

Chapter 1

Introduction

Abstract This chapter introduces and motivates the subject of the monograph, the rapidly growing field of research on the electronic, optical and magnetic properties of graphene quantum dots.

Graphene is a one-atom thick two-dimensional crystal of carbon atoms. Weakly bound planes of graphene form graphite with electronic properties engineered by intercalation [1], and rolled and folded graphene is a building block of fullerenes and carbon nanotubes [2].

Since the isolation of a single layer of graphene [3–6] and the demonstration of its excellent conductivity and optical properties, the research aiming at determining the electronic properties and potential applications of graphene progressed at a rapid pace. Much of the current understanding of the electronic properties of graphene has been reviewed by Castro-Neto et al. [7], transport properties by Das Sarma et al. [8] and many-body effects by Kotov et al. [9], Vozmedano et al. [10] and MacDonald et al. [11]. An excellent overview of many aspects of graphene, from chemistry to fundamental problems in quantum matter, can be found in a series of articles in the Proceedings of the Nobel Symposium 148 [12] on “Graphene and quantum matter” celebrating the 2010 Noble Prize in Physics for graphene for Geim and Novoselov. An extensive introduction to graphene can also be found in books by, e.g., Katsnelson [13], Aoki et al. [14] and Torres et al. [15].

The list of some of the exciting properties of graphene starts with graphene being an ideal, only one atom thick, two-dimensional crystal. Because graphene is built of carbon, pure graphene is free of nuclear spins and should be an attractive material for electron-spin based quantum circuits. However, carbon atom has no magnetic moment, hence realizing magnetism in graphene is challenging. The linear dispersion of quasiparticles in graphene, Dirac Fermions, leads to a number of interesting effects. The two-sublattice structure of graphene couples Dirac Fermions with sublattice index, pseudospin, and introduces Berry’s phase. The relativistic-like effects lead to Klein tunneling and absence of electrostatic confinement. The interaction among Dirac Fermions is different from the interaction among Schrödinger electrons and plays an important role in determining the electronic properties of graphene. The role of interactions in, e.g., renormalization of Fermi velocity continues to be a subject of intense research.

Given these interesting electronic properties and much progress in our understanding of graphene, a new challenge emerges: Can we take graphene as a starting material and engineer its electronic, optical and magnetic properties by controlling the lateral size, shape, type of edge, doping level, and the number of layers in “graphene quantum dots”? Graphene is a semimetal, i.e., it has no gap. By controlling the lateral size of graphene the energy gap can be tuned from THz to UV covering entire solar spectrum, the wavelength needed for fiber based telecommunication (telecom window) and THz spectral range. One can also envision building a magnet, a laser, and a transistor using carbon material only and creating disposable and flexible nanoscale quantum circuits out of graphene quantum dots [16]. The research on graphene quantum dots is rapidly expanding covering physics, chemistry, materials science, and chemical engineering. This monograph attempts to present the current understanding of graphene quantum dots. An attempt is made to cover the rapidly expanding and evolving field but the monograph focuses mainly on the work done at the Institute for Microstructural Sciences, National Research Council of Canada. The authors thank I. Ozfidan, O. Voznyy, E. Kadantsev, C.Y. Hsieh, A. Sharma and A. Wojs for their contributions.

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