Non-linear Landau Fan Diagram and Extraction of Landau Level Spacing by Open Orbit in Graphene Moiré Superlattices

Pilkyung Moon[1-3], Youngwook Kim[4,5], Mikito Koshino[6], Takashi Taniguchi[7], Kenji Watanabe[7], Jurgen H. Smet[4]

[1]*NYU Shanghai, China,* [2]*NYU-ECNU Institute of Physics at NYU Shanghai, China,*
[3]*New York University, USA,* [4]*Max-Planck-Institut für Festköperforschung, Germany,* [5]*DGIST, Korea,*
[6]*Osaka University, Japan,* [7]*National Institute for Materials Science, Japan*

pilkyung.moon@nyu.edu

Due to Landau quantization, the conductance of two-dimensional electrons exposed to a perpendicular magnetic field exhibits oscillations that generate a fan of linear trajectories when plotted in the parameter space spanned by density and magnetic field. This fan looks identical regardless of the details of the electron dispersion that determines the field dependence of the Landau level energy. This is not surprising since the location of the conductance minima depends only on the level degeneracy which is linear in flux. The fractal energy spectrum that emerges within each Landau band when electrons are exposed to a two-dimensional superlattice potential produces a number of additional oscillations, but they also create just linear fans for the same reason. Thus, such a regular Landau fan cannot give any information about the spectral gap of Landau levels.

In this talk, we report conductance oscillations in graphene electrons exposed to moiré potentials that deviate from the general law of magnetic flux linearity (Fig. 1a) [1]. Then, we explain that such anomalous behavior is due to the coexistence of multiple orbits, resulting from the simultaneous occupation of multiple minibands and magnetic breakdown (Fig. 1b). Finally, we propose a novel method to extract the spectral gaps, without measuring activation energy or carrying out tunneling spectroscopy, by using the density of states of open orbits as a measure (Fig. 1c). This method is quite general, so it can be applicable to any systems with multiple bands.

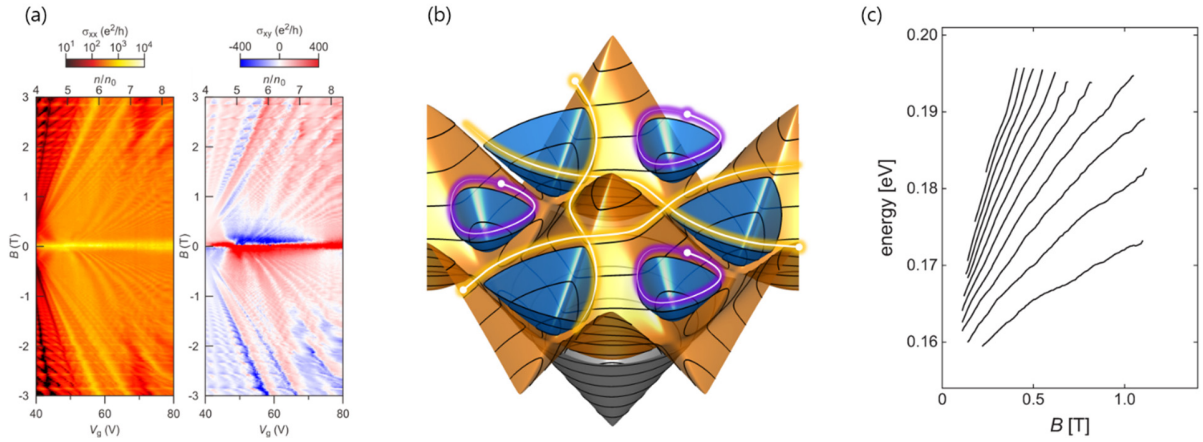

Fig. 1. (a) Longitudinal (σ_{xx}, left) and Hall (σ_{xy}, right) conductivities of a graphene/hBN moiré superlattice measured as a function of magnetic field strength B and back-gate voltage V_g (and normalized electron density n/n_0). Both plots show the anomalous, non-linear trajectories of conductance oscillations which converge to $n/n_0 \sim 5.5$. (b) Conduction band structures calculated with an effective continuum model [2]. The gray, orange, and blue surfaces show the first, second, and third bands, respectively. The purple and yellow lines indicate the closed and open orbits that give rise to the non-linear Landau fan diagram in (a). (c) Energy spectrum of the Landau levels which emerge from the closed orbits in (b), decoded from the peaks of σ_{xx} measured in experiment.

References

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