IOP Publishing Journal of Physics: Condensed Matter
J. Phys.: Condens. Matter **25** (2013) 215301 (10pp) doi:10.1088/0953-8984/25/21/215301

Transfer matrix method for optics in graphene layers

Tianrong Zhan, Xi Shi, Yunyun Dai, Xiaohan Liu and Jian Zi

Department of Physics, Key Laboratory of Micro and Nano Photonic Structures (MOE), and State Key Laboratory of Surface Physics, Fudan University, Shanghai 200433, People's Republic of China

E-mail: jzi@fudan.edu.cn

Received 25 February 2013, in final form 26 February 2013
Published 30 April 2013
Online at stacks.iop.org/JPhysCM/25/215301

Abstract
A transfer matrix method is developed for optical calculations of non-interacting graphene layers. Within the framework of this method, optical properties such as reflection, transmission and absorption for single-, double- and multi-layer graphene are studied. We also apply the method to structures consisting of periodically arranged graphene layers, revealing well-defined photonic band structures and even photonic bandgaps. Finally, we discuss graphene plasmons and introduce a simple way to tune the plasmon dispersion.

(Some figures may appear in colour only in the online journal)

1. Introduction

Graphene is a flat monolayer of graphite with carbon atoms closely packed in a two-dimensional honeycomb lattice. A hallmark of graphene is the existence of Dirac cones in the electronic band structure, resulting in extraordinary structural and electronic properties with great potential for nanoelectronics [1–3].

In addition to outstanding electrical, mechanical and chemical properties, graphene has interesting optical response. One of the striking optical properties of graphene is that its reflectance, transmittance and absorbance are determined by the fine structure constant [4, 5]. Despite being only one-atomic-layer thick with negligible reflection, a single free-standing graphene layer shows significant absorbance, universally about 2.2% in a spectral range from near-infrared to visible [4, 6, 7]. In the infrared regime, graphene absorption can be altered by applying gate voltages [8, 9]. For few-layer graphene, the optical absorption is proportional to the number of layers [10], leading to a visual image contrast which can be used practically to identify the number of graphene layers on a substrate. The highly transparent and outstanding electrical properties of graphene make it attractive for transparent electrodes [11, 12]. The broadband absorption implies that graphene has potential as an active medium for use in broadband photodetectors [13, 14], ultra-fast lasers [15] and optical modulation [16]. By applying an external magnetic field, giant Faraday rotations can be generated in graphene [17, 18].

In doped or gated graphene, collective excitations—plasmons—exist with interesting optical features such as deep subwavelength and high confinement of optical fields [19–25], similar to surface plasmons in metal surfaces [26–28]. As a result, graphene may serve as a one-atom-thick platform for infrared and terahertz metamaterials [29, 30]. A number of photonic devices such as waveguides, splitters and combiners and superlenses could be envisioned [30, 31]. Numerical simulations suggest that periodically patterned arrays of doped graphene nanodisks may completely absorb infrared light at certain resonant wavelengths [32]; this was soon confirmed experimentally [33]. These interesting optical properties of graphene may also offer potential applications in photonics [34].

In this paper, we develop a transfer matrix method to study optical properties in non-interacting graphene layers. This paper is organized as follows. In section 2, we introduce the transfer matrix method to study the propagation of light through graphene layers, together with the optical conductivity of graphene used in our calculations. In sections 3–5, we apply the transfer matrix method to the study of optics in graphene layers. Specifically, in section 3 we discuss reflection, transmission and absorption in single-, double- and multi-layer graphene. In section 4, we discuss photonic band structures in periodical graphene layers. In

