High-mobility *h*-BN/graphene/*h*-BN devices: zero-field electrical transport and quantum Hall criticality

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Abstract

We performed a wide experimental study on multi-terminal field-effect devices made of exfoliated graphene flakes (both single and double-layer) sandwiched between two thin hexagonal boron nitride (*h*-BN) flakes. The use of *h*-BN allowed reaching high mobility ($\mu \approx 4 \times 10^4$ $cm^2V^{-1}s^{-1}$ for the bilayer sample shown in Fig.1) and provided exceptional stability to the samples, which physical properties are preserved over long time.

The samples were prepared at HQGraphene (Groningen) using a dry transfer method [1]. *h*-BN flakes were first mechanically exfoliated with scotch tape and deposited onto a p-doped Si wafer with a 500 nm-thick SiO_2 layer on top. Graphene flakes were exfoliated on top of a transparent mask consisting in a stacking of glass slide, scotch tape and methyl/n-butyl methacrylate copolymer. Suitable single and few-layer graphene flakes were identified with an optical microscope in reflection mode. Using micromanipulators, the selected graphene flake was deposited on top of a thin (10-60 nm) *h*-BN one by lowering the polymer side of the mask onto the SiO_2 wafer, while it was heated up to 75-100° C. The polymer melts and it is released from the mask to the substrate, while the graphene flake adheres to the *h*-BN by means of van der Waals forces. The polymer is then dissolved in organic solvents and an analogous transfer step is repeated for the uppermost *h*-BN flake.

The first part of the work involved low-temperature (300 mK < T < 50 K) electrical transport measurements, performed with low-frequency ac lock-in technique. The resistivity (conductivity) of a bilayer graphene device was measured in four-probe configuration, at zero-magnetic field, while varying the carrier density with a back-gate contact connected the underneath p-doped silicon wafer. Our main results are reported in Ref. 2. We were able to identify a temperature-independent crossing point in the curves of resistivity as a function of back-gate voltage (V_g) (see Fig. 2), corresponding to a carrier density $n \approx 2.5 \times 10^{11}$ cm^{-2}, indicating a transition from insulating ($d\rho/dT < 0$) to metallic behavior ($d\rho/dT > 0$). By analyzing the temperature-dependence of the resistivity (conductivity) we characterized four different transport regimes, which are realized by tuning T and V_g over easily accessible ranges. Close to the neutrality point the low-T data (T < 10 K) are compatible with variable range hopping (VRH) with a characteristic exponent 1/3, i.e. transport is dominated by localized states. Above 10 K the resistivity grows linearly with T as expected from the parabolic energy-momentum relation, which translates into a constant density of states. At carrier density above the crossing point, the VRH exponent is renormalized to 1/2 as expected if Coulomb interaction is taken into account, while at higher temperature the data are compatible with ballistic transport, both for electrons and holes.

The second part of our work involved the use of a superconducting magnet, generating a perpendicular magnetic field (B) of intensity up to 9 Tesla. We centered on the so-called plateau-plateau (p-p) quantum phase transitions in the integer quantum Hall regime, aiming at measuring the critical exponents that govern such phenomenology. Our main results are reported in Ref. 3. We measured the exponent *k* by fitting the temperature-dependence of the maximum first derivative of the Hall resistivity ($d\rho_{xy}^{max}/dB$, shown in Fig.3) in correspondence of various plateau-plateau (P-P) quantum phase transitions. The *k* value we found was not in agreement with previous studies, both on graphene [4] and 2DEGs [5]. We therefore performed an independent determination of the parameters *p* and γ, that give *k* via the relation $k = p/2\gamma$. *p* was measured by analyzing the weak localization correction to the longitudinal conductivity in non-quantizing fields, which allowed to determine the T-dependence of the coherence length. Subsequently, we obtained the critical exponent of the localization length γ by studying the temperature dependence of the longitudinal resistivity in correspondence of the tails of the Landau levels. The measured values confirmed that the relation $k = p/2\gamma$ is valid in our bilayer sample. On the other hand the value of γ indicates that these phase transitions can't be properly treated by assuming an Anderson-liker disorder: the system seems to approach the classical percolation limit, probably due to smooth long-range potential fluctuation produced in the substrate.

References

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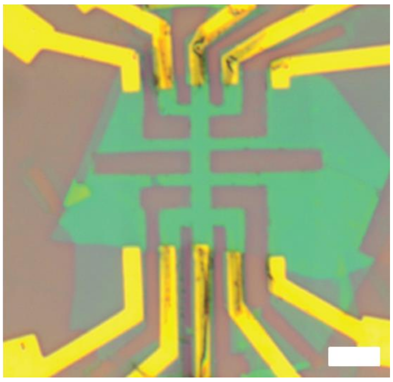
Figures

(1)



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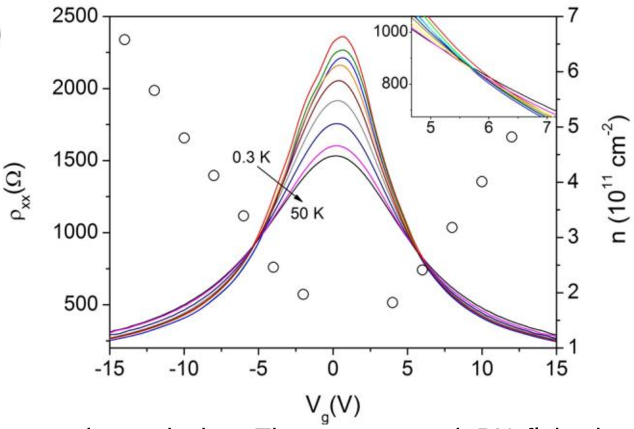

Fig.1 Optical microscopy image of a bilayer graphene device. The uppermost *h*-BN flake is clearly visible on top of the graphene/lower-*h*-BN mesa and the metallic contacts. The scale bar is 5 μm.

Fig.2 Solid lines: longitudinal resistivity as a function of the gate voltage V_g, at T between 300 mK and 50 K. Open circles: carrier density as a function of gate voltage, obtained from low-field Hall measurements at T = 0.3 K. (inset) ρ_{xx} (Ω) vs V_g (V) in the vicinity of the T-independent crossing point for electrons. Adapted from Ref. 2.

(3)

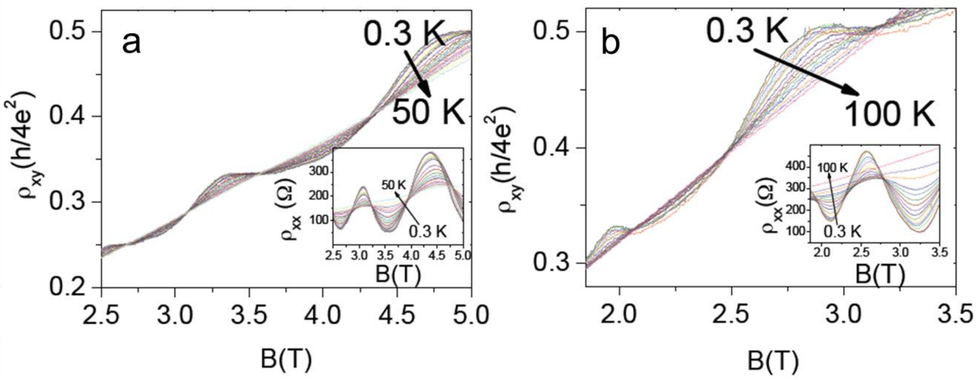

Fig.3 Panels (a) and (b) show the isotherms of the Hall resistivity ρ_{xy} as a function of the magnetic field in the electron-like regime at densities $n = 10.2 \times 10^{11}$ cm^{-2} and $n = 6.1 \times 10^{11}$ cm^{-2} respectively. The P-P transitions 8-4 and 12-8 are visible in (a), the 8-4 in (b). The insets show the isotherms the longitudinal resistivity ρ_{xx} as a function of the magnetic field. Adapted from Ref. 3.