Advanced Analytical Techniques for Characterization of 2D Materials

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Advanced Analytical Techniques for Characterization of 2D Materials

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To everyone who pursues research in materials science.

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PREFACE

Marie Curie precisely articulated "Have no fear of perfection, you will never reach it." This quote always acts as a stimulus to scientists and researchers to bend over backwards for uplifting the standard of research and development over the years. The consideration of nanomaterials over their bulk counterparts has not only opened the gates of endless opportunity but also diminished the struggle for real time application. In this context, two-dimensional layered materials have gained tremendous attention in recent years owing to their great promise in the 21st century solid state device technology. After the discovery of graphene, other graphene analogous 2D nanomaterials with novel tunable properties associated with their metallic, semimetallic, semiconducting, insulating, superconducting, Mott-insulating nature, etc., are being explored. The tunable properties, flexibility, good mechanical properties, high packing densities, etc., make them suitable candidate for the development of different thin, flexible, and wearable devices. Transition metal dichalcogenides (TMDs) are one class of 2D materials and are being investigated extensively due to their versatile and interesting properties. They own lamellar crystal structure, where each MX_2 layer is composed of one layer on transition metal atoms M (Mo, W, V, Sn, Nb, Ta, Ti, etc.) sandwiched between two layers of chalcogen atoms X (S, Se, Te) with covalent bonds. The neighboring MX_2 layers are weakly coupled together by van der Waals interactions. Nanomaterials with one atom thickness and infinite lateral size are the ideal 2D material that holds the novel properties associated with it due to their quantum confinement effect. Hence, the characterization of these 2D materials is the first step to investigate their layer-dependent changes in their properties and to use them in different multitude applications. Since the number of layers, the size of the flakes, crystallinity, the presence of defects and vacancies, or adsorbed molecules significantly affect these material properties, advanced analytical techniques are essential to address its morphological and functional properties.

Depending on the requirement, various characterization techniques, such as optical microscopy, atomic force microscopy (AFM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Raman spectroscopy, x-ray diffraction (XRD), and x-ray photoelectron spectroscopy (XPS) have been widely used to characterize the 2D materials. Each technique has its own advantages and limitations. Therefore, combining different characterization techniques is highly desirable to understand different structural features and properties of the as-synthesized 2D materials. Furthermore, different operando spectroscopic techniques such as Raman spectroscopy, UV-Vis, XRD, and XPS are being used to understand the mechanism involved in the growth process and device performance of the 2D materials by *in situ* experimental investigations. The probe based analytical techniques such as AFM and STM can provide the information on the orientation, smoothness, the number of layers, grain size, depth profile, and dielectric and mechanical properties of the 2D materials. Electron diffraction-based techniques such as TEM, SEM, and EDS are useful for determining thickness, number of layers, high-resolution imaging, surface properties, composition, and morphology. X-ray diffraction (XRD), x-ray fluorescence (XRF), x-ray absorption fine-structure (XAFS), and x-ray photoelectron spectroscopy (XPS) deliver rapid qualitative as well as quantitative determination of a wide variety of 2D materials. Similarly, spectroscopy-based analytical tools such as Raman spectroscopy, UV-Vis, and zeta potential analyzer are useful to determine the composition, quality, bandgap, doping, surface charge, thickness, the number of layers, orientation, chemical bonding, etc. By considering these aspects, in this book, we aim to provide detailed information on these analytical techniques, their importance, and recent progress, which have been widely used to characterize different 2D nanomaterials. This book will be useful for the researchers and scientists in the areas of materials science and engineering. Furthermore, this book will serve as a textbook for both beginners and experienced researchers who are pursuing their research in 2D layered materials and their advanced applications.

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