MXenes

Next-Generation 2D Materials: Fundamentals and Applications

Edited by Jay Singh • Kshitij RB Singh
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In loving memory of the ***Late Professor Ravindra Pratap Singh****, whose insightful guidance and unwavering support shaped this book into its finest form. Your dedication to excellence and commitment to nurturing the written word will forever inspire us. Your legacy lives on through these pages. Sorrow fills our hearts, for we miss you dearly.*

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Editor Biographies

Dr. Jay Singh

Dr. Jay has been working as an assistant professor at the Department of Chemistry, Institute of Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, since 2017. He received his PhD degree in polymer science from Motilal Nehru National Institute of Technology in 2010 and his MSc and BSc from Allahabad University, Uttar Pradesh, India. He was a postdoctoral fellow at National Physical Laboratory, New Delhi; Chonbuk National University, South Korea; and Delhi Technological University, Delhi. Dr. Jay has received many prestigious fellowships like CSIR (RA), DST-Young Scientist fellowship, and DST-INSPIRE faculty award. He is actively engaged in the development of nanomaterials (CeO_2, NiO, rare-earth metal oxide, Ni, $Nife_2O_4$, Cu_2O, graphene, RGO, etc.) based nanobiocomposite, conducting polymer and self-assembled monolayers-based clinically important biosensors for estimation of bioanalaytes such as cholesterol, xanthine, glucose, pathogens, and pesticides/toxins using DNA and antibodies. Dr. Jay has published more than 105 international research papers with total citations of more than 4300 and an h-index of 38. He has completed/running various research projects for different funding agencies. He has edited more than 8 books and has authored more than 40 book chapters for internationally reputed press publications, namely, Elsevier, Springer Nature, IOP, Wiley, and CRC. He is actively engaged in fabricating metal oxide-based biosensors for clinical diagnosis, food packaging applications, drug delivery, and tissue engineering applications. His research has contributed significantly toward the fundamental understanding of interfacial charge transfer processes and sensing aspects of metal nanoparticles.

Mr. Kshitij RB Singh

Mr. Singh is a postgraduate in biotechnology from Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh, India. He is currently working in the laboratory of Dr. Jay Singh, Department of Chemistry, Institute of Science, Banaras Hindu University, Varanasi, Uttar Pradesh, India. He has more than 60 peer-reviewed publications to his credit, has edited 12 books, and has authored more than 50 book chapters published in internationally reputed press, namely, Elsevier, IOP Publishing, Springer Nature, Wiley, and CRC Press. He is currently also involved in editing books with international publishing houses, including IOP Publishing, Elsevier, and Springer Nature. His research interests include biotechnology, biochemistry, epidemiology, nanotechnology, nanobiotechnology, biosensors, and materials science.

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Dr. Singh received his BSc from Allahabad University, India, and his MSc and PhD in biochemistry from Lucknow University, India. He is currently working as an assistant professor in the Department of Biotechnology, Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh, India. He has previously worked as a scientist at various esteemed laboratories globally, namely, Sogang University, IGR Paris. His work and research interests include biochemistry, biosensors, nanobiotechnology, electrochemistry, material sciences, and biosensor applications in biomedical, environmental, agricultural, and forensics. He has to his credit several reputed national and international honors/awards. Dr. Singh has authored over 70 articles in international peer-reviewed journals, more than 70 book chapters of international repute, and has edited 14 books. He serves as a reviewer for many reputed international journals and is also a member of many international societies. He is currently also involved in editing various books, which will be published by internationally reputed publication houses, namely, IOP Publishing, CRC Press, Elsevier, and Springer Nature. Moreover, he is a book series editor of "Emerging advances in Bionanotechnology," CRC Press, Taylor and Francis Group. He is also actively involved in guest-editing special issues (SIs) for reputed international journals, and one of the latest edited SI by Dr. Singh is "Smart and Intelligent Nanobiosensors: Multidimensional Applications" for *Materials Letters*, Elsevier, and "Smart and Intelligent Optical Materials for Sensing Applications" for *Luminescence*, Wiley.

Professor Charles Oluwaseun Adetunji

Professor Adetunji is presently a faculty member at the Microbiology Department, Faculty of Sciences, Edo State University Uzairue (EDSU), Edo State, Nigeria, where he utilized the application of biological techniques and microbial bioprocesses for the actualization of sustainable development goals and agrarian revolution, through quality teaching, research, and community development. He is currently the Ag Dean for the Faculty of Science and the Head of the Department of Microbiology at EDSU. He is a visiting professor and the executive director of the Center of Biotechnology, Precious Cornerstone University, Ibadan. He has won several scientific awards and grants from renowned academic bodies. He has published many scientific journal articles and conference proceedings in refereed national and international journals with over 370 manuscripts. He was ranked among the top 500 prolific authors in Nigeria from 2019 till date by SciVal/SCOPUS. His research interests include microbiology, biotechnology, postharvest management, and nanotechnology. He was recently appointed as the President and Chairman Governing Council of the Nigerian Bioinformatics and Genomics Network Society. He is presently the General/Executive Secretary of the Nigerian Young Academy. He is presently a series editor with Taylor and Francis in the United States, editing several textbooks on agricultural biotechnology, nanotechnology, pharmafoods, and environmental sciences. He is an editorial board member of many international journals and serves as a reviewer for many double-blind peer-reviewed journals of renowned publishing houses such as Elsevier, Springer, Francis and Taylor, Wiley, PLOS One, Nature, American Chemistry Society, and Bentham Science Publishers.

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Preface

Two-dimensional (2D) nanomaterials have attracted great attention since 2004. Owing to reduced dimension and size, 2D materials have exhibited many intriguing properties that are not found in their bulk counterparts, holding tremendous promise for a host of applications ranging from electronic, biomedical, and optoelectronic devices to electrochemical catalysis. Among them, in 2011, first reported a newly discovered large family of 2D early transition few-atoms-thick layers of transition metal carbides, nitrides, or carbonitrides nanosheets of Ti_3C_2 named “MXenes” is a rapidly rising star in current growing research. The efficient and unique electronic, optical, chemical, and mechanical properties of MXenes coupled with the ease of processing have helped to exhibit their marvelous pledge to revolutionize various science and technological developments. MXenes are exfoliated from their ternary carbide and nitride ceramics and have a common formula in composition: $M_{n+1}X_nT_x$, ($n = 1, 2, 3$, or 4), where M is a transition metal, X presents carbon/nitrogen (C/N), T means the surface group, and x represents the equivalent amount. The strong hydrophilicity, exceptional conductivity, high elastic mechanical strength, large surface-to-volume ratio, chemical stability, and improved electrochemical properties make MXenes open broad prospects for their applications in material science and technology areas, including energy storage, optoelectronics, spintronics, environmental, biomedical, and electronic industries include electro-catalysis, photocatalysis, membrane separation, supercapacitors, hybrid-ion capacitors, batteries, point-of-care devices, hydrogen storage, nanoelectronics, and sensors/biosensors. However, the aggregation, difficulty obtaining a single layer, restacking, and oxidation of MXene nanosheets significantly hinder their performance; and to overcome these issues, an effective and easy strategy is to combine MXene (due to good flexibility) with other materials, including polymers, metal oxides, metal nanoparticles, and carbon, to form MXene hybrid nanocomposites. MXene hybrid nanocomposites provide an opportunity to integrate the outstanding properties of different materials in a complementary way. Therefore, MXenes and MXene-based composites have attracted considerable research interest, holding great promise for numerous applications. Therefore, due to the increased demands of these interesting and fascinating 2D advanced futuristic nanomaterials, there have been increasing concerns regarding the development of high-performance energy storage devices, efficient electrochemical behavior, optoelectronic and flexible spintronics, catalysis industries, and effective management strategies to be urgently nodded. Therefore, the application of nanostructured MXenes and MXene-based composite materials has been discovered as effective techniques that could be sustainable, efficient, effective, and innovative to combat all the challenges mentioned earlier.

This book aims to spotlight the highly promising topic of MXenes, focusing on their fundamental, detailed preparation methods, physicochemical and biological characteristics, functionalization, processing techniques, and multi-domain applications. It presents the current advances in MXenes and their nanocomposites, including electrochemical energy storage, biomedical fields, catalysis and electro/photocatalysis, and environmental applications. In addition, it also provides an overview of the current state-of-the-art progress in the field of gas sensors and electrochemical biosensors for the detection of various biomolecules, pharmaceutical drugs, and environmental pollutants. Finally, this book also highlighted the limitations, advantages, future perspectives, and challenges of MXenes and MXene-based materials.

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