Correlated Electrons in Twisted Bilayer Graphene near Magic Angle

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Introduction

Recent experiments on twisted bilayer graphene (TBG) at the first magic angle (1.1 degree) have discovered the correlated insulator phase and the neighboring superconductivity at the certain concentrations of charge carriers. This discovery leads to a phase diagram curiously similar to unconventional superconductors and thus stimulates widespread interest among theorists to understand the correlation effects. Most of the studies are based on the model with the on-site repulsions and various hoppings on the honeycomb lattice. In this project, we derive a new, and somewhat exotic, form of the interactions and construct a model as the starting point to understand the insulator and superconductivity in this system.

Results and Discussion

As the first step to understand the correlation effects, we build the localized Wannier states (WSs) for the four narrow bands around the charge neutrality point and construct the corresponding low energy tight binding model. Although the interference between two graphene sheets forms a triangular superlattice, the WSs should be placed on the dual honeycomb lattice sites by symmetry arguments. Moreover, each WS contains three peaks at its neighboring triangular lattice sites. The associated tight-binding model reproduces the four narrow bands that are consistent with the result by DFT [1].

As the next step, we project the gate-screened Coulomb interaction onto the constructed WSs. The interaction is found to be larger than the bandwidth, suggesting that the system is in the strong coupling regime. The structure of the WSs has deep implications for the nature of the electron-electron interactions within the four narrow bands. Due to the three-peak structure of the WSs, the density-density repulsion becomes nonlocal and has to include even the next-next nearest neighbor repulsion. Because of the nontrivial topological properties of the four narrow bands, the interaction also contains novel terms beyond the description of any extended Hubbard model. [2]

We further solved the ground state at certain concentrations of the charge carriers in the strong coupling limit. Different from the on-site repulsion in Hubbard model, the interaction in TBG leads to strong ferromagnetic correlations between different sites even without any single particle hoppings. At 1/4 (or 3/4) filling, the largely degenerate states are found to be SU(4) ferromagnetic in the strong coupling limit. The kinetic terms, treated as the perturbation, break SU(4) symmetry and select the state in which two valleys with opposite spins are equally mixed. Furthermore, we also argue that the stripe ferromagnetic insulator phase is the ground state at 1/8 filling [2].

Conclusions

In summary, we have constructed a model with interaction to understand the correlated insulator and superconductivity in the system, and proposed specific candidate states for the experimentally observed insulators at commensurate fillings.

Acknowledgements

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References:

[1] J. Kang and O. Vafek, Phys. Rev. X, **8**, 031088 (2018).
[2] J. Kang and O. Vafek, arXiv:1810.08642.

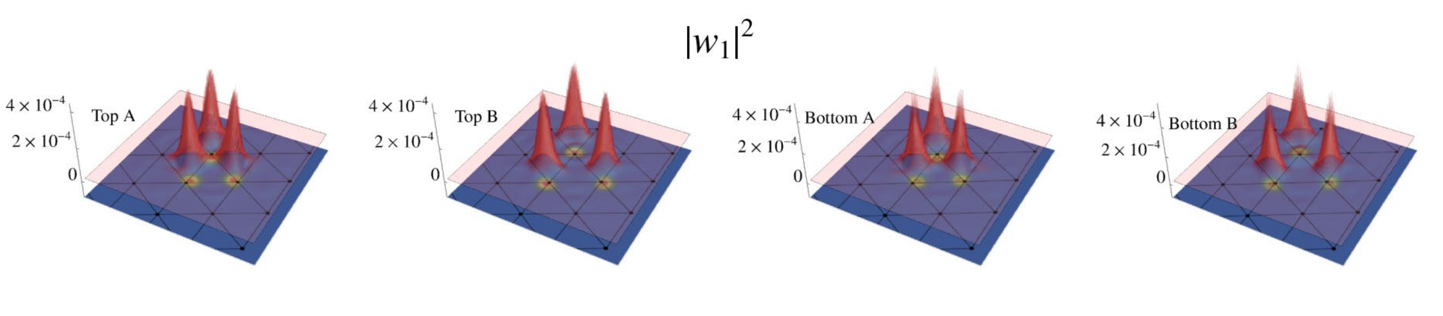

Fig.1 The magnitude of the WS on different sublattice and layer.