Preface

Ever since the discovery of carbon nanotubes (CNTs) by Iijima in 1991, there have been extensive research efforts on their synthesis, physics, electronics, chemistry, and applications due to the fact that carbon nanotubes were predicted to have extraordinary physical, chemical, mechanical, optical, and electronic properties. Among the various forms of carbon nanotubes: single-walled and multi-walled, random and aligned, semiconducting and metallic, aligned carbon nanotubes are especially important since fundamental studies and many important applications will not be possible without the alignment. The CNTs have been aligned by various in situ and ex situ techniques. These aligned CNTs have been widely applied in various fields including high energy storage batteries, extremely strong composites, highly sensitive sensors and devices, etc., covering physics, chemistry, biology, engineering, and more. Up to now there have been thousands of scientific publications on fabrication, characterization, physical properties, and applications of aligned CNTs in various aspects. It is the right time now to review the accomplishments on aligned CNTs.

Although there have been significant endeavors on growing carbon nanotubes in an aligned configuration since their discovery in 1991, little success had been made before our first report on growing individually aligned carbon nanotubes on various substrates by plasma enhanced chemical vapor deposition (PECVD) [1]. Aligned CNT arrays have been extensively studied as field emission devices, optical devices, chemical sensors, and biosensors. Based on a recent review article [2], we further expanded to include more recent work on aligned CNTs to write this book. In the book, we introduce the main results of aligned CNTs including CNT growth mechanisms and techniques, CNT microstructures and physical properties, alignment techniques, applications of aligned CNTs, and related physical mechanisms.

In this book, we first review the fundamental structures of CNTs and their unique anisotropic properties in Chap. 2 (*Carbon Nanotubes*), general growth methods in Chap. 3 (*Growth Techniques of Carbon Nanotubes*) and in Chap. 4 (*Chemical Vapor Deposition of Carbon Nanotubes*). Because of the wide and important application of DC-PECVD method to align CNTs, Chap. 5 (*Physics of*

Direct Current Plasma-Enhanced Chemical Vapor Deposition) is specially dedicated to discuss the experimental setup, physical principle, and experimental parameters in more detail. Various in situ and ex situ alignment techniques are introduced in Chap. 6 (*Technologies to Achieve Carbon Nanotube Alignment*). Major fabrication methods are illustrated in detail, particularly the most widely used PECVD growth technique on which various device integration schemes are based. The orientation of aligned CNT systems is vertical, parallel, or at other angles to the substrate surface. The techniques to examine the alignment of CNTs are discussed in Chap. 7 (*Measurement Techniques of Aligned Carbon Nanotubes*). These chapters provide the necessary initial techniques for the following in-depth introduction of the state of-the-art applications of aligned CNT arrays that we talk about in Chap. 8 (*Properties and Applications of Aligned Carbon Nanotube Arrays*) and in Chap. 9 (*Potential Applications of Carbon Nanotube Arrays*). In these two chapters, we introduce the applications of aligned CNTs in field emission, optical antennas, nanocoax solar cells, subwavelength light transmission, electrical interconnects, nanodiodes, and many others. At the end, the current limitations and challenges are discussed to lay down the foundation for future developments.

In the book, we list detailed experimental procedures and explain the physical mechanisms of sensors and devices to help the readers to understand the aligned CNTs for practical devices. At the same time, a lot of references including review papers and books are also listed. The book can be used as a textbook on aligned CNTs for beginners, and a reference book for advanced readers. In order to understand the aligned CNT well, we strongly encourage the readers, especially beginners on CNTs to first read other books on CNTs, such as *Carbon Nanotubes: Synthesis, Structure, Properties, and Applications* (Edited by M. S. Dresselhaus, G. Dresselhaus, and P. Avouris, Springer, 2000), *Carbon Nanotubes: Preparation and Properties* (Edited by T. W. Ebbesen, CRC Press, 1996), and *Physics of Carbon Nanotube Devices* (Authored by F. Léonard, William Andrew Inc., 2008).

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