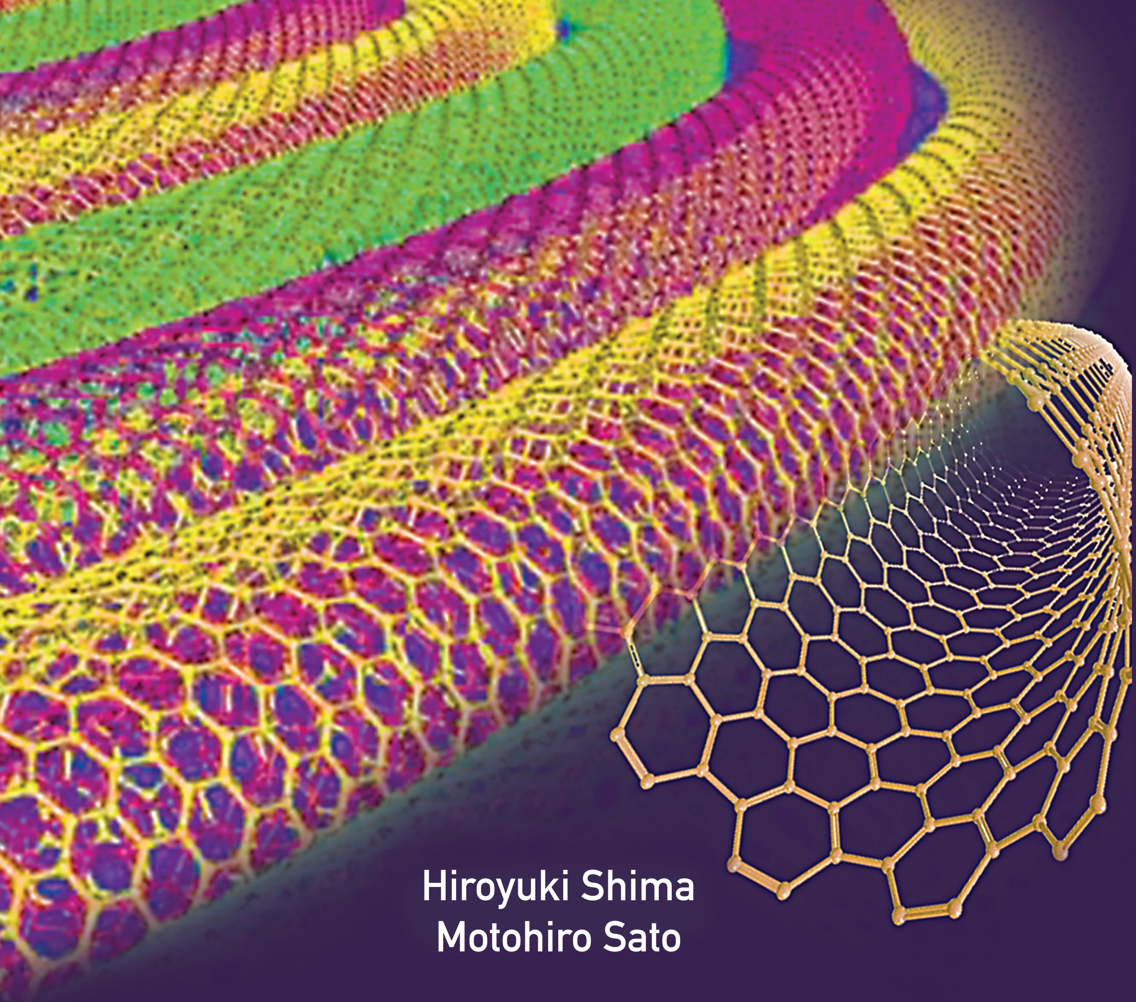

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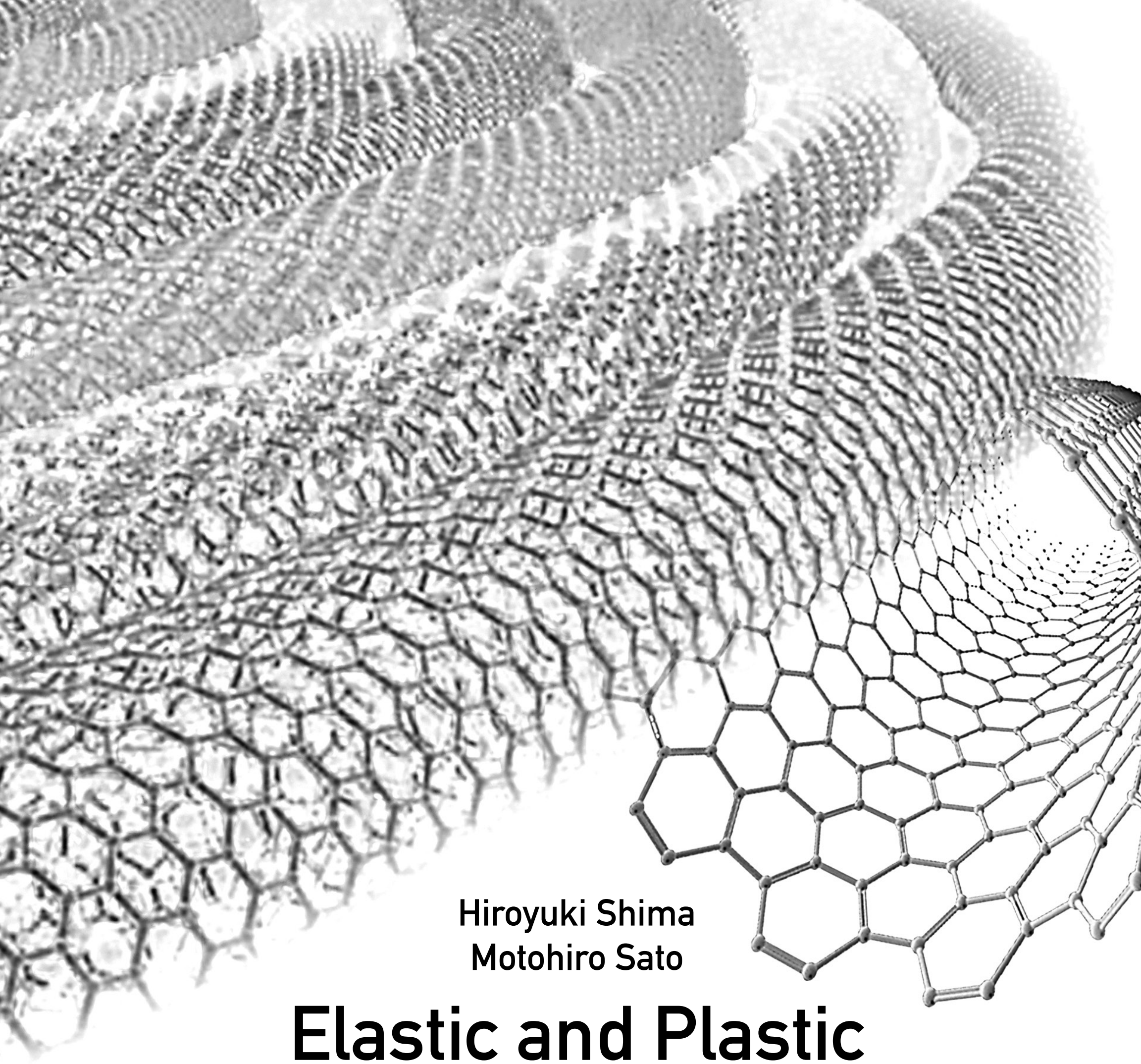

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Pan Stanford Publishing

Published by

Pan Stanford Publishing Pte. Ltd.
Penthouse Level, Suntec Tower 3
8 Temasek Boulevard
Singapore 038988

Email: editorial@panstanford.com
Web: www.panstanford.com

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

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ISBN 978-981-4310-75-8 (Hardcover)
ISBN 978-981-4364-15-7 (eBook)

Printed in the USA

To Rena and Shiho

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Preface

The key players in the materials field continually change with the times. The 19th century saw the rise of iron, followed by silicon in the 20th century. In the 21st century, nano-carbon materials look set to take center-stage.

Carbon is a rare substance that can take various structures and forms. When carbon atoms form a three-dimensional structure, their glittering beauty as diamonds captivates people. When aligned in a two-dimensional plane, carbon atoms become just black graphite and lose their sparkle. In addition to these two macroscale carbon materials, several other nano-carbon materials have been discovered in just the last 20 years, opening new horizons in physics and chemistry. It all began with the C_{60} molecule (fullerene), whose existence was predicted by Osawa in 1970 and evidenced by Kroto *et al*. in 1985. Subsequent studies, including those on carbon nanotubes by Iijima in 1991 and on graphene by Novoselov *et al*. in 2004, have had a tremendous impact, driving developments in science and engineering around the turn of the century.

Of these three types of nano-carbon materials, carbon nanotubes are attracting greatest attention in both industry and academia. Research on carbon nanotubes has focused on two characteristics not usually seen in other fields. First and foremost is the sheer breadth of the research, which encompasses physics, chemistry, materials science, electric and electronic engineering, and life science. The second characteristic is that basic research and applied research are extremely close to each other. A succession of the phenomena of interest to scientists has been discovered like a treasure chest, each leading to an innovative application or development. Thanks to these two characteristics, applied research extends as far as electronic devices, fuel cells, panel display materials and gas absorption and has seen dramatic progress. It is difficult even for experts in the field to understand the progress being made outside of their specialties.

One of the reasons why carbon nanotubes offer huge potential in so many fields is their mechanical properties, specifically the following four:

- **Rigidity**: Young's modulus in the longitudinal direction exceeds that of diamond.
- **Resilience**: The original structure is recovered with few defects after large bending or deformation.
- **Toughness**: Cracks do not easily form or advance, so carbon nanotubes retain their cylindrical shape without breaking even when a large external force is applied.
- **Anisotropy**: Reflecting the cylindrical carbon shell structure with concentric axis, they show mechanical properties with extremely large anisotropy.

In addition to these significant mechanical properties, studies have shown that mechanical deformation causes considerable changes in electronic, optical, magnetic and chemical properties. Thus, many studies on new technologies to utilize the correlation between deformation and properties are under way in various fields, including electronics, biotechnology, and material design. For example, nanoscale devices that use the changes in electrical conductivity or optical response due to deformation are one of the most popular fields in nanotechnology. Meanwhile, ultrahigh-strength materials are being developed for the next-generation infrastructure such as superhigh-rise buildings and large aerospace equipment by utilizing the high thermal and environmental resistance of nanotubes. The application of these low-density substances containing only light carbon atoms for aircraft and automobile parts is expected to raise fuel efficiency and save energy, as well as dramatically reduce exhaust gas emissions and environmental impact.

Despite so many new phenomena and technologies based on the mechanical functions of nanotubes in diverse fields, there are surprisingly few books and overall reviews of nanotubes. Independent books and review papers have tended to focus on specific topics such as quantum devices utilizing the mechanical properties of nanotubes and composite strength materials utilizing the mechanical strength of nanotubes. There have been few reports on the most basic characteristic of nanotubes, which is the unique applicability of their mechanical properties in so many fields.

This book draws on various documents to give a comprehensive overview of the research progress to date, focusing on the mechanical properties of carbon nanotubes. The first half examines minute deformations in the elastic region, reviewing the huge body of literature immediately after nanotubes were discovered to the latest results still in press, without assuming detailed background knowledge. The latter half takes a closer look at the major themes of common interest to researchers in diverse fields, such as the plastic deformation of nanotubes under extreme conditions, including giant deformation, high temperature and pressure, and electron beam irradiation. In introducing prior studies, we have minimized the number of citations to avoid exhaustive descriptions, and instead have included a good balance of visually appealing figures and photographs to assist the readers' understanding. To avoid redundancy with existing books, we have cited the latest studies being reported while this book was being written. We hope it will give readers a broad view of the mechanical properties of nanotubes and help them find new research themes.

The authors express cordial gratitude to Profs. Kousuke Yakubo, Takashi Mikami, Shunji Kanie, and Minoo H. Patel. Thanks to their strict yet devoted instruction in our young researcher ages, we were able to gain the skill required to complete this book. One of the authors, Shima, wrote part of this book within his stay at Universitat Politècnica de Catalunya in Barcelona, Spain, for almost a year, during which time Prof. Marino Arroyo and Dr. Susanta Ghosh were very kind to him. Shima also deeply thanks Prof. Emeritus Eiji Osawa, Profs. Jun Onoe, Hideo Yoshioka, Yoshitaka Umeno, and Dr. Shota Ono, as communications with them have sparked his interest in the study of nano-carbon materials. The other author, Sato, was able to complete this book with the help of Dr. M. Ahmer Wadee while working for half a year at Imperial College London. Jenny Rompas, Stanford Chong, and Arvind Kanswal of Pan Stanford Publishing encouraged us to write this book and provided continuous support.

Finally, we thank our beloved wives, Rena and Shiho, and our children, Yuuka, Ayaka, Tatsuya, and Kana, for easing our fatigue through their smiles and kind words every day. We are grateful to all of them for looking after us, and for the friendships between us.

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July 2013