Thermodynamic evidence of fractional Chern insulator in moiré $MoTe_2$

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Primary CNF Tools Used: Zeiss Supra SEM, Nabity Nanometer Pattern Generator System (NPGS), Angstrom E-Beam Evaporator, SC4500 Odd/Even-Hour Evaporator, Autostep i-line Stepper, Hamatech Wafer Processor Develop, Heidelberg Mask Writer - DWL2000, Photolithography Spinners, Dicing Saw – DISCO, Yes Asher

Abstract:

Fractional Chern insulators are the lattice analogues of the fractional quantum Hall effects, characterized by Hall conductance quantized to rational fractional multiples of e^2/h in the absence of external magnetic field or Landau levels [1, 2, 3]. By employing a new technique to optically readout the local thermodynamics [4], we discover thermodynamic evidence of both integer and fractional Chern insulators in a 3.4° twisted homo-bilayer $MoTe_2$ moiré device. Specifically, we obtain local electronic compressibility through a monolayer semiconductor sensor capacitively coupled to the tMoTe2 moiré and show that the correlated insulators at hole filling factors v = 1 and 2/3 spontaneously break time-reversal symmetry. We further demonstrate that they are integer and fractional Chern insulators with Chern numbers 1 and 2/3, respectively, from the dispersion of the insulating states in moiré filling with applied magnetic field. Our findings pave pathways for uncovering other new fractional topological phases and demonstrating the fractional statistics in moiré semiconductor materials.

Summary of Research:

Fractional topological phases represent a unique class of quantum states that combine strong interactions with nontrivial band topology. Transition-metal dichalcogenide (TMD) semiconductor moiré materials, which support tunable topological flat bands, provide a highly tunable platform for realizing fractional topological phases [5, 6]. Our experiment demonstrates that, in 3.4° tMoTe2 moiré, the correlated-insulating states at hole filling v = 1 and 2/3 are integer and fractional Chern insulators.

Figure 1 illustrates the schematic of a dual-gated 3.4° twisted homo-bilayer MoTe2 device with a monolayer WSe2 sensor for thermodynamic measurements. Inset shows the schematic of tMoTe2 lattices. The twisted bilayers form a honeycomb moiré superlattice, with two sublattices (red and blue) residing in two different layers. Mo atoms in the top layer are aligned with Te atoms in the bottom layer at the red sublattice sites, and the arrangement is reversed at blue sublattice sites.

We employ our newly developed technique to optically readout the local thermodynamics of tMoTe2 moiré. Figure 2(a) exhibits a simplified measurement scheme. A monolayer semiconductor sensor (green) is capacitively coupled to the sample (blue), allowing an interlayer bias Vs to be applied between sample and sensor. For each measurement, sensor chemical potential is actively adjusted through a feedback circuit to lock the reflection count at a chosen reference point. The amount of adjustment directly reads the chemical potential μ of the sample.

Figure 2(b) shows an example reflectance spectrum as a function of WSe_2 sensor chemical potential (tuned by V_{bg}). The neutral exciton resonance peak quenches rapidly upon electron doping near 4.69V. In Figure 2(c) the integrated photon count drops sharply upon electron doping, enabling accurate determination of WSe2 band edge, making it a natural reference point. During each measurement, V_{bg} is tuned through a feedback loop to lock the reflection count the chosen reference point (vertical dashed line). As shown in Figure 2(d), under this arrangement, sensor chemical potential (dashed green line) is kept at sensor conduction band edge, while sample chemical potential (dashed blue line) is at eVs below it, with μ=0 defined at the moiré band edge. Therefore, sample's chemical potential is given by

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$$\mu/e = \left(1+\frac{C_{bg}}{C_s}\right)V_S - \frac{C_{bg}}{C_s}V_{bg},$$

where C_{bg} and C_s are the bottom-gate-to-sensor and sensor-to-sample geometrical capacitances, respectively.

We apply this technique to the 3.4° $tMoTe_2$ moiré device shown in Figure 1. Figure 3(a) and (b) show moiré chemical potential (μ) and incompressibility (dμ/dv) as a function of doping density (v), respectively, when the moiré is tuned to near zero interlayer potential dfference (E ≈ 0). The steps in chemical potential, or peaks in incompressibility, correspond to insulating states at ν = 1, 2/3 and 2. Figure 3(c) and (d) shows the magnetic circular dichroism (MCD) as a function of perpendicular magnetic field (B) at ν = 1 (c), and ν = 2/3 (d). Spontaneous magnetization and magnetic hysteresis can be clearly identified for both states, indicating that correlated insulators at ν = 1 and 2/3 spontaneously break time reversal symmetry.

Figure 4(a) shows the electronic incompressibility as a function of ν and B at E ≈ 0. We observed that the incompressible states at ν = 1 and 2/3 disperse linearly with B. Empty circles denote the center of mass of the incompressibility peaks. Filled circles in Figure 4(b) mark the corrected dispersion with respect to a trivial Mott insulator at large E. Linear fits to the corrected dispersions are denoted by the solid lines in Figure 4(b), which yield the quantum numbers (t, s) according to the Diophantine equation

$$\nu = t\frac{e}{h}\frac{B}{n_M} + s$$

We conclude that for ν = 1, t = 1.0 ± 0.1 (corresponding to Chern number 1), while for ν = 2/3, t = 0.63 ± 0.08 (corresponding to Chern number 2/3).

Conclusions and Future Steps:

By employing the optical readout of local chemical potential on a 3.4° tMoTe2 device, we obtain thermodynamic evidence of fractional Chern insulators at ν = 2/3, with Chern number 2/3. Our results indicate that TMD moiré flat bands can host topologically ordered states carrying fractionalized excitations in the absence of magnetic fields.

References:

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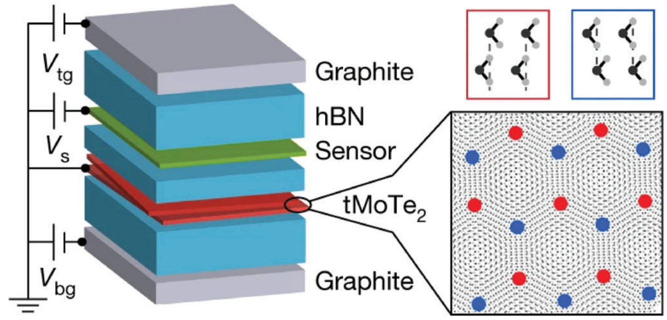


Figure 1: Device schematic. Inset: schematic representation for $tMoTe_2$ moiré lattice.

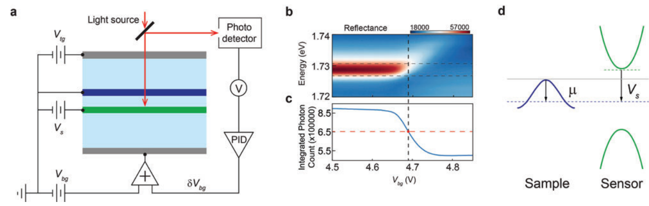


Figure 2: a, schematic for optical measurement of thermodynamics in a typical dual-gated device. b, V_{bg} dependence of reflectance contrast near monolayer WSe2 sensor's neutral exciton resonance. c, spectrally integrated photon counts over the window in b horizontal dashed lines) as a function of V_{bg}. d, schematic of the band alignment.

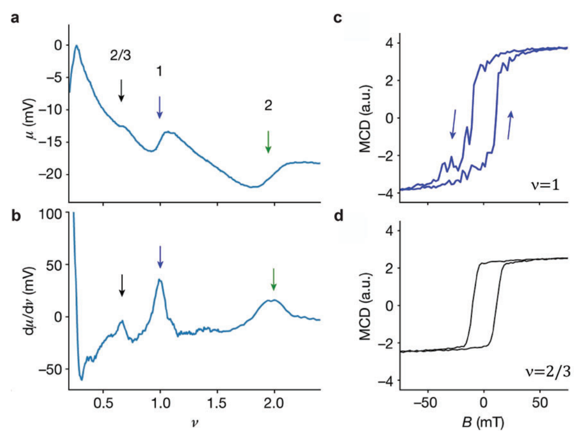
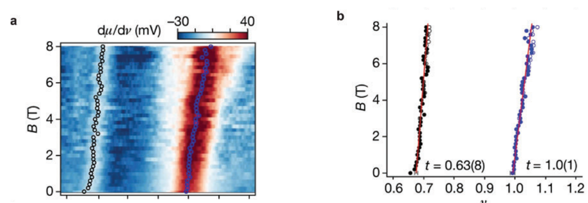


Figure 3: a, b, chemical potential (a) and charge incompressibility (b) as a function of $tMoTe_2$ moiré filling (ν). c, d, MCD as a unction of B at ν = 1 (c) and ν = 2/3 (d). All measurements performed at E ≈ 0.



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