EDGE FREE GRAPHENE NANOSYSTEMS

Thomas Fabian, Florian Libisch

E136 - Institute of Theoretical Physics at TU Wien

INTRODUCTION

We simulate electronic transport through nanostructures in the ballistic regime. This means that we use quantum mechanics – especially the Schrödinger equation – to investigate the properties of novel materials.

Only few problems in quantum mechanics can be solved by hand, with pen and paper. But the equations can easily be discretized and turned into matrix equations, which can then be solved numerically. In practice this requires reasonable approximations of the Schrödinger equation – approximative enough that the problem at hand can be solved by a (super)computer, yet accurate enough that it captures all the essential features.

Since the first experimental realization of graphene – a one-atom thin sheet of carbon atoms – lots of effort has been undertaken to study this and similar materials. One is eager to find and understand mechanisms that make a material ideal for a special application. As an example, one might want to have materials which can efficiently convert light to electricity – as is done in photovoltaic cells. One might try to conduct electricity without resistance – as we find in a superconductor. We can also think of controlling individual quantum states to eventually obtain a quantum computer.

Our group contributes to the world-wide effort to better understand such nanostructures by close collaboration with experimentalists and by accurate modeling of their current work. Good models improve the understanding of the underlying mechanisms and can further be used to make predictions and suggestions for future lines of research.

SIZE QUANTIZATION IN GRAPHENE AND BILAYER GRAPHENE NANORIBBONS

Quantum mechanics predicts that in a ribbon of a certain width W, the current propagates in so-called modes. These modes resemble the oscillations in a vibrating string. By increasing the vibrational energy, the string (and the quantum mode) at some point obtains enough energy to form an additional node (a node is a point with constant vanishing amplitude). In a quantum transport measurement this sudden increase in the allowed number of modes leads to a sudden, step-like increase in the current we can send through the system.

Unfortunately in all graphene nanoribbons the edge – which means adsorbates, defects, roughness – washes out these clean conductance steps. The group of Christoph Stampfer at the RWTH Aachen recently undertook the effort [4] to improve the resolution of individual quantum states by additionally tuning the edge away with an electric potential. In this setting we investigated the evolution of quantum states in a magnetic field B, see 1.

Researchers at the ETH Zürich and the Karlsruhe Institute of Technology ([1, 3]) were able to electrostatically define a channel in a bilayer graphene ribbon. Bilayer graphene consists – as the name suggests – of two layers of graphene stacked on top of each other. In this system a spatially varying electric potential landscape leads to different potential on the two graphene layers, which can be used to define a channel without the usual rough edges for the current measurement. In this system it is possible to measure the quantum mechanical modes with unprecedented accuracy.

We come back to monolayer graphene where it is under certain circumstances (a high magnetic field, which quantum mechanically confines electrons to fixed energies) also possible to define an edge free “quantum dot”. This is for example done in the group of Markus Morgenstern in Aachen where a scanning tunneling microscope creates a potential well in the graphene sample. After we have collaboratively studied the effects of a substrate [2] our group is currently investigating the influence of lattice defects on individual energy levels.

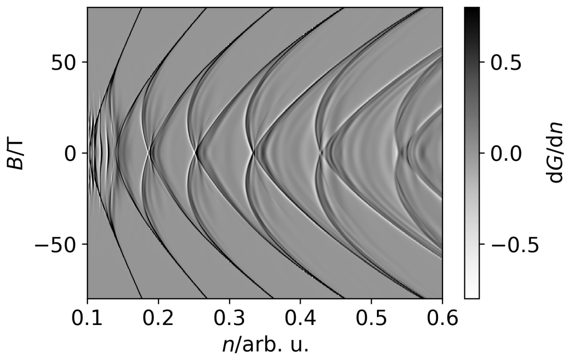

Figure 1: Crossover to Landau quantization in a graphene nanoribbon

CONCLUSION AND OUTLOOK

We have studied several ways to cleanly (edge-free) confine electrons in graphene nanostructures. We have shown that we experimentally and theoretically understand and are able to control individual quantum levels in these systems.

Future lines of research will be the investigation of electrostatically confined quantum dots in bilayer graphene, as well as the investigation of mechanisms which can control an additional defining property of states in graphene called “valley”

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