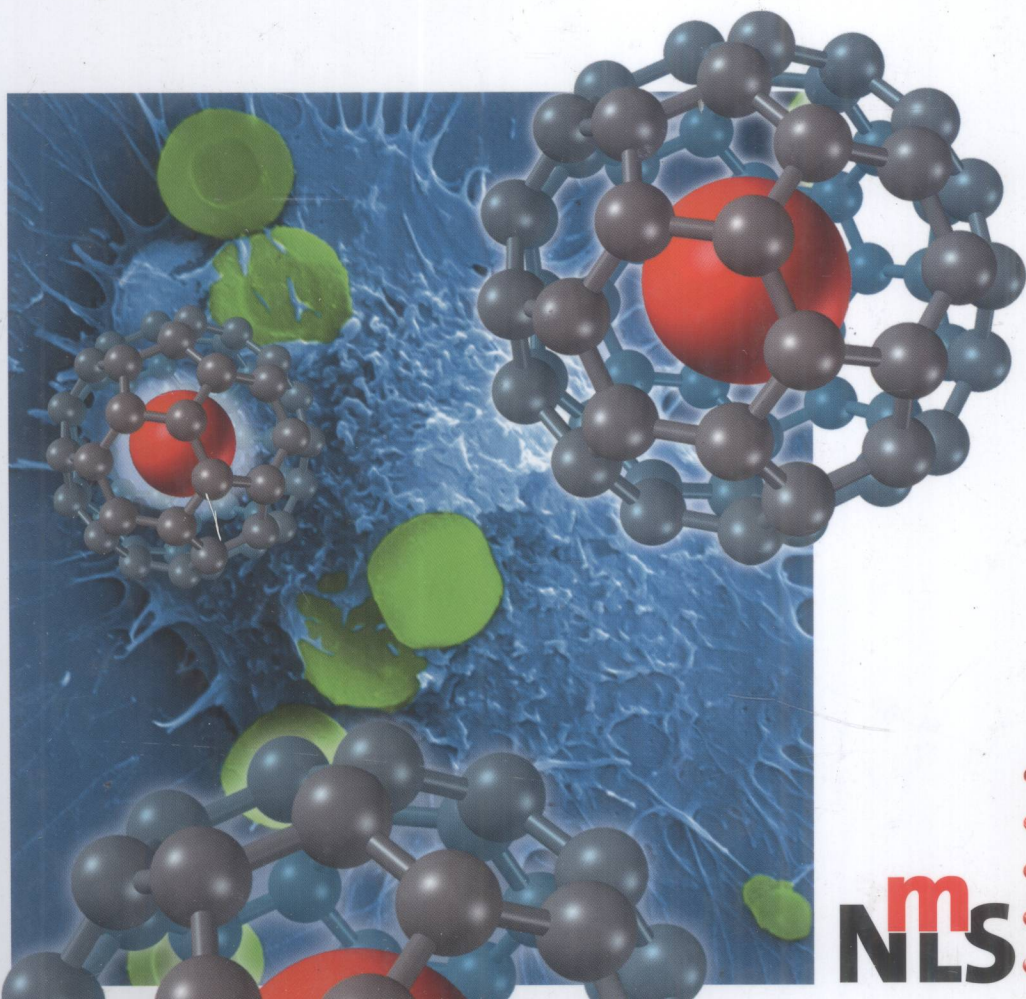


Edited by Challa Kumar

 WILEY-VCH

# Metallic Nanomaterials



**m**  
**NLS** 

TB385  
M587.3

*Nanomaterials for the Life Sciences*  
Volume 1

## **Metallic Nanomaterials**

*Edited by*  
*Challa S. S. R. Kumar*



E2009002816

WILEY-VCH Verlag GmbH & Co. KGaA

#### **The Editor**

***Dr. Challa S. S. R. Kumar***

The Center for Advanced Microstructures and  
Devices (CAMD)  
Louisiana State University  
6980 Jefferson Highway  
Baton Rouge, LA 70806  
USA

■ All books published by Wiley-VCH are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

**Library of Congress Card No.:** applied for

#### **British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

#### **Bibliographic information published by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <<http://dnb.d-nb.de>>.

© 2009 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

**Typesetting** SNP Best-set Typesetter Ltd., Hong Kong

**Printing** Strauss GmbH, Mörlenbach

**Binding** Litges & Dopf GmbH, Heppenheim

**Cover Design** Grafik-Design Schulz, Fußgönheim

Printed in the Federal Republic of Germany  
Printed on acid-free paper

**ISBN:** 978-3-527-32151-3

*Nanomaterials for the  
Life Sciences*  
Volume 1  
**Metallic Nanomaterials**

*Edited by Challa S. S. R. Kumar*

## ***Further Reading***

Kumar, C. S. S. R. (Ed.)

### **Nanotechnologies for the Life Sciences (NtLS)**

**10 Volume Set**

2007

ISBN: 978-3-527-31301-3

Kumar, C. S. S. R. (Ed.)

### **Nanomaterials for the Life Sciences (NmLS)**

**Book Series, 10 Volumes**

*Vol. 1*

#### **Metallic Nanomaterials**

2009

ISBN: 978-3-527-32151-3

*Vol. 2*

#### **Nonmagnetic Inorganic Nanomaterials**

2009

ISBN: 978-3-527-32152-0

*Vol. 3*

#### **Bimetallic and Metal Oxide Nanomaterials**

2010

ISBN: 978-3-527-32153-7

*Vol. 4*

#### **Polymeric Nanomaterials**

2010

ISBN: 978-3-527-32154-4

*Vol. 5*

#### **Semiconductor Nanomaterials**

2010

ISBN: 978-3-527-32155-1

## Preface

The global demand for nanomaterials is currently estimated to be around US\$ 3.7 billion, driven mainly by nanoscale metals and oxides. Moreover, this demand is likely to grow further as they find more and more newer applications. With the increasing realization that nanoscale systems are very similar to biological systems—not only in terms of size but also in terms of multifunctionality—there is a constant communication between research groups and those industries fabricating nanomaterials and those specializing in biology, biotechnology, medicine, environmental sciences, agricultural and food science and in general life sciences. This communication is leading to a rapid convergence between nanomaterials and the life sciences, paving the way for the establishment of one of the most promising and exciting scientific fields of today—Nanotechnologies/Nanomaterials for the Life Sciences. With a vision to promote ‘nano thinking’ and to act as a catalyst in ensuring the rapid dissemination of knowledge in this field, I previously had an opportunity to present to the scientific community a 10-volume series on *Nanotechnologies for the Life Sciences* (NtLS). With over 4600 pages in 124 chapters, these 10 volumes represented the first major effort to cover the whole breadth and width of this highly dynamic and exciting field. However, as the NtLS series focused more on the influence of nanotechnologies on the life sciences, there remained an unfulfilled gap in the knowledge base that required a greater focus on materials properties and the implications for their application in the life sciences. So, thanks to yet another wonderful team of nanoresearchers, we are now in the process of filling this gap. On behalf of this new team, I am now pleased to introduce to the scientific community a comprehensive 10-volume series entitled *Nanomaterials for the Life Sciences* (NmLS). Whilst the NmLS series can be seen as continuation of the NtLS series, adding new information from the research findings of the past few years, it takes us a step higher in appreciating the interplay of nanomaterials and applications in life sciences. The NmLS series also takes us to newer heights in ensuring that the field of life sciences is changed for ever. The NmLS series will include 10 volumes covering a broad range of nanomaterials—metals, metal oxides and magnetic materials—all of which will impact on the life sciences.

Before discussing in detail the contents of the first volume, I would like to share with you some nuggets regarding the rest of the nine volumes. The second and third volumes in this series are already in print. The second volume,

*Nanostructured Oxides for Life Sciences*, and the third volume, *Mixed Metal Nanomaterials for Life Sciences*, are the first of their kind ever to be published. The remainder of the volumes will cover the application of other types of nanomaterial, such as thin films, polymeric materials and quantum dots. Each of these volumes will contain more than 500 printed pages, and provide an in-depth source of information related to a particular type of nanomaterial. I am honored by the enthusiasm of the contributing authors and am very grateful to them for being part of this exciting project by contributing high-quality manuscripts, on time, while keeping in tune with the design and theme of each volume and the vision for the whole book series. Indeed, the only reason you have this book in your hand is due to their dedication, perseverance and commitment. The Center for Advanced Microstructures and Devices (CAMD), Baton Rouge, USA, continues to demonstrate its strong commitment to research in high-technology areas, and this is an example of its support. I am humbled to be working for such a great organization. However, a venture of this magnitude can only become a reality when timely support is provided from all sides, and I therefore appreciate the understanding of my family and the support from Wiley-VCH publishers. It has been a fantastic experience working with the team from Wiley—Dr. Martin Ottmar, Dr. Rainer Münz and Dr. Martin Preuss. Thank you Wiley-VCH!

I am now pleased to present to you the first volume, *Metallic Nanomaterials for the Life Sciences*. This covers different metallic nanomaterials, and more specifically gold, silver, copper, palladium and platinum nanomaterials, and their applications in the life sciences. The book is divided into three distinct parts. In Part One, the focus is on copper, silver and gold nanomaterials, both spherical as well as anisotropic. Part Two discusses palladium and platinum nanomaterials, while Part Three provides an overview of all different types of metallic nanomaterials and their applications in the life sciences.

Part One begins with a chapter entitled *Approaches to Synthesis and Characterization of Spherical and Anisotropic Copper Nanomaterials*, by Professor Nicola Cioffi and her team from the Università di Bari, Bari, Italy. In this chapter, the authors provide a 'bird's-eye view' of the main approaches for the synthesis and characterization of nanosized copper and structures, together with characterization data regarding their morphology, structure and surface chemical composition. While copper nanomaterials are just on the verge of being utilized in the field of life sciences, the second chapter by Chi-Chung Chou and his team from National Chung-Hsing University, Taichung, Taiwan, provides an overview of developments in the application of copper nanomaterials in medical diagnosis. This chapter, *Spherical and Anisotropic Copper Nanomaterials in Medical Diagnosis*, covers the application of copper nanomaterials as contrast agents for MRI or PET scanning and as biosensors for detecting early changes in biological metabolites/elements that carry significant implications in disease identification. Chapters 3 to 5 focus on silver nanomaterials, their synthesis and characterization and application in medical diagnosis, therapy and environment. Chapter 3, *Approaches to Synthesis and Characterization of Spherical and Anisotropic Silver Nanomaterials*, is contributed by Professor John Kelly and his team from Trinity College Dublin, Dublin, Ireland, while

Professor Kenneth Wong and his team from the University of Hong Kong, Hong Kong (Chapter 4) and Professor Ralph A. Tripp and colleagues from the University of Georgia, Athens, USA (Chapter 5) have done a remarkable job in capturing the up-to-date information in their chapters entitled *Spherical and Anisotropic Silver Nanomaterials in Medical Therapy* and *Spherical and Anisotropic Silver Nanomaterials in Medical Diagnosis*, respectively. Silver nanomaterials are well studied, and their extraordinary physical and chemical properties make them useful in medical therapy and diagnosis. In addition to these applications, Professor Il Je Yu from the Korea Environment & Merchandise Testing Institute, Incheon, Korea, and Bruce Kelman from Veritox, Redmond, USA, in Chapter 6—*Health and Environmental Impact of Silver Nanomaterials*—stress the importance of the impact of silver nanomaterials on human health and the environment. A combination of these three chapters on silver nanomaterials makes this volume a comprehensive source of information on these nanomaterials and their applications to the life sciences. The final two chapters of Part One are contributed by Professor Tai Hwan Ha and his team from the Korea Research Institute of Bioscience and Biotechnology, Daejeon, Republic of Korea, and by Professor Takuro Niidome and colleagues from Kyushu University, Fukuoka, Japan. In Chapter 7, *Approaches to Synthesis and Characterization of Spherical and Anisotropic Gold Nanomaterials*, Professor Ha rationalizes the current approaches for the syntheses of gold nanomaterials and the control of their size and shape. In Chapter 8, *Spherical and Anisotropic Gold Nanomaterials in Medical Therapy*, Professor Niidome reviews the current research trends in the use of gold nanomaterials, especially of gold nanospheres and gold nanorods, in diagnosis and therapy.

Part Two of the volume is dedicated to palladium and platinum nanomaterials, in Chapters 9 and 10, respectively. Chapter 9 is a contribution from the laboratories of Professor Sherine Obare, at The University of North Carolina at Charlotte, Charlotte, USA. In her chapter, *Approaches to Synthesis and Characterization of Spherical & Anisotropic Palladium Nanomaterials*, Professor Obare describes the synthetic procedures to create spherical and anisotropic palladium nanostructures with controlled size and shape. Current applications of palladium nanoparticles in the life sciences are primarily in the area of environmental remediation and biosensing. Hence, Chapter 10 provides up-to-date information on *Approaches to the Synthesis and Characterization of Spherical and Anisotropic Platinum Nanomaterials*, with Professor Hong Yang and his team having done a commendable job in examining the basic principles for the shape control of platinum nanostructures. As examples of applications of platinum nanomaterials in life science are limited, the authors hope that the easy-to-read information provided on their synthesis will motivate life science researchers to begin exploring the use of these materials in life science applications.

The final part of this volume provides the reader with an overview of metallic nanomaterials, their characteristics and life science applications. Part Three begins with Chapter 11, on *Approaches to the Synthesis and Characterization of Spherical and Anisotropic Noble Metal Nanomaterials*, where Professor Ru-Shi Liu and his team discuss a number of useful parameters that can be tuned to control the



formation of anisotropic noble metal nanomaterials in a solution-phase synthesis. The general modalities presented are also applicable to other types of metallic nanomaterial. In addition to wet chemical methods, there is a growing appreciation of biologically based synthetic methods. Thus, Chapter 12—aptly entitled *Biological and Biomaterials-Assisted Synthesis of Precious Metal Nanoparticles*—focuses on the biological formation of metallic nanoparticles. In this chapter, which is a contribution from the University of Texas at El Paso, USA, the authors—led by Professor Jorge L. Gardea-Torresdey—also highlight the differences between wet-chemical synthesis and biological synthesis of metallic nanomaterials. The authors of Chapter 13, led by Professor Adela Ben-Yakar, provide the reader with a comprehensive review of the current state of therapeutic nanobiophotonics using metallic nanomaterials. Their chapter, entitled *Spherical and Anisotropic Metal Nanomaterials in Laser-Based Cancer Therapy*, provides several examples of the clinical application of metallic nanoparticles, especially gold nanoparticles, and demonstrates the clear potential of plasmonic phototherapy to become a ‘gold standard’ among cancer treatments. The final chapter of Part Three highlights the unique applications of metallic nanomaterials in textiles. In addition, Professor Vigneswaran and the team from the Central Institute for Research on Cotton Technology, Mumbai, India, describe the functionalization of textiles with metal nanoparticles, the methods of application onto textile materials, and their evaluation. This chapter, *Application of Metallic Nanoparticles in Textiles*, describes the impact of nanotechnology on commercial textile industrials, together with their environmental concerns.

Finally as I conclude this preface, I recollect the preface that I wrote for the first volume in the NtLS series, in which I talked about the growing number of ‘nano thinkers’. The NmLS series is a testimony to the fact that the followers of ‘nano thinking’—the so-called ‘nano thinkers’—are growing in number day by day, and their presence is now very strong in the field of the life sciences. I am very confident that the firm knowledge foundation provided with the availability of the NtLS and NmLS series will pave the way for many exciting discoveries in the field of life sciences.

Challa S.S.R. Kumar  
25th September 2008

## List of Contributors

### ***Damian Aherne***

School of Chemistry  
Trinity College Dublin  
Dublin 2  
Ireland

### ***Nitin C. Bagkar***

National Taiwan University  
Department of Chemistry  
Taipei 106  
Taiwan

### ***Rudrapatna H. Balasubramanya***

Chemical and Biochemical  
Processing Division  
Central Institute for Research on  
Cotton Technology  
Adenwala Road  
Matunga  
Mumbai-400 019  
India

### ***Adela Ben-Yakar***

University of Texas at Austin  
Department of Mechanical Engineering  
Austin, TX 78722  
USA

### ***University of Texas at Austin***

Department of Biomedical Engineering  
Austin, TX 78722  
USA

### ***Jen-Lin Chang***

National Chung-Hsing University  
Department of Chemistry  
250 Kuo-Kuang Road  
Taichung 402  
Taiwan

### ***Hao Ming Chen***

National Taiwan University  
Department of Chemistry  
Taipei 106  
Taiwan

### ***Chi-Chung Chou***

National Chung-Hsing University  
Department of Veterinary Medicine  
College of Veterinary Medicine  
250-1 Kuo-Kuang Road  
Taichung 402  
Taiwan

**Nicola Cioffi**

Università di Bari  
Dipartimento di Chimica  
Via Omodeo 4  
70126 Bari  
Italy

**Nicoletta Ditaranto**

Università di Bari  
Dipartimento di Chimica  
Via Omodeo 4  
70126 Bari  
Italy

**Kenneth M. Dokken**

University of Texas at El Paso  
Chemistry Department  
500 West University Ave  
El Paso, TX 79968  
USA

**Ozgur Ekici**

University of Texas at Austin  
Department of Mechanical  
Engineering  
Austin, TX 78722  
USA

**Daniel Eversole**

University of Texas at Austin  
Department of Biomedical  
Engineering  
Austin, TX 78722  
USA

**Ruel G. Freemantle**

The University of North Carolina  
at Charlotte  
Department of Chemistry and the  
Nanoscale Science Program  
Charlotte, NC 28223  
USA

**Jorge L. Gardea-Torresdey**

University of Texas at El Paso  
Chemistry Department  
500 West University Ave  
El Paso, TX 79968  
USA

**Wen Guo**

The University of North Carolina at  
Charlotte  
Department of Chemistry and the  
Nanoscale Science Program  
Charlotte, NC 28223  
USA

**Tai Hwan Ha**

BioNanotechnology Research Center  
Korea Research Institute of Bioscience  
and Biotechnology  
111 Gwahangno  
Yuseong-gu  
Daejeon 305-806  
Republic of Korea

**Yeu-Kuang Hwu**

Institute of Physics  
Academia Sinica  
Taipei 115  
Taiwan

**John M. Kelly**

School of Chemistry  
Trinity College Dublin  
Dublin 2  
Ireland

**Bruce Kelman**

Veritox, Inc.  
18372 Redmond-Fall City Road  
Redmond, WA 98052  
USA

**Deirdre M. Ledwith**

School of Chemistry  
Trinity College Dublin  
Dublin 2  
Ireland

**Minghong Liu**

The University of North Carolina  
at Charlotte  
Department of Chemistry and the  
Nanoscale Science Program  
Charlotte, NC 28223  
USA

**Ru-Shi Liu**

National Taiwan University  
Department of Chemistry  
Taipei 106  
Taiwan

**Takuro Niidome**

Kyushu University  
Department of Applied Chemistry  
Faculty of Engineering  
744 Motooka  
Nishi-ku  
Fukuoka 819-0395  
Japan

Kyushu University  
Center for Future Chemistry  
744 Motooka  
Nishi-ku  
Fukuoka 819-0395  
Japan

PRESTO  
Japan Science and Technology  
Corporation  
Kawaguchi  
332-0012  
Japan

**Yasuro Niidome**

Kyushu University  
Department of Applied Chemistry  
Faculty of Engineering  
744 Motooka  
Nishi-ku  
Fukuoka 819-0395  
Japan

**Sherine O. Obare**

The University of North Carolina at  
Charlotte  
Department of Chemistry and the  
Nanoscale Science Program  
Charlotte, NC 28223  
USA

**Harshala J. Parab**

National Taiwan University  
Department of Chemistry  
Taipei 106  
Taiwan

Academia Sinica  
Institute of Physics  
Taipei 115  
Taiwan

**Jason G. Parsons**

University of Texas at El Paso  
Chemistry Department  
500 West University Ave  
El Paso, TX 79968  
USA

**Zhenmeng Peng**

University of Rochester  
Department of Chemical Engineering  
Gavett Hall 206  
Rochester, NY 14627-0166  
USA

***Jose R. Peralta-Videa***

University of Texas at El Paso  
Chemistry Department  
500 West University Ave  
El Paso, TX 79968  
USA

***Luigia Sabbatini***

Università di Bari  
Dipartimento di Chimica  
Via Omodeo 4  
70126 Bari  
Italy

***Atsushi Shiotani***

Kyushu University  
Department of Applied Chemistry  
Faculty of Engineering  
744 Motooka  
Nishi-ku  
Fukuoka 819-0395  
Japan

***Yoshiki Katayama***

Kyushu University  
Department of Applied Chemistry  
Faculty of Engineering  
744 Motooka  
Nishi-ku  
Fukuoka 819-0395  
Japan

Kyushu University  
Center for Future Chemistry  
744 Motooka  
Nishi-ku  
Fukuoka 819-0395  
Japan

CREST  
Japan Science and Technology  
Corporation  
Kawaguchi  
332-0012  
Japan

***Luisa Torsi***

Università di Bari  
Dipartimento di Chimica  
Via Omodeo 4  
70126 Bari  
Italy

***Ralph A. Tripp***

University of Georgia  
Department of Infectious Diseases  
Athens, GA 30602  
USA

***Din Ping Tsai***

National Taiwan University  
Department of Physics  
Taipei 106  
Taiwan

***Perianambi V. Varadarajan***

Chemical and Biochemical Processing  
Division  
Central Institute for Research on  
Cotton Technology  
Adenwala Road  
Matunga  
Mumbai-400 019  
India

***Nadanathangam Vigneshwaran***

Chemical and Biochemical Processing  
Division  
Central Institute for Research on  
Cotton Technology  
Adenwala Road  
Matunga  
Mumbai-400 019  
India

***Kenneth K. Y. Wong***

The University of Hong Kong  
Department of Surgery  
Pokfulam Road  
Hong Kong

**Hong Yang**

University of Rochester  
Department of Chemical  
Engineering  
Gavett Hall 206  
Rochester, NY 14627-0166  
USA

**Shengchun Yang**

University of Rochester  
Department of Chemical  
Engineering  
Gavett Hall 206  
Rochester, NY 14627-0166  
USA

**Il Je Yu**

Korea Environment &  
Merchandise Testing Institute  
7-44 Songdo-dong  
Yeonsu-gu  
406-840  
Incheon  
Korea

**Jyh-Myng Zen**

National Chung-Hsing University  
Department of Chemistry  
250 Kuo-Kuang Road  
Taichung 402  
Taiwan

**Yiping Zhao**

University of Georgia  
Department of Physics and Astronomy  
Athens, GA 30602  
USA

## Contents

**Preface** XVII

**List of Contributors** XXI

### **Part One Copper, Silver and Gold Nanomaterials** 1

- 1 Approaches to Synthesis and Characterization of Spherical and Anisotropic Copper Nanomaterials** 3  
*Nicola Cioffi, Nicoletta Ditaranto, Luisa Torsi and Luigia Sabbatini*
  - 1.1 Introduction 3
  - 1.2 Physical/Mechanical and Vapor-Phase Approaches 7
    - 1.2.1 Mechanical and Mechanochemical Milling 7
    - 1.2.2 Electrical Wire Explosion and Electrospinning Approaches 8
    - 1.2.3 Spray and Flame-Spray Pyrolysis 9
    - 1.2.4 Arc-Discharge Approaches 10
    - 1.2.5 Metal Vapor Condensation 12
    - 1.2.6 Metal–Organic Chemical Vapor Condensation 12
  - 1.3 Chemical Approaches 13
    - 1.3.1 Wet-Chemical Routes without Surfactants 14
    - 1.3.2 Wet-Chemical Routes Based on Surfactants and Low-Molecular-Weight Capping Agents 14
      - 1.3.2.1 Aerosol OT (AOT)-Capped Cu Nanomaterials 14
      - 1.3.2.2 Alkyl-Phosphate-Capped Cu NPs 22
      - 1.3.2.3 Alkyl-Sulfate-Capped Cu NPs 22
      - 1.3.2.4 Alkyl-Thiol-Capped Cu NPs 22
      - 1.3.2.5 Cu NPs Capped by Quaternary Ammonium Surfactants 25
      - 1.3.2.6 Cu NPs Capped by Nonionic Surfactants or Stabilizers 25
      - 1.3.2.7 Cu NPs Capped by Cysteine, Oleic Acid and Other Small Molecules with Biological Relevance 26
    - 1.3.3 Wet-Chemical Routes Based on Polymer and Dendrimer Capping Agents 28
      - 1.3.3.1 The Polyol Process 30
      - 1.3.3.2 Polymer-Based Soft-Template Processes 30
      - 1.3.3.3 Encapsulation in Dendrimers 31

1.3.4	Wet-Chemical Routes Based on Biotemplate Systems	32
1.3.5	Redox Routes in Compressed and Heated Fluids: Hydrothermal, Solvothermal and Supercritical Fluid Methods	33
1.3.5.1	Hydrothermal Routes	33
1.3.5.2	Solvothermal Routes	34
1.3.5.3	Routes Based on Supercritical Fluids	34
1.3.6	Redox Routes in Ionic Liquids	37
1.3.7	Ultrasonic-Chemical Processes	38
1.4	Photochemical, Laser Ablation and Radiation- or Electron Beam-Assisted Processes	38
1.4.1	Photochemical Reduction in the Presence of Capping Agents and Sensitizers	39
1.4.2	Laser Ablation and Photo-Fragmentation Processes	40
1.4.3	$\gamma$ -Irradiation	41
1.4.4	Electron Beam Irradiation	42
1.5	Electrochemical Approaches	42
1.5.1	Sacrificial Anode Electrolysis in the Presence of Surfactants	43
1.5.2	Electrochemical Milling	46
1.5.3	Ultrasonic-Electrochemical	46
1.5.4	Electrolysis in Ionic Liquids	48
1.5.5	Template-Assisted Electrochemical Growth of Cu Nanorods and Nanowires	48
1.6	Conclusions	49
	References	51

## 2 Spherical and Anisotropic Copper Nanomaterials in Medical Diagnosis 71

*Chi-Chung Chou, Jen-Lin Chang and Jyh-Myng Zen*

2.1	Introduction	71
2.2	Copper Nanoparticles	73
2.3	Synthesis of Copper Nanoparticles	75
2.3.1	Chemical Reduction in Aqueous Media	75
2.3.2	Chemical Reduction in Organic Media	76
2.3.3	Photoreduction	77
2.3.4	Sonochemical Production	77
2.3.5	Machine-Chemical Reduction	78
2.3.6	Electrochemical Reduction	78
2.4	Applications of Cu-NPs in Medical Diagnosis	80
2.4.1	Medical Imaging	80
2.4.1.1	Magnetic Resonance Imaging	80
2.4.1.2	Positron Emission Tomography (PET)	81
2.4.2	Diagnosis of Metabolic Disorders	81
2.4.2.1	Glucose	81



2.4.2.2	Organic Acids	82
2.4.2.3	Amino Acids	83
2.4.2.4	Urate and Uric Acid	85
2.4.3	Other Medical Applications	85
2.4.3.1	Drug Delivery and Therapy	85
2.4.3.2	Antibacterial Activity	86
2.5	Conclusions	87
	References	89

### **3 Approaches to the Synthesis and Characterization of Spherical and Anisotropic Silver Nanomaterials 99**

*Deirdre M. Ledwith, Damian Aherne and John M. Kelly*

3.1	Introduction	99
3.2	Optical Properties of Metal Nanoparticles	99
3.3	Preparation of Spherical Nanoparticles	101
3.3.1	Stability of Electrostatically Stabilized Nanoparticles	101
3.3.2	Aqueous Synthetic Methods	103
3.3.2.1	Chemical Reduction	103
3.3.2.2	Physical Methods	104
3.3.3	Organic Solvents	106
3.3.3.1	Stability of Sterically Stabilized Nanoparticles	106
3.3.3.2	Reduction by the Solvent	107
3.3.3.3	Microemulsion Methods	107
3.3.3.4	Thiol-Stabilized Nanoparticles	109
3.4	Synthesis of Anisotropic Silver Nanoparticles	109
3.4.1	Nanorods and Nanowires	110
3.4.1.1	Aqueous Surfactant-Based Methods	111
3.4.1.2	Organic (Polyol-Based) Methods	113
3.4.2	Cubes	117
3.4.2.1	Aqueous Surfactant-Based Methods	117
3.4.2.2	Organic Polyol-Based Methods	117
3.4.3	Other Morphologies Prepared by the Polyol Process	119
3.4.3.1	Right Bipyramids	119
3.4.3.2	Nanobeams	120
3.4.3.3	Nanobars and Nanorice	120
3.4.4	Nanoplates and Nanoprisms	122
3.4.4.1	Photochemical Methods	122
3.4.4.2	Thermal Methods	127
3.4.4.3	Physical Aspects	133
3.5	Applications	137
3.6	Conclusions	137
	Abbreviations	138
	References	139