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Control of Spin and Valley in Ultra-Clean Graphene Devices

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Introduction

The microscopic ordering in a 2D electron system is determined by the competition between electron-electron interactions and single particle energy gaps. Dual-gated graphene devices offer a high degree of control over of the internal (spin and valley) degrees of freedom. Bulk magneto-capacitance and magneto-resistance measurements of graphene heterostructures allow quantitative characterization of new phase transitions evident in the size of fractional quantum Hall (FQH) gaps.

Experimental

Graphite/hexagonal boron nitride (hBN) encapsulated graphene exhibit much more robust FQH states than previous device architectures. Graphene band structure are modified by adding a substrate-induced sublattice splitting [1,3] or by introducing spin-orbit coupling by proximal layers of WSe2 [2]. In order to exclude the effects of uncontrolled gate electrostatics and chemistry at the graphene crystal edges we perform bulk measurements, which allows us to explore the multi-dimensional phase diagram in graphene heterostructures. For bulk conductivity measurements we have developed a new fabrication technique [1] for making edgeless Corbino geometry devices. Magnetocapacitance and magnetoresistance measurements were done at cryogenic temperatures and high magnetic fields at NHMFL in 35T (Cell 12), 31T (Cell 9) and the SCH (Cell 14) magnets in 2018.

Results and Discussion

FQH states in edgeless Corbino devices with sublattice splitting show particle-hole symmetry across individual spin valley resolved Landau levels, indicating single component FQH states. Thermal activation measurements of these gaps are well matched to exact diagonalization calculations with only a single fitting parameter that captures the effects of disorder. Tuning the strength and direction of the magnetic field we observe new multicomponent states including a FQH state at ν =+-1/2 around 18T is observed accompanied by vanishing odd-denominator FQH gaps, and a valley-ordered ferromagnetic state at integer filling ν=-4.

Magnetocapacitance measurements of encapsulated bilayer graphene with a proximity induced spin-orbit coupling (SOC) reveal integer quantum Hall gap closures at ν=+-3 that are asymmetric under an applied electric field. The direction of asymmetry is flipped as the magnetic field strength is increased, providing a direct probe of induced SOC coupling.

Conclusions

Our work at the NHMFL studied the interplay of graphene's electronic properties, interactions, and magnetic fields to demonstrate that new degrees of freedom can result in exotic, sometimes unpredicted, fractional quantum Hall states. Magnetic field, electric field and - added in this recent work - spin-orbit coupling and coupling to hBN substrates provide a plethora of knobs with which to control FQH states.

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References

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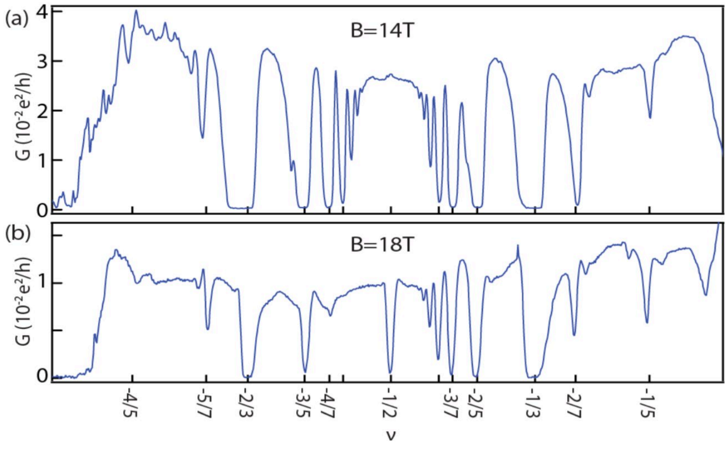

Fig. 1 Conductance measurements in a dual graphite-gated Corbino device showing FQH states near a multicomponent phase transition at B=18T.