

Contents

Foreword *xvii*

Preface *xxi*

1	Graphene Chemical Derivatives Synthesis and Applications: State-of-the-Art and Perspectives	1
	<i>Maxim K. Rabchinskii, Maksim V. Gudkov, and Dina Yu. Stolyarova</i>	
1.1	Introduction	1
1.2	Graphene Oxide: Synthesis Methods and Chemistry Alteration	3
1.3	Graphene Oxide Reduction and Functionalization	6
1.4	Applications of CMGs	13
1.5	Concluding Remarks	15
	Acknowledgments	15
	References	16
 2	 2D/2D Graphene Oxide-Layered Double Hydroxide Nanocomposite for the Immobilization of Different Radionuclides	 21
	<i>Paulmanickam Koilraj and Keiko Sasaki</i>	
2.1	Introduction	21
2.2	Synthesis of GO/LDH Composite	22
2.2.1	Co-precipitation	22
2.2.2	Hydrothermal Preparation	23
2.2.3	Self-Assembly of LDH Nanosheets with GO Nanosheets	24
2.3	Removal of Radionuclides	24
2.3.1	U(VI) Removal	24
2.3.2	Sorption of Eu(III) with the Presence of GO on LDH	25
2.3.3	Co-remediation Anionic SeO_4^{2-} and Cationic Sr^{2+}	26
2.4	Conclusion	29
	References	29

3	2D Nanomaterials for Biomedical Applications	31
	<i>Poliraju Kalluru and Raviraj Vankayala</i>	
3.1	Introduction	31
3.1.1	Photothermal and Photodynamic Therapy	31
3.1.2	Bioimaging and Drug/Gene Delivery	34
3.1.3	Biosensors	37
3.1.4	Antibacterial Activity	39
3.1.5	Tissue Engineering and Regenerative Medicine	41
3.2	Conclusions	43
	References	43
4	Novel Two-Dimensional Nanomaterials for Next-Generation Photodetectors	47
	<i>Khurelbaatar Zagazusem and Zumuukhorol Munkhsaikhan</i>	
4.1	Introduction	47
4.2	2D Materials for PDs	49
4.2.1	Graphene	49
4.2.2	TMDs (Transition Metal Dichalcogenides)	49
4.2.3	MXenes (2D Transition Metal Carbides/Nitrides)	50
4.2.4	Xenes (Monoelemental 2D Materials)	50
4.3	The Physical Mechanism Enabling Photodetection	50
4.4	Characterization Parameters for Photodetectors	51
4.4.1	Responsivity	51
4.4.2	Detectivity	52
4.4.3	External Quantum Efficiency	52
4.4.4	Gain	52
4.4.5	Response Time	52
4.4.6	Noise Equivalent Power	52
4.5	Synthesis Methods for 2D Materials	53
4.5.1	Mechanical Exfoliation	53
4.5.2	Liquid Exfoliation	53
4.5.3	Chemical Vapor Deposition (CVD)	53
4.6	Photodetectors Based on 2D Materials	55
4.6.1	Photodetectors Based on Graphene	55
4.6.2	Photodetectors Based on MoS ₂	55
4.6.3	Photodetectors Based on BP	55
4.7	Photodetectors Based on 2D Heterostructures	56
4.8	Conclusions and Outlook	58
	References	58
5	2D Nanomaterials for Cancer Therapy	63
	<i>Naresh Kuthala</i>	
5.1	Introduction	63
5.2	2D Nanomaterials for Cancer Therapy	64
5.2.1	2D Nanomaterials for Combination PTT with PDT	64

- 5.2.2 2D-Nanomaterials for Combination PTT Therapy with Radiotherapy (RT) 68
- 5.2.3 2D Nanomaterials for Combination PTT Therapy with Sonodynamic Therapy (SDT) 70
- 5.2.4 2D Nanomaterials for Combination PTT Therapy with Immune Therapy (ImT) 73
- 5.3 Summary and Future Perspectives 76
- References 76

6 Graphene and Its Derivatives – Synthesis and Applications 81

Amer Al-Nafey

- 6.1 Introduction 81
- 6.2 Graphite 81
 - 6.2.1 Define 81
 - 6.2.2 Synthetic Graphite 82
 - 6.2.3 Characterized and Properties of Graphite 82
 - 6.2.3.1 Structure 82
 - 6.2.4 Applications 84
- 6.3 Graphene Oxide 84
 - 6.3.1 Define 84
 - 6.3.2 Synthetic of Graphene Oxide 84
 - 6.3.3 Characterized and Properties of Graphene Oxide 84
 - 6.3.3.1 Structure 84
 - 6.3.3.2 Properties of Graphene Oxide 87
 - 6.3.3.3 Applications of Graphene Oxide 88
 - 6.3.3.4 Few Examples 88
- 6.4 Reduced Graphene Oxide 89
 - 6.4.1 Define 89
 - 6.4.2 Synthetic of Reduced Graphene Oxide or Reduction of Graphene Oxide 89
 - 6.4.2.1 Thermal Reduction of GO 90
 - 6.4.2.2 Photocatalytic Method 94
 - 6.4.2.3 Electrochemical Method 95
 - 6.4.2.4 Other Methods 95
- 6.4.3 Characterized, Structure, and Properties of Reduced Graphene Oxide 95
 - 6.4.3.1 Structure 96
 - 6.4.3.2 Properties and Applications of Reduced Graphene Oxide 97
- 6.5 Graphene 98
 - 6.5.1 Define 98
 - 6.5.2 Synthesis of Graphene 98
 - 6.5.2.1 Chemical Vapor Deposition (CVD) 101
 - 6.5.2.2 Epitaxial Growth 102
 - 6.5.2.3 Mechanical Exfoliation 104

6.5.2.4	Chemical Reduction of Graphene Oxide (GO)	105
6.5.3	Characterized, Structure, and Properties of Graphene	105
6.5.3.1	Surface Properties	105
6.5.3.2	Electronic Properties	105
6.5.3.3	Optical Properties	106
6.5.3.4	Mechanical Properties	107
6.5.3.5	Thermal Properties	107
6.5.3.6	Photocatalytic Properties	108
6.5.3.7	Magnetic Properties	109
6.5.3.8	Characterizations of Graphene	109
6.5.3.9	Morphology (SEM, TEM, and AFM)	109
6.5.3.10	Raman Spectroscopy	111
6.5.3.11	X-ray Photoelectron Spectroscopy (XPS)	111
6.5.3.12	UV-Visible Spectroscopy	112
6.5.3.13	X-ray Diffraction (XRD)	114
6.5.3.14	Thermogravimetric Analysis (TGA)	114
6.5.3.15	FTIR Spectroscopy	115
6.5.4	Application of Graphene	116
	References	116
7	Recent Trends in Graphene – Latex Nanocomposites	125
	<i>Anand Krishnamoorthy</i>	
7.1	Introduction	125
7.2	Polymer Lattices – An Overview	125
7.3	Graphene – Background	127
7.4	Preparation and Functionalization of Graphene	128
7.5	Graphene – Latex Nanocomposites: Preparation Properties and Applications	129
7.6	Conclusions	137
	References	138
8	Advanced Characterization and Techniques	141
	<i>Raja Murugesan</i>	
8.1	Introduction	141
8.2	Characterization Techniques	141
8.2.1	Optical Techniques – Dynamic Light Scattering (DLS)	141
8.2.2	Optical Spectroscopy	144
8.2.3	NMR-Nuclear Magnetic Resonance Spectroscopy	145
8.2.4	Infrared Spectroscopy (IR) and Raman Spectroscopy	145
8.2.5	X-Ray Photoelectron Spectroscopy (XPS)	146
8.2.6	Characterization Based on Interactions with Electrons or Electron Microscopy (EM)	147

8.2.6.1	Scanning Electron Microscopy (SEM)	147
8.2.6.2	Transmission Electron Microscopy (TEM)	149
8.2.6.3	Scanning Transmission Electron Microscopy (STEM)	150
8.2.6.4	Scanning Tunneling Microscopy (STM)	151
8.2.7	Atomic Force Microscopy (AFM)	151
8.2.8	Kelvin Probe Force Microscopy (KPFM)	152
8.2.9	X-Ray-Based Techniques	152
	References	154
9	2D Nanomaterials: Sustainable Materials for Cancer Therapy Applications	157
	<i>Mamta Chahar and Sarita Khaturia</i>	
9.1	Introduction	157
9.2	Types of 2D Nanomaterials	158
9.3	Methods for the Synthesis of 2D Nanomaterials	160
9.4	Mechanism of Cancer Theranostics	162
9.5	Applications of 2D Nanomaterials	163
9.6	Conclusion	163
	References	169
10	Recent Advances in Functional 2D Materials for Field Effect Transistors and Nonvolatile Resistive Memories	175
	<i>Adnan Younis, Jawad Alsaei, Basma Al-Najar, Hacene Manaa, Pranay Rajan, El Hadi S. Sadki, Aicha Loucif, and Shama Sehar</i>	
10.1	Introduction to 2D Materials	175
10.2	Electronic Band Structure in 2D Materials	176
10.3	Electronic Transport Properties of 2D Materials	178
10.4	Two-Dimensional Materials in Field Effect Transistors	180
10.4.1	Field Effect Transistors	180
10.4.2	The Rise of 2D Materials Research in FETs	180
10.4.3	Graphene-Based Field Effect Transistors	181
10.4.4	2D Transition Metal Dichalcogenides (TMDCs) in Transistors	183
10.5	Two-Dimensional Materials as Nonvolatile Resistive Memories	184
10.5.1	Nonvolatile Resistive Memories Based on Graphene and Its Derivatives	185
10.5.2	Resistive Switching Memories in 2D Materials “Beyond” Graphene	187
10.5.2.1	Solution-Processed MoS ₂ -Based Resistive Memories	187
10.5.2.2	Solution-Processed Black Phosphorous Nonvolatile Resistive Memories	188
10.5.2.3	Emerging NVM Based on Hexagonal Boron Nitride (h-BN)	188
10.6	Conclusions and Outlook	189
	References	190

11 2D Advanced Functional Nanomaterials for Cancer Therapy 199

Raj Kumar, Naveen Bunekar, Sunil Dutt, Pulikanti G. Reddy, Abhishek K. Gupta, Keshaw R. Aadil, Vivek K. Mishra, Shivendra Singh, and Chandrani Sarkar

- 11.1 Introduction 199
- 11.2 2D Nanomaterials Classification 202
 - 11.2.1 Graphene Family Nanomaterials 202
 - 11.2.2 Transition Metal Dichalcogenides (TMDs) 203
 - 11.2.3 Layered Double Hydroxides (LDHs) 205
 - 11.2.4 Carbonitrides (MXenes) 206
 - 11.2.5 Black Phosphorus (BP) 206
- 11.3 Cancer Therapy 208
 - 11.3.1 Mechanism of Action in Cancer Therapy 212
 - 11.3.1.1 Mode of Action of 2D Nanomaterials 212
 - 11.3.1.2 Photodynamic Therapy for Cancer Cell Treatment 215
 - 11.3.2.1 Mechanism of Photodynamic Therapy 215
 - 11.3.2.2 2D Nanomaterials as Photosensitizer for PDT 217
 - 11.3.2.3 Application of 2D Nanomaterials in Photodynamic Therapy 217
 - 11.3.3 2D Nanomaterials-Cancer Detection/Diagnosis/Theragnostic 218
- 11.4 Tissue Engineering 219
- 11.5 Conclusion 220
- Acknowledgment 221
- References 221

12 Synthesis of Nanostructured Materials Via Green and Sol–Gel Methods: A Review 235

Ankit S. Bartwal, Rahul Thakur, Sumit Ringwal, and Satish C. Sati

- 12.1 Introduction 235
- 12.2 Methods Used in Nanostructured Synthesis 236
 - 12.2.1 Green Method of Nanoparticles Synthesis 236
 - 12.2.2 Sol–Gel Method of Nanoparticles Synthesis 236
 - 12.2.3 Green Method of Nanocomposites Synthesis 241
 - 12.2.4 Sol–Gel Method of Nanocomposites 241
- 12.3 Discussion 241
- 12.4 Conclusion 244
- References 244

13 Study of Antimicrobial Activity of ZnO Nanoparticles Using Leaves Extract of *Ficus auriculata* Based on Green Chemistry Principles 249

Gurpreet Kour, Ankit S. Bartwal, and Satish C. Sati

- 13.1 Introduction 249
- 13.2 Materials and Methods 250
 - 13.2.1 Chemicals 250

13.2.2	Methodology	250
13.2.3	Antimicrobial Activity	251
13.3	Results and Discussion	251
13.3.1	Characterization of Synthesized Zinc-Oxide Nanoparticles (ZnONPs)	251
13.3.1.1	XRD Analysis	251
13.3.1.2	FT-IR Analysis	252
13.3.1.3	SEM Analysis	254
13.3.1.4	TEM Analysis	254
13.3.2	Antibacterial Activity	254
13.4	Conclusion	255
	Acknowledgments	255
	References	255
14	Piezoelectric Properties of $\text{Na}_{1-x}\text{K}_x\text{NbO}_3$ near $x = 0.475$, Morphotropic Phase Region	257
	<i>Surendra Singh and Narayan S. Panwar</i>	
14.1	Introduction	257
14.2	Experimental Procedure	259
14.3	Results and Discussion	260
	References	262
15	Synthesis and Characterization of SDC Nano-Powder for IT-SOFC Applications	265
	<i>Bharati B. Patil</i>	
15.1	Introduction	265
15.1.1	Solid Oxide Fuel Cells (SOFCs)	265
15.1.2	Intermediate Temperature Solid Oxide Fuel Cells (IT-SOFCs)	266
15.1.3	Why Samarium-Doped Ceria (SDC) Material?	266
15.1.4	Various Synthesis Methods for SDC	267
15.1.5	Why SDC Synthesis by Combustion Process?	268
15.1.6	Why SDC Synthesis by Glycine Nitrate Combustion Process (GNP)?	268
15.1.7	Applications of SDC Material Related to Intermediate Temperature Solid Oxide Fuel Cells	269
15.1.7.1	Applications of SDC as SOFC Electrolyte	269
15.1.7.2	Applications of SDC to Make Composite Anode	269
15.1.7.3	Applications of SDC to Make Composite Cathode	270
15.1.7.4	Applications of SDC as an Interlayer	270
15.1.7.5	Applications of SDC as an Additional Anode Layer	270
15.2	Experimental	270
15.2.1	Powder Synthesis	270
15.2.2	Powder Characterization	271
15.3	Results and Discussion	272
15.3.1	TG-DTG Study	272

15.3.2	XRD Analysis	272
15.3.3	Powder Microstructure	276
15.3.3.1	SEM Analysis	276
15.3.3.2	TEM Analysis	277
15.3.3.3	EDAX Analysis	277
15.3.3.4	BET Analysis	278
15.3.4	Electrical Properties	278
15.4	Conclusions	281
	Acknowledgments	281
	References	282

16 Introduction of 2D Nanomaterials and Their Photocatalytic Applications 285

Kallappa Ramchandra Sanadi

16.1	Introduction	285
16.2	Definitions of Nanomaterials	286
16.3	History of Nanotechnology	286
16.3.1	Top-down Approach	286
16.3.2	Bottom-up Approach	286
16.4	Classification of Nanomaterials	286
16.4.1	Zero-Dimensional (0-D)	287
16.4.2	One-Dimensional (1-D)	287
16.4.3	Three-Dimensional (3-D)	287
16.4.4	Two-Dimensional (2-D)	287
16.4.4.1	Synthetic Methods	288
16.5	Characterization Techniques for 2D Nanomaterials	290
16.6	Applications of 2D Nanomaterials	291
16.7	Photocatalytic Application	291
16.7.1	Why Photocatalyst?	291
16.7.2	Brief History of Photocatalysis	292
16.7.3	Principles of Heterogeneous Photocatalysis	292
16.7.4	Photocatalytic Study of 2D Nanomaterials	293
16.7.5	Challenges Behind 2D Nanomaterials as a Photocatalyst	294
	References	294

17 Graphene and Its Analogous 2D-Layered Materials for Flexible Persistent Energy Storage Devices in Consumer Electronics 297

Himadri Tanaya Das, K. Hariprasad, and T. E. Balaji

17.1	Introduction	297
17.2	Brief Sketch of the Types of SC and Its Working Mechanism	298
17.3	Evolution of Electrode Materials for Flexible Supercapacitors	300
17.4	Developing Graphene Electrodes with Different Nanocomposites	304
17.4.1	Other Carbon-Based Nanomaterials with Graphene	304
17.4.2	Using Organic Composites with Graphene	306

17.4.3	Conductive Polymer with Graphene	306
17.4.4	Combining Graphene with Other Metal Oxides/Hydroxides	308
17.4.5	Combining Graphene with Other 2D-Layered Materials	308
17.5	Novel Technologies to Develop Flexible Graphene-Based Supercapacitors	310
17.6	Conclusion	311
17.7	Future Aspects	313
	References	313
18	2D Dichalcogenides	317
	<i>Ram S. Singh, Varun Rai, and Arun K. Singh</i>	
18.1	Introduction	317
18.1.1	What Are 2D Dichalcogenides?	317
18.1.2	Properties	318
18.2	Methods of Synthesis	321
18.2.1	Top-Down Method	321
18.2.1.1	Micromechanical Exfoliation	321
18.2.1.2	Liquid Exfoliation	322
18.2.1.3	Chemical Intercalation and Exfoliation	322
18.2.1.4	Electrochemical Exfoliation	322
18.2.1.5	Thinning by Thermal Annealing, Laser, and Chemical Etching	323
18.2.2	Bottom-Up Method	323
18.2.2.1	Chemical Vapor Deposition	323
18.2.2.2	Solvo-Thermal	324
18.2.2.3	Molecular Beam Epitaxy	325
18.3	Modification of Properties	325
18.4	Applications	327
18.4.1	Optoelectronics	327
18.4.2	Sensors	329
18.4.3	Spintronics	329
18.4.4	Photocatalysis	329
18.4.5	Biomedical Applications	330
18.5	Conclusion	330
	Acknowledgment	330
	References	331
19	Recent Trends on Graphene-Based Metal Oxide Nanocomposites Toward Photoelectrochemical Water Splitting Application	335
	<i>Kashinath Lellala and Mouni Roy</i>	
19.1	Introduction	335
19.1.1	Basic of Photo-Anode/Cathode	335
19.1.2	Properties of PEC	336
19.1.3	Importance of Catalyst/Electrode	336
19.1.4	Fundamental Concept of Photo-Electrochemical Water Splitting	337

19.1.4.1	Light-Catalyst Interaction	337
19.1.4.2	Electron-Hole Pair	337
19.1.4.3	Carrier Transportation-Separation	338
19.1.4.4	Water Splitting Reaction	339
19.1.4.5	Nature of Electrolyte	339
19.1.4.6	Catalysis	339
19.1.4.7	Crystallinity and Size	340
19.1.4.8	Temperature and Pressure	340
19.1.4.9	Heterogeneous Electron Transfer	340
19.1.4.10	pH Dependency	340
19.2	Graphene and Graphene-Based Nanocomposites	340
19.2.1	Graphene	340
19.2.2	Graphene-Based Nanocomposites	341
19.3	Synthesis of Graphene-Based Metal Oxide Nanocomposites	342
19.4	Application of Graphene-Metal Oxide Composites Toward Photoelectrochemical Water Splitting	345
19.5	Summary and Future Perspective	349
	References	349
20	2D MOFs Nanosheets	357
	<i>Arezou Mohammadinezhad</i>	
20.1	Introduction	357
20.2	Synthetic Strategies	357
20.2.1	Top-Down Method	358
20.2.1.1	Sonication Exfoliation	358
20.2.1.2	Mechanical Exfoliation Method	359
20.2.1.3	Chemical Exfoliation	359
20.2.1.4	Langmuir-Blodgett Method	359
20.2.1.5	Solvent-Induced Exfoliation	359
20.2.2	Bottom-Up Method	359
20.2.2.1	Interfacial Synthesis Method	360
20.2.2.2	Surfactant-Assisted Method	360
20.2.2.3	Template Method	360
20.2.2.4	Sonication Synthesis Method	360
20.2.3	Other Synthesis Methods	361
20.3	Applications of 2D MOFs Nanosheets	361
20.3.1	Gas Separation	361
20.3.2	Energy Conversion and Storage	361
20.3.3	Catalysis	362
20.3.4	Sensing Platforms	362
20.3.5	Biomedicine	362
20.4	Composites of 2D MOF Nanosheets	362
20.5	Conclusion	363
	References	363

21	Introduction and Applications of 2D Nanomaterials	369
	<i>Atta U. Rehman, Fatima Afzal, Muhammad T. Ansar, Amna Sajjad, and Muhammad A. Munir</i>	
21.1	Introduction	369
21.2	Applications of 2D Nanomaterials	371
21.2.1	Photodetectors	371
21.2.2	Phototransistors	371
21.2.3	p-n Junction Photodetectors	372
21.2.4	Field-Effect Transistors	373
21.2.5	Gas Sensors	373
21.2.6	Lithium-Ion Batteries	374
21.2.7	Lithium-Ion Battery Anodes	374
21.2.8	Lithium-Ion Battery Cathodes	375
21.2.9	Graphene as Current Collector	376
21.2.10	Graphene in Supercapacitors	376
21.2.11	Graphene Nanocomposites with Distinct Materials	377
21.2.12	Doping and Surface Modifications	378
21.2.13	Graphene for Gas Sensors	379
21.3	Conclusion	379
	References	380
22	2D Nanomaterials for Photocatalysis and Photoelectrocatalysis	383
	<i>Gubbala V. Ramesh, N. Mahendar Reddy, Muvva D. Prasad, D. Saritha, and Kola Ramesh</i>	
22.1	Introduction	383
22.2	Photocatalytic CO ₂ Reduction	385
22.3	Photoelectrocatalytic CO ₂ Reduction	388
22.4	Photocatalytic Hydrogen Production	391
22.5	Photoelectrocatalytic Hydrogen Production	395
22.6	Photocatalytic Dye Degradation	397
22.7	Conclusion	401
	References	402
	Index	413