

Multiscale Characterization of Biological Systems

Vikas Tomar • Tao Qu • Devendra K. Dubey
Devendra Verma • Yang Zhang

Multiscale Characterization of Biological Systems

Spectroscopy and Modeling

 Springer

Vikas Tomar
Purdue University
West Lafayette, IN, USA

Tao Qu
Purdue University
West Lafayette, IN, USA

Devendra K. Dubey
Indian Institute of Technology Delhi
New Delhi, Delhi, India

Devendra Verma
Purdue University
West Lafayette, IN, USA

Yang Zhang
Purdue University
West Lafayette, IN, USA

ISBN 978-1-4939-3451-5
DOI 10.1007/978-1-4939-3453-9

ISBN 978-1-4939-3453-9 (eBook)

Library of Congress Control Number: 2015953098

Springer New York Heidelberg Dordrecht London
© Springer Science+Business Media New York 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer Science+Business Media LLC New York is part of Springer Science+Business Media
(www.springer.com)

To Samarth, Yash, and Swati

Preface

Inspired by a remarkable combination of physical and mechanical properties in biological materials, a new research field has evolved that focuses on studying these materials for the underlying principles and mechanisms of operation in order to incorporate such into the engineered materials. This field or stream of materials science referred to as “Bioenabled and Biomimetic Materials” has attracted imagination of a range of scientific disciplines. The key of natural- or nature-inspired design of materials is different, organized scale levels (nano- to macroscale) of structural arrangement with the presence of the interface between the organic and inorganic phases at each level. The accurate knowledge of such design principle is needed to optimize performance of biomimetic materials for required loading condition and operation. Two aspects of this knowledge are the accurate characterization of the organic–inorganic interfaces and the quantitative study of the contributor of different interfaces and structural arrangements to the consequent improvements in mechanical properties (e.g., stiffness, strength, toughness, etc.). Another important aspect of this design is the development of an ability to better manufacture traditionally developed composites. This collection focuses on the work done by Interfacial Multiphysics Lab and collaborators on the first aspect. The field of biomimetic materials is still in its beginning and growing. This work’s primary contribution is in its focus on interfaces from the point of views of experiments and multiscale models.

Authors are immensely grateful to collaborators such as Prof. Christian Hellmich at TU Vienna, Prof. Kalpana Katti at North Dakota State University, Prof. Huajian Gao at Brown University, Prof. Markus Buehler at MIT, and Prof. Glen Niebur at University of Notre Dame in indirectly or directly providing great motivation and discussions. The book contains a discussion of work by a range of researchers in

this area. Permission was obtained for figures borrowed to appear in review papers and book chapters on which the book is based. We remain indebted for the related colleagues for providing required permissions.

West Lafayette, IN, USA
West Lafayette, IN, USA
New Delhi, Delhi, India
West Lafayette, IN, USA
West Lafayette, IN, USA

Vikas Tomar
Tao Qu
Devendra K. Dubey
Devendra Verma
Yang Zhang

Contents

1 Introduction	1
References.....	3
2 Spectroscopic Experiments: A Review of Raman Spectroscopy of Biological Systems	5
2.1 Introduction.....	5
2.2 Instrumentation	8
2.3 Identification of Algae Species Using Raman Spectroscopy.....	10
2.4 Study of Component Biomolecules	11
2.5 Conclusions.....	16
References.....	17
3 Nanomechanics Experiments: A Microscopic Study of Mechanical Property Scale Dependence and Microstructure of Crustacean Thin Films as Biomimetic Materials	21
3.1 Methods.....	23
3.1.1 Nanoindentation.....	23
3.1.2 Experimental Setup.....	24
3.1.3 Scanning Electron Microscopy (SEM) and Energy-Dispersive X-Ray (EDX)	26
3.1.4 Sample Preparation	26
3.1.5 Substrate Effect	26
3.2 Results.....	27
3.3 Conclusion	33
References.....	33
4 Molecular Modeling: A Review of Nanomechanics Based on Molecular Modeling	37
4.1 Introduction.....	37
4.2 Bioengineering and Biomimetics.....	38
4.2.1 Bone	39
4.2.2 Nacre.....	50

4.3 Discussion: Development of Materials with Controlled Nanoscale Interfacial Design	54
4.3.1 Biomaterials Inspired from Interfacial Design of Nacre and Bone	54
References	56
5 Multiscaling for Molecular Models to Predict Lab Scale Sample Properties: A Review of Phenomenological Models	61
5.1 Introduction	61
5.2 Hard Biological Materials	65
5.2.1 Role of Interfaces in Hard Biomaterial Mechanics	66
5.2.2 Modeling of TC–HAP and Generic Polymer–Ceramic Type Nanocomposites at Fundamental Length Scales	68
5.3 Bioengineering and Biomimetics	73
5.4 Summary	75
References	76
6 Multiscaling for Molecular Models: Investigating Interface Thermomechanics	81
References	91
Index	93