



Waqar Ahmed  
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# EMERGING NANOTECHNOLOGIES FOR MANUFACTURING

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# Emerging Nanotechnologies for Manufacturing

Edited by

Waqar Ahmed and Mark J. Jackson



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# **Emerging Nanotechnologies for Manufacturing**

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# Series Editor's Preface

This book aims to achieve the most difficult of combinations – simultaneous breadth and depth. As a collection of chapters written by individual experts, it manages to convey some of the coherence of the field, despite the fact that it is already vast. The opening chapter is introductory, but the remainder of the book deals with specialized topics at the cutting edge. Different chapters adopt somewhat different styles according to the nature of their subject matter. For example, Chapter 3 on advanced characterization techniques first explains them and then describes various applications in the manner of case studies. Other chapters are a delight even just to dip into – for example, Chapter 4 describes fascinating forests of nanowires and other more exotic structures that can be produced nowadays.

Because of the vastness of the field, it is almost impossible for any one person to be already acquainted with the topics selected for inclusion. Therefore, every nanotechnologist is likely to find something new and interesting in this book. The reader will also become aware that even if the end product of a manufacturing process is a microdevice, nanotechnology is nevertheless involved in the fabrication. Several chapters, while not concerned with manufacture per se, deal with matters closely related to nanomanufacturing (or nanofabrication as it is nowadays called). Thus, Chapter 9 deals with the safety of nanoparticles, an aspect that should certainly not be neglected.

An interesting feature of this book is the fact that the contributors are working in a diverse set of institutes in many different parts of the world. This very graphically underlines the extraordinary multidisciplinary nature of nanotechnology, as well as the fact that it is already a truly global technology.

Jeremy Ramsden  
Cranfield University, United Kingdom

# Foreword

For a number of years, nanotechnology has attracted considerable widespread attention from both scientists and industrialists. A great deal of research has been carried out with a range of interesting phenomena and applications emerging. The focus of this book is to present emerging nanotechnologies that are likely to be highly suitable for manufacturing products on a large scale and economically. This book contains contributions from international experts. Despite the wide range of areas, in-depth coverage of the topics has been a major objective of this book. It is widely believed that nanotechnology will cause a new revolution in fields such as medicine, materials, energy, electronics and agriculture. Therefore, to capitalize on this translation of nanotechnologies into manufactured products on a large scale in an economic manner will be critical.

In Chapter 1, the various approaches to nanotechnology and its transition to nanomanufacturing are described. Chapter 2 covers the use of nanotechnology in enhancing the performance of gas sensors. For a better understanding of the effects of nanomaterial on the functionality of various products, it is important to characterize nanostructures, and various techniques employed for this purpose are described in Chapter 3. In order to use nanotechnology to manufacture products, various techniques are used to pattern thin films and several self-assembly techniques are described in Chapter 4. Numerous new applications of carbon nanotubes are emerging and in Chapter 5 various routes for the synthesis of carbon nanotubes are discussed. Chapter 6 highlights the use of nanoparticles in biological specimens and it is highly likely that these will have important applications in medicine. Another important technology for manufacturing products is nano- and micromachining which is highlighted in Chapter 7. At the nanoscale, there are often very complex relationships among input design parameters and process or product outputs. It would be prohibitively time consuming to perform all of the combinatorially possible experiments in order to comprehend these relationships. However, statistical design of experiment is a technique that can be used to efficiently explore the relationships and develop greater understanding. Consequently, it is becoming increasingly central to the advancement of nanotechnology and nanomanufacturing and this topic is discussed in Chapter 8. There is considerable

debate going on about the environmental and health impact of nanotechnology, therefore, Chapter 9 describes issues involved in use of nanotechnology from a health and safety perspective. The impact of nanotechnology will be judged by many on its ability to generate commercial income; Chapter 10 describes commercialization issues involved in translating nanotechnology to manufactured products. Chapter 11 describes soft-lithographic techniques which have advantages over photolithography because they are inexpensive, simple and ideally suited for manufacturing products with micro- and nanoscale features. In Chapter 12, the applications of nanoscale diamond for RF-MEMS devices are discussed. The use of nanostructured coating on tools for micromachining is described in Chapter 13. Numerous new applications of nanoparticles are emerging and in Chapter 14, the techniques involved in the synthesis of metal oxide nanopowders to impart new functionality are described.

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# Nanotechnology to Nanomanufacturing

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## ABSTRACT

Nanotechnology is a term that is used to describe the science and technology related to the control and manipulation of matter and devices on a scale less than 100 nm in dimension. It involves a multidisciplinary approach involving fields such as applied physics, materials science, chemistry, biology, surface science, robotics, engineering, electrical engineering and biomedical engineering. At this scale the properties of matter is dictated and there are few boundaries between scientific disciplines. Generally, two main approaches have been used in nanotechnology. These are known as the 'bottom-up' and 'top-down' approaches. The former involves building up from atoms into molecules to assemble nanostructures, materials and devices. The latter involves making structures and devices from larger entities without specific

control at the atomic level. Progress in both approaches has been accelerated in recent years with the development and application of highly sensitive equipment. For example, instruments such as atomic force microscope (AFM), scanning tunnelling microscope (STM), electron beam lithography, molecular beam epitaxy, etc., have become available to push forward development in this exciting new field. These instruments allow observation and manipulation of novel nanostructures. Considerable research is being carried throughout the world in developing nanotechnology, and many new applications have emerged. However, a related term is nanomanufacturing, used to describe industrial scale manufacture of nanotechnology-based objects at high rate, low cost and reliability. In this paper we discuss the opportunities and challenges facing the transition from nanotechnology to nanomanufacturing. Tools, templates and processes are currently being developed that will enable high volume manufacturing of components and structures on a nanoscale and these are reviewed. These advancements will accelerate the development of commercial products and enable the creations of a new generation of applications in various different commercial sectors including drug delivery, cosmetics, biomedical implants, electronics, optical components, automotive and aerospace parts.

### 1.1 INTRODUCTION

Although nanotechnology has been around since the beginning of time, the discovery of nanotechnology has been attributed to Richard Feynman<sup>1</sup> who presented a paper called 'There is Plenty of Room at the Bottom' on 29 December 1959 at the annual meeting of the American Physical Society. Feynman talked about the storage of information on a very small scale, writing and reading in atoms, about miniaturization of the computer, building tiny machines, tiny factories and electronic circuits with atoms. He stated that 'In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction'. However, he did not specifically use the term 'nanotechnology'. The first use of the term 'nanotechnology' has been attributed to Norio Taniguchi<sup>2</sup> in a paper published in 1974 'On the Basic Concept of "NanoTechnology"'.

Since then several definitions<sup>3</sup> of nanotechnology have evolved. For example, the dictionary definition states that nanotechnology is 'the art of manipulating materials on an atomic or molecular scale especially to build microscopic devices'. Other definitions include the US government which state that 'Nanotechnology is research and technology development