Signatures of Wigner Localization in a Graphene Quantum Dot from Coulomb-Blockade Spectroscopy

K. A. Guerrero-Becerra[1-2], M. Rontani[1]

[1] S3, Istituto Nanoscienze-CNR, Modena, Italy
[2] NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Pisa, Italy.
* e-mail:k.guerrero@nano.cnr.it

In contrast to the two-dimensional electron gas of nonrelativistic electrons in conventional semiconductors, where the different scaling of kinetic and interaction energies drives the transition to Wigner crystal at the dilute limit, in graphene Wigner localization is absent since both the interaction and the kinetic energies scale with particle density in the same way. We propose graphene quantum dots (QDs) with a mass gap as a viable playground to disclose the strongly correlated physics that is hidden in bulk graphene. Our motivation is twofold: On one side, electrons in semiconductor QDs may form Wigner molecules, i.e., finite-size precursors of the Wigner crystal, including carbon-based nanostructures, as nanotubes, for which the effect is dramatic [1]. On the other side, a current trend in graphene-based QDs is to minimize the roles of disorder and edge states, being extrinsic sources of localization.

We present theoretical evidence that Dirac electrons in a disorder-free, circular graphene quantum dot with a mass gap, induced by the breaking of sublattice symmetry, form Wigner molecules for realistic values of device parameters. Our results rely on few-body observables obtained through the exact diagonalisation of the interacting Hamiltonian, which includes correlation at all orders. Here we will focus on the predicted experimental signatures of this strongly correlated behavior. In the absence of a magnetic field, the signatures of Wigner molecule formation are the suppression of the four-fold periodicity of the filling sequence and the quenching of the excitation energies [2]. We then show that the magnetic field imprints additional electron correlations favoring the stability of the Wigner molecule with respect to the noninteracting phase. Our predictions, relevant for other graphene-based nano-devices featuring a mass gap, are accessible through magneto-tunneling spectroscopy [3].

References

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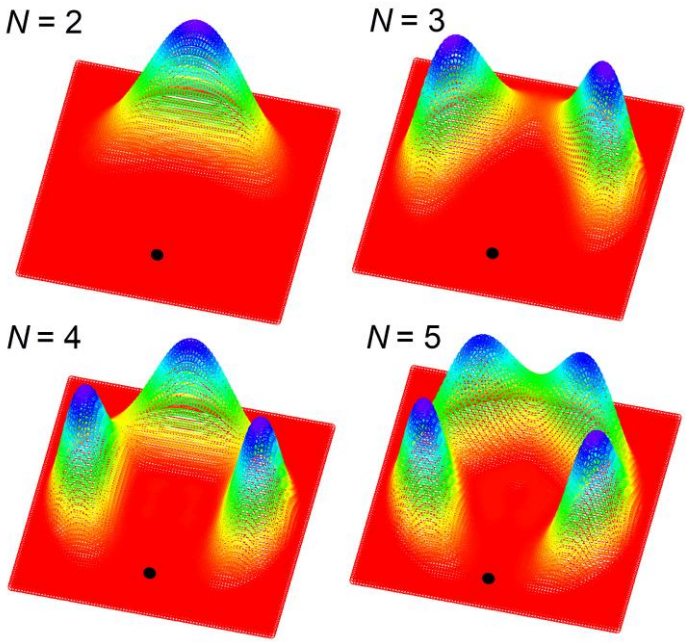

Fig 1: Polygonal Wigner molecules. Three-dimensional contour plots of pair correlation functions for a graphene quantum dot of radius R = 25 nm at low screening conditions (dielectric constant $\varepsilon = 2$).