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《纳米科学与技术》丛书序

在新兴前沿领域的快速发展过程中，及时整理、归纳、出版前沿科学的系统性专著，一直是发达国家在国家层面上推动科学与技术发展的重要手段，是一个国家保持科学技术的领先权和引领作用的重要策略之一。

科学技术的发展和应用，离不开知识的传播：我们从事科学研究，得到了"数据"(论文)，这只是"信息"。将相关的大量信息进行整理、分析，使之形成体系并付诸实践，才变成"知识"。信息和知识如果不能交流，就没有用处，所以需要"传播"(出版)，这样才能被更多的人"应用"，被更有效地应用，被更准确地应用，知识才能产生更大的社会效益，国家才能在越来越高的水平上发展。所以，数据→信息→知识→传播→应用→效益→发展，这是科学技术推动社会发展的基本流程。其中，知识的传播，无疑具有桥梁的作用。

整个20世纪，我国在及时地编辑、归纳、出版各个领域的科学技术前沿的系列专著方面，已经大大地落后于科技发达国家，其中的原因有许多，我认为更主要的是缘于科学文化的习惯不同：中国科学家不习惯去花时间整理和梳理自己所从事的研究领域的知识，将其变成具有系统性的知识结构。所以，很多学科领域的第一本原创性"教科书"，大都来自欧美国家。当然，真正优秀的著作不仅需要花费时间和精力，更重要的是要有自己的学术思想以及对这个学科领域充分把握和高度概括的学术能力。

纳米科技已经成为21世纪前沿科学技术的代表领域之一，其对经济和社会发展所产生的潜在影响，已经成为全球关注的焦点。国际纯粹与应用化学联合会(IUPAC)会刊在2006年12月评论："现在的发达国家如果不发展纳米科技，今后必将沦为第三世界发展中国家。"因此，世界各国，尤其是科技强国，都将发展纳米科技作为国家战略。

兴起于20世纪后期的纳米科技，给我国提供了与科技发达国家同步发展的良好机遇。目前，各国政府都在加大力度出版纳米科技领域的教材、专著以及科普读物。在我国，纳米科技领域尚没有一套能够系统、科学地展现纳米科学技术各个方面前沿进展的系统性专著。因此，国家纳米科学中心与科学出版社共同发起并组织出版《纳米科学与技术》，力求体现本领域出版读物的科学性、准确性和系统性，全面科学地阐述纳米科学技术前沿、基础和应用。本套丛书的出版以高质量、科学性、准确性、系统性、实用性为目标，将涵盖纳米科学技术的所有领域，全面介绍国内外纳米科学技术发展的前沿知识；并长期组织专家撰写、编辑出版下去，为我国

纳米科技各个相关基础学科和技术领域的科技工作者和研究生、本科生等，提供一套重要的参考资料。

这是我们努力实践“科学发展观”思想的一次创新，也是一件利国利民、对国家科学技术发展具有重要意义的大事。感谢科学出版社给我们提供的这个平台，这不仅有助于我国在科研一线工作的高水平科学家逐渐增强归纳、整理和传播知识的主动性（这也是科学研究回馈和服务社会的重要内涵之一），而且有助于培养我国各个领域的人士对前沿科学技术发展的敏感性和兴趣爱好，从而为提高全民科学素养作出贡献。

我谨代表《纳米科学与技术》编委会，感谢为此付出辛勤劳动的作者、编委会委员和出版社的同仁们。

同时希望您，尊贵的读者，如获此书，开卷有益！

中国科学院院长

国家纳米科技指导协调委员会首席科学家

2011 年 3 月于北京

Preface

Nanotechnology is one of the continuously emerging scientific areas combining knowledge from the fields of Physics, Chemistry, Biology, Medicine, Informatics and Engineering. Nanostructured materials and nanosystems are fabricated and fully characterised by nanotechnological tools and techniques, at sizes below 100 nm. Although there are restrictions related to nanoscale size, it is the handling and processing of matter at this scale that leads to the development of new and novel materials which may have the same bulk composition but widely varying properties. The diverse applications of nanomaterials ranging from electronic and engineering systems and devices, to optical and magnetic components, nanodevices in medicine, cosmetic merchandise, agricultural and food products are believed to pave the way and have a significant economical and societal impact.

This book gives an overview of nanostructures and nanomaterials applied in the fields of energy and organic electronics (*Chap. 1*). It combines the knowledge of advanced deposition and processing methods of nanomaterials, and state-of-the-art characterization techniques with special emphasis on the optical, electrical, morphological, surface and mechanical properties (mainly in *Chaps. 5 and 6*). Furthermore, it contains theoretical and experimental aspects for different types of nanomaterials, such as nanoparticles, nanotubes and thin films for organic electronics applications. Specifically it includes topics on carbon nanomaterials and nanotubes focusing on their different synthesis routes *(as shown in Chaps. 2 and 3)*, and full characterisation of their properties at a theoretical and experimental level for optoelectronics applications *(as shown in Chaps. 7–9)*. The different deposition techniques used to fabricate nanostructured thin films and the processing methods such as self-assembly and nanopatterning of surfaces are extensively described in *Chaps. 4 and 10.*

Thessaloniki *Stergios Logothetidis*
July 2011

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Contents

Chapter 1
Nanotechnology: Principles and Applications

S. Logothetidis

Abstract Nanotechnology is one of the leading scientific fields today since it combines knowledge from the fields of Physics, Chemistry, Biology, Medicine, Informatics, and Engineering. It is an emerging technological field with great potential to lead in great breakthroughs that can be applied in real life. Novel nano- and biomaterials, and nanodevices are fabricated and controlled by nanotechnology tools and techniques, which investigate and tune the properties, responses, and functions of living and non-living matter, at sizes below 100 nm. The application and use of nanomaterials in electronic and mechanical devices, in optical and magnetic components, quantum computing, tissue engineering, and other biotechnologies, with smallest features, widths well below 100 nm, are the economically most important parts of the nanotechnology nowadays and presumably in the near future. The number of nanoproducts is rapidly growing since more and more nanoengineered materials are reaching the global market The continuous revolution in nanotechnology will result in the fabrication of nanomaterials with properties and functionalities which are going to have positive changes in the lives of our citizens, be it in health, environment, electronics or any other field. In the energy generation challenge where the conventional fuel resources cannot remain the dominant energy source, taking into account the increasing consumption demand and the CO_2 emissions alternative renewable energy sources based on new technologies have to be promoted. Innovative solar cell technologies that utilize nanostructured materials and composite systems such as organic photovoltaics offer great technological potential due to their attractive properties such as the potential of large-scale and low-cost roll-to-roll manufacturing processes The advances in nanomaterials necessitate parallel progress of the nanometrology tools and techniques to characterize and manipulate nanostructures. Revolutionary new approaches in nanometrology

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will be required in the near future and the existing ones will have to be improved in terms of better resolution and sensitivity for elements and molecular species. Finally, the development of specific guidance for the safety evaluation of nanotechnology products is strongly recommended.

1.1 Introduction

The term nanotechnology comes from the combination of two words: the Greek numerical prefix nano referring to a billionth and the word technology. As an outcome, Nanotechnology or Nanoscaled Technology is generally considered to be at a size below 0.1 μm or 100 nm (a nanometer is one billionth of a meter, 10^{-9} m). Nanoscale science (or nanoscience) studies the phenomena, properties, and responses of materials at atomic, molecular, and macromolecular scales, and in general at sizes between 1 and 100 nm. In this scale, and especially below 5 nm, the properties of matter differ significantly (i.e., quantum-scale effects play an important role) from that at a larger particulate scale. Nanotechnology is then the design, the manipulation, the building, the production and application, by controlling the shape and size, the properties-responses and functionality of structures, and devices and systems of the order or less than 100 nm [1, 2].

Nanotechnology is considered an emerging technology due to the possibility to advance well-established products and to create new products with totally new characteristics and functions with enormous potential in a wide range of applications. In addition to various industrial uses, great innovations are foreseen in information and communication technology, in biology and biotechnology, in medicine and medical technology, in metrology, etc. Significant applications of nanosciences and nanoengineering lie in the fields of pharmaceutics, cosmetics, processed food, chemical engineering, high-performance materials, electronics, precision mechanics, optics, energy production, and environmental sciences.

Nanotechnology is an emerging and dynamic field where over 50,000 nanotechnology articles have been published annually worldwide in recent years, and more than 2,500 patents are filed at major patent offices such as the European Patent Office [3].

Nanotechnology can help in solving serious humanity problems such as energy adequacy, climate change or fatal diseases: "Nanotechnology" Alcatel-Lucent is an area which has highly promising prospects for turning fundamental research into successful innovations. Not only to boost the competitiveness of our industry but also to create new products that will make positive changes in the lives of our citizens, be it in medicine, environment, electronics or any other field. Nanosciences and nanotechnologies open up new avenues of research and lead to new, useful, and sometimes unexpected applications. Novel materials and new-engineered surfaces allow making products that perform better. New medical treatments are emerging for fatal diseases, such as brain tumours and Alzheimer's disease. Computers are built with nanoscale components and improving their performance depends upon shrinking these dimensions yet further" [4].

Nanomaterials with unique properties such as: nanoparticles carbon nanotubes, fullerenes, quantum dots, quantum wires, nanofibers, and nanocomposites allow completely new applications to be found. Products containing engineered nanomaterials are already in the market. The range of commercial products available today is very broad, including metals, ceramics, polymers, smart textiles, cosmetics, sunscreens, electronics, paints and varnishes. However new methodologies and instrumentation have to be developed in order to increase our knowledge and information on their properties. Nanomaterials must be examined for potential effects on health as a matter of precaution, and their possible environmental impacts. The development of specific guidance documents at a global level for the safety evaluation of nanotechnology products is strongly recommended. Ethical and moral concerns also need to be addressed in parallel with the new developments.

Huge aspirations are coupled to nanotechnological developments in modern medicine. The potential medical applications are predominantly in diagnostics (disease diagnosis and imaging), monitoring, the availability of more durable and better prosthetics, and new drug-delivery systems for potentially harmful drugs. While products based on nanotechnology are actually reaching the market, sufficient knowledge on the associated toxicological risks is still lacking. Reducing the size of structures to nanolevel results in distinctly different properties. As well as the chemical composition, which largely dictates the intrinsic toxic properties, very small size appears to be a dominant indicator for drastic or toxic effects of particles. From a regulatory point of view, a risk management strategy is already a requirement for all medical technology applications [5–7].

In order to discuss the advances of nanotechnology in nanostructured materials, we presented first in Sect. 1.2 the methods and principles of nanoscale and nanotechnology, and the relevant processes. The impact of nanotechnology in the field of electronics is presented in Sect. 1.3. Energy harvesting and clean solar energy are presented in Sect. 1.4 focusing in a new emerging technology of plastic photovoltaics which is based on nanostructured materials. The techniques and the tools which are currently used to characterize and manipulate nanostructures are presented in Sect. 1.5. In Sect. 1.6, the future perspectives as well as the increasing instrumentational demands are discussed.

1.2 Methods and Principles of Nanotechnology

1.2.1 What Makes Nanostructures Unique

The use of nanostructured materials is not a recently discovered era. It dates back at the fourth century AD when Romans were using nanosized metals to decorate glasses and cups. One of the first known, and most famous example, is the Lycurgus

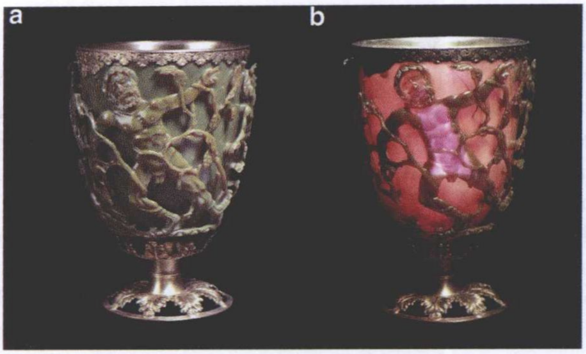

Fig. 1.1 The Lycurgus cup in reflected (**a**) and transmitted (**b**) light. Scene showing Lycurgus being enmeshed by Ambrosia, now transformed into a vine-shoot. Department of Prehistory and Europe, The British Museum. Height: 16.5 cm (with modern metal mounts), diameter: 13.2 cm. The Trustees of the British Museum [8]

cup (Fig. 1.1) [9], that was fabricated from nanoparticles (NPs) from gold and silver that were embedded in the glass. The cup depicts King Lycurgus of Thrace being dragged to the underworld. Under normal lighting, the cup appears green. However, when illuminated from within, it becomes vibrant red in color. In that cup, as well as in the famous stain glass windows from the tenth, eleventh, and twelfth centuries, metal NPs account for the visual appearance.

To shed light to the changes in visual appearance of gold, from the usual yellowish color to the reddish one that appears in the Lycurgus cup a comparison between differences of absorption spectra from a bulk gold metal film and a gold colloidal film (Fig. 1.2). The thin, bulk gold metal film absorbs across most of the visible part of the electromagnetic spectrum and very strongly in the IR and at all longer wavelengths. It dips slightly around 400–500 nm, and when held up to the light, such a thin film appears blue due to the weak transmission of light in this wavelength regime. On the contrary, the dilute gold colloid film displays total transparency at low photon energies (below 1.8 eV). Its absorption becomes intense in a sharp band around 2.3 eV (520 nm) This sharp absorption band is known as surface plasmon absorption band. Metals support SPs that are collective oscillations of excited free electrons and characterized by a resonant frequency. They can be either localized as for metal NPs or propagating as in the case of planar metal surfaces. Through manipulation of the geometry of the metallic structure, the SPR can be tuned depending on the application. The resonances of noble metals are mostly in the visible or near infrared region of the electromagnetic spectrum, which is of interest for decorative applications. Because of the plasmonic excitation of electrons in the metallic particles suspended within the glass matrix, the cup absorbs and scatters blue and green light – the relatively short wavelengths of the visible spectrum. When viewed in reflected light, the plasmonic scattering gives the cup a greenish hue, but if a white light source is placed within the goblet, the glass