Simulation of the development of Landau Levels in Graphene Quantum Dots

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We investigate the electronic eigenstates of graphene quantum dots with realistic size (~60 nm diameter) in the presence of a perpendicular magnetic field B. Numerical tight-binding calculations and Coulomb-blockade measurements performed near the Dirac point show the evolution from the linear density of states at B=0 to the Landau level regime as a function of magnetic field. For low fields, localization effects at the edges strongly influence eigenstates [see Fig. 1(a)], while for high fields the energy spectrum becomes independent of the confinement geometry [see Fig. 1(b)] and closely follows predictions based on the Dirac equation for massless fermions. We show how this parametric dependence of eigenenergies can be exploited to pin down the electron-hole crossover region in graphene quantum dots [1].

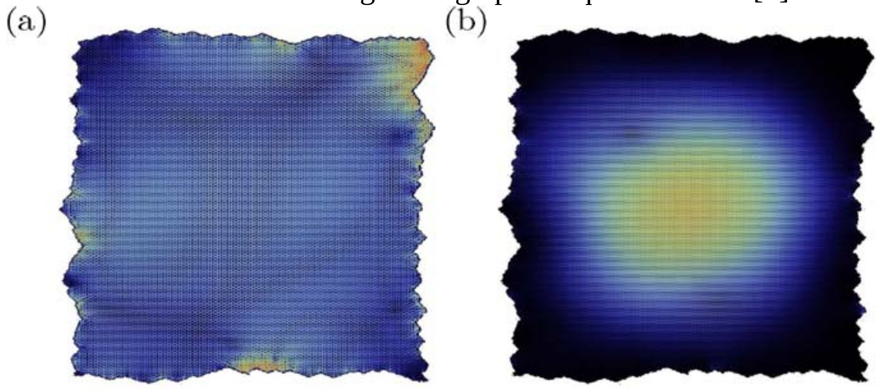

Figure 1. Wave-function density of an eigenstate close to the Dirac point of a rough-edged graphene quantum dot (diameter 60nm) for zero magnetic field B (a) and at $B=25$T (b).

Dirac-like signatures of the energy spectrum of graphene quantum dots have recently been studied experimentally [2]. Due to the K-K' symmetry of the graphene bandstructure, eigenstates of ideal graphene systems feature a twofold degeneracy (excluding spin) [3,4], which is lifted by realistic confinement. We study the parametric evolution of the resulting level splitting as a function of edge roughness, lattice defects and graphene-substrate interaction [5]. We observe signatures of the underlying graphene lattice structure including defects and localization effects at the edges. Our theoretical predictions are compared with our measurements of the parametric evolution of Coulomb blockade peaks around $B=0$. We find that the magnetic field dependence of graphene energy levels serves as sensitive indicator for the quality of graphene quantum dots and, in further consequence, for the validity of the Dirac-picture in describing the experiment.

References

[1] J. Güttinger et al., *Phys. Rev. Lett.* **103**, 046810 (2009)
[2] L. A. Ponomarenko et al., *Science* **320**, 356 (2008)
[3] P. Recher et al., *Phys. Rev. B* **79**, 085407 (2009)
[4] S. Schnez et al., *Phys. Rev. B* **78**, 195427 (2008)
[5] F. Libisch et al., *Phys. Rev. B* **79**, 115423 (2009)