Fractional Quantum Hall Effect in Monolayer and Bilayer Graphene

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Introduction

We have studied the Fractional Quantum Hall Effect (FQHE) in mono- and bilayer graphene. The observation of FQHE states in transport is particularly delicate due to their extreme sensitivity to disorder. As a result, prior to our work only a few of the most robust states have generally been observed [1], and little is known about their internal symmetries of spin and valley.

Experimental

Monolayer and bilayer graphene multiterminal devices with graphite back gates were measured in ^{3}He cryostats in cells 9, 12 and 15 at magnetic fields up to 45T.

Results and Discussion

We observed FQHE states in the Zeroth and First Landau Levels of monolayer graphene following the sequence predicted by composite fermion theory as shown in Fig.1A and in our recent publication [2]. The in-plane field dependences of the FQHE gaps suggest that most states in the First Landau Level are not yet spin-polarized even at high total fields. In addition, interactions with the boron nitride substrate break the sublattice symmetry in some graphene flakes, causing a gap opening at zero field as well as at odd-numerator fractions in the Zeroth Landau level which would otherwise be expected to be gapless. In bilayer graphene, we observed FQHE states in the First and Second Landau levels. First reported this year, FQHE in bilayer graphene possesses rich physics due to the interplay of spin, valley and orbital degrees of freedom [2-4]. Notably, we observed robust 13/3, 14/3, 16/3 and 17/3 fractions in the Second Landau Level (Fig. 1C). In-plane field-dependent studies of these fractions suggest that some states may be spin-polarized in their ground state.

Conclusions

We have observed FQHE states in low-disorder graphene mono- and bilayer graphene devices on boron nitride with a graphite back gate, and studied the nature of FQHE states with temperature- and field-dependent studies.

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References

[1] Dean, C. R. *et al.* Nature Phys. **7**, 693–696 (2011)
[2] Amet, F. *et al.* arXiv:1410.3549 (to appear in Nature Comm.)
[3] Kou, A. *et al.*. Science, **345**, 55-57 (2014)
[4] Lee. K. *et al*. Science, **345,** 58-61 (2014)
[5] Maher, P. *et al.* Science, **345, 61-64** (2014).

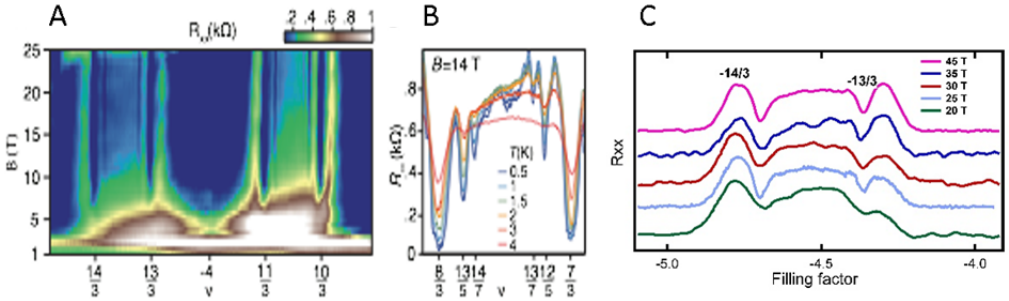

Fig. 1: A. R_{xx} (ν, B) measured at 300mK around half filling in 1LL. Vertical blue stripes indicate incompressible phases. B. Temperature dependence of R_{xx} between ν=2 and ν=3, measured at 14T. Activated behavior indicates the emergence of Fractional Quantum Hall gaps. C. Field-dependence of fractions between ν= -4 and ν = -5. Data with in-plane field (not shown here) are suggestive of some fractions in the range ν= -4 and ν = -7 having spin-polarized ground states.