NATIONAL HIGH MAGNETIC FIELD LABORATORY
2017 ANNUAL RESEARCH REPORT

New Fractional Quantum Hall States in Ultra-Clean Graphene Heterostructures

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Introduction

Interacting electrons in two dimensions subjected to a perpendicular magnetic field can exhibit a fractional quantum Hall (FQH) effects at fractional filling of a Landau level. The FQH state is insulating, and hosts fractional-charge quasiparticles with exotic quantum statistics as elementary excitations. Realizing robust FQH states requires low electronic disorder, particularly for the more exotic even-denominator FQH states. In contrast to odd-denominator FQH, these are less well theoretically understood and are thought to host quasiparticles with nonabelian statistics. Graphene heterostructures based on mono-, bi- and trilayer graphene have rich phase diagrams at high fields, which can result in novel tunability and new FQH states.

Experimental

Graphite/hexagonal boron nitride (hBN) encapsulated graphene exhibit much more robust FQH states than previous device architectures. We measured magnetocapacitance to probe the bulk electronic compressibility, which allows us to map the often complicated and multi-dimensional phase diagrams in search of novel FQH states, which we have done in SCM2, Cell 12, and the Hybrid magnet in 2017.

Results and Discussion

Graphene's unique band structure and valley degree of freedom can lead to novel FQH states. In graphene Landau levels, electrons can have different spin and valley polarizations, which form a highly symmetric 'isospin' degree of freedom. In monolayer graphene, we find a new transition between different isospin ground states, hallmarked by a weakening of odd-denominator FQH states nearly coincident with the appearance of unexpected even denominator FQH states, an example of which is shown in **Fig.1** [1]. The even-denominator FQH states are the result of pairing between electrons, which live on different sublattices, a new manifestation of a multi-component FQH effect. The underlying phase transition is tuned by coupling to the hBN substrate, and could be a long sought-after example of deconfined quantum criticality.

Adding a second layer of graphene (bilayer graphene) introduces more complexity, adding an "orbital" degree of freedom, but also gives a new tuning knob in the perpendicular electric field. Different orbitals (N=0,1) have wavefunctions with different spatial profile, which modified electron interactions. We observe even-denominator FQH states in N = 1 orbitals, which are predicted to host non-abelian anyons. Bilayer graphene's band structure predicts that the N=1 orbital wavefunction changes at high fields, allowing continuous tuning of the form of interactions. We directly observe this "pseudopotential tuning" by measuring the strength of even and odd denominator FQH states as a function of magnetic field [2].

Finally, in trilayer graphene devices we made the first inroads in measuring the FQH effects at high magnetic fields, and observe novel even-denominator states and a rich phase diagram [4].

Conclusions

In conclusion, our work at the NHMFL studied the interplay of graphene's electronic properties, interactions, and magnetic fields to show that new degrees of freedom can result in exotic, sometimes unpredicted, fractional quantum Hall states. Magnetic field, electric field, and coupling to hBN substrates provide a plethora of knobs with which to control FQH states.

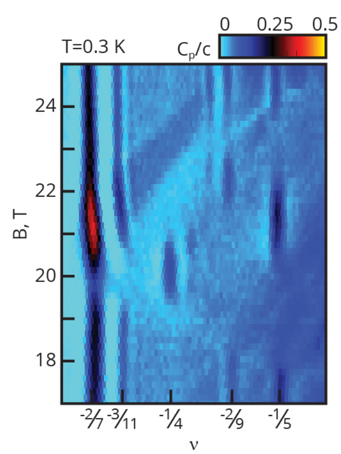

Fig.1 Penetration field capacitance (Cp/c) as a function of filling factor (ν) and magnetic field in Tesla (B) in a monolayer graphene sample. Dark blue regions indicate FQH states, including at ν = -1/4, accompanied by transitions in nearby odd FQH states.

Acknowledgements

A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490 and the State of Florida.

Magnetocapacitance measurements were funded by the NSF under DMR-1654186. A portion of the nanofabrication and transport measurements were funded by ARO under proposal 69188PHH.

References

[1] Zibrov, A.A., *et al.,* arXiv:1712.01968 (2017).
[2] Zibrov, A.A., *et al.*, Nature, **549**, 360-364 (2017).
[3] Kometter, C., *et al.*, In Preparation.