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THESIS DEFENSE: Investigation of the Interaction Driven Quantum Phases in Magic-Angle Twisted Bilayer Graphene

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The discovery of two dimensional materials opened a unique pathway to study the electronic properties of quantum materials which are otherwise absent in bulk systems. Soon after the discovery of graphene (2004), a plethora of 2D materials were found with various diverse properties such as, metals, insulators, semiconductors, superconductors, magnets etc. These materials can be assembled by using the van der Waals (vdW) force, which greatly extends the possibilities of studying new phenomena. Initially vdW heterostructures have been made by vertically stacking different layers. However, twist angle plays an interesting tuning knob to engineer the electronic properties of the 2D heterostructures. Following long standing theoretical predictions, people have observed exotic quantum phenomena in twisted bilayer graphene in 2018.

In this thesis, we have studied the electronic properties of magic angle twisted bilayer graphene (MATBG), which consists of two graphene layers rotated by an angle ? = 1.1°. It ha been experimentally shown that MATBG possesses flat electronic bands in the low energ scale, which hosts multiple correlated phenomena such as correlated insulators superconductivity, magnetism etc

We studied different phases of MATBG in the presence of a magnetic field to reveal th zero-field ground state of the system. In the presence of a small magnetic field (B < 3 T), th Hall conductance of MATBG shows quantisation with the Chern numbers C = ±1, ±2, ±3 an ±4 which nucleate from different integer fillings of the moire bands, ? = ±3, ±2, ?
1 and 0 respectively. These phases can be interpreted as spin and valley polarized many bo y Chern insulators. The exact sequence and correspondence of the Chern numbers and filling factors suggest that these states are directly driven by electronic interaction, which spec fically break the time-reversal symmetry in the
system. We have also studied the evolution of the phase space of MATBG in high magnetic f eld and explored the Hofstadter spectrum. Due to the large moire unit cell area, MATBG rea hes one full flux quantum (?0) per moire unit cell close to 30 T. We studied a
etailed magneto-transport behaviour of MATBG upto B = 31 T. At ?0, reentrant correlated in ulators are observed at ? = +2, +3. Interaction driven Fermi surface reconstruction is also obs rved at other fillings of the band which are identified by the emergence of a new set of Landa level
(LLs). We further studied the higher energy dispersive bands in the presence of a magneti field. The analysis of the LL crossings in the Rashba-like dispersive bands enables a parame er free comparison to a newly derived magic series of level crossings in a magnetic f eld and provides constraints on the parameters of the Bistritzer-MacDonald Hamiltonian. For t e first time, this allows us to experimentally verify the band structure o
MATBG. In the next section of this thesis, we have studied the effect of Coulomb screenin on the ground state of the quantum phases such as correlated insulator and superconduc or. The coexistence of these two states prompts intriguing questions about their relations ips. We have directly tuned the electronic correlations by changing the separation bet een the graphene and a metallic screening layer. Correlated insulators are suppressed hen the separations are smaller than the typical Wannier orbital size (~ 15 nm) and also in devices with twist angles slightly away from magic angle (? = 1.1° ± 0.05°). Upon extinc ion of the insulating orders, the vacated phase space is taken over by the superconductors. inally, we study the temperature depe0ndence of the resistance and unveil a strange metal phase upto a very low temperature
T = 40 mK. We thus have experimentally demonstrated the effect of several external parameters (magnetic field, screening, temperature etc.) on the ground state of MATBG a

d how they alter the microscopic mechanism of different correlated phenomena in

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