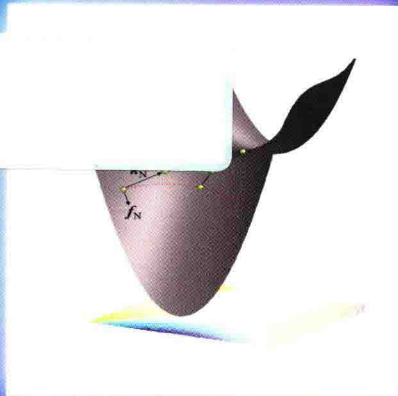

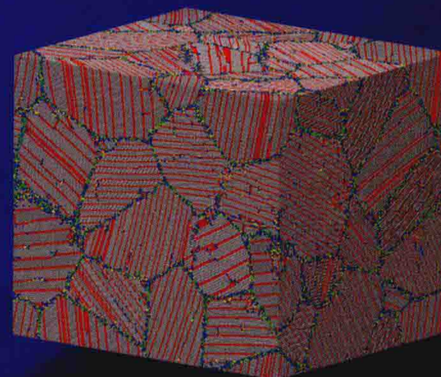

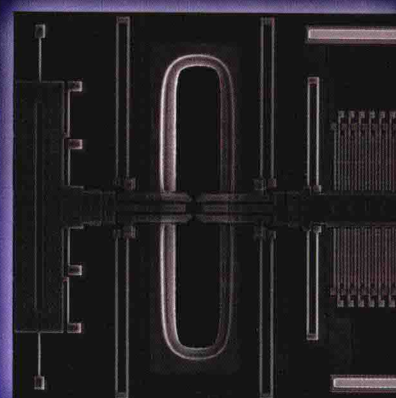

Nano and Cell Mechanics

Fundamentals and Frontiers

Editors
HORACIO D. ESPINOSA
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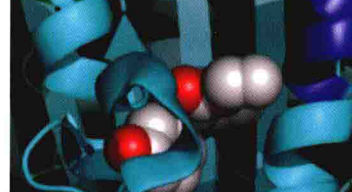

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NANO AND CELL MECHANICS

FUNDAMENTALS AND FRONTIERS

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WILEY
A John Wiley & Sons, Ltd., Publication

This edition first published 2013

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

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Library of Congress Cataloging-in-Publication Data

Nano and cell mechanics : fundamentals and frontiers / edited by Horacio D. Espinosa, Gang Bao.
p. cm. – Microsystem and nanotechnology series
Includes bibliographical references and index.
ISBN 978-1-118-46039-9 (hardback : alk. paper)
1. Biotechnology. 2. Mechanics. 3. Nanotechnology. I. Espinosa, H. D. (Horacio D.), 1957-
II. Bao, Gang, 1952-
TP248.2.N353 2013
660.6–dc23

2012027597

A catalogue record for this book is available from the British Library.

ISBN: 9781118460399

Typeset in 10/12pt Times by Laserwords Private Limited, Chennai, India
Printed and bound in Singapore by Markono Print Media Pte Ltd

NANO AND CELL MECHANICS

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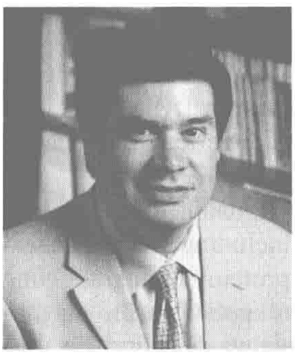

Horacio Dante Espinosa is the James and Nancy Farley Professor of Mechanical Engineering and the Director of the Theoretical and Applied Mechanics Program at the McCormick School of Engineering, Northwestern University. He received his PhD in Applied Mechanics from Brown University in 1992. He has made contributions in the areas of dynamic failure of advanced materials, computational modeling of fracture, and multiscale experiments and simulations of micro- and nanosystems. He has published over 200 technical papers in these fields. His work has received broad attention in the media, including United Press International, NSF Discoveries, Frost and Sullivan, Science Daily, EurekAlert, Small Times, PhysOrg, Nanotechwire, Bio-Medicine, NanoVIP, Nanowerk, Genetic Engineering and Biotechnology News, Medical News Today, Materials Today, Next Big Future, Beyond Breast Cancer, AZoNano, Spektrumdirekt, and MEMSNet.

Professor Espinosa has received numerous awards and honors recognizing his research and teaching. He was elected foreign member of the Russian Academy of Engineering in 2011 and of the European Academy of Sciences and Arts in 2010, Fellow of the American Academy of Mechanics in 2001, the American Society of Mechanical Engineers in 2004, and the Society for Experimental Mechanics in 2008. He was the Timoshenko Visiting Professor at Stanford University in 2011. He received two Young Investigator Awards: the NSF-Career in 1996 and the Office of Naval Research-Young Investigator Award in 1997. He also received the American Academy of Mechanics (AAM) 2002-Junior Award, the Society for Experimental Mechanics (SEM) 2005 HETENYI Award, the Society of Engineering Science (SES) 2007 Junior Medal, and the 2008 LAZAN award from the Society for Experimental Mechanics. He currently serves as Founding Principal Editor of *MRS Communications* and co-editor of the *Wiley Book Series in Microsystems and Nanotechnologies*. He also served as Editor-in-Chief of the *Journal of Experimental Mechanics* and Associate Editor of the *Journal of Applied Mechanics*. He is the 2012 President of the Society of Engineering Science and a member of the US National Committee for Theoretical and Applied Mechanics.

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Dr Bao's current research is focused on the development of nanotechnology and biomolecular engineering tools for biological and disease studies, including molecular beacons, magnetic nanoparticle probes, quantum dot bioconjugates, protein tagging/targeting methods, and engineered nucleases. These approaches have been applied to the diagnosis and treatment of cancer and cardiovascular disease, viral infection detection, and the development of gene correction approaches for treating single-gene disorders.

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Foreword

The articles included in this volume, compiled by Dr. Gang Bao and Dr. Horacio Espinosa, can be viewed as a benchmark along the evolutionary path of what our scholarly community views as its "field of research." Consequently, the preparation of this foreword provides an opportunity to lend perspective to the book as a whole.

Among senior researchers, it is common for one to feel that their own field reached its pinnacle when they were young, but that it has been suffering a steady decline ever since. The contents of this book will surely dissuade anyone involved in research on the mechanics of hard or soft materials from harboring such a view! When I was first exposed to the field of mechanics nearly a half century ago, the focus was on the mathematical solution of boundary-value problems, either exactly or approximately, and this point of view pervaded graduate courses. There was a small but active experimental community involved in measurement of deformation with strain gages, photoelastic strategies, and, occasionally, optical interference techniques. At about this time, a few visionaries in the community demonstrated to the Department of Defense that there was enormous potential for advances in engineering and technology through more effective exploitation of materials; as a result, a number of national materials research laboratories were established at universities around the country, with mechanics taking a central role in a number of these centers.

As a result, the organizational barriers between mechanics and materials were gradually overcome, and many of us opted to align our research efforts with the new area of mechanics of materials. Computational methods joined analytical and experimental methods as core activities, and advances in both fabrication and characterization of experimental samples introduced us to the exciting and complex world of deformation of materials at small size scales. Graduate education became much more diverse with the integration of mechanics and materials science, and the introduction of computation provided a powerful means for describing the behavior of materials quantitatively and for addressing issues of competition among potential mechanisms of deformation or failure.

The important role of mechanical stress on thin film materials and other small structures, which are largely intended for nonmechanical functions, arose as a focus of research efforts. Connections between macroscopic fracture strength of materials and the details of material microstructure were established, the inuence of plastic strain localization due to material instability in deformation was quantified, and the role of dislocation formation or crystallographic twinning or other phase transformations on the nonmechanical functional characteristics of materials was established, for example. The topics became important focal issues for graduate courses in the field, and a greatly increased range and sophistication in sample preparation and diagnostic tools became available in laboratories. This was the prevailing atmosphere in the field at about the time the editors of this volume emerged as active members of the community.

The field of mechanics of materials had changed fundamentally, having formed a focus on the physical and chemical aspects of phenomena as much as the mathematical 1 aspects, computation became an indispensable methodology, and methods of laboratory sample fabrication, observational techniques, and data analysis created opportunities that seemed unattainable only a short time earlier. Researchers could now apply this suite of tools to examine and quantitatively understand the behavior of materials at an even smaller scale. It was soon found that the mechanisms of biological functions, which before had been identified through the long and painstaking process of assaying, could be observed directly.

As we gaze forward in time from the current frontiers of mechanics research, we see that the "landscape" to be traversed is less well defined than it had been in the past. Mechanical phenomena at the smaller size scales are often inseparable from chemical, biological, and/or quantum mechanical inuences, and the rules governing behavior are no longer certain. Consequently, instead of reliance on precise analytical and/or numerical analyses, we must examine data obtained through brief glimpses of the nano-world in the laboratory or seek guidance from the global principles of thermodynamics. Although these aspects loom as impediments to progress, the task of overcoming them lends a sense of timeliness and excitement to the mechanics research field overall.

As illustrations of the broad consequences of these developments, this volume includes a report on the inuence of mechanical tension on neuronal growth and memory in the human brain. Another article reports on direct measurement of the mechanical properties of cylindrical test samples with diameters as small as 50 nm. There is a discussion of the connections between mechanical properties of cells and human disease, as well as a quantitative description of what can be learned by separating a pair of chemically bound molecules under controlled conditions, plus many others. We can learn a great deal from study of the articles individually, of course. It is equally important to consider their collective significance as an indicator of the excitement, broad relevance, and future promise of our field.

L. B. Freund
Champaign, IL, USA

Series Preface

Books in this series are intended, through scholarly works of the highest quality, to serve researchers and scientists wishing to keep abreast of advances in the expanding field of nano- and micro-technology. These books are also intended to be a rich interdisciplinary resource for teachers and students of specialized undergraduate and postgraduate courses.

A recent example includes the university textbook *Introduction to Microsystem Technology* by Gerlach and Dötzel, covering the design, production and application of miniaturised technical systems from the viewpoint that for engineers to be able to solve problems in this field they need to have interdisciplinary knowledge over several areas as well as the capability of thinking at the system level. In their book *Fluid Properties at Nano/Meso Scale*, Dyson *et al* take us step by step through the fluidic world bridging the nanoscale, where molecular physics is required as our guide, and the microscale where macro continuum laws operate. Jinghong Fan in *Multiscale Analysis of Deformation and Failure of Materials* provides a comprehensive coverage of a wide range of multiscale modeling methods and simulations of the solid state at the atomistic/nano/submicron scales and up through those covering the micro/meso/macroscopic scale. Most recently *Digital Holography for MEMS and Microsystem Metrology*, edited by Anand Asundi, offers timely contributions from experts at the forefront of the development and applications of this important technology.

In this book Professors Espinosa and Bao have assembled, through their own inputs and those of 47 other experts of their chosen fields of endeavour, 17 timely and exciting chapters that must surely represent the most comprehensive coverage yet presented of all aspects of the mechanics of cells and biomolecules. The editors have ensured, through the careful choice of the contents and their order of presentation in four main sections, that we have a coherent presentation of the extraordinary wide range of interdisciplinary components that make up this exciting frontier in applied mechanics. Apart from their clarity of presentations, all the authors have adopted a pedagogical style of writing, making much of this book's content suitable for inclusion in undergraduate and postgraduate courses. A foreword, both historic and insightful, has also been composed by Professor L Ben Freund - whose own contributions to various aspects of the mechanics of biological materials will have influenced the thinking of many of the contributors to this excellent book.

Ronald Pethig
Professor of Bioelectronics
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Preface

In the past decade, nano- and bio-technologies have received unprecedented attention from the government and private sectors as well as the general public owing to their potential in impacting our lives through fundamental discoveries, innovation, and translational research efforts. Engineers and applied scientists have played a major role in developing these technologies and made essential contributions to applying them to a wide range of industries, including manufacturing, healthcare, agriculture, energy, and defense.

Consistent with this, research in nano-mechanics and the mechanics of living cells and biomolecules has become a frontier in applied mechanics. Studies in this exciting research area are interdisciplinary in nature and draw engineers and scientists from a diverse range of fields, including nanoscale science and engineering, biology, statistical and continuum mechanics, and multiscale-multiphysics modeling and experimentation. As a result, original contributions to the development of nano- and cell-mechanics are published in a large number of specialized journals, which prompted us in editing this book. The book documents, for the first time, many recent developments in nano- and cell-mechanics and showcases emergent new research areas and techniques in engineering that are at the boundaries of mechanics, materials science, chemistry, biology, and medicine. As such, this book allows those entering the field a quick overview of experimental, analytical, and computational tools used to investigate biological and nanoscale phenomena. This book may also serve as a textbook for a graduate course in theoretical and applied mechanics, mechanical engineering, materials science, and applied physics.

The 17 chapters in this book are organized in four sections: (1) Biological phenomena, (2) Nanoscale phenomena, (3) Experimentation, and (4) Modeling. The biological phenomena section covers cell–receptors interactions, regulatory molecular motors, and the role of tension in neuronal growth and memory. The nanoscale phenomena section examines superhydrophobicity, multiscale mechanics of hierarchical carbon-based materials, mechanics of twinning in hierarchical metals, and size-dependent strength in single-crystalline metallic nanostructures. The experimentation section discusses *in-situ* electron characterization of nanomaterials, the engineering of nano-probes for live-cell imaging of gene expression, high-throughput cell mechanic assays for research and clinical applications, and microfabrication technologies for cell mechanics studies. The last section, modeling, spans a number of methods and applications: atomistic reaction pathway sampling, mechanics of curvilinear electronics, single molecular pulling, modeling of hierarchical protein materials, geometric models of protein secondary structure formation, and multiscale modeling for the vascular transport of nanoparticles.

We would like to thank Ben Freund for providing a historic perspective and an inspiring Foreword. Likewise, we are particularly thankful to all authors for providing authoritative and comprehensive reviews of recent advances in their field of expertise. We would also like to thank the Wiley staff, Anne Hunt and Tom Carter in particular, for guidance and assistance over the preparation of this book. Their experience and professionalism was essential to this project. A special thanks is also due to our assistants, Andrea DeNunzio and Amy Tang, who communicate regularly with the authors to collect all the needed materials.

Horacio D. Espinosa and Gang Bao

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