

# MXenes

**Next-Generation 2D Materials:  
Fundamentals and Applications**

Edited by **Jay Singh • Kshitij RB Singh**  
**Ravindra Pratap Singh**  
**Charles Oluwaseun Adetunji**



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## **MXenes: Next-Generation 2D Materials**



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Fundamentals and Applications

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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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## 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:  $M_{n+1}X_nT_x$ , ( $n = 1, 2, 3, \text{ or } 4$ ), 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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