

## Contents

**Preface** *xvii*

**About the Editors** *xix*

### **Part I Chemically Modified Carbon Nanotubes: Overview, Commercialization, and Economic Aspects 1**

<b>1</b>	<b>A Detailed Study on Carbon Nanotubes: Properties, Synthesis, and Characterization 3</b>
	<i>Nishant Tripathi, Prachi Sharma, Vladimir Pavelyev, Anastasiia Rymzhina, and Prabhash Mishra</i>
1.1	Introduction 3
1.2	Evolution of Carbon: Graphite to CNTs 4
1.2.1	Graphite 5
1.2.2	Diamond 5
1.2.3	Graphene 6
1.2.3.1	Direct Lattice 6
1.2.3.2	The Reciprocal Lattice 7
1.2.4	Carbon Nanotubes 7
1.2.4.1	SWNTs: Types and Structure 8
1.2.4.2	Chirality 10
1.2.4.3	Electronic Properties of CNTs 10
1.2.4.4	Optical Properties of CNTs 11
1.2.4.5	Chemical Properties of CNTs 12
1.2.4.6	Defects in CNTs 13
1.2.4.7	CNTs Properties Modification by Chemical Functionalization Process 15
1.2.4.8	Applications of CNTs 21
1.2.4.9	Synthesis of CNTs 22
1.2.4.10	Analysis of CNTs by Raman Spectroscopy 32
1.3	Conclusion 38
	Declaration of Competing Interest 38
	Companies Dealing with Chemically Modified CNTs 39

Acknowledgments 39

References 39

## **2 Surface Modification Strategies for the Carbon Nanotubes 51**

*Shiv K. Prajapati, Tejas Agnihotri, and Aakanchha Jain*

- 2.1 Introduction 51
- 2.2 Classification of Carbon Nanotubes and Their Fabrication 52
  - 2.2.1 Arc-Discharge Method 52
  - 2.2.2 Laser Vapor Deposition 53
  - 2.2.3 Chemical Vapor Deposition (CVD) 53
- 2.3 Purification of CNTs 53
- 2.4 Surface Modification of CNTs 54
  - 2.4.1 Methods of Functionalization 54
  - 2.4.2 Noncovalent Functionalization 55
  - 2.4.3 Covalent (Chemical) Functionalization 55
    - 2.4.3.1 Defect-Group Functionalization 56
    - 2.4.3.2 Sidewall Functionalization 56
    - 2.4.3.3 CNTs Functionalized with Polymer 56
    - 2.4.3.4 CNTs Functionalized with Biomolecules 58
    - 2.4.3.5 CNTs Functionalization with Ionic Liquid (ILs) 63
  - 2.4.3.6 Plasma Activated CNTs 65
- 2.5 Characterization of CNTs 65
- 2.6 Conclusion 65
- References 65

## **3 Latest Developments in Commercial Scale Fabrications for Chemically Modified Carbon Nanotubes 75**

*Shahidul Islam Bhat, Mohammad Mobin, Shayesta Islam, Mohd Irfan, Rabia Kouser, Kulsoom Koser, Ruby Aslam, and Saman Zehra*

Abbreviations 75

- 3.1 Introduction 75
- 3.2 Industrial Scale Fabrication Strategies 77
  - 3.2.1 Basic Chemical Vapor Deposition (CVD) Process 77
    - 3.2.1.1 Industrial Level Fabrication of CNT Through Various CVD Methods 77
    - 3.2.1.2 High-Pressure Chemical Vapor Deposition 78
    - 3.2.1.3 Atmospheric-Pressure Chemical Vapor Deposition (APCVD) 79
    - 3.2.1.4 Low-Pressure Chemical Vapor Deposition (LPCVD) 80
  - 3.3 CVD on the Basis of Reactor Wall Temperature 81
    - 3.3.1 Hot-Wall Chemical Vapor Deposition (Hot-Wall CVD) 81
    - 3.3.2 Cold-Wall Chemical Vapor Deposition (Cold-Wall CVD) 81
  - 3.4 Arc-Discharge 82
  - 3.5 Laser Vaporization 83
  - 3.6 Other Synthesis Methods 84
  - 3.7 Applications 85
    - 3.7.1 Transistors 85

3.7.2	Conductor	85
3.7.3	Composites	86
3.7.4	Aerogels	86
3.8	Future Scope	86
3.9	Conclusion	87
	Conflict of Interest	87
	Other Sources	87
	Acknowledgments	87
	References	88

#### **4 Economical Uses of Chemically Modified Carbon Nanotubes** 95

*Sheerin Masroor, Lalan Kumar, and Irshad Ahmad*

4.1	Introduction	95
4.2	Properties of Carbon Nanotubes	96
4.3	Synthesis of Carbon Nanotubes	97
4.4	Functionalization of Carbon Nanotubes	97
4.5	Characterization/Analysis of Functionalized Carbon Nanotubes	98
4.6	Economy of Carbon Nanotubes	99
4.7	Economic Importance of Carbon Nanotubes	99
4.8	Hydrogen Fuel Cells	99
4.9	Water Splitting	101
4.10	Dye-Sensitized Solar Cells	101
4.11	Quantum Dot Solar Cells	102
4.12	Silicon-Based Solar Cells	102
4.13	Thermoelectric Fabrics	102
4.14	Cost of Carbon Nanotubes	103
4.15	Globalization of Carbon Nanotubes	103
4.16	Conclusion	104
	References	104

### **Part II Chemically Modified Carbon Nanotubes: Energy and Environment Applications** 107

#### **5 Chemically Modified Carbon Nanotubes in Energy Production and Storage** 109

*Manal G. Mohamed, Ahmed A. Mousa, and Azza M. Mazrouaa*

Abbreviations 109

5.1	Introduction	110
5.2	Production of Carbon Nanotubes	111
5.3	History of Energy Storage Devices and Materials	113
5.4	Carbon Nanotubes for Energy Storage	114
5.4.1	Carbon Nanotube Hybrid for Lithium-Metal Batteries	117
5.4.2	Wearable Energy Storage with Fiberic Carbon Nanotube	118

5.4.3	Carbon Nanotube Hybrid for Supercapacitor Energy Storage	118
5.4.4	Carbon Nanotubes/Biochar for Energy Storage	120
5.5	Present and Future of Carbon Nanotubes	121
5.6	Commercial-Scale Application of Chemically Modified CNTs for Energy Storage	122
5.7	Companies Produced CNTs for the Application of Chemically Modified Carbon Nanotubes for Energy Storage	123
	References	123
<b>6</b>	<b>Chemically Modified Carbon Nanotubes for Pollutants Adsorption</b>	129
	<i>Suresh Ranganathan, Saravanan Rajendran, and Lorena C. Ponce</i>	
6.1	Introduction	129
6.2	Chemically Modified CNTs	131
6.3	Chemically Modified CNTs for Adsorptive Removal of Pollutants	133
6.3.1	Organic Dyes	134
6.3.2	Removal of Pharmaceuticals	134
6.3.3	Other Organic Pollutants	136
6.3.4	Metal Ions	137
6.4	Influencing Factors	139
6.5	Adsorption Mechanisms of Chemically Modified CNTs	141
6.6	Modified CNT-Based Materials Toward Commercialization	143
6.7	Conclusion and Future Perspectives	143
	Acknowledgments	144
	References	144
<b>7</b>	<b>Chemically Modified Carbon Nanotubes in Removal of Textiles Effluents</b>	151
	<i>Mohammad Ehtisham Khan, Akbar Mohammad, Wahid Ali, and Abdulrahman Ahmed Sharwani</i>	
7.1	Introduction	151
7.2	History of Removal of Textiles Effluents	152
7.3	Chemically Modified Carbon Nanotubes	152
7.3.1	Chemical Properties	152
7.3.2	Modification Through Chemical Reduction of Diazonium Salts	153
7.4	Dyes Removal Techniques	154
7.5	Adsorption	156
7.6	Carbon-Based Nanoadsorbents	156
7.7	Carbon Nanotubes	157
7.8	Carbon Nanotubes as an Adsorption of Dye Molecules	157
7.9	Industrial Application of Synthetic Dyes	158
7.10	Conclusion	160
	Acknowledgment	160
	References	161

<b>8</b>	<b>Chemically Modified Carbon Nanotubes in Membrane Separation</b>	<b>169</b>
	<i>R. Aiswarya and T. Kalaivani</i>	
8.1	Introduction	169
8.2	Carbon Nanotubes (CNTs) Overview	171
8.3	Method of Synthesis of Carbon Nanotube (CNT)	173
8.3.1	Arc Discharge	173
8.3.2	Laser Ablation	174
8.3.3	Chemical Vapor Deposition (CVD)	174
8.3.4	Hydrothermal	174
8.3.5	Electrolysis	174
8.4	Fabrication Methods of CNTs	175
8.4.1	Fabrication of CNT-Reinforced Metal Matrix Composites (CNT-MMCs)	175
8.4.2	Microwave-Assisted Fabrication of CNTs	176
8.5	Functionalization of CNTs	176
8.6	Chemically Modified Derivatization of CNTs	176
8.6.1	Electrochemically Assisted Covalent Modification	177
8.7	Polymer Grafting	178
8.8	Carbon Nanotubes Enhanced with Nanoparticles	179
8.9	Advantages of CNTs	180
8.10	Challenges in CNTs	180
8.11	Applications of CNTs as Membrane Separation	182
8.11.1	Water Treatment	182
8.11.2	Air Filtration	182
8.11.3	Energy Storage: Capacitors and Batteries	183
8.11.4	Electrochemical Separation and Catalysis	184
8.11.5	Electronic Devices Fabrication	184
8.11.6	Environment	184
8.11.7	Biology and Agriculture	185
8.12	Commercial-Scale of Chemically Modified CNTs in Membrane Separation	185
8.13	Future Insights	186
8.14	Conclusion	187
	References	188
<b>9</b>	<b>Chemically Modified Carbon Nanotubes for Water Purification System</b>	<b>197</b>
	<i>Azza M. Mazrouaa, Ahmed A. Mousa, and Manal G. Mohamed</i>	
	Abbreviations	197
9.1	Introduction	198
9.2	History of Water Purification Methods	199
9.3	Carbon Nanotubes CNTs Types	199
9.4	Vital of Modification of CNTs	200
9.5	Surface Modified CNTs for Water Purification	200

- 9.6 Polymer/CNTs Grafting for Water Purification 202
- 9.7 Bulk Modified CNTs for Water Purification 202
- 9.8 Important of Carbon Nanotubes for Water Purification 203
- 9.9 Conclusions and Future Research Directions 209
- 9.10 Commercial Application of Chemically Modified CNTs in Water Purification 209
- 9.11 Companies Produced CNTs for the Application of Chemically Modified Carbon Nanotubes for Water Purification System 210
- References 210

### **Part III Chemically Modified Carbon Nanotubes: Electronic and Electrical Applications 215**

#### **10 Chemically Modified Carbon Nanotubes for Electronics and Photonic Applications 217**

*Swetapadma Praharaj and Dibyaranjan Rout*

- 10.1 Introduction 217
- 10.2 Chemical Modifications of CNTs 218
  - 10.2.1 Oxidative Functionalization of CNTs 220
  - 10.2.2 Polymer/Ionic Liquid Modification of Oxidized CNTs 220
  - 10.2.3 Direct Covalent Modification of CNT 222
  - 10.2.4 Heteroatom Doping of CNTs 224
  - 10.2.5 Charge Transfer/Noncovalent Doping of CNTs 226
- 10.3 Chemically Modified CNTs in Electronics 227
  - 10.3.1 Transistors 227
  - 10.3.2 Rectifying Diodes 229
  - 10.3.3 Bioelectronics 229
- 10.4 Chemically Modified CNTs in Photonics 230
  - 10.4.1 Organic Photovoltaics (OPV) 231
  - 10.4.2 Organic Light-Emitting Diodes (OLEDs) 231
  - 10.4.3 Touch Panels 232
- 10.5 Summary and Future Scope 235
- References 236

#### **11 Chemically Modified Carbon Nanotubes for Electrochemical Sensors 241**

*Ajazar Khan, Khalid A. Alamry, and Raed H. Althomali*

- 11.1 Introduction 241
- 11.2 Functionalization of Carbon Nanotubes Toward Sensors 244
  - 11.2.1 Covalent Functionalization of CNTs Toward Sensing 244
  - 11.2.2 Noncovalent Functionalization of CNTs Toward Sensing 245
  - 11.2.3 Polymers Wrapping of CNTs Toward Sensing 246
  - 11.2.4 CNTs Decorated with Metal Nanoparticles Toward Sensing 247
- 11.3 Electrochemical Sensing Applications of CNTs 248

11.3.1	CNT-Based Sensors for Environment Protection	250
11.3.2	CNT-Based Sensors for Pharmaceutical Applications	251
11.3.3	Monitoring of Biomolecular Compounds	252
11.3.3.1	Glucose Sensor	252
11.3.3.2	DNA Sensor	254
11.3.4	CNTs-Based Sensors for Real Sample Analysis	256
11.4	Summary and Outlook	257
	References	259
<b>12</b>	<b>Chemically Modified Carbon Nanotubes for Lab on Chip Devices</b>	<b>271</b>
	<i>Sudhakar Bansod, Tanvir Arfin, Reena Singh, Shaz Ahmad, and Krishna Neeti</i>	
	Abbreviations	271
12.1	Introduction	272
12.2	Allotropes of Carbon	273
12.2.1	Diamond	273
12.2.2	Graphite	274
12.2.3	Fullerenes	274
12.2.4	Carbon Nanotubes	275
12.2.4.1	SWCNT: Various Synthesis Methods	276
12.2.4.2	Growth Catalysts for SWCNT	279
12.2.4.3	Approach of Introducing the Catalyst on SWCNTs (CVD) Growth	280
12.2.5	Double-Walled Carbon Nanotubes (DWCNTs)	280
12.2.5.1	Development of DWCNTs	280
12.2.5.2	Purification of DWCNTs	281
12.3	Carbon Nanotube Used in Solar Cells	281
12.4	Carbon Nanotube Used in Optical Sensors	282
12.5	Carbon Nanotube Used in Light-Emitting Diodes	283
12.6	Carbon Nanotube Used in Electronic Device Fabrication	283
12.7	Carbon Nanotube Used in Lithium-Ion Batteries (LIBs)	284
12.8	Carbon Nanotube Used in Chip Cooling	284
12.9	Carbon Nanotube Used in Photovoltaic Devices	285
12.10	Carbon Nanotube Used in Nonvolatile Random Access Memory	286
12.11	Carbon Nanotube Used in Potential Device	286
12.12	Carbon Nanotube Used in On-Chip Inductor	286
12.13	Carbon Nanotube Used in Electronic Device	287
12.14	Carbon Nanotube Used in Quantum CNFETs	287
12.15	Carbon Nanotube Used in Schottky-Barrier Ballistic CNFETs	288
12.16	Carbon Nanotube Used in Chemical Sensors and Biosensors	288
12.17	Carbon Nanotube Used in Field Emission of Electrons	289
12.18	Carbon Nanotube Used in Supercapacitor Devices with Enhanced Electrochemical Performance	290
12.19	Carbon Nanotube Used in Flip-Chip High Power Amplifiers	290
12.20	Carbon Nanotube Used in Transistor Device Application	291
12.21	Carbon Nanotube Used in Supercapacitors and Batteries	291

12.22	Future Scope	292
12.23	Conclusion	292
	Acknowledgments	292
	References	293

## **Part IV Chemically Modified Carbon Nanotubes: Biomedical Applications 299**

<b>13</b>	<b>Chemically Modified Carbon Nanotubes in Cancer Therapy</b>	<b>301</b>
	<i>Tejas Agnihotri, Shiv K. Prajapati, Shyam S. Gomte, and Aakanchha Jain</i>	
13.1	Introduction	301
13.2	Carbon Nanotubes as Novel Nanocarriers	302
13.2.1	CNTs as an Alternative to Conventional Carriers	302
13.2.2	Biodistribution, Biocompatibility, and Cellular Uptake Mechanism of CNTs	304
13.3	The Need for Chemical Modification and Its Importance	305
13.4	Chemically Modified Approaches of Carbon Nanotubes	306
13.4.1	Covalent Chemical Modifications of CNTs	306
13.4.1.1	Oxidation of CNTs	307
13.4.1.2	1,3-Dipolar Cycloaddition of Azomethine Ylides	309
13.4.1.3	Halogenation	311
13.4.1.4	Nucleophilic and Electrophilic Additions	311
13.4.1.5	Electrochemical Modifications	312
13.4.1.6	Radical Additions	312
13.4.1.7	Nitrene Cycloaddition	312
13.4.2	Non-Covalent Modifications of CNTs	313
13.4.2.1	Electrostatic and $\pi$ - $\pi$ Interactions	313
13.4.2.2	Adsorption of PEGylated Derivatives	314
13.4.2.3	Adsorption of Enzymes, Proteins, DNA, Polymers, and Carbohydrates	314
13.5	Chemically Modified Carbon Nanotubes as a Nanocarrier for Cancer Delivery System	314
13.5.1	Chemotherapeutic Agents (Small Drugs)	314
13.5.2	Biologicals, Vaccines, Tumor-Derived Antigens	316
13.5.3	Adjuvants	317
13.5.4	Gene Therapy	317
13.5.4.1	Oligonucleotides (ODNs)	318
13.5.4.2	DNA/RNA Aptamers	318
13.5.5	Diagnostic Tool for Cancer	319
13.6	Limitations and Challenges of Chemically Modified CNTs	322



13.7	Conclusion and Future Perspective	323
	References	324
<b>14</b>	<b>Chemically Modified Carbon Nanotubes in Drug Delivery</b>	<b>331</b>
	<i>Sougata Ghosh, Sirikanjana Thongmee, and Ebrahim Mostafavi</i>	
14.1	Introduction	331
14.2	Antibacterial	332
14.3	Antifungal	333
14.4	Anticancer	336
14.5	Others	338
14.6	Conclusions and Future Perspectives	339
	Acknowledgments	341
	References	341
<b>15</b>	<b>Chemically Modified Carbon Nanotubes in Tissue Engineering</b>	<b>347</b>
	<i>Richika Ganjoo, Shveta Sharma, and Ashish Kumar</i>	
15.1	Introduction	347
15.2	Applications of Modified Carbon Nanotubes in Tissue Engineering	348
15.2.1	Neural Tissue Engineering	348
15.2.2	Cardiac Tissue Engineering	351
15.2.3	Bone Tissue Engineering	354
15.2.4	Dental Tissue Engineering	357
15.3	Conclusion and Future Outlook	360
	Few Websites Related to CNTs Engineering	361
	References	361
<b>16</b>	<b>Applications of Chemically Modified Carbon Nanotubes for Tissue Engineering</b>	<b>365</b>
	<i>Yasaman Esmaeili, Seyede Z. Mirahmadi-Zare, Ashkan Bigham, Maryam Boshtam, Saba Gharghish, and Raha Zomorodi</i>	
16.1	Introduction	365
16.2	Biochemical Modifications for Tissue Engineering	366
16.2.1	Polymer-based Modification	366
16.2.2	Hydrogel-based Modification	369
16.2.3	Nanoparticle-based Modification	372
16.3	Tissue Engineering Applications of Carbon Nanotubes	376
16.3.1	Application in Bone Tissue Engineering	376
16.3.2	Application in Nervous System Engineering	379
16.3.3	Application in Cardiovascular Tissue Engineering	384
16.4	Challenges and Future Perspectives	387
	References	388

## Part V Chemically Modified Carbon Nanotubes: Construction Applications 397

- 17 Chemically Modified Carbon Nanotubes in Cement and Concrete Field 399**  
*Ruby Aslam*
- 17.1 Introduction 399
- 17.2 CNT Dispersion in Cement-Based Materials: Methodologies 401
- 17.3 Improvement of Concrete Properties by Addition of CNTs 401
- 17.4 Improvement in the Hydration Reaction 401
- 17.5 Improvement in Mechanical Properties and Relevant Mechanisms 402
- 17.6 Enhanced Durability 406
- 17.7 Improvements in Electrical and Thermal Conductivity 407
- 17.8 Improvements in Corrosion Resistance Properties of Cement/Concrete 408
- 17.9 Potential Structural Applications of CNTs Reinforced Cement-Based Materials 411
- 17.10 Challenges 412
- 17.11 Conclusions and Future Scope 413
- References 414

## Part VI Chemically Modified Carbon Nanotubes: Emerging Applications 419

- 18 Chemically Modified Carbon Nanotubes in 3D and 4D Printing 421**  
*Krishna K. Yadav, Arushi Arora, Sushma Jangra, and Menaka Jha*
- 18.1 Introduction 421
- 18.2 Method for the Carbon Nanotubes (CNTs) Modification 425
- 18.2.1 Polymer Grafting 426
- 18.2.2 Electrodeposition 427
- 18.2.3 Electroless Deposition (ELD) 428
- 18.2.4 Modification Through Covalent Attachment 428
- 18.2.5 Thermal-Assisted Chemical Covalent Functionalization 428
- 18.3 Chemically Modified CNT for 3D Printing 428
- 18.3.1 Commercially Available CNTs for Printing Technology 429
- 18.4 Application of Chemically Modified CNTs for 3D Printing 430
- 18.4.1 Mechanical Properties Enhancement 430
- 18.4.2 Energy Storage Devices 431
- 18.5 Modified CNTs for 4D Printing Technique 432
- 18.5.1 Shape Memory Functionalized for Liquid Sensors 432
- 18.5.2 4D Printing of Stretchable Supercapacitors 434
- 18.6 Boundaries for 3D/4D Printings and Prospects 434

18.6.1	Material Revolution	434
18.6.2	Interfacial Properties of Polymer-CNT and Homogeneous Distribution	435
18.6.3	Future Scope	435
18.7	Conclusions	436
	References	436
	Questions	439
<b>19</b>	<b>Chemically Modified Carbon Nanotubes for Tribology Applications</b>	<b>441</b>
	<i>Aslam Hossain, R. Manu, and S.M.A. Shibli</i>	
19.1	Introduction	441
19.2	Tribological Phenomena – Principle, Mechanism, and Application	442
19.3	Contemporary Research on Carbon Nanomaterials for Tribological Application	443
19.4	Improvement of Tribological Behaviors of Bulk CNT Materials	445
19.4.1	Molecular Simulation for Functionalized CNT Materials for Nano Tribology	446
19.4.2	Probing Complexities in Friction and Wear Properties of Functionalized CNT Materials	448
19.4.3	Advances in Surface Engineering of CNTs for Tuning Friction and Wear Properties	449
19.5	Recent Advances in Hybrid CNT Materials in Tribological Application	449
19.5.1	Lubrication Properties of CNTs	450
19.5.2	Tuning Additive Morphology and Wettability for Superlubricity in CNTs	450
19.5.3	Development of CNTs-Based Frictionless Surface Coatings	451
19.5.3.1	Single-Walled CNTs (SWCNTs)	451
19.5.3.2	Multi-Walled CNTs (MWCNTs)	452
19.5.4	Synergistic Effect CNT and Conventional Tribo-Filler Materials in Property Enhancement	452
19.6	High-Temperature Tribology of CNTs	453
19.6.1	Friction and Wear at High Temperature	453
19.6.2	Control of Friction and Wear at High Temperatures	453
19.7	Biotribology of CNTs	453
19.7.1	Joint Tribology	454
19.7.2	Inspiring Biomimetic Materials in Tribology Application	454
19.8	Modified CNTs for Commercial-Scale Tribology Applications	455
19.9	Other Nanomaterials for Tribological Applications	456
19.10	Summary and Outlook	456
	References	458

## **20 Chemically Modified Carbon Nanotubes for Corrosion Protection 463**

*Iman Mohammadi, Seyyed Arash Haddadi, Mazdak Izadi, and Mohammad Mahdavian*

- 20.1 Introduction 463
- 20.2 Modification Approaches 464
  - 20.2.1 Oxidized CNTs 464
    - 20.2.1.1 CNTs-Based Barrier Coatings 465
    - 20.2.1.2 CNTs-Based Conductive Coatings 465
    - 20.2.1.3 CNTs-Based Sacrificial Coatings 466
  - 20.2.2 Silanized CNTs 468
  - 20.2.3 Polymer Grafting 469
    - 20.2.3.1 CPs 470
    - 20.2.3.2 Other Polymers 477
  - 20.2.4 Decoration with Inorganic Materials 478
  - 20.2.5 Loading with Corrosion Inhibitor 481
- 20.3 Commercial-Scale Application 482
- 20.4 Summary 482
- References 483

## **21 Chemically Modified Carbon Nanotubes and Sustainability 491**

*Shahidul Islam Bhat, Mohammad Mobin, Shayesta Islam, Mohd Irfan, Rabia Kouser, Kulsoom Koser, Ruby Aslam, and Saman Zehra*

- Abbreviations 491
- 21.1 Introduction 491
- 21.2 Chemically Modified Carbon Nanotubes 492
  - 21.2.1 Surface Modification 492
    - 21.2.1.1 Chemical Functionalization (Covalent Functionalization) 493
    - 21.2.1.2 Physical Modification (Non-covalent Functionalization) 496
- 21.3 Future Scope 499
- 21.4 Conclusion 499
  - Author's Contributions 499
  - Conflict of Interest 499
  - Other Sources 500
  - Acknowledgments 500
  - References 500

## **Index 505**