Unusual backscattering between quantum Hall edge states in CVD graphene

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The quantum Hall effect (QHE) observed in graphene is promising for an application to resistance metrology thanks to the energy spacing $\Delta E(B) = 36\sqrt{B[T]}$ meV between the first two Landau levels (Lls) much larger than in GaAs ($1.7B$[T]meV). This is an advantage to develop a resistance standard surpassing the GaAs-based ones by operating at $B < 4$ T and $T > 4$ K. This would ease the dissemination of the quantum resistance standard. Achieving this goal requires the fabrication of large graphene monolayer (a few 10000 μm^2) with an homogeneous low carrier density ($< 2 \times 10^{11} cm^{-2}$) and a carrier mobility higher than 5000 $cm^2V^{-1}s^{-1}$ [1]. The quantization of the Hall resistance was checked with an uncertainty of 9 parts in 10^{11} in a large monolayer sample (160×35 μm^2) made by sublimation of SiC[2]. Growth based on chemical vapor deposition (CVD) appears as another promising route to produce large graphene monolayers required for the development of a quantum resistance standard. Carrier mobilities up to 25000 $cm^2V^{-1}s^{-1}$ and 60000 $cm^2V^{-1}s^{-1}$ have been obtained in CVD graphene transferred on SiO_2 and Boron nitride substrates respectively[3].

We studied the transport properties of Hall bars of 200 µm × 400 µm size made of polycrystalline graphene grown by CVD on copper and then transferred on SiO_2/Si substrate. The Hall resistance reported as a function of gate voltage V_g at T=0.3 K and B=19 T features well developed Hall resistance plateaus at values $h/\nu e^2$ for integer Ll filling factors $\nu = -10, \pm 6, \pm 2$ (see fig. 1b). They coincide with minima of the longitudinal resistance. One can also observe specific behaviors of R_{xx} and R_H at the charge neutrality point (resistance peaks higher than h/e^2) and at $V_a \sim 8$ V (resistance peaks of lower amplitude). They corresponds to transverse conductivity plateaus $\sigma_{xy} = 0$ and $\sigma_{xy} = e^2/h$ respectively (as seen more clearly in inset of fig. 2). Such conductivity plateaus, usually observed in higher mobility graphene, are explained by the degeneracy lifting of the n=0 Landau level [4].

Although nice plateaus are observed, it turns out that the Hall resistance even on the $\nu = \pm 2$ plateau deviates from $R_K/2$ theoretically equal to $h/2e^2$ by more than 1 percent at a current of 1 µA. R_{xx}, that measures the dissipation of the system, is high even at low currents values resulting from backscattering of carriers between counter-propagating edge states (see inset of fig. 1). To characterize this lack of quantization, σ_{xx}, was measured versus the filling factor ν, between T=0.3 K and T=40 K (see fig. 2) and B=5 T and B=19 T. It appears that backscattering $\sigma_{xx}(T)$ does not follow an activated behavior (nor a variable range hopping behavior) except at the minimal value of $\sigma_{xx,}$ and the highest magnetic field (19 T) (see fig. 3a). Even at this particular point, the Arhenius-law behavior is characterized by a very low activation temperature of about 2.4 K which is much smaller than the

expected characteristic temperature $\Delta E/k_B$ ~ 1834 K where ΔE ~ 158 m*e*V is the energy gap at *B*=19 T. For all other filling factors and/or magnetic fields the temperature dependence is smoother. More precisely, $\sigma_{xx}(T)$ and $(\sigma_{xx}(B))$ follow power-laws dependences versus *T* (versus *B*). More importantly, it turns out that the temperature dependence is similar at ν values corresponding to minima and maxima ($\nu = -4$ in fig. 3) of σ_{xx}. Since conductivity peaks are due to transport through extended states existing close to LIs energies, this observation suggests that the strong backscattering observed at ν values around $\nu = \pm 6, \pm 2$ is caused by the existence of delocalized states at energies in between LIs.

Structural characterizations (Raman spectroscopy, optical and atomic force microscopy) were performed. They confirm a high density of line defects (GB, wrinkles) that form continuous networks connecting Hall bar edges. It is mandatory for carriers moving from source to drain to cross some of these line defects. Besides the impact on the Hall quantization of a grain boundary crossing a Hall bar was evaluated by performing numerical simulations. It is shown that non-chiral edge channels along the defect at Fermi energy value in between LIs short-circuit the counter-propagating edge states of the conductor. This supports that linear defects (grain boundaries and probably also pleats) are responsible for the strong backscattering observed in polycrystalline CVD graphene.

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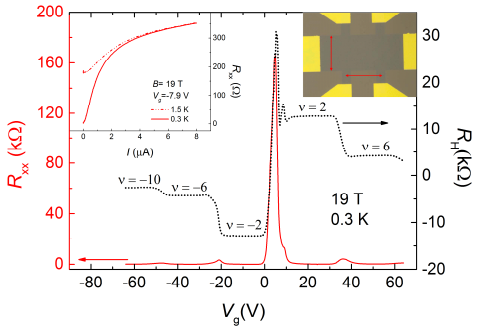

Figure 1: Hall and longitudinal resistance versus gate voltage. Inset: R_{xx} vs *I*

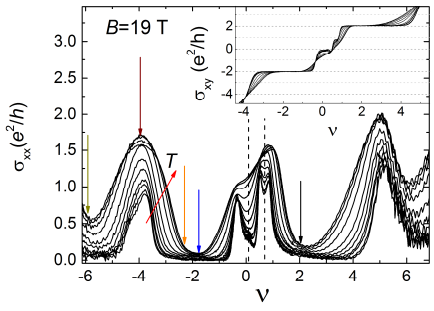

Figure 2: σ_{xx} (σ_{xy} in inset) versus the filling factor υ between 0.3 K and 40 K

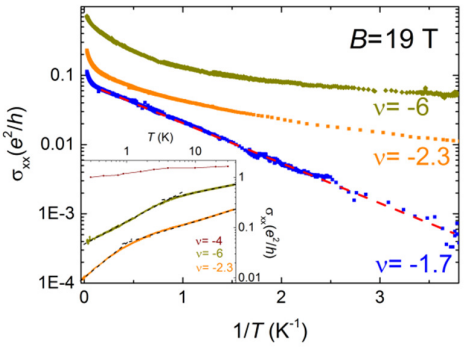

Figure 3 σ_{xx} versus *1/T* (versus *T* in log-log scale in inset)