Probing Quantum Hall and Quantum Valley Hall Effect in Bilayer Graphene Nanostructures

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The lowest N = 0 and 1 Landau levels (LLs) in bilayer graphene carry particularly rich physics due to the eight-fold degeneracy resulting from the spin, orbital isospin and valley degree of freedom. External knobs such as perpendicular electric field and tilted magnetic field put the ordering of electronic degree of freedom in bilayer graphene into a competitive fashion, which leads to a rich variety of many-body ground states such as postulated canted anti-ferromagnet, and a quantum spin Hall liquid have been observed. However, a general LL diagram in this system is still missing. We parameterize all the interaction effects and demonstrate an effective single-particle LL diagram for the quantum Hall (QH) octet in bilayer graphene in the presence of an electric field [1], which provides a framework to interpret a diverse group of experimental findings in the literature. This could serve as a starting point to explore more sophisticated effects of electron-electron interactions. Moreover, we demonstrate gate-controlled tunneling of QH edge states between two lateral QH systems in bilayer graphene by using a pair of dual split gates [2], which allow us to independently control the filling factors of the QH systems and also the potential profile in the tunnel junction. We observe sequential pinch-off of individual edge states, and the potential profile in the junction can be well understood using finite element simulations. The gate-controlled transmission of edge states is the foundation towards realizing more sophisticated nanostructures which enable further exploration of the intriguing fractional QH states in bilayer graphene.

In a separate project, we have demonstrated the existence of theory predicted valley-momentum locked edge states, i.e. quantum valley Hall (QVH) kink states, in a line junction of two oppositely gated bilayer graphene [3]. More recently, we have obtained ballistic QVH kink states with quantized conductance of $4e^2/h$, and furthermore valleytronic operations such as valley valve and electron beam splitter have been realized using these high quality kink states [4]. The versatile controls and potential scalability of this new helical 1D system open a door to many exciting possibilities in low dimensional topological applications.

[1] J. Li et al, Phys. Rev. Lett. 120, 047701 (2018)
[2] J. Li et al, Phys. Rev. Lett. 120, 057701 (2018)
[3] J. Li et al, Nat. Nanotech. 11, 1060-1065 (2016)
[4] J. Li et al, arXiv:1708.02311 (2017)

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