Emergent Dirac cones and valley Hall states in gated multilayer graphenes

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There are growing interests in multilayer variants of graphene such as bilayer and trilayer, which support chiral quasiparticles, characterized with non-trivial Berry phases. There, the trigonal-warping deformation of the energy band, which is intrinsic to graphite-based systems, gives rise to small Dirac cones near Dirac point in these multilayers. The Lifshitz transition, in which the Fermi circle breaks up into separate parts, takes place at a small energy scale around a few meV. On the other hand, it is possible to modify the band structure of multilayer graphenes by applying an electric field perpendicular to the layer, using external gate electrodes attached to the graphene sample. While it has been argued that, for bilayer graphene a perpendicular electric field opens a band gap, and, for ABA trilayer graphene it causes a band overlap, a situation where both the interlayer asymmetry and the trigonal warping are in effect has not been fully discussed so far.

Motivated by these, we study the electronic structures of ABA (Bernal) stacked multilayer graphenes in uniform perpendicular electric field, and show that the interplay of the trigonal warping and the potential asymmetry gives rise to a number of emergent Dirac cones nearly touching at zero energy [1] . The band velocity and the energy region (typically a few tens of meV) of these gate-induced Dirac cones are tunable with the external electric field. In ABA trilayer graphene, in particular, applying an electric field induces a non-trivial valley Hall state, where the energy gap at the Dirac point is filled by chiral edge modes which propagate in opposite directions between two valleys. In four-layer graphene, in contrast, the valley Hall conductivity is zero. A nontrivial valley Hall state generally occurs in asymmetric odd layer graphenes and is related to a hidden chiral symmetry which exists only in odd layer graphenes.

[1] Takahiro Morimoto and Mikito Koshino, Phys. Rev. B **87**, 085424 (2013).

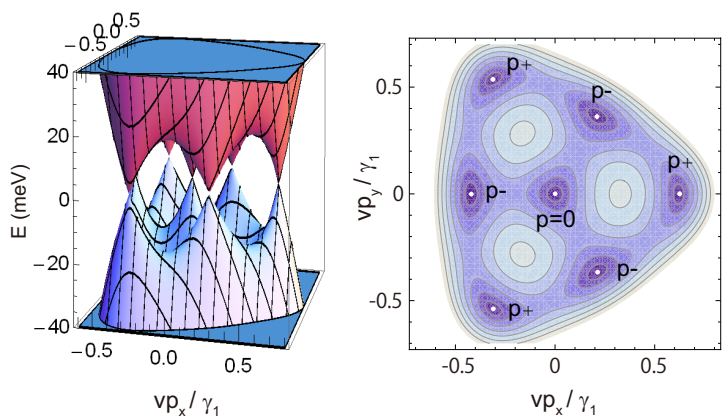

Figure 1: Band structures of ABA trilayer graphene in a perpendicular electric field with a trigonal warping effect, depicted in 3D plot (left panel) and contour plot (right).