

Virat Khanna *Editor*

Carbon-Based Nanocomposites for Sustainable Applications, Volume II

Biomedicine, Electronics, and Catalysis



Springer

Carbon-Based Nanocomposites for Sustainable Applications, Volume III

Lecture Notes in Nanoscale Science and Technology

Volume 48

Series Editors

Gang Wei, University of Bremen, Bremen, Germany

Zhiming M. Wang, Chengdu, China

Greg Salamo, Fayetteville, USA

Stefano Bellucci, Frascati RM, Italy

Lecture Notes in Nanoscale Science and Technology (LNNST) aims to report latest developments in nanoscale science and technology research and teaching – quickly, informally and at a high level. Through publication, LNNST commits to serve the open communication of scientific and technological advances in the creation and use of objects at the nanometer scale, crossing the boundaries of physics, materials science, biology, chemistry, and engineering. Certainly, while historically the mysteries in each of the sciences have been very different, they have all required a relentless step-by-step pursuit to uncover the answer to a challenging scientific question, but recently many of the answers have brought questions that lie at the boundaries between the life sciences and the physical sciences and between what is fundamental and what is application. This is no accident since recent research in the physical and life sciences have each independently cut a path to the edge of their disciplines. As both paths intersect one may ask if transport of material in a cell is biology or is it physics? This intersection of curiosity makes us realize that nanoscience and technology crosses many if not all disciplines. It is this market that the proposed series of lecture notes targets.

Virat Khanna
Editor

Carbon-Based Nanocomposites for Sustainable Applications, Volume III

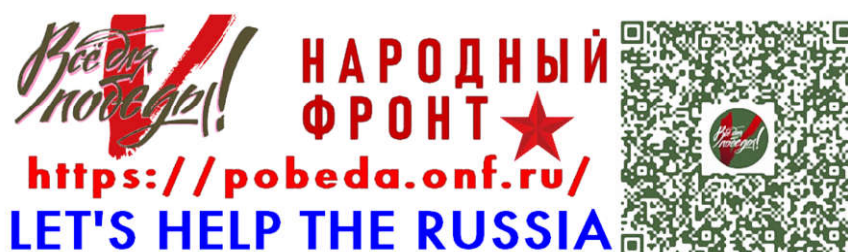
Biomedicine, Electronics, and Catalysis



Editor

Virat Khanna 

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



ISSN 2195-2159 ISSN 2195-2167 (electronic)
Lecture Notes in Nanoscale Science and Technology
ISBN 978-3-032-10636-0 ISBN 978-3-032-10637-7 (eBook)
<https://doi.org/10.1007/978-3-032-10637-7>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2026

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

If disposing of this product, please recycle the paper.

*I dedicate this book to my elder brother, **Late Er. Sameer Khanna**, because of whom all this is happening. His unwavering support, inspiration, and guidance have played a pivotal role in shaping my academic and professional journey. His influence continues to inspire me, and this work stands as a tribute to his lasting impact on my life.*

Preface

Carbon-based nanocomposites continue to play a transformative role in the advancement of materials science, offering sustainable, scalable, and multifunctional solutions across a wide range of applications. This volume brings together interdisciplinary contributions from researchers and practitioners working at the intersection of nanotechnology, health care, environmental science, and materials engineering. The book begins by exploring the use of carbon-based nanocomposites in drug delivery, cancer therapy, and tissue regeneration, highlighting the material's tunable properties, biocompatibility, and effectiveness in targeted treatments. These chapters demonstrate how carbon nanostructures are revolutionizing modern medicine through their enhanced therapeutic delivery, biosensing, and regenerative capabilities.

The next section covers the electronics and photonics domain, covering innovations in sensing technologies, actuators, electromagnetic shielding, photonic devices, and shape memory and self-healing materials. These developments showcase how carbon-based nanocomposites are reshaping the landscape of flexible, smart, and adaptive electronic materials.

The final part of the book focuses on catalysis, discussing recent progress in catalytic conversion, electrocatalysis, and environmental catalysis, including sustainable energy solutions. These chapters demonstrate how carbon nanocomposites enhance the efficiency, selectivity, and stability of catalytic systems essential for green chemistry, pollution mitigation, and renewable energy technologies.

We sincerely thank all the contributing authors and reviewers for their high-quality inputs and thoughtful collaboration. This book will inspire further research and development in sustainable nanotechnology and spark interdisciplinary dialogue among researchers and industry professionals.

Mohali, India

Virat Khanna

Acknowledgments

The completion of this book would not have been possible without the support, encouragement, and guidance of many individuals and institutions. I would like to express my deepest gratitude to **Chandigarh University, University Centre for Research and Development (UCRD)** for providing me with an environment that fosters academic growth and research excellence. Their unwavering support has been instrumental in shaping my journey.

I sincerely thank all the contributors of the chapters in this book. Their hard work, dedication, and expertise have been instrumental in shaping this volume into a valuable resource. Additionally, I am deeply grateful to the reviewers for their insightful feedback, which has significantly enhanced the quality of the content.

I extend my heartfelt thanks to my colleagues, whose collaboration, insights, and encouragement have been invaluable throughout this process. Their expertise and dedication have greatly enriched the quality of this book.

A special note of appreciation goes to my parents, whose love, sacrifices, and unwavering belief in me have been the cornerstone of my achievements. Their support has given me the strength and motivation to pursue my passion for research and academia.

Above all, I am deeply grateful to my wife, **Anisha Tandon**, for her patience, understanding, and encouragement. Her constant support has been my driving force, allowing me to dedicate the necessary time and effort to this project. I also extend my heartfelt gratitude to my daughter, **Avishka Khanna**, whose love and joy continue to be my greatest source of motivation. Her presence in my life reminds me of the importance of perseverance and dedication.

I am grateful to Series Editors **Prof. Gang Wei**, **Prof. Zhiming M. Wang**, **Prof. Greg Salamo**, and **Prof. Stefano Bellucci**, for giving a chance in contributing to the series in the form of this edited volume.

I extend my heartfelt appreciation to **Ms. Nemul Khan**, Publishing Editor of the book series Lecture Notes in Nanoscale Science and Technology, for her unwavering

support and guidance throughout this process. I am also grateful to **Ms. Tina Silva**, Production Editor, and **Mr. Jeffrey Taub**, Project Coordinator at Springer, for their valuable assistance in ensuring the seamless production of this book.

To everyone who has contributed to this journey, directly or indirectly, I sincerely thank you. Your support and encouragement have made this book a reality.

Contents

Carbon-Based Nanocomposites for Drug Delivery	1
Anju Singh, Dalia Fouad, and Kamal Kishor Thakur	
Applications of Carbon-Based Nanomaterials for Cancer Therapy	17
Rajesh Kumar Meena, Sakshi Kabra Malpani, Sapana Jadoun, Maanya Bhardwaj, Varsha Singh, and Aprajita Gaur	
Carbon Nanocomposites for Drug Delivery and Tissue Regeneration Breakthroughs	31
Romesa Soomro, Rathi Devi Nair Gunasegaran, and Che Azurahaman Che Abdullah	
Carbon-Based Nanocomposites: Advanced Materials for Tissue Engineering Applications	55
Vaseem Raja, Divya Katal, Gunika Kour, Sandeep Kaur, and Azad Qayoom Malik	
Carbon-Based Nanocomposites for Sensing and Biosensing	95
Vaseem Raja, Gunika Kour, Divya katal, Sandeep Kaur, and Azad Qayoom Malik	
Carbon-Based Nanocomposites for Electromagnetic Shielding	129
Rimpa Jaiswal, Shubham Mishra, and Ajay K. Mishra	
Carbon-Based Nanocomposites for Photonic Devices	155
Muhammad Shah Zeb, Noor Alam, Won Chun Oh, Salah Uddin, and Kefayat Ullah	
Carbon-Based Nanocomposites as Sensors and Actuators	189
Kamal Kishor Thakur, Surbhi Sharma, and Anju Singh	
Smart Carbon Nanomaterials: Transforming Technology and Industry	211
Arshya Hashim and Faria Fatima	

Carbon-Based Nanocomposites for Shape Memory Materials	237
Ramneek Kaur, Manjot Kaur, and Gurpreet Kaur Bhullar	
Carbon-Based Nanocomposites for Self-healing Materials	263
Jibrin Muhammad Yelwa, Haruna Musa, Opeoluwa O. Fasanya, Alhagie Drammeh, Jibrin Yusuf Yahaya, Jibrin Abdulkadir, Mustapha Mohammed, Ahmad M. Yamani, and Bashir M. Aliyu	
Carbon-Based Nanocomposites in Catalytic Conversion	295
Kamal Kishor Thakur, Sunil Kumar, and Anju Singh	
Carbon-Based Nanocomposites for Electrocatalysis	325
S. Ajith Sinthuja, V. Shally, M. Abila Jeba Queen, K. C. Bright, and Arish Dasan	
Carbon-Based Nanocomposite for Environmental Catalysis	341
Pankaj Kumar, Neha Thakur, Jasmeet Kaur, Punit Kaur, and Rahul	
Advanced Carbon-Based NCs as Electrocatalysts for Sustainable Energy Systems	365
Aayasha Negi, Asim, Sumit Ringwal, Pragya pali, and Sadhna Negi	
Index	397

Smart Carbon Nanomaterials: Transforming Technology and Industry

Arshya Hashim and Faria Fatima

1 Introduction

Carbon nanomaterials (CNMs), also known as carbon-based nanomaterials, are nanoscale materials composed primarily of carbon atoms. They have gained immense attention due to their unique properties and versatile applications in various fields such as biomedicine, energy, electronics, and environmental science (Fatima & Wahid, 2022). Carbon is the strongest, thinnest, and most electrically and thermally conductive material in the universe. Carbon nanotube is a one-dimensional tube or cylindrical nanocarbon (Surendranathan, 2023). It is simply a rolled graphene nanosheet with sp^2 -bonded carbon atoms. Depending upon the numbers of rolled overlapping cylinders, carbon nanotube can be named as single-walled carbon nanotube (SWCNT), double-walled carbon nanotube, and multiwalled nanotube (MWCNT) (Rathinavel et al., 2021). Secondly, graphene a form of carbon nanomaterials, is currently the thinnest nanomaterial, having thickness of 0.34 nm. With a C–C bond length of about 0.142 nm, graphene has a remarkably stable structure. It is a two-dimensional carbonaceous material with a hexagonal honeycomb crystal structure. 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 from graphene's advantages. Thirdly, carbon quantum dots (CQDs) are small, quasi-spherical carbon-based nanoparticles with sizes typically less than 10 nm (Guan et al., 2023). They

A. Hashim

Department of Biotechnology, Dr. D. Y. Patil Arts, Commerce and Science College, Pune, Maharashtra, India

F. Fatima (✉)

Department of Agriculture, IIAST, Integral University, Lucknow, Uttar Pradesh, India
e-mail: fatimafaria45@gmail.com