

1 Introduction

The physics of carbon nanotubes has rapidly evolved into a research field since their discovery by Iijima in multiwall form in 1991 and as single-walled tubes two years later. Since then, theoretical and experimental studies in different fields, such as mechanics, optics, and electronics have focused on both the fundamental physical properties and on the potential applications of nanotubes. In all fields there has been substantial progress over the last decade, the first actual applications appearing on the market now.

We present a consistent picture of experimental and theoretical studies of carbon nanotubes and offer the reader insight into aspects that are not only applicable to carbon nanotubes but are useful physical concepts, in particular, in one-dimensional systems. The book is intended for graduate students and researchers interested in a comprehensive introduction and review of theoretical and experimental concepts in carbon-nanotube research. Emphasis is put on introducing the physical concepts that frequently differ from common understanding in solid-state physics because of the one-dimensional nature of carbon nanotubes. The two focii of the book, electronic and vibrational properties of carbon nanotubes, rely on a basic understanding of the symmetry of nanotubes, and we show how symmetry-related techniques can be applied to one-dimensional systems in general.

Preparation of nanotubes is not treated in this book, for an overview we refer the reader to excellent articles, *e.g.*, Seo *et al.*^[1.1] on CVD-related processes. We also do not treat multiwall carbon nanotubes, because dimensionality affects their physical properties to be much closer to those of graphite. Nevertheless, for applications of carbon nanotubes they are extremely valuable, and we refer to the literature for reviews on this topic, *e.g.*, Ajayan and Zhou^[1.2] for more information on the topic.

The textbook Fundamentals of Semiconductors by Yu and Cardona^[1.3] and the series of volumes on Light-Scattering in Solids^[1.4] was most helpful in developing several chapters in this book. We highly recommend these books for further reading and for gaining a more basic understanding of some of the advanced concepts presented here when needed. There are also a number of excellent books on various topics related to carbon-nanotube research and applications that have appeared before. We mention the volume by Dresselhaus *et al.*,^[1.5] the book by Saito *et al.*,^[1.6] the book by Harris^[1.7] and the collection of articles that was edited by Dresselhaus *et al.*^[1.8] They offer valuable introductions and overviews to a number of carbon nanotube topics not treated here.

Beginning with the structure and symmetry properties of carbon nanotubes (Chap. 2), to which many results are intimately connected, we present the electronic band structure of single isolated tubes and of nanotube bundles as one of the two focii of this book in Chap. 3. The optical and transport properties of carbon nanotubes are then treated on the basis of the

electronic band structure in the optical range and near the Fermi level (Chaps. 4 and 5). We introduce the reader to the elastic properties of nanotubes in Chap. 6 and to basic concepts in Raman scattering, as needed in the book, in Chap. 7. The carbon-atom vibrations are related to the electronic band structure through single and double resonances and constitute the second main focus. We treat the dynamical properties of carbon nanotubes in Chap. 8, summarizing what we feel can be learnt from Raman spectroscopy on nanotubes.