Graphene Synthesis and Applications

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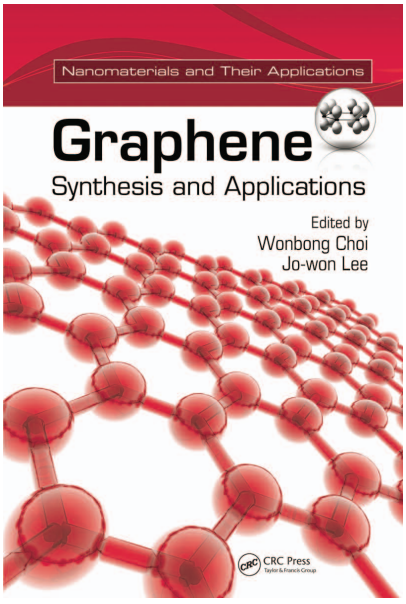
GRAPHENE HAS GAINED A GREAT amount of attention recently for its electrical, physical, and chemical properties. Primarily driving this interest is graphene's potential for replacing silicon in electronic devices, which increasingly incorporate nanotechnology-enhanced advances. As electronic and optoelectronic device dimensions shrink to atomic scales, material limitations become the impediment to further improvements in device performance; therefore, alternative materials such as graphene become candidates for incorporation into future electronic devices. Graphene is also being investigated as a possible replacement for transparent conducting oxides, which have applications in touch-screen devices and solar cells.



Graphene Synthesis and Applications is an edited volume published by CRC Press in 2012. The authors have attempted to capture graphene's potential for these device applications while addressing the fundamentals of graphene. *Graphene Synthesis and Applications* is intended for a general audience with a graduate-level understanding of physics and chemistry.

The first chapter introduces the basic properties of graphene along with its wide range of applications in electronics and optoelectronics as well as in mechanical and magnetic devices. The basic structure of graphene is described for these applications, and the overview continues into the second chapter, which provides detailed coverage on the routes to graphene synthesis. The overview of the synthesis takes into account engineering and economic issues, such as scalability for large-area synthesis that will be needed for possible integration into future electronics. There is also a good summary of laboratory and small-scale synthesis routes for research-scale studies of graphene. An example includes the unzipping of nanotubes to form nanoribbons, which are strips of graphene that could be used to fabricate transistors. Other graphene synthesis routes are also discussed, involving both mechanical and chemical exfoliation, thermal and plasma chemical vapor deposition, and epitaxial growth of graphene on a silicon carbide surface. The first two chapters also provide an overview of the graphene synthesis mechanisms, without delving too much into the details.

Chapters 3 and 4 detail quantum mechanical and quantization effects in graphene, along with their applications for electronic and optoelectronic devices. In nanoribbons and patterned graphene, quantization effects are more profound because edge effects become significant. Chapter 3 includes an overview of the quantum physics of electron transport and the associated electrostatics for electronics applications, such as graphene-based field effect transistors (FETs), along with a brief discussion of areas for improvement of device performance with mobility gap engineering. Chapter 4 deals with different types of FETs that could be fabricated from graphene, including a traditional FET incorporating a graphene channel (known as a "g-FET"), in addition to epitaxial graphene-on-silicon (GOS) FETs, back-gated GOS-FETs, top-gated GOS-FETs, and various FET components such as gate stack/insulator, source/drain ohmic contact, on/off ratio, and carrier doping and unipolar operation. Optoelectronic devices are also covered in Chapter 4 in both low- and high-temperature operations to take advantage of population inversion and negative conductivity in optically pumped graphene.

A book about graphene synthesis would not be complete without a discussion of the potential for large-scale synthesis of graphene as well as its use for nontraditional electronic and optoelectronic devices, such as transparent electrodes for touch-screen panels and electrodes for solar cells; these topics are covered in Chapter 5. Any potential commercial process involving graphene would require a cost-competitive manufacturing process, and scalable large-volume production is one way of achieving this, which this chapter addresses. Chapter 6 mostly discusses laboratory-based results, with limited application for practical devices involving "nanosized graphene," which is the name given to a family of polycyclic aromatic hydrocarbons with an average diameter between 1 and 10 nm.

Chapter 7 covers the synthesis and applications of graphene composites, which have applications in mechanical strengthening, supercapacitors, field

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emitters, lithium-ion battery anodes, photocatalysis, fuel cells, and sensors. This chapter should really be more integrated with the final four chapters (8–11) that cover graphene-based device applications that are not traditionally considered electronic or optoelectronic.

Chapter 8 describes graphene-based biosensors and gas sensors, with a brief historical discussion on the prior use of carbon nanotubes along with a compare/contrast discussion on the chemical structure with graphene. Biosensing and gas sensing are heavily dependent on electrochemistry, and there is thus a detailed discussion of enzyme, DNA, and heavy-metal ion interaction with graphene in the liquid phase. For gas-phase detection, chemical functionalization of graphene is discussed to improve gas detection; however, there is a lack of coverage of novel gas-sensing device structures that may also be used to improve graphene's capability for gas sensing.

Chapter 9 gives an overview of graphene for field-emission applications. This chapter provides a brief background on the principles of field emission and the materials that have been used in the past, both metals and other carbon-based devices (carbon nanotubes and nanofibers). What is missing is a discussion of the drawbacks and challenges necessary for integrating these field-emission devices into practice.

Chapter 10 is about graphene for solar cell applications but mostly for novel dye-sensitized solar cells, organic solar cells, or other hybrid cells such as those involving quantum dots. There is very little discussion about the potential of graphene for inorganic solar cells, which are the predominant type of solar cells that have been in use over the past several decades and are expected to continue to be dominant in the marketplace for the foreseeable future.

Finally, Chapter 11 involves thermal and thermoelectric properties. Due to the influence of nanotechnology on electronic devices, there has been an interest in thermal management to adequately remove heat generated from these devices. This chapter includes a discussion on thermal transport mechanisms on the nanoscale, with a comparison of graphene with other materials, including carbon (graphite and carbon nanotubes). But so far, work involving thermal properties has mostly been theoretical, with very few practical applications. Thermal transport through few-layer graphene is expected to exhibit an improvement over single-layer graphene, and there is a brief discussion on the comparison. The chapter's coverage on the thermoelectric properties of graphene takes about up 10% of the chapter, with the remainder of the chapter focusing on the thermal conductivity.

This book provides a good introduction and overview of graphene to the general audience. It is weighted about three-quarters applications and one-quarter synthesis. Overall, there is a good overview of the applications of graphene, along with sufficient detail of the relevant synthesis and scientific theory.