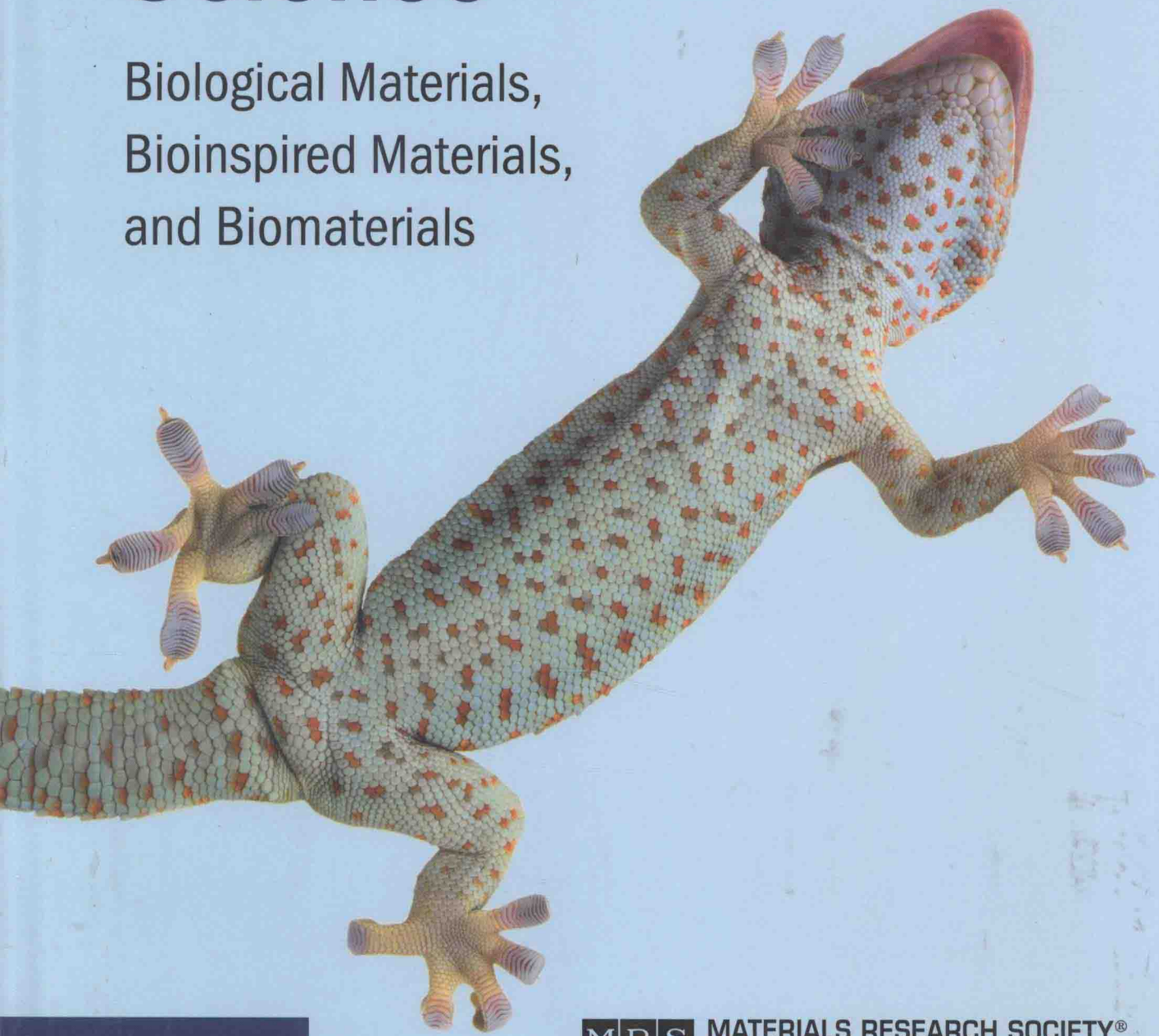
Marc André Meyers and Po-Yu Chen

Biological Materials Science

Biological Materials, Bioinspired Materials, and Biomaterials



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Biological Materials Science

Taking a unique materials science approach, this text introduces students to the basic concepts and applications of materials and biomedical engineering and prepares them for the challenges of the new interdisciplinary field of biomaterials science.

Split into three sections – Basic biology principles, Biological materials, and Bioinspired materials and biomimetics – the book presents biological materials along with the structural and functional classification of biopolymers, bioelastomers, foams, and ceramic composites. More traditional biomimetic designs such as VELCRO® are then discussed in conjunction with new developments that mimic the structure of biological materials at the molecular level, mixing nano-scale with biomolecular designs. Bioinspired design of materials and structures is also covered.

Focused presentations of biomaterials are presented throughout the text in succinct boxes, emphasizing biomedical applications, and the basic principles of biology are explained, so no prior knowledge is required. The topics are supported by approximately 500 illustrations, solved problems, and end-of-chapter exercises. PowerPoint slides and solutions for instructors are available online via www.cambridge.org/meyerschen.

Marc André Meyers, Distinguished Professor at the University of California, San Diego, is the author or co-author of three other books and approximately 400 papers. The recipient of important awards from Europe (Humboldt Senior Scientist Award, Heyn Medal from the DGM, and the J. S. Rinehart Award), China (Lee Hsun Lecture Award; Visiting Professor, Chinese Academy of Sciences), and the USA (Acta Materialia Materials and Society Award, TMS Educator Award, SMD/TMS Distinguished Scientist and Distinguished Service Awards, ASM Albert Sauveur Award, ASM Albert Easton White Award), he is a Fellow of TMS, APS, and ASM, and a member of the Brazilian Academy of Sciences. He is also the author of three fiction novels.

Po-Yu Chen, Assistant Professor of the Materials Science and Engineering Department at National Tsing Hua University, Taiwan, is a graduate of the University of California, San Diego. His current research is in the fields of biological (natural) materials, bioinspired/biomimetic materials, biomedical materials, and green and energy-related materials. He is the author or co-author of several highly cited review articles in biological and bioinspired materials. A member of the TMS Biomaterials Committee, he organized several bio-related symposiums and workshops at international conferences. He was the recipient of the *Materials Science and Engineering C* Young Researcher Award, the ASME Emerging Researchers in Biomedical Engineering Award in 2011, and the TMS Young Leaders Award, and he received the Distinguished Young Researcher Career Award from the Taiwan National Science Council.

"The union of the physical and biological sciences is in many respects one of the most exciting yet challenging aspects of scientific endeavor today. Nowhere is this more in evidence than in the area of biological materials science and engineering where many materials scientists struggle with the complex puzzle of biological form and function while biologists in turn have to deal with the invariably highly quantitative nature of the physical sciences and engineering. With this book, Meyers and Chen have delivered a true *tour de force* which takes the reader in clear and precise text from cells to virus-produced Li-ion batteries. This book is a must read for undergraduates, graduates and researchers alike in the rapidly expanding fields of biological, bioinspired and biomaterials science."

Robert Ritchie, *Lawrence Berkeley National Laboratory*

The works of the Lord are great,
sought out of all them that have pleasure therein.
Psalms 111:2
Frontispiece of the new Cavendish Laboratory, University of Cambridge

Preface

The field of materials science and engineering (MSE) has undergone a tremendous development since it was defined for the first time in the 1950s. Materials science and engineering has supplanted traditional curricula centered on metallurgy, ceramics, and polymers. In the USA alone, there are over 50 MSE academic university departments. Materials science and engineering has initially merged metals, polymers, ceramics, and composites into a broad and unified treatment. Whereas the twentieth century was marked by revolutionary discoveries in physics and chemistry, the twenty-first century has been prognosticated to be dominated by biology. Indeed, medical and biological discoveries are bound to have a profound effect on our future. Consistent with the increasing demands of engineering students to acquire basic working tools in this domain, many engineering curricula are adding appropriate courses or modifying existing courses to address biological aspects. Within MSE, the nascent field of biological materials science encompasses three areas.

- Biological (or natural) materials: materials that comprise cells, extracellular materials, tissues, organs, and organisms.
- Biomaterials: synthetic materials used to correct, repair, or supplement natural functions in organisms.
- Biomimetics: this area encompasses the materials and structures inspired in biological systems and/or functions.

This book focuses on these three areas in a balanced manner. This is a necessity of space, and many curricula offer separate biomaterials courses. The book has 13 chapters, and the contents can be covered comfortably in one semester (one chapter per week).

This book was developed for courses aimed at seniors and first-year graduate students. The course has been taught at the University of California, San Diego, and at National Tsing Hua University. Solved examples in the text (approximately two per chapter) and end-of-chapter problems are an important part of the text, and serve as a learning tool and an opportunity to cement the knowledge gained by applying it to specific problems. We provide a solutions manual and PowerPoint presentations of figures and key concepts in each chapter, which are available online via www.cambridge.org/meyerschen.

We present the principles of biology and the connections between structures and properties in biological materials. The intended audience for this course are MSE and ME students with a sound MSE foundation but poor biology background. We use the materials science and engineering approach which is based on the correlation of structure with structural and functional properties. This approach is familiar to MSE and ME students.

Many courses in biomaterials devote the first half to explaining the principles of MSE and are designed for bioengineering and medical students. The opposite approach is implemented here. In Part I: Basic biology principles, we introduce the basic biology concepts that engineering students need to penetrate this area. Some of these concepts are rather basic for biology students, but provide important background material for engineering students.

In Part II: Biological materials, in a manner similar to classical MSE, which divides materials into metals, ceramics, polymers, and composites, we introduce biological materials in broad categories according to their structure and properties: biological ceramics (biominerals); biological polymers and their composites; biological elastomers; biological foams. This classification was introduced by Wegst and Ashby (1994), and is very useful for engineers, who can understand biological materials better through this familiar approach.

In Part III: Bioinspired materials and biomimetics, we present more traditional biomimetic designs such as VELCRO® and proceed towards new developments that mimic the structure of biological materials at the molecular level, mixing nano-scale with biomolecular designs. This is a unique aspect of this book, not treated heretofore in classrooms. Some of these bioinspired materials are already used in biomedical applications.

Boxes placed throughout the text discuss biomaterials, an important field of utilization of the concepts learned here.

Although this book has only two authors, it represents the efforts of our research groups at UCSD and National Tsing Hua University. In particular, our colleague J. McKittrick contributed greatly to this book via her collaboration over the past eight years. She is also co-author of four review articles whose material was used in different parts of the book. We may have inadvertently used some of the text generated by her, for which we apologize.

Former graduate students, G. Serra Guimarães, J. Kiang, A. Y. M. Lin, J. Li, Y. S. Lin, R. Menig, L. S. Morais, E. E. Novistkaya, D. Ren, and Y. Seki; postdoctoral fellow Dr. W. Yang; current students, I. H. Chen, D. Fernandes, M. I. Lopez, M. Porter, V. Sherman, and B. Wang helped by providing material for the book. B. Wang also undertook the arduous task of seeking figure permissions and assistance in proofreading, and W. Yang provided immense assistance throughout the entire project. The presence of our own research results is disproportionally high, but we tried to keep a balance throughout. This is a rapidly evolving field and we might have accidentally excluded important information. We thank our colleagues and graduate students that contributed to this book through research, discussion of the literature, and problem-solving. The field of biological materials is critically dependent on specimens, and we thank Jerry Jennings at Emerald Forest Gardens (toucan feathers and beaks), the San Diego Museum of Natural History (Brad Hollingsworth and Phillip Unitt), and Raul Aguiar, Rancho La Bellota (vulture wings). The esteemed friend and colleague of MAM, the foot and ankle specialist Dr. João Francisco Figueiró, shared with him an early biological experiment (a secret night visit to the cadaver ascribed to him, in our university days) and provided a number of radiographs for this book.

The generous input of and collaboration with colleagues globally has been very important in defining the coverage of this book. We particularly would like to thank Professors George Mayer (University of Washington), R. Ritchie (University of California at Berkeley), C. T. Lim (National University of Singapore), Carlos Elias (Military Institute of Engineering, Brazil), A. Miserez (Nanyang University, Singapore), and R. Roeder (Notre Dame University). Three towering figures inspired us to write this book: Y. C. Fung and R. J. Skalak, both pioneers in this field and both, coincidentally and fortunately for us, from UCSD; and M. F. Ashby, Cambridge University, who has preceded us in this endeavor and has entered this field with clarity and vision, implementing the "materials" approach that we follow.

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Boxes

Contents