Transport Measurements on Twisted Graphene Monolayers

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Transport Measurements on Twisted Graphene Monolayers

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Abstract. Twisted graphene monolayers form a sample of two closely spaced two dimensional systems. We have performed transport measurements on such decoupled graphene layers being jointly contacted and conducting in parallel to investigate the properties of charge carriers in both layers. Varying the charge carrier concentration and applying perpendicular magnetic field, the electric field effect, Shubnikov-de Haas oscillations and plateaus in the Hall resistance are observed. At the charge neutrality point, the resistance decreases by 15 percent with increasing temperature from 1.5 to 50 Kelvin.

Keywords: graphene, decoupled monolayers, magnetotransport
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Since the first use of the micromechanical cleavage technique to produce freestanding and atomically thin layers of carbon [1] called graphene, this truly two dimensional crystals have drawn huge attention because of their outstanding electronic and mechanical properties [2][3]. Type and concentration of the majority charge carriers can be tuned continuously due to the zero gap bandstructure. Magnetotransport measurements show a Berry's phase of π in the Shubnikov-de Haas (SdH) oscillations and an anormal half integer Quantum Hall effect (QHE) [4] which can, in the presence of high magnetic fields, even be observed at room temperature [5]. During the preparation process, not only single layer graphene is produced, but also multi- and bilayer systems. The latter can be separated into two types, those being Bernal stacked and forming a single crystal bilayer [6] and those being rotated with respect to this stacking order and therefore decoupled. Such twisted samples can be for example formed by a monolayer which is folded during the preparation process.

For sample preparation, micromechanical cleavage is used to rip off thin samples from bulk graphite and then place them on top of a silicon wafer which is covered with a layer of SiO_2. A suitable flake is selected via optical microscopy and a device as shown in Figure 1 is fabricated via E-beam lithography. Plasma etching is used to form the Hall-bar and after that Cr/Au contacts are evaporated.

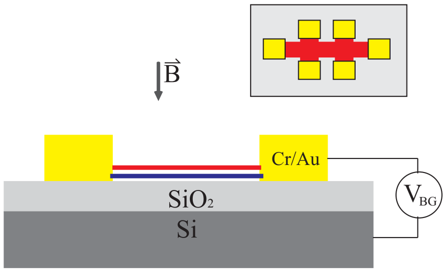

FIGURE 1. Sketch of the used sample. A Hall-bar structure (inset:topview) containing the two graphene layers (bottom blue, top red) is produced and contacted with chromium/gold leads. To characterize the sample, an electric field and a perpendicular magnetic field are applied.

To characterize the sample, magnetotransport measurements are carried out at temperatures down to 1.5 K. An applied backgate voltage is used to tune the charge carrier densities in both layers. While sweeping a perpendicular magnetic field at a fixed carrier concentration, two sets of superimposed SdH oscillations are observed in the longitudinal resistance as shown in Figure 2a). Both exhibit a Berry's phase of π and constant periods over 1/B, from which the carrier concentrations of the two layers can be deducted [7]. The two planes conduct in parallel but with different electronic properties. The charge carrier densities are significantly different due to screening of the electric field, being $0.69 \cdot 10^{12}/cm^2$ in the top and $4.9 \cdot 10^{12}/cm^2$ in the bottom layer at a backgate voltage of -60 V. Additionally, the top layer shows increased mobilities and scattering times [8]. While electron mobilities corresponding to the part of the resistivity due to long range disorder yield 3800 cm^2/Vs in the bottom layer, 12800 cm^2/Vs are observed in the upper one. This improved electronic properties in the top layer are attributed to the screening of substrate influence, normally decreasing the charge carriers mobilities in graphene. Additional to the longitudinal resistance, the Hall resistance is measured while sweeping the magnetic field as shown in Figure 2b. Different plateaus can be identified at filling factors according to the longitudinal oscillations in both planes. However because only three terminal measurements are performed, two layers

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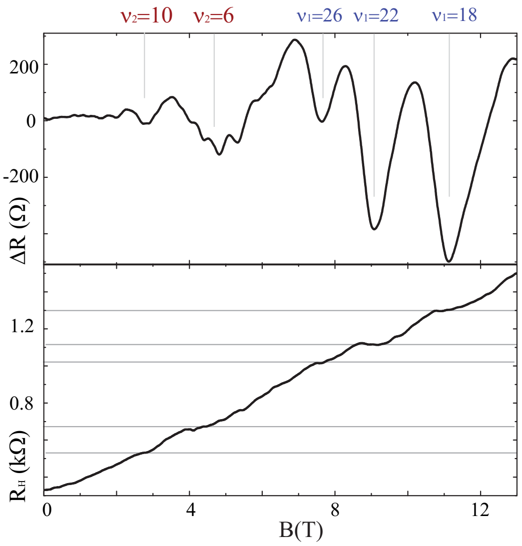

FIGURE 2. a) Longitudinal resistance at 1.5 K and -60V backgate voltage showing two sets of SdH oscillations. A background measured at 50 K is substracted for better visibility. Filling factors are marked for both oscillations (ν_1 bottom layer, ν_2 top layer). b) Hall resistance at T=1.5 K and V$_{BG}$=-60 V.

contribute and the longitunial resistance does not go down to zero, the plateaus' values can not be assigned to quantized values of the von-Klitzing constant.

While the so far mentioned results can be explained by the model of two independent monolayers conducting in parallel with additional screening effects, there are some differences which are observed at temperature dependent measurements. From the temperature dependent damping of the SdH oscillations, cyclotron masses are deducted [9], showing values higher as expected for a single monolayer devices. This is directly connected to a reduced Fermi velocity in such twisted samples, as predicted by theory [10]. Another difference can be observed at the temperature dependence of the field effect peak. Figure 3a) shows the longitudinal resistivity as a function of backgate voltage at different temperatures ranging from 1.5 to 50 Kelvin. While at high carrier concentrations no difference is observed, the resistivity close to the charge neutrality point is reduced by up to 15 percent with increasing temperature. Figure 3b) shows the maximum resistivity versus the temperature and a linear fit with a slope of -11.2 Ω/K. This behaviour is somewhat different from measurements reported for single monolayer devices on silicon dioxide [11], at which the peak resistivity barely changes. On the other hand, if the substrate is completely removed for suspended samples, a decrease is observed [12]. Therefore

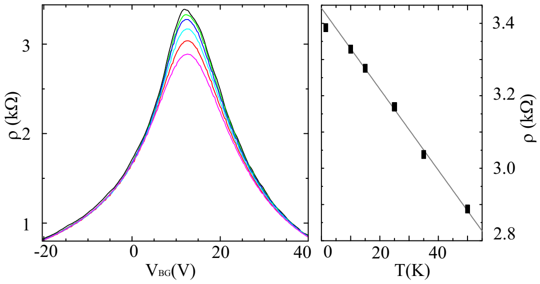

FIGURE 3. a) Electric field effect measurements at different temperatures (bottom down:1.5 K, 10 K, 15 K, 25 K, 35 K, 50 K). b) Temperature dependence of the maximum resistivity. A linear fit excluding the 1.5 K value is shown in grey.

we attribute the observed behaviour in the two layer sample to the upper layer. The increased mobilities and scattering times in this layer show reduced substrate influence which may lead to a behaviour comparable to the samples with removed substrate.

In summary, electronic properties of a system consisting of two jointly contacted decoupled graphene monolayers are investigated. The system is described by a model of two parallel conductors with different charge carrier densities and mobilities due to screening effects. The longitudinal resistance shows SdH oscillations for both layers and in the Hall resistance plateaus are observed. Changing the temperature, a significant change of maximum resistivity is shown.

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