

## Contents

**Preface** XIII

**List of Contributors** XVII

<b>1</b>	<b>Gold Nanoshells in Biomedical Applications</b>	<b>1</b>
	<i>Tim A. Erickson and James W. Tunnell</i>	
1.1	Introduction	1
1.2	Physical Properties of Gold Nanoshells	2
1.2.1	Overview of General Optical Properties	2
1.2.2	The Physics of Gold Nanoshells	5
1.2.2.1	The Dielectric Function of Gold	6
1.2.2.2	The Quasi-Static Approximation and Conditions for Surface Plasmon Resonance	7
1.2.2.3	Mie Theory	13
1.2.2.4	Near-Field Enhancement	13
1.2.2.5	Photoluminescence	14
1.2.3	Photo-Thermal Material Characteristics	14
1.3	Synthesis and Bioconjugation	16
1.3.1	Synthesis	16
1.3.2	Bioconjugation: Smarter Nanoshells	18
1.4	Biodistribution, Toxicity Profile and Transport	19
1.4.1	Biodistribution Studies	20
1.4.2	Transport Mechanisms	22
1.4.3	Toxicity	25
1.5	Biomedical Applications	26
1.5.1	<i>In Vitro</i> Cancer Detection and Imaging	26
1.5.2	<i>In Vivo</i> Detection and Imaging	28
1.5.3	Integrated Cancer Imaging and Therapy Agents	29
1.5.4	<i>In Vitro</i> Studies	29
1.5.5	<i>In Vivo</i> Photothermal Therapy	31
1.5.6	Drug Delivery	34
1.5.7	Tissue Welding	35
1.5.8	Biosensors	35
1.5.8.1	Absorbance-Based Biosensing	37

1.5.8.2	SERS Biosensing	37
1.6	Concluding Remarks	38
	References	39
<b>2</b>	<b>Anisotropic Bimetallic/Oxide Nanomaterials for The Life Sciences</b>	<b>45</b>
	<i>Jessica B. Graham, Megan E. Pearce and Aliasger K. Salem</i>	
2.1	Introduction	45
2.2	Synthesis and Functionalization of Anisotropic Bimetallic Nanoparticles	45
2.2.1	Nanorods	45
2.2.2	Nanowires	47
2.3	Applications in the Life Sciences	48
2.3.1	Biosensing	48
2.3.2	Imaging	49
2.3.3	Gene Delivery	49
2.3.4	Vaccine Applications	52
2.4	Conclusions	54
	References	54
<b>3</b>	<b>Au–Pt Nanomaterials and Enzymatic Catalysts for Biofuel Cell Applications</b>	<b>57</b>
	<i>Aurélien Habrioux, Karine Servat, Boniface Kokoh and Nicolas Alonso-Vante</i>	
3.1	Introduction	57
3.2	Oxygen Reduction Reaction (ORR)	58
3.2.1	ORR Metal Catalysts	60
3.2.2	ORR Enzymatic Catalysts	61
3.2.2.1	Techniques Used for Enzyme Immobilization	61
3.2.2.2	Enzymatic Reduction of Oxygen to Water	63
3.3	Glucose Oxidation	70
3.3.1	Process on Metal Electrodes	70
3.3.1.1	Synthesis and Structural Properties of Gold–Platinum Nanoparticles	71
3.3.1.2	Electrocatalytic Oxidation of D-(+)-Glucose on Gold–Platinum Catalysts	73
3.3.2	Glucose Oxidation via Enzymes	77
3.3.2.1	Glucose Oxidation Catalyzed by GDH	78
3.3.2.2	Glucose Oxidation Catalyzed by GOx	79
3.4	Application to Fuel Cell Systems	85
3.4.1	Glucose/Oxygen Biofuel Cells	85
3.4.2	Glucose/Oxygen Biofuel Cells with Au–Pt Nanoparticles as Anode Catalysts	90
3.5	Summary and Outlook	91
	Acknowledgments	92
	Abbreviations	93
	References	93

<b>4</b>	<b>Spherical and Anisotropic Metallic Nanomaterials-Based NSET Biosensors</b>	<b>103</b>
	<i>Paresh Chandra Ray, Jelani Griffin, Wentong Lu, Oleg Tovmachenko, Anant K. Singh, Dulal Senapati and Gabriel A. Kolawole</i>	
4.1	Introduction	103
4.1.1	Nanotechnology Promises on Biological Detection	105
4.2	Size- and Shape-Dependent Super Quenching Properties of Nanomaterials	106
4.3	Nanomaterial Surface Energy Transfer (NSET)	109
4.3.1	Portable NSET Probes	111
4.3.2	NSET Probe for DNA/RNA Hybridization Detection	112
4.3.2.1	Size-Dependence Sensitivity	114
4.3.3	Distance-Dependent NSET	115
4.3.4	Multiplex DNA Detection	119
4.3.5	NSET for Monitoring Mg <sup>2+</sup> -Dependent RNA Folding	121
4.3.6	NSET for DNA Cleavage Detection	125
4.3.7	NSET for Cancer Cell Detection	128
4.4	Gold Nanoshell-Based Biosensors	129
4.5	Problems and Challenges	131
4.6	Summary	131
	Acknowledgments	132
	References	132
<b>5</b>	<b>Mixed-Metal Oxide Nanomaterials for Environmental Remediation</b>	<b>139</b>
	<i>Dambar B. Hamal, Kennedy K. Kalebaila and Kenneth J. Klabunde</i>	
5.1	Introduction	139
5.2	TiO <sub>2</sub> Heterogeneous Photocatalysis for Environmental Remediation	141
5.2.1	Metal-Doped TiO <sub>2</sub> Mixed-Metal Oxides as UV-Light-Sensitive Photocatalysts	141
5.2.2	Metal-Doped TiO <sub>2</sub> Mixed-metal Oxides as Visible-Light-Sensitive Photocatalysts	146
5.3	Other Mixed-metal Oxide Photocatalysts	150
5.4	Conclusions	156
	References	157
<b>6</b>	<b>Building Nonmagnetic Metal@Oxide and Bimetallic Nanostructures: Potential Applications in the Life Sciences</b>	<b>161</b>
	<i>Mao-Song Mo and Xu-Sheng Du</i>	
6.1	Introduction	161
6.2	Building Nonmagnetic Metal@Oxide and Bimetallic Nanostructures	162
6.2.1	Core-Shell Nanostructures and Building Strategy	162
6.2.2	Metal@Oxide Core-Shell Nanostructures	163
6.2.3	Bimetallic Nanostructures	164
6.2.3.1	Bimetallic Core-Shell Nanostructures	164

6.2.3.2	1-D Bimetallic Heteronanostructures	174
6.2.3.3	Bimetallic Alloy Nanostructures	179
6.2.4	3-D Mesoscale Bimetallic Patterning	185
6.3	Current and Future Applications in the Life Sciences	188
6.4	Summary and Outlook	191
	Acknowledgments	192
	References	192
<b>7</b>	<b>Biofunctionalization of Spherical and Anisotropic Bimetallic Nanomaterials</b>	<b>197</b>
	<i>Davide Prospero, Laura Polito, Carlo Morasso and Diego Monti</i>	
7.1	Introduction	197
7.2	Spherical Core-Shell Bimetallic Nanoparticles	198
7.2.1	Ag <sub>Core</sub> /Au <sub>shell</sub> Nanoparticles	198
7.2.2	Au <sub>Core</sub> /Ag <sub>shell</sub> Nanoparticles	201
7.2.3	Silver Enhancement of Gold Nanoparticles	204
7.2.4	DNA-Assisted Synthesis of Core-Shell Nanoparticles	205
7.2.5	Biofunctionalization for the Construction of Core-Shell Bimetallic Nanostructures	206
7.3	Anisotropically Shaped Nanoparticles: Nanorods and Nanowires	209
7.3.1	Surface Modifications	210
7.3.2	NW/NR Functionalization with Protein Molecules	212
7.3.3	NW/NR Functionalization by DNA	218
7.3.4	Detection and Sensing	220
7.4	Profunctional Bimetallic Alloys	224
7.4.1	Dendrimer-Encapsulated Bimetal Nanoparticles	225
7.4.2	Surface Stabilization by Ligand Exchange	228
7.4.3	DNA Metallization	228
7.4.4	Miscellaneous	229
7.5	Outlook	234
	References	234
<b>8</b>	<b>Multielemental Nanorods (Nanowires): Synthesis, Characterization and Analytical Applications</b>	<b>241</b>
	<i>Yang-Wei Lin, Zong-Hong Lin, Chih-Ching Huang and Huan-Tsung Chang</i>	
8.1	Introduction	241
8.2	Synthetic Strategies	243
8.2.1	Organic-Phase Synthesis	243
8.2.1.1	Bimetallic NRs	243
8.2.1.2	Semiconductor NRs	245
8.2.2	Aqueous-Phase Synthesis	248
8.2.2.1	Bimetallic NRs	248
8.2.2.2	Multisegmented NRs	250
8.2.2.3	Bimetallic/Trimetallic Oxide NRs	252
8.2.2.4	Semiconductor NRs	254

8.3	Properties	255
8.3.1	Absorption	256
8.3.2	Emission	258
8.3.3	Surface-Enhanced Raman Scattering	260
8.3.4	Catalytic Properties	262
8.3.5	Magnetism	263
8.4	Analytical Applications	264
8.4.1	Detection of Gaseous Molecules	265
8.4.2	Detection of Metal Ions	265
8.4.3	Separation and Sensing of Proteins	267
8.4.4	DNA Detection	269
8.4.5	Detection of Pathogens and Bacteria	271
8.5	Conclusions	271
	Abbreviations	272
	References	273
<b>9</b>	<b>Spherical and Anisotropic Nonmagnetic Core-Shell Nanomaterials: Synthesis and Characterization</b>	<b>281</b>
	<i>Tewodros Asefa, Abhishek Anan, Cole Duncan and Youwei Xie</i>	
9.1	Introduction: Core-Shell Nanomaterials and Their Biological/Medical Applications	281
9.2	Nonmagnetic Core-Shell Nanomaterials	287
9.3	Synthesis of Cores in Core-Shell Nanostructures	288
9.3.1	Metal Cores	288
9.3.2	Metal Oxide Cores	289
9.3.3	Polymeric Cores	290
9.3.4	Semiconductor Cores	290
9.4	Deposition of Shells over the Core Nanomaterials	290
9.5	Types of Core-Shell Nanomaterial	291
9.5.1	Metal–Insulator Core-Shell Nanomaterials	291
9.5.1.1	Metal-Dense Metal Oxide Core-Shell Nanomaterials	292
9.5.1.2	Metal-Functionalized Metal Oxide Core-Shell Nanoparticles	294
9.5.1.3	Metal–Porous Metal Oxide Core-Shell	294
9.5.1.4	Metal–Polymer Core-Shell Nanoparticles	295
9.5.1.5	Hollow Metal–Metal Oxide Shells by Controlled Core-Dissolution	298
9.5.1.6	Metal Core–Dendrimer Core-Shell Nanoparticles	300
9.5.1.7	Metal Core–Semiconducting Metal Oxide Shell Nanoparticles	300
9.5.2	Insulator–Metal Core-Shell Nanomaterials	301
9.5.2.1	Metal Oxide–Metal Core-Shell Nanostructures	301
9.5.2.2	Polymer–Metal Core-Shell Nanostructures	301
9.5.3	Insulator–Insulator Core-Shell Nanoparticles	302
9.5.3.1	Polymer–Metal Oxide Core-Shell Nanomaterials	302
9.5.3.2	Polymer–Polymer Core-Shell Nanomaterials	303
9.5.3.3	Biomolecule (Protein) Core–Polymer Shell Core-Shell Nanoparticles	304
9.5.3.4	Metal Oxide–Metal Oxide Core-Shell Nanomaterials	305

- 9.5.3.5 Metal Oxide–Dye-Doped Silica and Dye-Doped Silica–Metal Oxide Core-Shell Nanostructures 305
- 9.5.3.6 Metal Oxide–Polymer Core-Shell Nanoparticles 305
- 9.5.3.7 Other Inorganic Materials Cores: Metal Oxide Shells 306
- 9.5.4 Semiconductor–Insulator Core-Shell Nanomaterials 307
- 9.5.5 Semiconductor–Semiconductor Core-Shell Nanomaterials 308
- 9.5.6 Semiconductor–Semiconductor–Dendrimer Core-Shell-Shell Nanoparticles 308
- 9.5.7 Insulator–Semiconductor Core-Shell Nanomaterials 309
- 9.5.8 Metal–Metal Core-Shell 310
- 9.5.9 Insulator–Metal Core-Shell Nanoparticles 313
- 9.5.10 Carbon-Containing Core-Shell Nanomaterials 313
- 9.5.10.1 Metal Oxide–Carbon Core-Shell Nanoparticles 313
- 9.5.11 Other Carbon-Containing Core-Shell Nanomaterials 313
- 9.5.12 Synthetic Methods to Create Core-Shell Nanomaterials, and their Characterizations 316
- 9.6 Applications 317
  - 9.6.1 Applications in Biology and Medicine 317
    - 9.6.1.1 Bioimaging and Immunoassay 318
    - 9.6.1.2 Drug or Biomolecular Delivery Vehicles 319
  - 9.6.2 Core-Shell Nanomaterials for Catalysis 319
- 9.7 Conclusions and Future Prospects 320
  - Acknowledgments 321
  - References 321

## 10 Spherical and Anisotropic Silica Shell Nanomaterials 331

*Chih-Wei Lai, Jong-Kai Hsiao, Yu-Chun Chen and Pi-Tai Chou*

- 10.1 Introduction 331
- 10.2 Silica-Coated Metal Nanoparticles 332
  - 10.2.1 Noble Metal Nanoparticles: An Overview 332
    - 10.2.1.1 Sol–Gel method for Silica Coating 334
  - 10.2.2 Silica Shell for Biofunctionalization 338
  - 10.2.3 Application of Silica-Coated Metal Nanoparticles 338
    - 10.2.3.1 Silica Shell Modified with Oligonucleotides 338
    - 10.2.3.2 Surface-Enhanced Raman Scattering Effect 339
    - 10.2.3.3 Enhanced Luminescence Intensity 342
  - 10.2.4 Coating Silica Gold Nanorods 344
  - 10.2.5 Silica-Encapsulated Platinum 345
- 10.3 Silica-Coated Quantum Dots 345
  - 10.3.1 The Advantages of Coating QDs with Silica 346
  - 10.3.2 Different Types of Silica-Coated QDs 347
    - 10.3.2.1 Hydrophobic QDs 347
    - 10.3.2.2 Hydrophilic QDs 349
- 10.4 Silica-Encapsulated Magnetic Nanoparticles 351
  - 10.4.1 Silica-Coated Alloy Metal Nanoparticles 354
  - 10.4.2 Silica-Coated Magnetic Metal Oxide Nanoparticles 356

10.4.3	Applications of Silica-Coated Magnetic Nanoparticles	359
10.4.3.1	Forming Hybrid Materials with Optic Materials Dopant	359
10.5	Hollow Silica Spherical Structures	363
10.5.1	Au and Pt Nanoparticles in Hollow Spheres	363
10.6	Conclusions	367
	References	368
<b>11</b>	<b>Spherical and Anisotropic Core-Shell and Alloy Nanomaterials: Characterization Using X-Ray Absorption Spectroscopy</b>	<b>377</b>
	<i>Loka Subramanyam Sarma, Hung-Lung Chou, Ming-Yao Cheng, Fadlilatul Taufany, Feng-Ju Lai, Meng-Che Tsai, Shih-Hong Chang and Bing-Joe Hwang</i>	
11.1	Introduction	377
11.2	Nanoparticle Systems for Biomedical Applications	381
11.2.1	Bioimaging (Magnetic Resonance Imaging)	381
11.2.2	Drug Delivery	382
11.3	Characterization of Spherical and Anisotropic Core-Shell and Alloy Nanomaterials using X-Ray Absorption Spectroscopy (XAS)	383
11.3.1	XAS Fundamentals	384
11.3.2	XAS Data Collection and Analysis	386
11.3.3	Structural Characterization: XAS Methodologies	387
11.3.3.1	Particle Size, Shape and Aspect Ratio of Nanoparticles	387
11.3.3.2	Alloy Versus Core-Shell Structure, Atomic Distribution and Degree of Alloying of Nanomaterials: An XAS Methodology	389
11.3.3.3	Surface and Core Composition in Bimetallic Nanoparticles: An XAS Methodology	391
11.3.4	Review of XAS Characterization Methodologies for Nanomaterials	392
11.3.5	XAS Characterization of Surface Interactions	399
11.4	Conclusions	400
	Acknowledgments	401
	References	401
<b>12</b>	<b>Anisotropic Hexagonal Boron Nitride Nanomaterials: Synthesis and Applications</b>	<b>411</b>
	<i>Wei-Qiang Han</i>	
12.1	Introduction	411
12.2	Synthesis of BN Nanotubes	412
12.2.1	Introduction	412
12.2.2	Arc Discharge	413
12.2.3	Laser Ablation	416
12.2.4	Carbon Nanotubes-Substitution Reaction	420
12.2.5	Chemical Vapor Deposition	426
12.2.6	Solid-Gas Reaction	429
12.2.7	Low-Temperature Autoclaving	430
12.2.8	Pore-Template	430
12.2.9	Arc-Jet Plasma	432

12.3	BNNT-Based Nano-Objects	433
12.3.1	Filled BNNTs	433
12.3.2	Functionalized BNNTs	436
12.4	Porous BN and BN Mesh	439
12.4.1	Direct Pyrolyzing Borazinic Precursors	439
12.4.2	Use of Mesoporous Molds	440
12.4.3	Carbon Template-Substitution Reaction	441
12.5	BN Mono- or Few-Layer Sheets	443
12.6	Physical Properties of h-BN	446
12.7	Applications	447
12.7.1	Pharmaceutical Table Lubricant	447
12.7.2	Cosmetic Materials	448
12.7.3	$^{10}\text{BNNTs}$ for Cancer Therapy and Diagnostics	449
12.7.4	BNNT Composites	449
12.7.5	Gas Adsorption	450
12.7.6	Electrical Nanoinsulators	452
12.7.7	Ultraviolet Lasers and LEDs	452
12.7.8	BN as Support for Catalysts	452
12.8	Concluding Remarks	453
	Acknowledgments	453
	References	453

### 13 Spherical and Anisotropic Boron Nitride Nanomaterials: Synthesis and Characterization 463

*Chengchun Tang and Yangxian Li*

13.1	Introduction	463
13.2	BN Nanomaterials Synthesis	464
13.2.1	Spherical BN Particles	464
13.2.2	Anisotropic BN Nanostructures	470
13.2.2.1	Multiwalled Nanotubes	470
13.2.2.2	Single-Walled Nanotubes	476
13.2.2.3	Collapsed BN Nanotubes	478
13.2.2.4	Nanowires	480
13.3	Remarks on Properties and Applications	483
13.3.1	High-Temperature Chemical Inertness	484
13.3.2	Electrical Properties	484
13.3.3	High Thermal Conductivity	485
13.3.4	Mechanical Properties	486
13.3.5	Hydrogen Storage	487
13.3.6	Life Sciences	487
13.4	Concluding Remarks	489
	Acknowledgments	491
	References	491

**Index** 499