Abstract

The discovery of graphene and analogous van der Waals materials offers a platform for the discovery and exploration of various novel physical phenomena. Here we study the effects of local interaction and strong localisation on electrical transport in heterostructures of graphene and hexagonal boron nitride, where high carrier mobility allows us to address unexplored fundamental phenomena, as well as define the limits of device performance. A key requirement for our study is the understanding of the scattering mechanisms for charge transport in the underlying system, but nanoscale and atomically thin systems present unique challenges, such as large susceptibility of charge carriers to the effects of external Coulomb fluctuations and dominant scattering from metal junctions.

We first explore the effects of metal-graphene junctions, or the contacts, on the low frequency noise in graphene devices with a large range of carrier mobility, on multiple substrates with various device and lead geometries. We report that contact noise is often the dominant noise source in graphene devices and the influence of contacts is most severe in high-mobility graphene transistors. Our analysis suggests that contact noise is caused by strong mobility fluctuations in the charge transfer region under the metal contacts, due to the fluctuating electrostatic environment.

We further report the discovery of a transmission resonance for charge carriers in graphene that occurs due to their interaction with an attractive Coulomb impurity in proximity to one of the metal contacts. The resulting effect is known as the Fermi-edge singularity (FES). In high-mobility graphene on hexagonal boron nitride, the FES manifests as abrupt changes in conductance with a large magnitude _ $e2/h$ at resonance, indicating total many-body screening of a local Coulomb impurity with fluctuating charge occupancy. Furthermore, we exploit the extreme sensitivity of the transmission resonance to the local density of states and demonstrate a new defect-spectroscopy tool to investigate strongly correlated phases in graphene in the quantum Hall regime.

Finally, we design our devices to eliminate all contact effects and study the conductance statistics in the regime of strong localisation in bilayer graphene. This is especially interesting in view of the recent studies on the robust edges-modes in bilayer graphene. However, the nature of transport deep within the subgap in not known. An independent control over the bandgap and the Fermi energy in bilayer graphene allows investigation of different strengths and configurations of disorder at the same chemical potential. We show that in strongly localised bilayer graphene the logarithm of conductance g (= $G/[e2/h]$) shows marginal self-averaging, i.e. the relative fluctuations $V ar$ (ln g)$/$hln gi2 diminish marginally with increasing system size, a known signature of unavoidable large resistance hops in one-dimension. Our analysis strongly suggests that transport in this localised regime occurs via one-dimensional channels, possibly along the robust edge-modes, highlighting a new localisation mechanism.