to the graphene layer.

In graphite, the conductance in z-direction perpendicular to the layers is per layer $\sigma_{IL} = \sigma_{gr}/(\zeta d)$ where σ_{gr} is the in-plane conductivity of a graphene layer, d the distance between two layers (or between the graphene layer and the localized states) and $\zeta \approx 100$ the ratio between the conductivity within the layers and perpendicular to them [1].

We can now calculate for a current I_{IL} in z-direction:

$$I_{IL} = \frac{V\sigma_{IL}A}{d} = \frac{dQ}{dt} = e\frac{dN}{dt} = e\nu_{LS}\frac{d\mu}{dt}A \tag{1}$$

Here $V = \mu/e$ is the voltage between the localized states and the channel, proportional to the difference in the chemical potential, A the area through which the current flows, Q is the total charge that flows, N the number of charge carriers, d is the distance to and ν_{LS} the density of states (DOS) of the localized states, and e the electron charge.

Using the Einstein relation with ν the DOS and D the diffusion coefficient of the graphene channel we get:

$$V\frac{\nu}{\nu_{LS}}\frac{D}{d^2}\frac{1}{\zeta} = \frac{dV}{dt} \tag{2}$$

This equation includes the ratio of the DOS of the localized states and the graphene channel $\eta = \nu_{LS}/\nu$ that was discussed in the main text of this letter.

With the coupling rate $\Gamma \sim \frac{1}{V}\frac{dV}{dt}$ we receive :

$$\Gamma = \frac{1}{\eta}\frac{D}{d^2}\frac{1}{\zeta}. \tag{3}$$

With this model we get for bilayer graphene with $\zeta = 100$, $\nu = \nu_{LS}$, $d = 0.3$ nm and the typical graphene value $D \approx 0.02$ m^2/s

$$\Gamma_{BLG} \approx 10^{15}\ \mathrm{s}^{-1}. \tag{4}$$

For our system we have $\eta \sim 50$ while the other parameters stay the same and get therefore

$$\Gamma_{LS} \approx 2 \times 10^{13}\ \mathrm{s}^{-1}. \tag{5}$$

This value gives the order of magnitude of the coupling rate between the localized states and the graphene channel. With this value we are in the limit of strong coupling of the system as depicted in Fig. 2 of the main text.

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[1] K. Matsubara, K. Sugihara, and T. Tsuzuku, Phys. Rev. B **41**, 969 (1990).