## **Table of Contents**

List of Contributors xv

Introduction xvii

**1 Diversity of Microbes in Synthesis of Metal Nanoparticles: Progress and Limitations 1** *Mahendra Rai, Irena Maliszewska, Avinash Ingle, Indarchand Gupta, and Alka Yadav* 

1.1 Introduction 1

1.2 Synthesis of Nanoparticles by Bacteria 2

1.3 Synthesis of Nanoparticles by Fungi 9

1.4 Synthesis of Nanoparticles by Algae 12

- 1.5 Applications of Metal Nanoparticles 16
- 1.5.1 Nanoparticles as Catalyst 16
- 1.5.2 Nanoparticles as Bio ]membranes 17
- 1.5.3 Nanoparticles in Cancer Treatment 17
- 1.5.4 Nanoparticles in Drug Delivery 17
- 1.5.5 Nanoparticles for Detection and Destruction of Pesticides 17
- 1.5.6 Nanoparticles in Water Treatment 18
- 1.6 Limitations of Synthesis of Biogenic Nanoparticles 18

References 20

## **2 Role of Fungi Toward Synthesis of Nano ]Oxides 31** Rajesh Ramanathan and Vipul Bansal

- 2.1 Introduction 31
- 2.2 Fungus ]mediated Synthesis of Nanomaterials 34
- 2.2.1 Biosynthesis of Binary Nano ]oxides using Chemical Precursors 34

2.2.2 Biosynthesis of Complex Mixed ]metal Nano ]oxides using Chemical Precursors 39

2.2.3 Biosynthesis of Nano ]oxides using Natural Precursors employing

**Bioleaching Approach 42** 

2.2.4 Biosynthesis of nano ]oxides employing bio ]milling approach 44

2.3 Outlook 46

References 47

3 Microbial Molecular Mechanisms in Biosynthesis of Nanoparticles 53 Atmakuru Ramesh, Marimuthu Thiripura Sundari, and Perumal Elumalai Thirugnanam

3.1 Introduction 53

- 3.2 Chemical Synthesis of Metal Nanoparticles 54
- 3.2.1 Brust-Schiffrin Synthesis 55
- 3.3 Green Synthesis 57
- 3.4 Biosynthesis of Nanoparticles 58
- 3.5 Mechanisms for Formation or Synthesis of Nanoparticles 61
- 3.5.1 Biomineralization using Magnetotactic Bacteria (MTB) 61
- 3.5.2 Reduction of Tellurite using Phototroph Rhodobacter capsulatus 62
- 3.5.3 Formation of AgNPs using Lactic Acid and Bacteria 62
- 3.5.4 Microfluidic Cellular Bioreactor for the Generation of Nanoparticles 62
- 3.5.5 Proteins and Peptides in the Synthesis of Nanoparticles 65
- 3.5.6 NADH ]dependent Reduction by Enzymes 65
- 3.5.7 Sulfate and Sulfite Reductase 66
- 3.5.8 Cyanobacteria 67
- 3.5.9 Cysteine Desulfhydrase in Rhodopseudomonas palustris 68

3.5.10 Nitrate and Nitrite reductase 68

3.6 E xtracellular Synthesis of Nanoparticles 69

3.6.1 Bacterial Excretions 69

3.6.2 Fungal Strains 71

3.6.3 Yeast: Oxido ]reductase Mechanism 72

3.6.4 Plant Extracts 73

3.7 Conclusion 76

References 78

**4 Biofilms in Bio ]Nanotechnology: Opportunities and Challenges 83** *Chun Kiat Ng, Anee Mohanty, and Bin Cao* 

4.1 Introduction 83

4.2 Microbial Synthesis of Nanomaterials 84

4.2.1 Overview 84

4.2.2 Significance of Biofilms in Biosynthesis of Nanomaterials 89

4.2.3 Synthesis of Nanomaterials using Biofilms 90

- 4.3 Interaction of Microbial Biofilms with Nanomaterials 90
- 4.3.1 Nanomaterials as Anti ]biofilm Agents 90
- 4.3.2 Nanomaterials as a Tool in Biofilm Studies 92

4.4 Future Perspectives 93

References 94

5 Extremophiles and Biosynthesis of Nanoparticles: Current and Future Perspectives 101 Jingyi Zhang, Jetka Wanner, and Om V. Singh

5.1 Introduction 101

## 5.2 Synthesis of Nanoparticles 104

5.2.1 Microorganisms: An Asset in Nanoparticle Biosynthesis 104

5.2.2 E xtremophiles in Nanoparticle Biosynthesis 104

5.3 Mechanism of Nanoparticle Biosynthesis 108

5.4 Fermentative Production of Nanoparticles 111

- 5.5 Nanoparticle Recovery 114
- 5.6 Challenges and Future Perspectives 115

5.7 Conclusion 115

References 116

**6** Biosynthesis of Size-Controlled Metal and Metal Oxide Nanoparticles by Bacteria 123 Chung-Hao Kuo, David A. Kriz, Anton Gudz, and Steven L. Suib

6.1 Introduction 123

6.2 Intracellular Synthesis of Metal Nanoparticles by Bacteria 124

6.3 E xtracellular Synthesis of Metal Nanoparticles by Bacteria 129

6.4 Synthesis of Metal Oxide and Sulfide Nanoparticles by Bacteria 131

6.5 Conclusion 135

References 135

7 Methods of Nanoparticle Biosynthesis for Medical and Commercial Applications 141 Shilpi Mishra, Saurabh Dixit, and Shivani Soni

7.1 Introduction 141

7.2 Biosynthesis of Nanoparticles using Bacteria 144

7.2.1 Synthesis of Silver Nanoparticles by Bacteria 144

7.2.2 Synthesis of Gold Nanoparticles by Bacteria 145

7.2.3 Synthesis of other Metallic Nanoparticles by Bacteria 145

7.3 Biosynthesis of Nanoparticles using Actinomycete 146

7.4 Biosynthesis of Nanoparticles using Fungi 147

7.5 Biosynthesis of Nanoparticles using Plants 148

7.6 Conclusions 149

References 149

8 Microbial Synthesis of Nanoparticles: An Overview 155 Sneha Singh, Ambarish Sharan Vidyarthi, and Abhimanyu Dev

8.1 Introduction 156

8.2 Nanoparticles Synthesis Inspired by Microorganisms 157

8.2.1 Bacteria in NPs Synthesis 162

8.2.2 Fungi in NPs Synthesis 167

8.2.3 Actinomycetes in NPs Synthesis 170

8.2.4 Yeast in NPs Synthesis 171

8.2.5 Virus in NPs Synthesis 173

8.3 Mechanisms of Nanoparticles Synthesis 174

8.4 Purification and Characterization of Nanoparticles 176

8.5 Conclusion 177

References 179

**9 Microbial Diversity of Nanoparticle Biosynthesis 187** *Raveendran Sindhu, Ashok Pandey, and Parameswaran Binod* 

9.1 Introduction 187

9.2 Microbial-mediated Nanoparticles 187

9.2.1 Gold 188

9.2.2 Silver 190

9.2.3 Selenium 191

9.2.4 Silica 192

9.2.5 Cadmium 192

9.2.6 Palladium 193

9.2.7 Zinc 193

9.2.8 Lead 194

9.2.9 Iron 195

9.2.10 Copper 195

9.2.11 Cerium 196

9.2.12 Microbial Quantum Dots 196

9.2.13 Cadmium Telluride 197

9.2.14 Iron Sulfide-greigite 198

9.3 Native and Engineered Microbes for Nanoparticle Synthesis 198

9.4 Commercial Aspects of Microbial Nanoparticle Synthesis 199

9.5 Conclusion 200

References 200

10 S ustainable Synthesis of Palladium(0) Nanocatalysts and their Potential for Organohalogen Compounds Detoxification 205 Michael Bunge and Katrin Mackenzie

10.1 Introduction 205

10.2 Chemically Generated Palladium Nanocatalysts for Hydrodechlorination: Current Methods and Materials 206

10.2.1 Pd Catalysts 206

10.2.2 Data Analysis 207

10.2.3 Pd as Dehalogenation Catalyst 207

10.2.4 Intrinsic Potential vs. Performance 208

10.2.5 Concepts for Pd Protection 210

10.3 Bio-supported Synthesis of Palladium Nanocatalysts 211

10.3.1 Background 211

10.4 Current Approaches for Synthesis of Palladium Catalysts in the Presence of Microorganisms 212

10.4.1 Pd(II)-Tolerant Microorganisms for Future Biotechnological Approaches 213

10.4.2 Controlling Size and Morphology during Bio-Synthesis 214

10.4.3 Putative and Documented Mechanisms of Biosynthesis of Palladium Nanoparticles 215

10.4.4 Isolation of Nanocatalysts from the Cell Matrix and Stabilization 216

10.5 Bio-Palladium(0)-nanocatalyst Mediated Transformation of Organohalogen Pollutants 217

10.6 Conclusions 218

References 219

**11 E nvironmental Processing of Zn Containing Wastes and Generation of Nanosized Value-Added Products 225** *Abhilash and B.D. Pandey* 

11.1 Introduction 225

11.1.1 World Status of Zinc Production 226

11.1.2 E nvironmental Impact of the Process Wastes Generated 226

11.1.3 Production Status in India 227

11.1.4 Recent Attempts at Processing Low-Grade Ores and Tailings 228

11.2 Physical/Chemical/Hydrothermal Processing 229

11.2.1 E xtraction of Pb-Zn from Tailings for Utilization and Production in China 229

11.2.2 Vegetation Program on Pb-Zn Tailings 229

11.2.3 Recovering Valuable Metals from Tailings and Residues 229

11.2.4 E xtraction of Vanadium, Lead and Zinc from Mining Dump in Zambia 230

11.2.5 Recovery of Zinc from Blast Furnace and other Dust/Secondary Resources 230

11.2.6 Treatment and Recycling of Goethite Waste 231

11.2.7 Other Hydrometallurgical Treatments of Zinc-based Industrial Wastes and Residues 231

11.3 Biohydrometallurgical Processing: International Scenario 233

11.3.1 Bioleaching of Zn from Copper Mining Residues by Aspergillus niger 233

11.3.2 Bioleaching of Zinc from Steel Plant Waste using Acidithiobacillus ferrooxidans 234

11.3.3 Bacterial Leaching of Zinc from Chat (Chert) Pile Rock and Copper from Tailings Pond Sediment 234

11.3.4 Dissolution of Zn from Zinc Mine Tailings 234

- 11.3.5 Microbial Diversity in Zinc Mines 234
- 11.3.6 Chromosomal Resistance Mechanisms of A. ferrooxidans on Zinc 235
- 11.3.7 Bioleaching of Zinc Sulfides by Acidithiobacillus ferrooxidans 235
- 11.3.8 Bioleaching of High-sphalerite Material 235
- 11.3.9 Bioleaching of Low-grade ZnS Concentrate and Complex Sulfides (Pb-Zn) using Thermophilic Species 236
- 11.3.10 Improvement of Stains for Bio-processing of Sphalerite 236
- 11.3.11 Tank Bioleaching of ZnS and Zn Polymetallic Concentrates 237
- 11.3.12 Large-Scale Development for Zinc Concentrate Bioleaching 237
- 11.3.13 Scale-up Studies for Bioleaching of Low-Grade Sphalerite Ore 238

11.4 Biohydrometallurgical Processing: Indian Scenario 238

11.4.1 E lectro-Bioleaching of Sphalerite Flotation Concentrate 239

11.4.2 Bioleaching of Zinc Sulfide Concentrate 239

11.4.3 Bioleaching of Moore Cake and Sphalarite Tailings 239

11.5 Synthesis of Nanoparticles 240

11.6 Applications of Zinc-based Value-added Products/Nanomaterials 244

11.6.1 Hydro-Gel for Bio-applications 244

11.6.2 Sensors 244

11.6.3 Biomedical Applications 245

11.6.4 Antibacterial Properties 245

11.6.5 Zeolites in biomedical applications 246

11.6.6 Textiles 246

11.6.7 Prospects of Zinc Recovery from Tailings and Biosynthesis of Zinc-based Nano-materials 246

11.7 Conclusions and Future Directions 247

References 248

**12 Interaction Between Nanoparticles and Plants: Increasing Evidence of Phytotoxicity 255** *Rajeshwari Sinha and S.K. Khare* 

12.1 Introduction 255

12.2 Plant-Nanoparticle Interactions 256

12.3 E ffect of Nanoparticles on Plants 256

12.3.1 Monocot Plants 257

12.3.2 Dicot Plants 257

12.4 Mechanisms of Nanoparticle ]induced Phytotoxicity 257

12.4.1 Endocytosis 257

12.4.2 Transfer through Ion Channels Post ]ionization 262

12.4.3 Aquaporin Mediated 262

12.4.4 Carrier Proteins Mediated 262

12.4.5 Via Organic Matter 262

12.4.6 Complex Formation with Root Exudates 262

12.4.7 Foliar Uptake 263

12.5 E ffect on Physiological Parameters 263

12.5.1 Loss of Hydraulic Conductivity 263

12.5.2 Genotoxic Effects 263

12.5.3 Absorption and Accumulation 263

12.5.4 Generation of Reactive Oxygen Species (ROS) 264

12.5.5 Biotransformation of NPs 264

12.6 Genectic and Molecular Basis of NP Phytotoxicity 266

12.7 Conclusions and Future Perspectives 266

References 267

13 Cytotoxicology of Nanocomposites 273 Horacio Bach

13.1 Introduction 273

13.2 Cellular Toxicity 274

13.2.1 Mechanisms of Cellular Toxicity 274

13.2.2 E ffect of Glutathione (GSH) in Oxidative Stress 276

13.3 Nanoparticle Fabrication 281

13.3.1 Physico ]chemical Characteristics of NPs 282

13.3.2 Cellular Uptake 284

13.3.3 Factors Affecting the Internalization of NPs 287

13.4 Immunological Response 289

13.4.1 Cytokine Production 289

13.4.2 Cytotoxicity, Necrosis, Apoptosis, and Cell Death 290

13.5 Factors to Consider to Reduce the Cytotoxic Effects of NP 292

13.6 Conclusions and Future Directions 293

References 294

**14 Nanotechnology: Overview of Regulations and Implementations 303** *Om V. Singh and Thomas Colonna* 

14.1 Introduction 303

- 14.2 Scope of Nanotechnology 305
- 14.3 Safety Concerns Related to Nanotechnology 310
- 14.4 Barriers to the Desired Regulatory Framework 311
- 14.4.1 Regulatory Framework in the United States 312
- 14.4.2 Global Efforts toward Regulation of Nanotechnology 315
- 14.5 Biosynthesis of Microbial Bio ]nanoparticles: An Alternative Production Method 317

14.6 Conclusion 325

References 326

Name index 331

Subject index 333