微纳技术著作丛书（影印版）

纳米科学与技术

Nanoscale Sci. & Tech.

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内 容 简 介

本书覆盖了从电磁微纳结构到分子自组织以及生物微纳技术的整个微纳技术领域，由该领域内的专家组撰写，包括了微纳米科学技术的各个方面，互相紧密联系，并可前后对照。

本书保持了多学科性，涉及到物理、化学、生物学、材料科学、电子工程等多个学科，有以下特点：循序渐进的介绍了微纳米科学，覆盖面广，具有教科书的风格；采用举例的方式介绍了微纳米科学各个领域的研究结果，所用的例子都是非常有代表性的研究结果；讨论了微纳米科学技术今后发展的特点和主要突破口。

本书为刚刚进入微纳米技术领域的读者提供了非常有价值的资料，适合于微纳米技术相关专业的研究生、博士生参考，并可作为该专业博士后的参考书，还可以供毕业课题与微纳米技术相关的毕业生做参考。

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序

科学出版社准备出版一套《微纳技术著作丛书》，包括原创作品和引进作品（影印或翻译）两种形式，并聘请专家组成编委会。这是一件大事，希望能坚持把它办好。

微纳米技术作为21世纪重要的一项技术，已成为国际科学界和工程技术界研究的热点。近年来，微米纳米技术进展迅速，已经发展成为一个包含机械、材料、电子、光学、化学、生物、基因工程、医学等基础学科的综合领域，而不仅仅属于任何单一的科学和技术门类。就其产品而言，也早已超越了人们广为熟悉的微型加速度传感器和纳米碳管等，呈现出向各个科学和技术领域全面渗透的趋势。

由于微纳米技术使得人们除了可以在同一基片上实现包括机械、流体、化学、生物、光学等器件外，也可以将信号处理和传输系统集成在同一基片上用以处理信息，决定计划，控制周围环境，从而大大提高最终产品的综合性能，实现高度智能化。在未来的航空航天、生物医学、环境监控、无线通信、汽车和交通、石油化工、能源、工农业、国家安全、食品和消费的各个领域都将有广泛应用，对国民经济、科学技术、社会发展与国家安全具有重要意义。今后的几十年里，随着微米纳米技术的迅速发展和向现代科学和技术的各个门类渗透，其对我们现代生活的各个方面带来的影响将是长期和深远的。从某种意义上来说，微米纳米技术的发展，可能改变人类的工作和生活方式，乃至基本概念，其潜在的影响有可能和以计算机技术为代表的微电子工业对世界的影响相提并论。

正是由于其诱人的应用前景和巨大的潜在市场，微米纳米技术目前已成为世界各国大力投资进行研究和发展的热点领域，其研究范围包括了材料、器件和系统，涉及的技术包含机理研究、设计分析、计算仿真、制造工艺、系统集成或组装、测控技术和应用研究等。随着微纳米技术的迅猛发展，近年来国外有大量这方面的专业书籍出版。

《微纳技术著作丛书》涵盖材料开发、系统设计、检测技术、集成技术、通信网络、传感系统、微加工技术等方面，它们都是本领域的研究热点。这套丛书的出版对促进我国微米纳米技术的发展将有很大的推动作用。

这套丛书中，原创作品收录的都是国内从事微纳技术的一线研究人员在本领域的研究成果与心得，具有很强的独立性、创造性和系统性。引进作品都是与国际知名的出版集团合作，经国内专家的甄别，挑选出能反映国外最新研究成果、对国内读者又有借鉴价值的作品，具有权威性、前瞻性和可读性。因为微纳米技

术是一个交叉学科领域，我们有意识的选择了一些由多人合写的专著。通常这类著作都是由相关领域的知名专家，各自在每一章节涵盖一个专题，既有进行综合性的论述，也有个人的具体独创性研究。这样的书籍，通常能帮助读者既获得某一领域的研究概况，又能从一个具体的应用专题中获得收益。

2007年初推出的第一批影印版图书，我和王万军教授进行了评读，此套丛书很实用，不少作者在该领域有很高的声望。我们建议致力于微米纳米技术的研究人员，包括研究生、技术人员，能够花些时间阅读。

总之，我们对科学出版社组织出版这套丛书的举措很赞赏，也希望他们能将这一工作认真、长期地做下去。同时，我们也希望国内的专家能够积极、踊跃地加盟，为我国微米纳米技术的推进做出贡献。

周兆英 王万军

2006年12月7日

Contents

1

Generic methodologies for nanotechnology: classification and fabrication

1.1 INTRODUCTION AND CLASSIFICATION

1.1.1 What is nanotechnology?

Nanotechnology is the term used to cover the design, construction and utilization of functional structures with at least one characteristic dimension measured in nanometres. Such materials and systems can be designed to exhibit novel and significantly improved physical, chemical and biological properties, phenomena and processes as a result of the limited size of their constituent particles or molecules. The reason for such interesting and very useful behaviour is that when characteristic structural features are intermediate in extent between isolated atoms and bulk macroscopic materials; i.e., in the range of about 10^{-9} m to 10^{-7} m (1 to 100 nm), the objects may display physical attributes substantially different from those displayed by either atoms or bulk materials. Ultimately this can lead to new technological opportunities as well as new challenges.

1.1.2 Classification of nanostructures

As we have indicated above, a reduction in the spatial dimension, or confinement of particles or quasiparticles in a particular crystallographic direction within a structure generally leads to changes in physical properties of the system in that direction. Hence one classification of nanostructured materials and systems essentially depends on the number of dimensions which lie within the nanometre range, as shown in Figure 1.1: (a) systems confined in three dimensions, (b) systems confined in two dimensions, (c) systems confined in one dimension.

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(a)

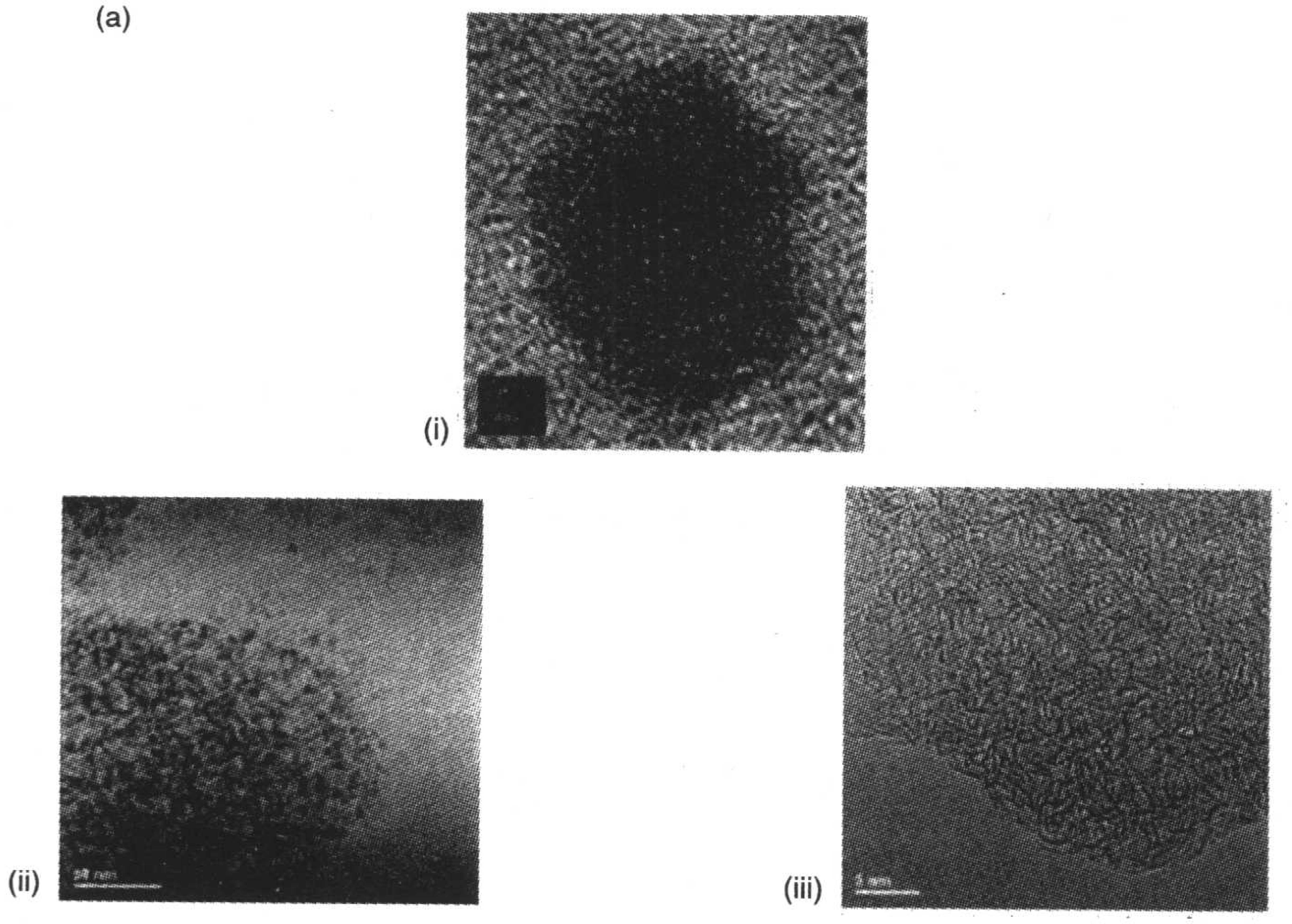

Figure 1.1 Classification of nanostructures. (a) Nanoparticles and nanopores (nanosized in three dimensions): (i) high-resolution TEM image of magnetic iron oxide nanoparticle, (ii) TEM image of ferritin nanoparticles in a liver biopsy specimen, and (iii) high-resolution TEM image of nanoporosity in an activated carbon). (b) Nanotubes and nanofilaments (nanosized in two dimensions): (i) TEM image of single-walled carbon nanotubes prepared by chemical vapour deposition, (ii) TEM image of ordered block copolymer film, and (iii) SEM image of silica nanotube formed via templating on a tartaric acid crystal. (c) Nanolayers and nanofilms (nanosized in one dimension): (i) TEM image of a ferroelectric thin film on an electrode, (ii) TEM image of cementite (carbide) layers in a carbon steel, and (iii) high-resolution TEM image of glassy grain boundary film in an alumina polycrystal. Images courtesy of Andy Brown, Zabeada Aslam, Sarah Pan, Manoch Naksata and John Harrington, IMR, Leeds

Nanoparticles and nanopores exhibit three-dimensional confinement (note that historically pores below about 100 nm in dimension are often sometimes confusingly referred to as micropores). In semiconductor terminology such systems are often called quasi-zero dimensional, as the structure does not permit free particle motion in any dimension.

Nanoparticles may have a random arrangement of the constituent atoms or molecules (e.g., an amorphous or glassy material) or the individual atomic or molecular units may be ordered into a regular, periodic crystalline structure which may not necessarily be the same as that which is observed in a much larger system (Section 1.3.1). If crystalline, each nanoparticle may be either a single crystal or itself composed of a number of different crystalline regions or grains of differing crystallographic orientations (i.e., polycrystalline) giving rise to the presence of associated grain boundaries within the nanoparticle.

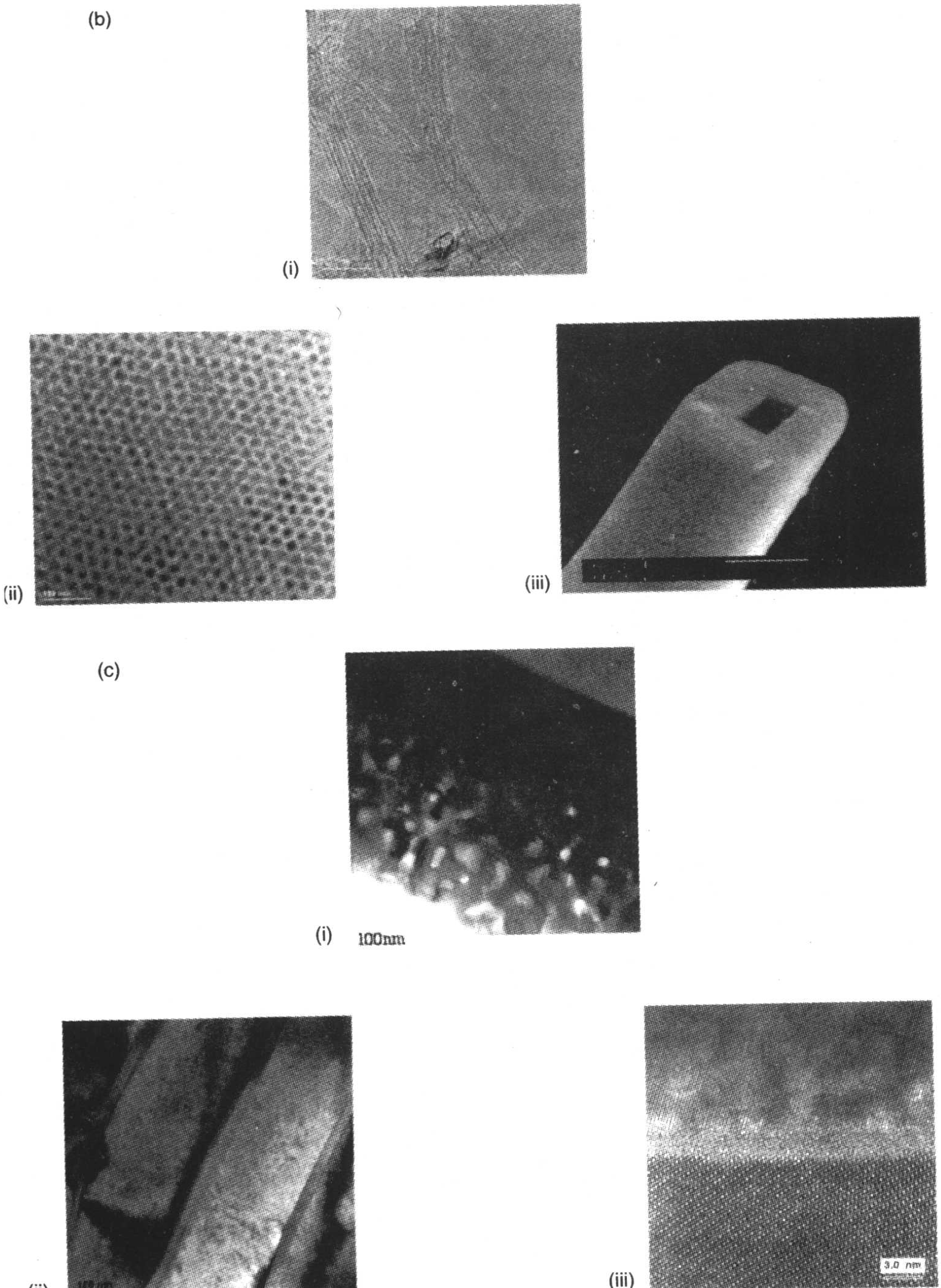

Figure 1.1 Continued

Nanoparticles may also be quasi-crystalline, the atoms being packed together in an icosahedral arrangement and showing non-crystalline symmetry characteristics. Such quasi-crystals are generally only stable at the nanometre or, at most, the micrometre scale.

Nanoparticles may be present within another medium, such as nanometre-sized precipitates in a surrounding matrix material. These nanoprecipitates will have a specific morphology (e.g., spherical, needle-shaped or plate-shaped) and may possess certain crystallographic orientation relationships with the atomic arrangement of the matrix depending on the nature (coherency) of the interface which may lead to coherency strains in the particle and the matrix. One such example is the case of self-assembled semiconductor quantum dots, which form due to lattice mismatch strain relative to the surrounding layers and whose geometry is determined by the details of the strain field (Chapter 3). Another feature which may be of importance for the overall transport properties of the composite system is the connectivity of such nanometre-sized regions or, in the case of a nanoporous material, nanopore connectivity.

In three dimensions we also have to consider collections of consolidated nanoparticles; e.g., a nanocrystalline solid consisting of nanometre-sized crystalline grains each in a specific crystallographic orientation. As the grain size d of the solid decreases the proportion of atoms located at or near grain boundaries, relative to those within the interior of a crystalline grain, scales as $1/d$. This has important implications for properties in ultrafine-grained materials which will be principally controlled by interfacial properties rather than those of the bulk.

Systems confined in two dimensions, or quasi-1D systems, include nanowires, nanorods, nanofilaments and nanotubes: again these could either be amorphous, single-crystalline or polycrystalline (with nanometre-sized grains). The term 'nanoropes' is often employed to describe bundles of nanowires or nanotubes.

Systems confined in one dimension, or quasi-2D systems, include discs or platelets, ultrathin films on a surface and multilayered materials; the films themselves could be amorphous, single-crystalline or nanocrystalline.

Table 1.1 gives examples of nanostructured systems which fall into each of the three categories described above. It can be argued that self-assembled monolayers and multi layered Langmuir–Blodgett films (Section 1.4.3.1) represent a special case in that they represent a quasi-2D system with a further nanodimensional scale within the surface film caused by the molecular self-organization.

1.1.3 Nanoscale architecture

Nanotechnology is the design, fabrication and use of nanostructured systems, and the growing, shaping or assembling of such systems either mechanically, chemically or biologically to form nanoscale architectures, systems and devices. The original vision of Richard Feynman[1] was of the 'bottom-up' approach of fabricating materials and devices at the atomic or molecular scale, possibly using methods of self-organization and self-assembly of the individual building blocks. An alternative 'top-down' approach is the

1 R. Feynman, There's plenty of room at the bottom, *Eng. Sci.* **23**, 22 (1960) reprinted in *J. Micromech Systems* **1**, 60 (1992).