Hofstadter Butterfly in the Strongly Interacting Regime

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Introduction

The moiré pattern that develops in graphene/BN heterostructures act as a periodic potential, providing a nearly ideal system to study the effect of superlattice patterning on 2D systems. Under large magnetic fields, interplay between the moiré and magnetic length scales gives rise to a self-similar recursive energy spectrum, known as Hofstadter's butterfly. The Hofstadter spectrum arises in a purely single particle picture, and in fact the role of electron-interactions has received only limited theoretical attention. For example it remains unclear whether fractionally filled Hofstadter bands will support FQHE states. Does the composite Fermion (CF) picture continue to hold and if so do the CF states also exhibit fractal structure? The possibility of anomalous orbital magnetism under certain conditions has been theorized.

Experimental

Very high mobility monolayer and bilayer graphene/hexagonal boron nitride heterostructure samples were measured utilizing a combination of the SC magnet facilities for fields ranging between 0-18T, and the resistive magnet facilities at fields up to 45 T.

Results and Discussion

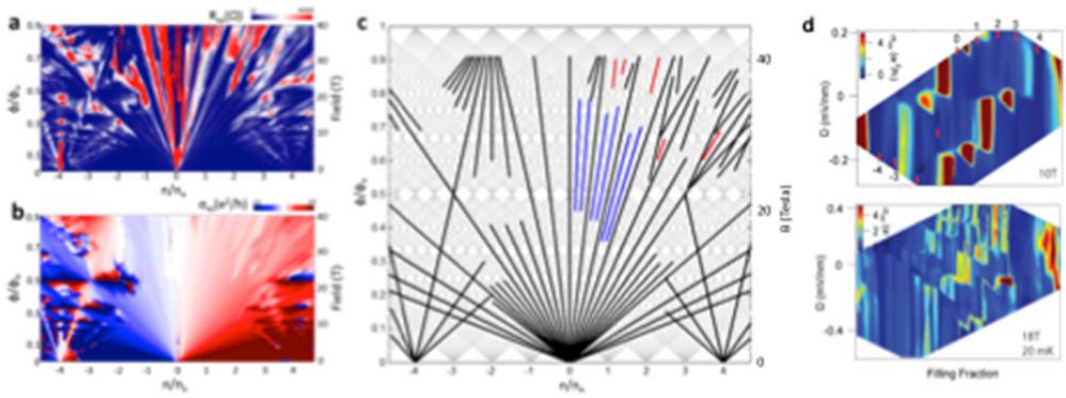

Fig. 1

Fig.1a and 1b show a plot of longitudinal resistivity and transverse Hall resistivity, respectively, as a function of normalized carrier density and normalized flux. A summary of the observed states is plotted in the simplified Wannier diagram, shown in Fig. 1c. The exceptional device exhibits clear signatures of interaction-driven integer symmetry broken states within the conventional QHE hierarchy and within the Hofstadter mini-fans (black lines). Simultaneously, we observe signatures of the fractional quantum Hall effect at filling fractions 1/3, 2/3, 4/3, 5/3, 7/3 and 8/3 (blue lines). As the magnetic field is increased above 30 Tesla, the FQHE states give way to mini-band states associated with the Hofstadter spectrum, in agreement with recent theoretical predictions.

Fig. 1d shows data acquired from a dual-gated bilayer graphene in which displacement field and carrier density can be tuned independently. The presence of a moiré-superlattice again results in mini-gaps outside of the conventional quantum Hall hierarchy of states, but well explained by the Hoftstadter single particle formalism. Apparently, the Hofstadter states can be varied with application of displacement field in a non-trivial manner, with anti-diagonal symmetry in the D-ν space suggest that the competing energy states are governed by layer-polarization together with electrical doping.

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References

[1] Dean et al., "Hofstadter's Butterfly and the fractal quantum Hall effect in Moiré superlattices " Nature, 497, 598 (2013).