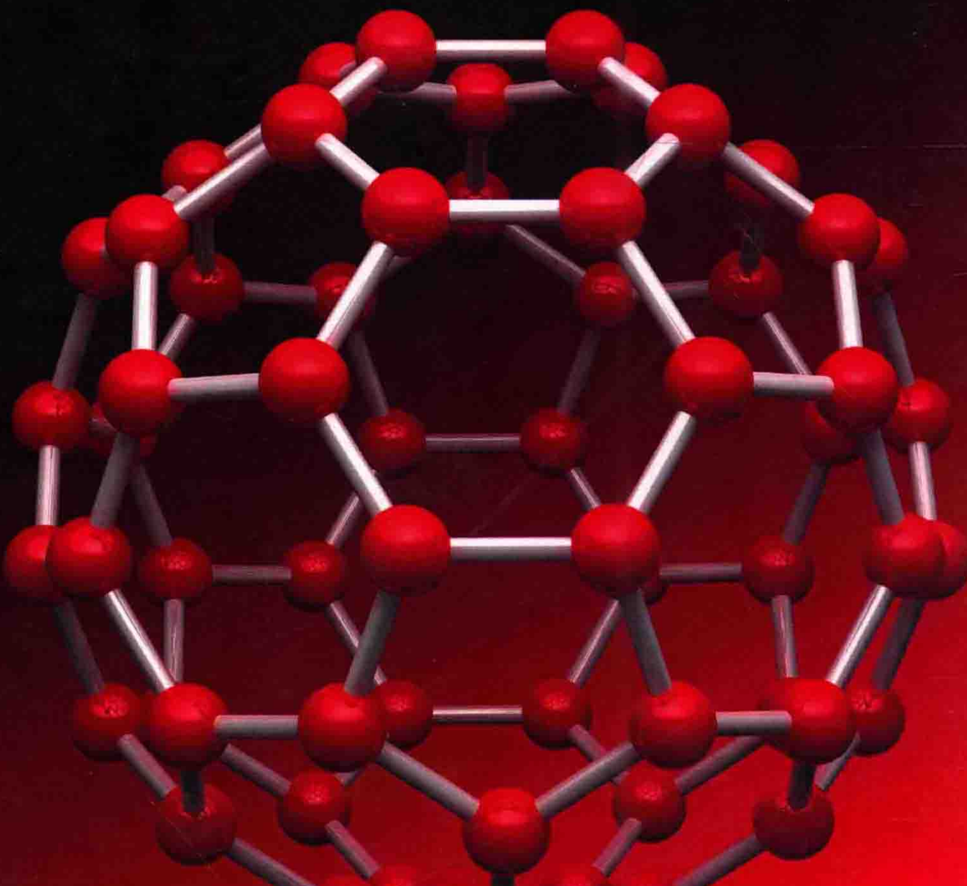
INTRODUCTION TO nanoscience and nanomaterials



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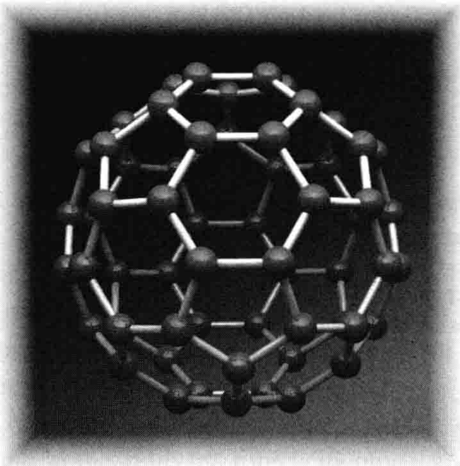

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Dinesh C. Agrawal

Indian Institute of Technology
Kanpur, India

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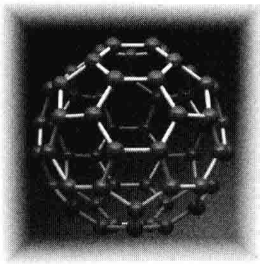

INTRODUCTION TO

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Preface

This book is meant as a textbook for the senior undergraduate and the first year graduate students from different science and engineering departments. Researchers in the area will also find the book useful as a reference material for topics which are outside their expertise. The text assumes only a basic level of competency in physics, chemistry and mathematics.

Apart from the first few chapters, which deal with the topics of surfaces and some relevant topics in physics, the rest of the book is mostly organized according to the dimensionality of the nanomaterials, *i.e.* zero, one and two dimensional nanomaterials followed by bulk nanocrystalline metals and the nanocomposites. The last two chapters are devoted to the topics on the molecules for nanotechnology and the self assembly. A significant amount of space is devoted to "soft matter" which is becoming increasingly important in the fields of nanomaterials and nanotechnology. The focus is on the basics rather than on providing a large volume of information. Sufficient number of solved examples and end of the chapter problems have been included.

Students in a course on nanoscience and nanomaterials are expected to have diverse backgrounds; it is therefore necessary to provide some amount of introductory matter in each chapter. It may be assigned for self study by the instructor if thought fit.

It is hoped that after going through a course based on the book, the student will have a good understanding of the field and will also be able to comprehend the current research literature.

Despite the author's best efforts, there are likely to be some errors. The readers' comments and suggestions to improve the book will be greatly appreciated.

Dinesh C Agrawal

Acknowledgments

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Dinesh C. Agrawal

Contents

Chapter 1

Introduction

A nanometer (nm) is one billionth (10^{-9}) of a meter. Nanoscience can be defined as the science of objects and phenomena occurring at the scale of 1 to 100 nm. The range of 1–100 nm was taken as the defining range by the US National Science and Technology Council in its report titled "National Nanotechnological Initiative: Leading to the Next Industrial Revolution", in February 2000 and a subsequent report in 2004. The committee noted that "Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. ....At this level, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules of bulk matter" [1]. It was also mentioned that "novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm". Actually, in most cases, this happens below 10 nm. On the other hand, some nanoscale phenomena extend beyond 100 nm. The range of 1 to 100 nm appears therefore to be appropriate for the purpose of defining the field as long as it is kept in mind that in some cases one may have to step across these boundaries.

Although the field of nanoscience and nanotechnology has consolidated and emerged as a distinct field only in the decades of eighties and nineties, the activities encompassed by the field have been carried on for decades and in fact for centuries prior to that. Some prominent examples are the use of noble metal particles to impart beautiful colors to the windows of the medieval cathedrals (dating back to fourth century CE), explanation of this effect by Gustav Mie in 1908, development of the ferrofluids in the 1960s, discovery of the magic numbers in the metal clusters in the 1970s, fabrication of the quantum wells in 1970s and many such developments including the development of photography and catalysis.

In 1959 Richard Feynman delivered his famous talk at Caltech titled "There is plenty of room at the bottom" [2]. In it Feynman visualized building of nanosized circuits for use in computers and using precisely positioned assembly of atoms to store vast amounts of information. The Feynman's talk was much ahead of its time — the field of nanoscience and nanotechnology can be said to have come into its own only in the 1990s. The development of newer characterization tools such as the scanning probe microscope and the atomic force microscope and the technique of electron beam lithography capable of making 10 nm structures in 1980s contributed much to the development of the field.

Another factor which provided a great impetus to the area was the need of the computer chip industry. The manufacture of integrated circuits used in the electronics industry is at present carried out by the so called "top down" method in which a thin film is first deposited and parts of it are then etched away to yield the desired pattern. The feature size on the integrated circuits that can be produced by this method has exponentially decreased over the years as predicted by Moore in 1965 [3, 4]. Table 1.1 illustrates this by showing how the line width and the number of transistors per chip in the microprocessors have changed over the years. The number of transistors per chip has increased from 2300 per chip in 1971 to 410 million in 2007 — an increase by a factor of 200,000! This is roughly in accordance with the prediction of Moore that the number of transistors that are placed on a chip should double approximately every two years. Continuing with this trend would mean that the transistor size would have to be scaled down to 9 nm by the year 2016 and to still lower size after that. Photolithography with excimer laser is currently used to fabricate integrated circuits with features below 45 nm and this trend is expected to continue to reach a feature size of about 10 nm. It is apparent that to sustain the growth of the massive semiconductor industry the feature size on the chips will have to be reduced to a few nanometers and new techniques will be needed to accomplish this.

The strategies that are going to be adapted for going below 10 nm are not yet clear. The bottom–up approach in which a structure is assembled from elementary building blocks using noncovalent interactions is of