HIGH FIELD QUANTUM HALL EFFECT IN DISORDERED GRAPHENE NEAR THE DIRAC POINT

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Graphene flakes deposited on SiO_2 substrates were considered, in the early times of their discovery, as perfect two-dimensional mono-layer of carbon atoms arranged in a honeycomb lattice. However, it was soon realised that topographic corrugations, lattice defects, adsorbed molecules as well as interactions with the substrate strongly affect their electronic properties [1]. In particular, this last type of perturbation leads to charge carrier-density inhomogeneities, often referred to as "charge puddles", which have been directly visualized using scanning probe techniques [2]. Their presence is assumed to originate mainly from charged impurities trapped in the silicon oxide layer supporting the graphene sample. The fundamental electronic properties of graphene in the presence of charge puddles have been extensively studied both theoretically [3] and experimentally [4]. However, little is known about their implications at very high magnetic field. For this purpose, pulsed-field magneto-transport experiments of up to 60 T have been performed in disordered graphene samples having mobility in the range 2000 to 10000 cm^2/Vs. The charge carrier density can be continuously varied through the application of a back-gate voltage. The mobility and residual doping of the samples is modified using either vacuum annealing or direct exposure to air. In a Hall bar configuration, both the longitudinal and Hall resistances are recorded simultaneously during a magnetic field pulse, at liquid helium temperature, for different back-gate voltages.
For high carrier density, the typical Quantum Hall Effect (QHE) for graphene is observed as a sequence of quantized plateaus of the Hall resistance and vanishing longitudinal resistance for filling factors ν=2, 6, 10 etc... On the other hand, as the system is driven close to the charge neutrality point, the Hall resistance is progressivily attenuated suggesting the contribution of both electron- and hole-like charge carriers. This effect is directly attributed to the presence of local charge puddles which start to dominate the transport properties when the overall carrier density is low. Actually, we have found that their impact on transport is particularly strong in high magnetic field, when only the lowest Landau Level (LL) remains

populated. In this regime, electron and hole-type carriers coexist and their ratio depends on the Fermi energy position within the LL band-structure, which is strongly magnetic field dependent [5]. As a result, the Hall resistance tends to vanish at low filling factor. We show that the threshold magnetic field marking the onset of this effect is directly related to the mobility of the sample.

Furthermore, in disordered graphene, the Hall and longitudinal magneto-resistances are distorted with large fluctuations. We experimentally observe that the amplitude of the fluctuations is larger in the vicinity of the CNP and within an intermediate magnetic field range 10 T¡B¡35 T. Again we attribute this effect to the presence of charge puddles, turning graphene into an inhomogeneously doped medium. Depending on position of the Fermi energy, local patches of the sample, having different carrier density, successively enter into different QH states and lead to magneto-resistance fluctuations [6]. The maximum amplitude of the fluctuations is expected when the magnetic length is similar to the mean diameter of the puddles [7].

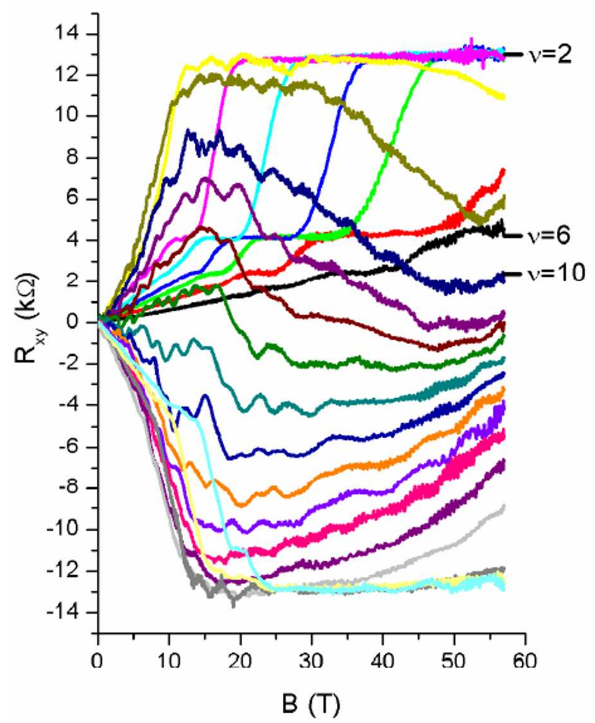

Figure 1: Evolution of the Hall resistance in disordered graphene as the system is driven in the close vicinity of the charge neutrality point. The carrier density is modulated through the application of a gate voltage and varies from n=10.1×10^{12} cm^{-2} (black curve) in the electron doped regime to n=-1.65×10^{12} cm^{-2} (light blue curve) in the hole doped regime.

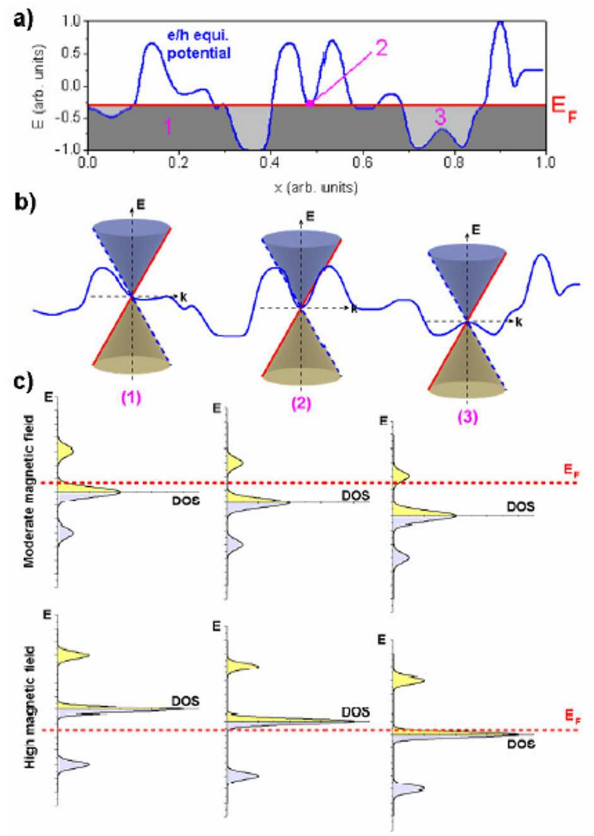

Figure 2: a) and b) illustration of a fluctuating potential landscape, due to the presence of charge puddles. c) When a large magnetic field is applied, the Landau level structure is locally shifted according to the local charge carrier density, leading to vanishing Hall resistance at the charge neutrality point.

References

[1] J.H. Chen *et al.*, Nature Physics, 4 (2008) 377.
[2] Y. Zhang *et al.*, Nature Physics, 5 (2009) 722.
[3] R.P. Tiwari *et al.*, Phys. Rev. B, 79 (2009) 165408.
[4] S. Cho *et al.*, Phys. Rev B, 77 (2008) 081402(R).
[5] J.M. Poumirol *et al.*, Phys. Rev. B, 82 (2010) 121401.
[6] J.M. Poumirol *et al.*, New J. Phys., 12 (2010) 083006.
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