



THE 2-DIMENSIONAL WORLD OF GRAPHENE

Editors:

Virat Khanna
Vishal Chaudhary
Anam Munawar
Reddicherla Umapathi
Kamaljit Singh

Bentham Books

The 2-Dimensional World of Graphene

Edited By

Virat Khanna

*University Centre for Research & Development
Chandigarh University
Mohali, Punjab, India*

Vishal Chaudhary

*Department of Physics
Bhagini Nivedita College
University of Delhi, Delhi, India*

Anam Munawar

*Department of Forensic Medicine
University of Health Sciences
Lahore, Pakistan*

Reddicherla Umapathi

*Department of Biological Sciences and Bioengineering
Inha University, Incheon, Republic of Korea*

&

Kamaljit Singh

*Department of Mechanical Engineering
Chandigarh Engineering College
Jhanjeri, Mohali, India*

The 2-Dimensional World of Graphene

Editors: Virat Khanna, Vishal Chaudhary, Anam Munawar, Reddicherla Umapathi & Kamaljit Singh

ISBN (Online): 978-981-5238-93-8

ISBN (Print): 978-981-5238-94-5

ISBN (Paperback): 978-981-5238-95-2

© 2024, Bentham Books imprint.

Published by Bentham Science Publishers Pte. Ltd. Singapore. All Rights Reserved.

First published in 2024.

BENTHAM SCIENCE PUBLISHERS LTD.

End User License Agreement (for non-institutional, personal use)

This is an agreement between you and Bentham Science Publishers Ltd. Please read this License Agreement carefully before using the book/echapter/ejournal (“**Work**”). Your use of the Work constitutes your agreement to the terms and conditions set forth in this License Agreement. If you do not agree to these terms and conditions then you should not use the Work.

Bentham Science Publishers agrees to grant you a non-exclusive, non-transferable limited license to use the Work subject to and in accordance with the following terms and conditions. This License Agreement is for non-library, personal use only. For a library / institutional / multi user license in respect of the Work, please contact: permission@benthamscience.net.

Usage Rules:

1. All rights reserved: The Work is the subject of copyright and Bentham Science Publishers either owns the Work (and the copyright in it) or is licensed to distribute the Work. You shall not copy, reproduce, modify, remove, delete, augment, add to, publish, transmit, sell, resell, create derivative works from, or in any way exploit the Work or make the Work available for others to do any of the same, in any form or by any means, in whole or in part, in each case without the prior written permission of Bentham Science Publishers, unless stated otherwise in this License Agreement.
2. You may download a copy of the Work on one occasion to one personal computer (including tablet, laptop, desktop, or other such devices). You may make one back-up copy of the Work to avoid losing it.
3. The unauthorised use or distribution of copyrighted or other proprietary content is illegal and could subject you to liability for substantial money damages. You will be liable for any damage resulting from your misuse of the Work or any violation of this License Agreement, including any infringement by you of copyrights or proprietary rights.

Disclaimer:

Bentham Science Publishers does not guarantee that the information in the Work is error-free, or warrant that it will meet your requirements or that access to the Work will be uninterrupted or error-free. The Work is provided "as is" without warranty of any kind, either express or implied or statutory, including, without limitation, implied warranties of merchantability and fitness for a particular purpose. The entire risk as to the results and performance of the Work is assumed by you. No responsibility is assumed by Bentham Science Publishers, its staff, editors and/or authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products instruction, advertisements or ideas contained in the Work.

Limitation of Liability:

In no event will Bentham Science Publishers, its staff, editors and/or authors, be liable for any damages, including, without limitation, special, incidental and/or consequential damages and/or damages for lost data and/or profits arising out of (whether directly or indirectly) the use or inability to use the Work. The entire liability of Bentham Science Publishers shall be limited to the amount actually paid by you for the Work.

General:

1. Any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims) will be governed by and construed in accordance with the laws of Singapore. Each party agrees that the courts of the state of Singapore shall have exclusive jurisdiction to settle any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims).
2. Your rights under this License Agreement will automatically terminate without notice and without the

need for a court order if at any point you breach any terms of this License Agreement. In no event will any delay or failure by Bentham Science Publishers in enforcing your compliance with this License Agreement constitute a waiver of any of its rights.

3. You acknowledge that you have read this License Agreement, and agree to be bound by its terms and conditions. To the extent that any other terms and conditions presented on any website of Bentham Science Publishers conflict with, or are inconsistent with, the terms and conditions set out in this License Agreement, you acknowledge that the terms and conditions set out in this License Agreement shall prevail.

Bentham Science Publishers Pte. Ltd.

80 Robinson Road #02-00

Singapore 068898

Singapore

Email: subscriptions@benthamscience.net



CONTENTS

PREFACE	i
LIST OF CONTRIBUTORS	iii
CHAPTER 1 DEVELOPMENT OF LIGHT ENERGY CONVERTERS BY USING SHORT-CHAIN DYAD-GRAPHENE OXIDE AND GRAPHENE QUANTUM DOT NANOCOMPOSITES: A COMPARATIVE APPROACH	1
<i>Ishani Mitra and Tapan Ganguly</i>	
INTRODUCTION	1
THE EXPERIMENTAL DETAILS	7
Materials	7
Synthesis of Dyad	8
Synthesis of GQD	9
Synthesis of GO and RGO	9
Synthesis of CQD and NCQD	10
RESULTS AND DISCUSSIONS	12
UV-Vis Absorption	12
Measurements of the Fluorescence Lifetime using the TCSPC Method	13
CONCLUSION	16
ACKNOWLEDGEMENT	17
REFERENCES	17
CHAPTER 2 GRAPHENE-BASED NANOMATERIALS FOR FORENSIC APPLICATION ...	20
<i>Ahsan Riaz, Iqra Zafeer and Anam Munawar</i>	
INTRODUCTION	20
GRAPHENE-BASED SENSORS	23
GRAPHENE-BASED ELECTRONIC SENSORS	23
For Health	23
Forensic Application	23
<i>Forensic Nanosensors</i>	24
NANOSENSORS FOR EXPLOSIVE DETECTION	25
NANOSENSORS IN QUESTIONED DOCUMENTS ANALYSIS	26
THE TIME OF DEATH ESTIMATION BY NANOSENSORS	26
BLOODSTAIN EXAMINATION BY NANOSENSORS	27
DRUG ANALYSIS BY NANOSENSORS	27
PCR EFFICIENCY ENHANCEMENT BY NANOTECHNOLOGY	28
TRACE EVIDENCE ANALYSIS BY NANOSENSORS	28
SECURITY FEATURES BY NANOTECHNOLOGY	29
FINGERPRINT DEVELOPMENT BY NANOMATERIALS	30
EMERGING USE OF NANOTECHNOLOGY IN FORENSIC APPLICATIONS	30
DISADVANTAGES OF GRAPHENE	31
SECURITY OF HOMELAND	31
DNA ANALYSIS	32
PESTICIDES DETECTION	33
HEAVY METALS DETECTION	36
FUTURE PROSPECTS	37
CONCLUSION	38
REFERENCES	38
CHAPTER 3 GRAPHENE FROM SOLID WASTE MATERIALS FOR WATER PURIFICATION	43

<i>Shobha Waghmode and Deepali P. Butala</i>	
INTRODUCTION	43
SOLID WASTE	44
Plastic Wastes	45
Agro-Waste	45
Other Industrial Waste	46
METHODS TO PREPARE GRAPHENE THROUGH WASTE	46
Method 1: Solid State Chemical Vapor Deposition (CVD)	47
Method 2: Two-Step Pyrolysis Method	48
Method 3: Flash Joule Heating Process	48
Preparation of Graphene Oxide (GO) from Biowastes	48
WATER POLLUTION	48
DIFFERENT METHODS OF WATER PURIFICATION	49
USE OF GRAPHENE FOR WATER PURIFICATION	51
Removal of Microorganisms	51
Removal of Inorganic Pollutants	52
Arsenic Removal from Water	52
Mercury Removal from Water	52
Copper Removal from Water	52
Removal of Organic Pollutants using Graphene or Graphene Oxide	52
CONCLUSION	53
REFERENCES	53
CHAPTER 4 IMPORTANCE OF GRAPHENE IN ENERGY STORAGE AND PRODUCTION DEVICES	56
<i>Bakht Mand Khan, Reshma Wadood, Won Chun Oh and Kefayat Ullah</i>	
INTRODUCTION	56
STRUCTURE AND PROPERTIES OF GRAPHENE	57
DERIVATIVES OF GRAPHENE	59
SYNTHESIS OF GRAPHENE	60
Top-Down Approaches	60
<i>Mechanical Exfoliation</i>	60
<i>Liquid-phase Exfoliation</i>	61
<i>Chemical Exfoliation</i>	62
<i>Chemical Synthesis</i>	62
Bottom-Up Approaches	64
<i>Epitaxial Growth</i>	64
<i>Chemical Vapour Deposition</i>	64
APPLICATION OF GRAPHENE IN ENERGY STORAGE AND PRODUCTION DEVICES	65
Lithium-ion Batteries	65
Supercapacitors	66
Solar Cells	67
Fuel Cells	67
Photocatalytic Hydrogen Production	68
CONCLUSION	69
REFERENCES	69
CHAPTER 5 GREEN SYNTHESIS OF REDUCED GRAPHENE OXIDE UTILIZING AGRICULTURAL WASTE AND NANOCOMPOSITE FOR POTENTIAL ENVIRONMENTAL AND HEALTH APPLICATIONS	78
<i>Dharshini Perumal, Che Azurahaman Che Abdullah and Emmellie Laura Albert</i>	

INTRODUCTION	79
GRAPHENE-BASED NANOPARTICLES	80
Graphene	80
Graphene Oxide (GO)	80
Reduced Graphene Oxide (rGO)	82
<i>Green Reduction of GO</i>	82
<i>Green Fabrication of rGO from the Extracts of Agricultural Wastes</i>	83
METAL-BASED NANOPARTICLES	85
Graphene-based Metal Nanocomposite	85
<i>rGO Based Iron Nanocomposites</i>	86
<i>rGO Based Gold Nanocomposites</i>	89
<i>rGO Based Silver Nanocomposites</i>	91
CONCLUSION	93
REFERENCES	93

CHAPTER 6 GRAPHENE NANOPARTICLES: TECHNOLOGICAL CONCEPTS AND FUTURE APPLICATIONS

<i>Manaal Zahera, Aquib Khan, Katyayani Mishra and Faria Fatima</i>	100
INTRODUCTION	100
MANUFACTURING PROCESS	101
Chemical Vapor Deposition/Chemical Vapor Transport (CVT) Method	101
Wet Chemical Synthesis Method	102
Laser-Assisted Graphene Method	103
PROPERTIES OF GRAPHENE	103
Electrical Characteristics	104
Optical Attributes	104
Thermal Properties	105
Mechanical Characteristics	105
APPLICATIONS OF GRAPHENE	105
“Stretchable” Electronics Applications	107
As Lubricant	107
In Solar Cell	108
As Photothermal Therapy	109
Magnetic Applications	109
Detoxification of Water	110
Photocatalytic Magnetic Medication	110
Medical Applications	111
<i>Drug Delivery Applications and Conjugation Strategies</i>	111
<i>Biosensors</i>	112
<i>Biofunctionalization with Proteins</i>	112
<i>Biofunctionalization with DNA</i>	113
<i>Gene Delivery</i>	113
<i>Small Molecule Drug Delivery</i>	114
<i>Antimicrobial Effect</i>	114
<i>Biomedical Implantation</i>	115
Agriculture	117
Environmental Applications	118
Heavy Metal Removal	119
Humidity Sensor	120
Gas Transport	120
In Food Industry	120

In Construction Materials	121
CONCLUSION	122
ACKNOWLEDGEMENT	122
REFERENCES	122
CHAPTER 7 SYNTHESIS, PREPARATION, AND PROPERTIES OF 2D-GRAPHENE FOR ELECTROCHEMICAL ENERGY STORAGE AND CONVERSION	127
<i>Abdul Shakoor, Rabia Siddiqui, Malika Rani, Khizra Arif, Marvi Dashi, Muhammad Faiz Junaid, Jamal Yousaf, Muhammad Atif, Muhammad Awais, Behram Khan Ajat Khel and Muhammad Waseem</i>	
INTRODUCTION	128
ELECTROCHEMICAL ENERGY STORAGE DEVICES (EESDS): GRAPHENE PROPERTIES AND PREPARATION TECHNIQUES	130
THE MORPHOLOGY AND PRODUCTS OF GRAPHENE	135
GQDs-Graphene Quantum Dots	136
1D-Graphene Products	137
Two Dimensional Graphene Structures	138
<i>Nanostructures Aligned Vertically</i>	138
<i>Films/Papers</i>	139
<i>Graphene and Graphdiyne</i>	141
Three Dimensional Graphene Structures and their Products	141
<i>MicroFlower Structures</i>	141
<i>Self Assembly Structures: Self-Folding</i>	141
<i>Aerogels and Foams</i>	142
NOVEL DESIGNS AND PREPARATION METHODS OF GRAPHENE FOR ELECTROCHEMICAL ENERGY STORAGE DEVICES (EESDS)	142
CONCLUSION	143
REFERENCES	144
CHAPTER 8 A REVIEW OF CRACK GROWTH ANALYSIS OF GRAPHENE NANOCOMPOSITES	151
<i>Mamta Dahiya, Virat Khanna and Suneev Anil Bansal</i>	
INTRODUCTION	151
MODELLING	153
EXTENDED FINITE ELEMENT METHOD	153
Crack Growth or Damage Analysis of GNC	155
Gr Shape and Interfacial Properties Effect	156
DISCUSSION	157
CONCLUSION	157
REFERENCES	158
CHAPTER 9 GRAPHENE-BASED MATERIALS FOR ELECTROCHEMICAL ENERGY STORAGE DEVICES-EESDS; OPPORTUNITIES AND FUTURE PERSPECTIVE	160
<i>Khizra Arif, Abdul Shakoor, Muhammad Awais, Marvi Dashi, Behram Khan Ajat Khel, Sami Ur Rehman, Khansa Masood, Farah Hussain, Waheed Alam and Muhammad Atif</i>	
INTRODUCTION: GRAPHENE-BASED MATERIALS FOR ENERGY STORAGE	161
GRAPHENE-BASED MATERIALS IN LIBS	163
GRAPHENE MATERIALS FOR LITHIUM-OXYGEN (LI-O) BATTERIES	165
GRAPHENE MATERIALS FOR LITHIUM-SODIUM (LI-NA) BATTERIES	168
GRAPHENE-BASED MATERIALS IN SUPERCAPACITORS	169
CONCLUSION	172

REFERENCES	173
CHAPTER 10 EFFECT OF GRAPHENE ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF METAL MATRIX COMPOSITES	177
<i>Kamaljit Singh, Virat Khanna and Vishal Chaudhary</i>	
INTRODUCTION	177
SYNTHESIS AND CHARACTERIZATION OF GRAPHENE	179
Different Methods used for the Synthesis of Graphene	179
<i>Mechanical Exfoliation</i>	180
<i>Liquid Phase Exfoliation</i>	180
<i>Arc Discharge Method</i>	181
<i>Chemical Vapor Deposition</i>	182
<i>Epitaxial Growth</i>	182
<i>Epitaxial Growth of Graphene on Silicon Carbide</i>	182
<i>Epitaxial Growth of Graphene on Hexagonal Boron Nitride</i>	183
Characterization Techniques used to Evaluate the Quality and Properties of Graphene	183
<i>Optical Microscopy</i>	183
<i>Scanning Electron Microscopy</i>	184
<i>Transmission Electron Microscopy</i>	185
<i>X-ray Diffraction</i>	185
<i>Raman Spectroscopy</i>	185
FABRICATION OF GRAPHENE REINFORCED MMCS	186
Powder Metallurgy	186
Stir Casting	187
Chemical Vapour Deposition	187
Electrochemical Deposition	188
Molecular Level Mixing	188
Accumulative Roll Bonding	189
MICROSTRUCTURE ANALYSIS	189
MECHANICAL PROPERTIES OF GRAPHENE	190
Analysis of the Mechanical Properties of the Graphene-reinforced MMCs	190
<i>Graphene-Aluminium MMCs</i>	190
<i>Graphene-Copper MMCs</i>	192
<i>Graphene-Magnesium MMCs</i>	193
Factors Affecting the Mechanical Properties of the Composite	194
POTENTIAL APPLICATIONS OF G-MMCS	195
CONCLUSION	195
REFERENCES	196
SUBJECT INDEX	208

PREFACE

The field of graphene research has flourished over the past decade, and it continues to captivate scientists, engineers, and innovators alike. Graphene, a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice, exhibits extraordinary properties that set it apart from conventional materials. Its exceptional electrical conductivity, thermal stability, and mechanical strength have paved the way for a myriad of groundbreaking applications.

The chapters featured in this book span a broad spectrum of topics, each exploring a unique facet of graphene's immense potential. Starting with the development of light energy converters, our contributors present a comparative analysis of short-chain dyad graphene oxide and graphene quantum dot nanocomposites—a critical step forward in harnessing renewable energy sources. Forensic applications take the center stage in the next chapter, where graphene-based nanomaterials demonstrate their prowess in enhancing forensic investigations, making a significant impact in the field of law enforcement and criminal justice. The global importance of water purification drives our attention to another chapter, which ingeniously showcases how graphene derived from solid waste materials can be a key player in tackling water contamination issues. Environmental consciousness remains a core theme as we delve into the green synthesis of reduced graphene oxide using agricultural waste—a compelling solution with immense potential for various environmental and health applications. Energy storage and conversion, essential components of the sustainable future we strive for, are eloquently discussed in the chapter dedicated to the synthesis, preparation, and properties of 2D graphene for electrochemical energy storage and conversion. Mechanical properties and structural integrity take precedence in the exploration of crack growth analysis of graphene nanocomposites, an essential aspect for ensuring the reliability of materials in various engineering applications. Finally, the impact of graphene on metal matrix composites is thoroughly examined, showcasing the enhancement of mechanical properties in these advanced materials.

Each chapter in this book represents a dedicated effort by the authors to contribute to the growing body of knowledge on graphene's potential. We are proud to say that this collection not only captures the current state of the field but also offers a glimpse into the exciting possibilities that lie ahead. We extend our heartfelt gratitude to all the authors who have passionately contributed their expertise, knowledge, and insights to make this book a reality. Their commitment to advancing scientific research has been pivotal in shaping the content of this publication.

We hope that "The 2-Dimensional World of Graphene" will ignite your curiosity, inspire further exploration, and spark new ideas that will drive the future of graphene research and its transformative applications.

Virat Khanna

University Centre for Research & Development
Chandigarh University
Mohali, Punjab, India

Vishal Chaudhary

Department of Physics
Bhagini Nivedita College
University of Delhi, Delhi, India

Anam Munawar
Department of Forensic Medicine
University of Health Sciences
Lahore, Pakistan

Reddicherla Umapathi
Department of Biological Sciences and Bioengineering
Inha University, Incheon, Republic of Korea

&

Kamaljit Singh
Department of Mechanical Engineering
Chandigarh Engineering College
Jhanjeri, Mohali, India

Graphene Nanoparticles: Technological Concepts and Future Applications

Manaal Zahera¹, Aquib Khan², Katyayani Mishra³ and Faria Fatima^{4,*}

¹ Department of Biotechnology, Era University, Sarfarazganj, Lucknow, Uttar Pradesh, India

² Department of Polytechnic, Integral University, Lucknow, Uttar Pradesh, India

³ Department of Biochemistry, Era University, Sarfarazganj, Lucknow, Uttar Pradesh, India

⁴ Department of Agriculture, IIAST, Integral University, Lucknow, Uttar Pradesh, India

Abstract: Graphene, one of the most recent materials, has unique physical and chemical properties. The low weight and honeycomb structure of graphene gives it extraordinary unique properties. According to a recent study, experts from many different disciplines, such as biological science, energy, and the environment, are interested in graphene-based composites. These nanoparticles also show certain biologically undesirable effects that need to be clarified. As a result, it became important to analyse graphene's characteristics and potential uses. In this chapter, recent advancements in the synthesis process for composites consisting of nanoparticles and graphene, examine their properties and discuss their advantages for a variety of applications. Additionally, the important properties of the unit cell's edges, bond formation, bond electronic structure, and stacking sequence were emphasized. Investigations are also conducted into how these illnesses affect the thermal, electrical, mechanical, and chemical characteristics of graphene. Following a brief explanation of the fundamental composition, production methods, and their properties are discussed. Finally, present challenges in surface modification are explored, along with prospective directions for future study. Thus this paper detailing the excellent techniques and some cutting-edge graphene applications is necessary.

Keywords: Biomedical, Construction, Graphene, Medical, Magnetic, Manufacturing.

INTRODUCTION

The strength, flexibility, lightness, and resistance of graphene are noteworthy. This substance is thought to be five times lighter and 200 times more resistant than steel. The fields of energy, building, health, and electronics may all benefit

* Corresponding author Faria Fatima: Department of Agriculture, IIAST, Integral University, Lucknow, Uttar Pradesh, India; E-mail: fatimafaria45@gmail.com

from graphene's advantages [1]. Carbon is the strongest, thinnest, and most electrically and thermally conductive material in the universe. Nippon Electric Company (NEC) Ltd. published the first study on carbon nanotubes and the growth of the family of carbon materials in 1991. Micro-computer scraping was used to remove graphene from its monolithic state, defying the two-dimensional crystalline theory [2]. It is a two-dimensional carbonaceous material with a hexagonal honeycomb crystal structure. Graphene is currently the thinnest nanomaterial, having a thickness of 0.34 nm. Each carbon is joined to three other C atoms. With a C-C bond length of about 0.142 nm, graphene has a remarkably stable structure. Graphene has a very strong connection between each carbon atom. The atomic surface within graphene deforms and bends when an external force is applied to it in order to counteract it. As a result, the carbon atoms do not rearrange or go out of alignment, creating a constantly stable structure [3]. When graphene electrons move in the internal orbit, there is no scattering effect caused by the interference of external atoms or lattice flaws. The exceptional qualities of graphene are a result of its unusual lattice structure. Today, there are several ways to make graphene, but the four most common ones are chemical vapour deposition, liquid phase stripping, mechanical stripping, and epitaxial growth. Recent years have seen significant studies on graphene quantum dots (GQD) and carbon doped with other elements, chemicals, or organic compounds. The scientific community has taken a keen interest in graphene due to its extraordinary mechanical, physical, and thermal characteristics. A number of preparation techniques for graphene have been created recently. It has several uses in numerous industries as a result of its fascinating features.

MANUFACTURING PROCESS

Various methods have been developed for producing graphene, such as chemical vapor deposition (CVD)/chemical vapor transport (CVT), conversion of SiC, reduction of GO, chemical/liquid/solid/gas/mechanical exfoliation of graphite, and laser-assisted manufacturing.

Chemical Vapor Deposition/Chemical Vapor Transport (CVT) Method

The most widely used method, CVD, has a lower yield and higher cost but can produce high-quality graphene with superior layer control, including single crystals. The most popular method of bulk preparation involves physically or electrochemically exfoliating graphite, either with or without a solvent. Chemical exfoliation may be produced by oxidizing GO, and subsequent reduction produces an FLG, that processes damaged graphene planes. Although bottom-up synthesis can employ tiny halogenated molecules as precursors to create graphene with well-defined structures and properties, the scales are too small for practical usage