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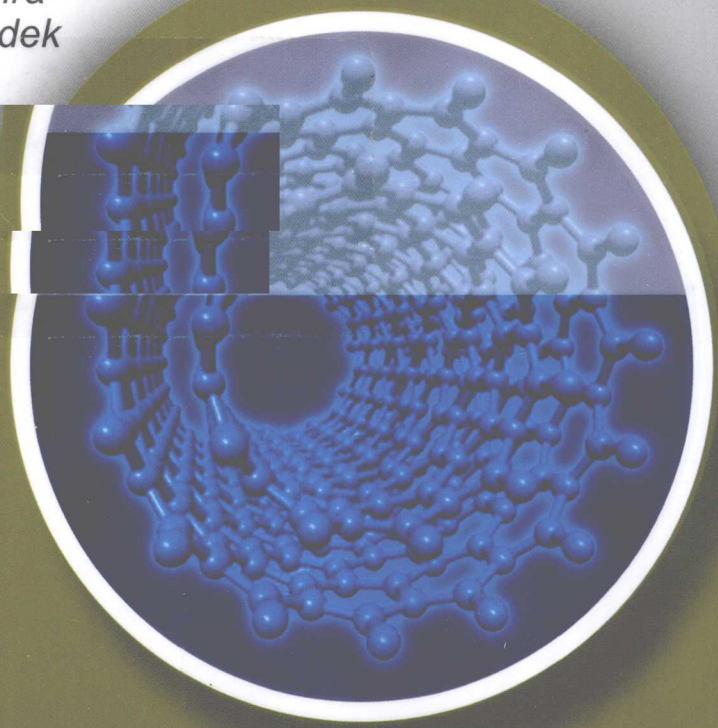
纳米材料、纳米技术及设计

Nanomaterials,Nanotechnologies and Design

Michael F. Ashby
Paulo J. Ferreira
Daniel L. Schodek



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导　读

纳米材料和技术是纳米科学和技术（nano science and technology，Nano ST）领域的重要分支。普遍认为，纳米科学和技术的研究和开发是21世纪一个紧迫的科学技术问题。可以这样说，谁掌握了纳米技术，谁就占领了科学的一个制高点。纳米科学和技术的迅速发展，将使人类从纳米尺度上加深和拓宽对材料科学的认识，并且从全新的角度出发，设计、调控和制备具有重要用途的材料。可以预测，纳米材料和技术将会逐渐渗透到人类生活的各个领域，并且产生革命性的影响。

纳米材料和技术涉及的领域极为广阔，从物理、化学、能源、信息科学到生物和医学等专业领域，几乎无所不包。在这样的一个前提下，撰写一本全面介绍纳米材料和技术的专著是非常困难的。剑桥大学工程系的Michael F. Ashby、哈佛大学建筑系的Daniel L. Schodek教授和得州大学奥斯汀分校电镜中心主任Paulo J. Ferreira副教授，学科交叉，以材料设计（design）和应用为出发点，阐述材料性能和纳米结构的内在联系，并且对纳米材料的制备技术做了较为全面的叙述。

本书共分12章，主要内容如下：

- 第1章　纳米材料和纳米技术概述
- 第2章　纳米技术的发展历程
- 第3章　纳米材料和设计
- 第4章　材料的分类：结构和性能
- 第5章　材料性能导图和应用
- 第6章　纳米材料的分类和基础
- 第7章　纳米材料的性能
- 第8章　纳米材料的合成和表征
- 第9章　设计环境和系统
- 第10章　纳米材料产品和功能
- 第11章　健康和环境领域中的纳米材料和技术
- 第12章　更宽领域中的纳米材料和纳米技术

本书的前3章对纳米材料和技术进行了简要的概括。第1章介绍了纳米材料的概念、定义，以及纳米材料所表现的一般特性，以及纳米材料和技术领域。第2章回顾了自然界中的材料和纳米材料，以及早期手工制品和艺术品中发现的纳米材料。第3章结合日益出现的纳米材料，讨论了材料在建筑领域的应用，包括建筑设计思路、建筑类型选择等。第4章从定性和定量的角度，介绍材料的分类、结构和性能，包括力学性能、电学性能、磁性、热学性能、光学性能和声学性能等。这些内容除材料领域的研究人员和工程师应熟悉和掌握外，对建筑领域的技术人员亦会有所帮助。第5章介绍基于材料性能导图，进行材料的选择、优化设计和设计矛盾的解决。本章的主要读者是建筑设计

师和建筑工程师。第6～8章较为深入地介绍了纳米材料的主要类型和一般特性，以及它们的制备方法和表征手段。这些章节针对具有相关材料知识背景的读者，尤其是纳米材料领域的研究人员和工程师；此外，对想要深入了解纳米材料的建筑设计师和建筑工程师，亦会有所帮助。第9章针对不同设计环境，从定性的角度出发，探讨纳米材料和技术可能发挥的作用。对于非设计领域的专业人员，本章较为深刻地提供了纳米材料对实际应用的影响，以及实际应用对发展新材料思路的启发。第10章介绍与建筑、工程、产品设计等领域相关的纳米材料的形式和功能，适合各种背景的专业人员阅读。第11章概述了纳米材料和技术在医疗、医药等领域，以及改善环境方面的应用，也涉及健康方面的一些问题。不同背景的专业人员均可阅读本章内容。本书的最后一章简介纳米材料和技术在其他工业领域的应用，以及未来的发展预测。

纳米材料和技术是非常受关注的，所涉及的领域不断地加深和拓展。其不仅为科学家、工程师、建筑师和产品设计人员所熟知，也逐渐被广大的群众所认识和理解。因其具有小尺寸、轻量化、高性能等特点，除一般应用，如建筑和工业产品，纳米材料预期可以广泛应用于汽车、航空航天、能源等工业领域。在能源领域，如纳米材料制造燃料电池和太阳能电池，较传统材料制造的产品能量转换效率更高。

尽管纳米材料和技术已逐渐被人们所认识，但是有关纳米的概念常常被误解，甚至夸大其作用。本书从最基本的原理出发，来阐明什么是纳米材料，以及应用纳米材料可能会带来的好处和可能的后果。本书的显著特点是结合作者在建筑领域的专业知识，对纳米材料的应用，尤其是材料的选择、设计和有效利用，做了较为新颖和详细的阐述。在新材料的应用上，尤其是建筑业，常常存在理论和实践脱节的现象。本书的另一个主要特点是试图有机结合纳米材料的理论和实际应用，使二者形成相互促进的关系。为使纳米材料及技术获得更大的发展，设计人员、工程师和材料科学家应密切合作，本书为上述人员提供了有效的信息交换和相互理解的基础知识和平台。

本书有所侧重，详细叙述了其他文献所包括一些专业性内容。如第8章介绍了不同的纳米材料的合成制备技术。对于一些合成技术，如软刻蚀和溶胶凝胶法，其他文献已有深入的阐述。但是，对于另外一些纳米材料制备技术的叙述尚不够系统和完善。在大量资料调研的基础上，本书对基本和重要的纳米合成技术，以及合成纳米材料的力学、光学、热学和电学性能，都做了较为系统的整理和叙述。从设计和使用的角度，引入材料性能导图，帮助设计者有效地选择纳米材料，并且进行相关的设计和使用。

本书的编写是以应用为导向的，问题讨论沿纳米材料的使用环境展开，如建筑和产品等。材料的发展离不开使用，其使用性能是材料科学的重要组成部分。

本书的主要读者是与材料相关的工程和建筑专业大学生、工程师、建筑师和产品设计人员，对材料领域的工作者亦有指导性和启发性。鉴于本书所面向的读者群比较广，所介绍的内容亦比较宽泛。读者阅读本书时，应有所选择。对于材料科学领域的工作者，可参考清华大学朱静院士主编的《纳米材料和器件》和王鸣阳等人翻译的《纳米技术手册》，作为补充。

本书编写的显著特点是从实际出发，理论结合实际。书中对一些科学现象的描述生

动有趣，对基本原理的解释深入浅出。除适合从事或对纳米材料和技术有兴趣的非材料领域专业人员阅读外，亦可作为科普读物。

于荣海
清华大学材料科学与工程系

致　　谢

作者感谢学生 Joshua Sahoo 先生帮助收集、分析和建立纳米材料统计图；Alda Black、Elizabeth、Nathan Fash、Ben Schodek、Xue Zhou 和其他学生绘制了很多本书所采用的图表。

关于透射电镜照片方面，作者感谢橡树岭国家实验室高温材料研究部提供电镜等设备的使用便利。作为橡树岭国家实验室高温材料研究部设备使用项目的一部分，研究获得了美国能源部高效和可再生能源研究计划的支持（合同号：DE-AC05OO0R22725），项目的具体管理部门是自由运载车辆技术办公室。

（于荣海　译）

Preface

There is currently an extraordinary amount of interest in *nanomaterials* and *nanotechnologies*, terms now familiar not only to scientists, engineers, architects, and product designers but also to the general public. Nanomaterials and nanotechnologies have been developed as a consequence of truly significant recent advances in the material science community. Their use, in turn, is expected to have enormous consequences on the design and engineering of everything from common consumer products and buildings all the way through sophisticated systems that support a wealth of applications in the automotive, aerospace, and other industries. Hopes exist for being able to make things smaller, lighter, or work better than is possible with conventional materials. Serious problems facing society might also be positively addressed via the use of nanomaterials and nanotechnologies. In the energy domain, for example, nano-based fuel cells or photovoltaics can potentially offer greater efficiencies than are possible with conventional materials. Developments in nanomaterials and nanotechnologies have consequently aroused the interest of many individuals involved in engineering, architecture, and product design, whether in the automotive, building, or even the fashion industries.

In the excitement surrounding these new materials and technologies, however, their potential can, and has been, frequently overhyped. A mystique surrounds these words that can cloud understanding of what nanomaterials and nanotechnologies really are and what they can deliver. One of the purposes of this book is to demystify the subject and distinguish what is real from what is not. Though there is a need to better understand what benefits and costs might be associated with using nanomaterials, in the design fields little true understanding exists about what these new materials and technologies actually are and how they might be used effectively. In the science and engineering domain the situation is often the converse. The fundamental science-based knowledge is

there, but not necessarily an understanding of how these materials and technologies might be used to address real societal needs or, more simply, to provide a basis for useful applications—a situation often best described by the classic phrase "a technology looking for an application." Relatively few applications in architecture and product design exist at this point, so there are few role models or case studies to explore. Still, the core belief reflected in this book is that nanomaterials and nanotechnologies *do* offer new ways of addressing many current needs as well as providing the basis for a positive vision for future developments. The book explores these kinds of forward-looking potential applications.

The field is clearly in an emerging state, but its potential is evident. The question is one of how to move forward. The position reflected in this book is that this can only be accomplished by designers, engineers, and material scientists working together. Yet simply suggesting that these groups "collaborate" is usually ineffective. There needs to be a common basis for communication and idea exchange. The language of understanding spoken by one group can be foreign to the other. Within this context, a primary goal of this book is to provide both a common ground and a common language for better understanding how to use nanomaterials and nanotechnologies effectively. It seeks to convey the necessary technical understanding of the essential ideas underlying these new materials and technologies to designers so that they might better be able to understand how to exploit their characteristics effectively within a design context. At the same time it seeks to introduce material scientists and engineers knowledgeable about nanomaterials to design issues and design processes. What design problems need to be solved, and how do designers think about solving them? Only with this mutual understanding can they effectively become engaged in developing meaningful applications.

To meet these aspirations, the scope of the book is inherently large, seeking to explore what nanomaterials and nanotechnologies are and how they might be applied in diverse industries. However, though the scope is large, the approach followed in this book is based on the well-explored premise that most effective design applications occur when there is a true in-depth understanding of the materials or technologies involved and not when an overly simplified approach is taken wherein discussions of technological issues are reduced to an almost meaningless state.

The book has many unique features. It summarizes discussions of many different ideas and technologies normally found distributed

all across the literature. A case in point occurs in Chapter 8 of this book, which presents coverage of the many different synthesis processes used for making nanomaterials. There are many in-depth discussions throughout the literature of specific synthesis methods, such as soft lithography or sol-gel deposition methods, but these same discussions do not comprehensively cover other techniques. The approach here is to explore all primary methods of nanosynthesis and the mechanical, thermal, optical, and electrical properties they create—a comprehensive view that will be welcomed by teachers of engineering and material scientists. A broad knowledge of resulting properties is important, too, for any designer or engineer trying to use nanomaterials. It can be difficult to locate real values for properties of nanomaterials; a mechanical property may be reported in one source, a thermal property in another. In writing this book, considerable effort was put into sifting through the literature to identify credible values for primary properties.

Even once some of these properties are known, experience in the design world suggests that these values have to be placed in comparison to more traditional materials before they will be used, particularly given the higher costs of nano-based materials. A good way to explore materials and to select them to meet specific design objectives is to present their properties as "material property charts." These charts give a graphical overview of material attributes and allow comparisons to be made between them, as well as serving as a basis for more advanced material selection and related design techniques. Critical properties of various nanomaterials have now been incorporated into these kinds of charts, facilitating an understanding of where and how to effectively use nanomaterials within a design context.

In a broader sense, another unique feature of the book is the overall orientation to applications. Discussions are focused around thinking about products and buildings via the nature of the involved physical *environments, systems,* and *assemblies.* Environments may alternatively be considered either as an integral part of a design, such spaces as within a building, or as defining the context within which a product operates or is reflective of its salient mode of operation. Systems are generally defined as physical components or parts that work interactively to provide some particular type of *function.* In both products and buildings, broad considerations of *thermal, sound, lighting,* and *mechanical* environments and their related functional systems are invariably important and invariably influence the definition of needed material properties; consequently

they influence the role that nanomaterials and nanotechnologies might or might not effectively play. This kind of perspective reflects the way designers think about how and where to introduce new materials or technologies—a perspective that would be well worth scientists and engineers interested in applications of nanomaterials knowing something about.

The book is organized in a direct way and makes extensive use of illustrations. The first two chapters are self-contained nontechnical overviews of the general characteristics of nanomaterials and provide examples of ways in which nanomaterials can be found in both nature and in an historical context. Chapter 3 sets the broad design context and explores fundamental design processes. Chapter 4 then reviews basic technical properties of materials as a prelude for focusing on nanomaterials. This is followed in Chapter 5 by an introduction to material property charts, material indices, and their use for optimized material selection. Formal material screening and selection procedures are also presented, providing a methodology for comparing the benefits of using nanomaterials to other kinds of more traditional high-performance materials.

This introduction leads into an in-depth treatment of nanomaterials that begins in Chapter 6. A major contribution here is that of clarifying ways that various nanomaterial types can be formally classified. Size effects and other defining characteristics of nanomaterials are explored. Specific mechanical, thermal, and electrical properties of common nanomaterial types are detailed in Chapter 7. Processes for synthesizing and characterizing nanomaterials are next described and illustrated in Chapter 8. Several material property charts illustrating various properties of nanomaterials are included.

The book then turns to design or application-oriented considerations. A discussion of specific applications in common design environments—thermal, mechanical, electrical, and optical—follows in Chapter 9. These sections broadly explore a range of nanomaterial and nanotechnology applications as they relate to these different design environments. Chapter 10 looks at applications from specific product or industry perspectives—nanotextiles, nanopaints, nanosealants, nanotechnologies for self-cleaning, antimicrobial or self-healing, and others. Chapter 11 briefly examines nanomaterials in relation to health and the environment. Chapter 12 concludes with a whirlwind tour of the driving forces underlying nanomaterial and nanotechnology developments in several industries.

The target audience for this book includes students in engineering and architecture, professional engineers, architects, and product designers who are interested in exploring how these new materials and technologies might result in better products or buildings. Firms and industry groups who are planning to be intimately involved in the nanotechnology field will find the broad perspective interesting. Obviously, individuals in these fields have quite different backgrounds, interests, and understanding of materials and their properties as well as technologies. Having a single book address these multiple audiences is inherently difficult. Designers have primary goals of making products and buildings interesting, efficient, and useful, with materials being an important enabling design component. Their interests revolve more around final design qualities and applications than on achieving a quantitative understanding of materials and their properties. Many design-oriented engineers have similar interests but are more focused on the way material properties affect design, and they employ quantitative methods to achieve these ends. Material engineers and scientists are clearly interested in fundamental properties and how to create new materials for broad usage. Therefore, depending on the reader's background, the following two paragraphs suggest general guidelines on how to read this book.

In the field of engineering, second- or third-year undergraduate students and first-year graduate students will find the book useful as supplementary reading. These students should find familiar ground in the more technically oriented discussions of basic material properties in Chapter 4, as will engineers in firms. Chapter 5 on material selection processes based on material attribute charts will be of great interest to any who have never been exposed to this approach before and will provide a concise review for those who have already used them. Chapters 6, 7, and 8 provide a good introduction to classification systems, basic fundamentals, synthesis, characterization methods, and properties of nanomaterials—information that is currently scattered among many sources and difficult to find in one place. Obviously, whole in-depth courses could be built around many of the topics succinctly addressed in these chapters. The intent, however, is to provide a solid conceptual understanding of these topics, not to go into depth. Individuals interested in further depth should refer to the entries described in "Further Readings." The application-oriented sections in Chapters 9, 10, 11, and 12 provide overviews of ways that nanomaterials and nanotechnologies are either used or poised to be used in practice. Engineers and material scientists not actively engaged in design practices

will benefit from reviewing these chapters as a way of understanding what material characteristics are needed and considered useful by the design community. Some of the basic ways designers conceptualize the use of materials in products and buildings are also introduced in Chapter 3, which is useful reading for anyone who does not have a design background.

Architects and product designers range widely in their interests and need to understand material properties in depth. For typical architects in firms or students who have had basic courses in materials and who have a general curiosity about nanomaterials and how they might ultimately impact design, quantitative treatments are rarely needed. Chapters 1, 2, and 3 provide an insight into what nanomaterials are all about and are useful here. Chapter 5 on material selection processes is highly relevant to designers. Chapters 9, 10, 11, and 12 contain discussions on nanomaterials that are particularly appropriate for the design community. These chapters contain only qualitative technical descriptions and should be generally accessible to all interested readers. Many designers, however, are indeed quite technically inclined and have focused interests on materials and on technologically based innovations and are willing to put in the time necessary to understand them in some depth. This group would indeed find it useful to review the chapters on basic nanomaterial types and processing methods mentioned previously. Indeed, it is to this group that the design focus in this book is largely oriented, not to the casual reader.

We hope that you enjoy the book!

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Materials Science and Engineering Program
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Harvard University

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目　录

本书前 3 章介绍纳米材料性质。第 1 章概述了纳米材料的一般属性和应用领域。

第 2 章回顾了自然界中的材料和纳米材料，以及工匠工作中发现的纳米材料。

第 3 章讨论了材料在建筑、产品设计、一般产品、建筑类型和设计过程中的一般应用。所有这些都强调了纳米材料的新作用。

第4章从定性和定量两方面介绍了材料的基本性能。工程师和材料学家应该熟悉这些主题，技术导向的设计师也会感兴趣。

第 5 章依据材料性能统计图介绍了结构设计过程，统计图用于材料选择和解决设计目标冲突问题。设计导向的工程师和技术导向的设计师对这种方法感兴趣。

第 6，7，8 章介绍了纳米材料的分类和基本性质，如何合成和表征及其性能。具有一定材料技术背景的人员适合参考。这些章节对进入纳米材料领域的工程师和材料学家有兴趣。打算深入理解纳米材料的技术导向的建筑师和设计师也能从中找到有用的章节。