INTEGER QUANTUM HALL EFFECT IN TRILAYER GRAPHENE

J.M. Poumirol[a],W. Escoffier[a] ,A. Kumar[a]
C. Faugeras[b], D. P. Arovas [c], M. Fogler[c]
P. Guinea [d], S. Roche [e], M. Goiran [a] and B. Raquet [a]

[a] LNCMI, CNRS
143 av. de rangueil, 31400 Toulouse, France
[b] LNCMI, CNRS
38042 Grenoble, France
[c] Department of Physics, Univ. of California
San Diego, 9500 Gilman Drive, La Jolla
[d] Instituto de Cienca de Materiales de Madrid
CSIC, Cantoblanco E28049 Madrid, Spain
[e] Centre d'Investigaci en Nanocincia i Nanotecnologia (CSIC-ICN)
UAB, 08193 Barcelona, Spain

The Integer Quantum Hall Effect (IQHE) constitutes the hallmark of two-dimensional systems subjected to a strong perpendicular magnetic field. So far, three different realizations of 2D systems displaying distinctive IQHE features have been reported in the literature. These are conventional semiconducting heterostructures, graphene and bi-layer graphene. In the case of graphene-based systems, it has been anticipated that the dynamics of charged carriers drastically change every time an extra graphene layer in added [1,2]. Therefore, the LL spectrum of N-layer graphene systems would display unique IQHE features eventually characterizing their N.π Berry's phase [3]. This property particularly applies to trilayer graphene for which 3π Berry's phase would drastically change the Quantized Hall (QH) resistance plateau sequence as compared to mono or bi-layer graphene systems. Despite many experimental efforts, no clear signature of the Hall resistance quantization has been unveiled in tri-layer graphene so far. Actually, trilayer graphene flakes are difficult to isolate experimentally, they usually display low mobility and may exist with different stacking order, making IQHE difficult to observe even at moderate magnetic fields.

Making use of both Raman spectroscopy and high field magneto-transport, we report for the first time on a fourth type of IQHE in tri-layer graphene. The QH resistance plateau sequence is similar to graphene, however the v=2 QH plateau is missing. The experimental data are supported by a theoretical analysis where both the Bernal and rhombohedral stacking order have been considered. The model includes the presence of an electric field across the graphene layers, induced by the back gate voltage. The charge distribution across the layers has been computed self-consistently together with Fermi energy pinning as the magnetic field is increased. We notice that a nice comparison between theoretical and experimental results is achieved only for the rhombohedral stacking order. At very high magnetic field, the QH resistance departs from its expected value and tends to vanish as the system is driven close to CNP.

We show that the presence of charge puddles is necessary to explain this trend, which is further confirmed by analysing the zero-field temperature and carrier density dependence of the resistance [4]. We believe that our present study, based on both experimental and theoretical grounds, unravels for the first time an exhaustive picture of the Landau Level quantization in trilayer graphene with rhombohedral stacking.

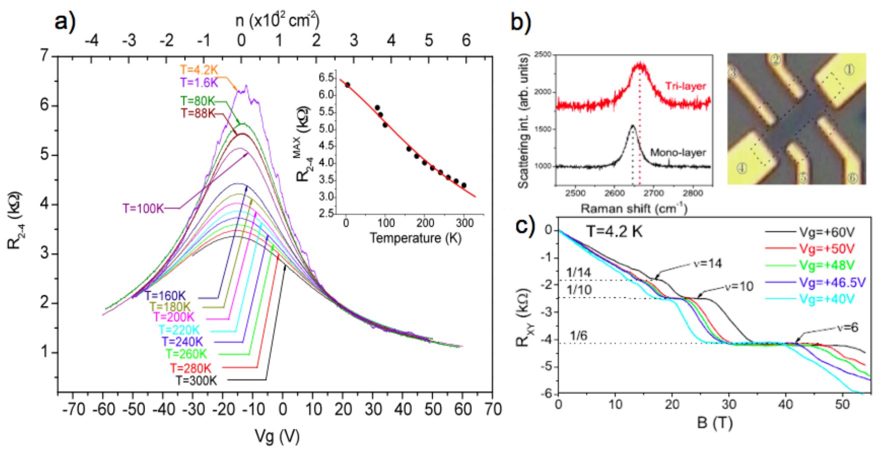

Figure 1: (a) Resistance as a function of carrier concentration and temperature. Insert: experimental and theoretical fit of the resistance maximum versus temperature according to the model developed in [5] for inhomogeneous system made of electron/hole puddles. (b) left: Raman spectrum of trilayer graphene and mono layer graphene measured on the same substrate, for comparison. Right panel: optical image of the sample. (c) Quantum Hall Effect in trilayer graphene for selected back gate voltage.

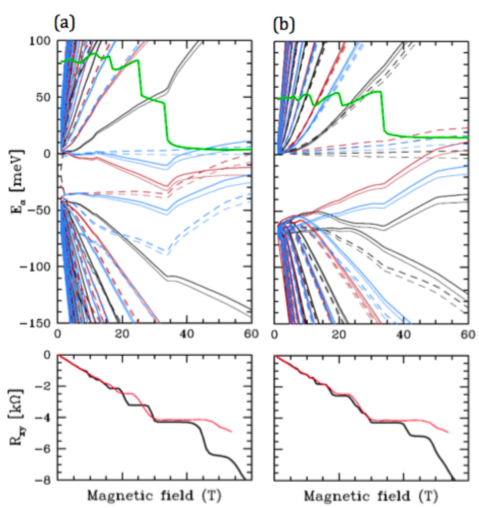

Figure 2: (a) Self-consistent calculations displaying the Landau Level structure for Bernal trilayer graphene with Vg = 50V, T = 5K, g=2. Positively charged impurities are added to the top layer in order to account for the offset bias voltage necessary to reach the charge neutrality point. Experimental and theoretical IQHE results are shown in red and black solid curves respectively in the lower left panel. (b) Same analysis as in (a), but with rhombohedral stacking order. Notice the agreement between theoretical and experimental data for field up to 40T

References

[1] F. Guinea et al., Physcal Review B 73, 245426 (2006)
[2] Daniel P. Arovas and F. Guinea, Phys. Rev. B 78, 245416 (2008)
[3] M. Koshino et al., Physcal Review B 79, 125443 (2009)
[4] J.M. Poumirol et al., Physical Review B 82, 121401(R) (2010)
[5] E.H. Hwang et al., Physical Review B 82, 081409(R) (2010)
[6] This research was supported by EuroMagNET II under EU Contract No. 228043, by the French National Agency for Research (ANR) under Contract No. ANR-08-JCJC-0034-01, and by the technological platform of LAAS-CNRS, member of the RTB network. DPA was supported by NSF grant DMR-1007028. The authors are very grateful to M. Potemski for very helpful and fruitful discussions.