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Carbon Nanotube Reinforced Composites

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Marcio Loos

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To my wife Cristimari, my son Leonardo and Baby, for their dedication, patience, and support. This book is also dedicated to the many wonderful students and professors I had the chance to work with. Without them, this book surely would not have been possible.

Foreword

It was the emergence of carbon nanotubes (CNTs) which really motivated funding agencies worldwide to support research in all fields of nanoscience and technology. Researchers immediately saw the great potential of this fascinating new, strong, electrical, and thermal conductive material as an excellent additive to reinforce polymers or to transfer them into a conductor when used as a filler.

However, in the last two decades, CNTs did not reach the expected success, partly due to overestimating its potential, partly due to an early involvement of multinational companies, trying to define own quality standards, which banned further optimization development toward the best-suited CNTs. It was partly not seen (suppressed) that CNTs can and must be tailored toward application. They can be sythesized in numerous shapes and structures (SWCNT, DWCNT, MWCNT, chirality, etc.), length, and diameter, all having influence on properties. They can even be optimized toward electrical conductivity. Finally, CNTs are graphite-based nanostructures, which need and can be produced in individual standards which best fit the properties needed for a specific application.

Some people think that with the emergence of graphene the CNTs' story ends. No, graphene is just another graphite-based nanostructure. It opens the door wide open for further applications, in which nanocomposites are only one field of application. While most of the findings on CNT/polymer composites are transferable to graphene composites, it is not only a book on CNTs.

Just at the right time this new textbook on CNTs is to be published for the scientific audience. The understanding of CNT growth has come to a level that further efforts in CNT development are promising and tailored CNTs will be produced. A profound understanding of chemical treatments for CNTs enables to optimize the tube/polymer interface with the result of best performance. The book gives a comprehensive overview on the state of art achieved in CNT/polymer research until today and does not omit critical aspects.

It is an excellent textbook for scientists who want to learn more about this exciting research field and for students to learn and be informed about CNTs and CNT/polymer composites in detail and generally about carbon-based nanoparticles. It is enriched in each chapter with questions, exercises, and examples, which best support learning and understanding.

Dr.-Ing. Karl Schulte (Professor Emeritus)
Hamburg University of Technology (TUHH)
Hamburg (Germany)

Preface

Why can't we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?

This question, posed by Richard Feynman in 1959 during a lecture, can be considered one of the early milestones for nanoscience and nanotechnology (N&N). The problem of manipulating and controlling things on an atomic scale was then put into debate.

Since then many technological developments occurred: man walked on the moon, valves were replaced by tiny transistors, and electronic microscopes capable of increasing our ability to see detail by millions of times were invented.

In 1985 a new allotropic form of carbon, fullerene, a spherical molecule in which carbon atoms are bonded in an arrangement shaped like a soccer ball, was discovered by Richard Smalley, Robert Curl, and Harry Kroto. Sumio Iijima, 6 years later, published his article on carbon nanotubes (CNTs) and thereafter the interest of the scientific community and industries in the topic N&N has been extraordinary. The number of publications and patents covering CNT and N&N grows exponentially year after year. Nanotubes are 250 times stronger than steel, and also have the advantage of being 10 times lighter! CNTs are considered ideal for reinforcement of polymers. The addition of small amounts of CNT has the potential to impart thermal and electrical conductivities to insulating materials.

This book assumes that the reader is relatively new to the area of CNT-reinforced composites without extensive knowledge of the concepts of nanoscience, nanotechnology, composites, and nanotubes. Thus, the first chapters of the book aim to create a solid background in these topics, starting from basic themes such as the importance of size, and why the properties of materials change at the nanoscale. The following chapters will then apply the knowledge gained in the "basic concepts" part of the book creating an easy to follow flow of ideas and concepts. In addition the potential of CNTs to improve mechanical, electrical, and thermal properties of composites is presented with the relevant theoretical models. The expectations of using CNTs are compared to the results obtained in labs, and the reason for the discrepancy between theoretical and experimental results is presented. The processing of polymer composites containing CNTs, which is so important for new researchers on this area, is discussed. Finally a look forward on the potential of CNTs and application of CNTs in the manufacture of polymer composites is presented through two chapters entitled "Is it Worth the Effort to Reinforce Polymers with Carbon Nanotubes?" and "Reinforcement Efficiency of Carbon Nanotubes—Myth and Reality."

This book is written in simple language and is a great addition for undergraduate and graduate courses on the areas of physics, chemistry, and engineering. The book is also very useful for researchers working in the area of N&N, carbon nanotubes, and composites. The examples given in the book, such as applications of composites, are linked to our daily life making the text more attractive. Moreover many questions and exercises with answers are available as an appendix of the book.

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Joinville—Brazil

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CHAPTER

Nanoscience and Nanotechnology

1

CHAPTER OUTLINE

1.1 Introduction to the nanoscale

The term nano has etymological origins in the Greek, and means dwarf. This term indicates that physical dimensions are on the order of a billionth of a meter (10^{-9} m or nanometer). This range is colloquially called nanometric scale or simply nanoscale. By convention, dimensions between 1 and 100 nm are accepted as belonging to the nanoscale. Based on Table 1.1 we can understand the context of the nanoscale

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Table 1.1 Prefixes for the International System of Units (SI)

Factor	Prefix	Symbol
10^{-24}	yocto	y
10^{-21}	zepto	z
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	P
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{-1}	deka	da
10^{-2}	hecto	h
10^{-3}	kilo	k
10^{-6}	mega	M
10^{-9}	giga	G
10^{-12}	tera	T
10^{-15}	peta	P
10^{-18}	exa	E
10^{-21}	zetta	Z
10^{-24}	yotta	Y

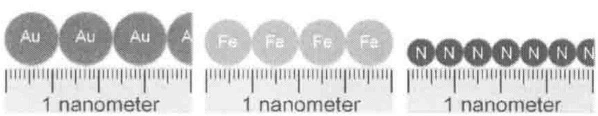

FIGURE 1.1 Different atoms aligned in a 1 nm long ruler: 3.5 gold atoms, 4 iron atoms, and 6.67 nitrogen atoms.

The atoms are considered as hard spheres and the covalent radius is assumed.

in relation to other scales of the international system (SI). Hydrogen atoms, for example, have a diameter of 0.074 nm. Thus, a cube with 1 nm edge could contain about 2500 atoms. The smallest integrated circuit currently known has a lateral dimension of 250 nm and contains 10^6 atoms in an atomic layer thickness. Considering the covalent radius (rigid sphere) of gold, iron, and nitrogen atoms as 0.144, 0.125, and 0.075 nm, respectively, a different amount for each type of atom may be aligned on a 1 nm long ruler (Figure 1.1).

Figure 1.2 compares the size of objects and natural organisms at different scales.