

Contents

Preface *xi*

List of Abbreviations *xiii*

1 Graphene-Based Materials: Structure and Properties *1*

Xiaoyang Deng and Yue Li

1.1 Introduction to Carbon Materials *1*

1.2 History of Graphene *5*

1.3 Structure of Graphene *6*

1.4 Properties of Graphene *7*

1.5 Structure Defects of Graphene *9*

1.5.1 Carbon Adatoms Defects *10*

1.5.2 Graphene Extrinsic Defects *11*

1.6 Different Dimensional Graphene *12*

1.6.1 3D Graphene Architectures (3DG) *14*

1.7 Graphene Composites *15*

1.7.1 Graphene/Conductive Polymer Composites *15*

1.7.2 Graphene/Inorganic Composites *16*

1.8 Applications of Graphene *17*

References *18*

2 Graphene Synthesis: An Overview of Current Status *25*

Simi Sui

2.1 Top-Down Approaches *25*

2.1.1 Mechanical Cleavage *25*

2.1.2 Exfoliation *26*

2.1.2.1 Liquid Exfoliation *26*

2.1.2.2 Solid Exfoliation *27*

2.1.2.3 Oxidation–Exfoliation–Reduction *27*

2.1.2.4 Intercalation Exfoliation *28*

2.2 Bottom-up Approaches *29*

2.2.1 Epitaxy Growth *29*

2.2.1.1 Direct Thermal Annealing *29*

2.2.1.2 Molecular-Beam Epitaxy (MBE) *29*

2.2.2	Chemical Vapor Deposition on Metal Substrate	29
2.2.3	CVD on Nanoporous Metal Template	31
2.2.4	Powder Metallurgy Template Method	31
2.2.5	Soluble-Salt-Template Methods	32
2.2.6	Other Methods	33
2.2.6.1	CNTs Unzipping	33
2.2.6.2	Molecular Self-Assembly	33
2.2.6.3	Laser Ablation	34
2.2.6.4	Pyrolysis of Solid Carbon Sources	34
	References	35
3	Nanoporous Metal Template Methods	41
	<i>Kaiqiang Qin</i>	
3.1	Introduction	41
3.2	Dealloying Method for the Preparation of Nanoporous Metal Foil	41
3.3	Nanoporous Ni as the Substrate for the Growth of 3D Nanoporous Graphene	42
3.3.1	3D Nanoporous Graphene	42
3.3.2	Heteroatoms-Doped 3D Nanoporous Graphene	44
3.3.2.1	N-Doped 3D Nanoporous Graphene	44
3.3.2.2	N, S Co-Doped 3D Nanoporous Graphene	46
3.3.2.3	N, S, P Tri-Doped 3D Nanoporous Graphene	47
3.3.2.4	N and Ni Single Atoms Co-Doped 3D Nanoporous Graphene	47
3.3.2.5	Li Metal Anode Application of 3D Nanoporous Graphene	48
3.3.3	3D Nanoporous rGO	48
3.3.4	3D Nanoporous Graphene-Based Composite Materials	49
3.4	Nanoporous Cu as the Substrate for the Growth of 3D Nanoporous Graphene	49
3.4.1	Continuously Hierarchical Nanoporous Graphene	49
3.4.2	Heteroatoms-Doped 3D Nanoporous Graphene	51
3.4.3	3D Nanoporous Graphene-Based Composites	54
	References	57
4	Soluble-Salt-Template Methods	61
	<i>Ming Liang and Chunnian He</i>	
4.1	Salt-Template Methods	61
4.1.1	The Effects of Different Kinds of Salts	62
4.1.2	The Acquisition Method of Salt Templates	68
4.1.3	The Other Important Influencing Parameters	72
4.2	Salt-Template-Directed Graphene-Based Materials	73
4.2.1	2D Graphene-Based Materials	73
4.2.2	3D Porous Graphene-Based Materials	78
4.3	Outlook	86
	References	87

5	Powder Metallurgy Templates Methods	95
	<i>Junwei Sha, Xiaoyu Chu, Yuxuan Wang, Meixian Li, Chunnnian He, and Naiqin Zhao</i>	
5.1	Powder Metallurgy	95
5.2	Powder Metallurgy Templates Methods	96
5.2.1	Basic Synthesis Procedures of PMT Method	96
5.2.2	The Selection of Metal Templates	97
5.2.3	The Selection of Carbon Sources	102
5.2.4	The Influence of Metal Templates/Carbon Sources Ratio	103
5.2.5	The Influence of Heating Temperature and Heating Method	104
5.2.6	The Influence of Cold-Pressing Pressure	105
5.3	Mechanism of Powder Metallurgy Templates Method	106
5.4	3D GM and Its Composites Prepared by PMT Method	108
5.5	Additive Manufacturing	113
5.6	Outlook for PMT and Additive Manufacturing Method	118
	References	118
6	Graphene-Based Materials for Lithium/Sodium-Ion Batteries	123
	<i>Biao Chen</i>	
6.1	Introduction	123
6.2	Graphene-Based Insertion Composites	125
6.2.1	TiO ₂ /Graphene Composites	125
6.3	Graphene-Based Alloying-Type Composites	131
6.3.1	Metal/Graphene Alloy-Type Composites	131
6.3.2	Nonmetal/Graphene Alloy-Type Composites	136
6.4	Graphene-Based Conversion-Type Composites	139
6.4.1	Transition Metal Oxides/Graphene Composites	139
6.4.2	Transition Metal Sulfides/Graphene Composites	142
6.4.2.1	Conventional Metal Sulfides/Graphene Composites	142
6.4.2.2	2D Metal Disulfides/Graphene Composites	146
6.5	Summary and Outlook	151
	References	152
7	Graphene-Based Materials for Lithium-Metal Batteries	163
	<i>Rui Zhang</i>	
7.1	Graphene-Based Nanoscale Layers	166
7.2	Graphene-Based Hosts for Li Storage	169
7.2.1	Graphene-Based Hosts with High SSA	170
7.2.2	Free-Standing 3D Graphene-Based Hosts	170
7.3	Heteroatom-Doped Graphene for Uniform Lithium Nucleation	174
7.4	Graphene Combined with Other “lithiophilic” Materials	179
7.5	Outlook	183
	References	183

8	Graphene-Based Materials for Li–S Batteries	189
	<i>Ning Wang</i>	
8.1	Development History of Li–S Batteries	189
8.2	Working Mechanism of Li–S Battery	190
8.3	Challenges of Li–S Batteries	191
8.4	Overview of the Graphene as Host for S	193
8.4.1	High-Quality Graphene	194
8.4.2	Heteroatom-Doped Graphene	195
8.4.3	Functionalized Graphene	197
8.4.4	Structure-Designed Graphene	197
8.4.5	Graphene-Based Composites	199
8.4.6	Metal Compound Anchored on Graphene	201
8.4.7	Metal Compounds Anchored on Carbon Composite Material	204
8.4.8	Graphene Used in Separator	206
8.4.8.1	Carbon Material as a Coating Layer	207
8.4.8.2	Carbon Material/Inorganic Metal Compound Composite as a Coating Layer	208
	References	210
9	Graphene-Based Materials for Supercapacitors	215
	<i>Shan Zhu, Chunlian He, and Naiqin Zhao</i>	
9.1	Supercapacitor	215
9.1.1	Fundamentals	215
9.1.2	Mechanism	216
9.1.3	Comparison Between Supercapacitor and Li-Ion Battery	218
9.1.4	Influencing Factors of Carbon-Based Supercapacitor	219
9.2	Graphene-Based Supercapacitor	221
9.2.1	Advantages of Graphene Used in Supercapacitors	221
9.2.2	Improving the Performance of Graphene-Based Supercapacitors	222
9.2.2.1	Design of Graphene Electrode	222
9.2.2.2	Heteroatom-Doping of Graphene	224
9.2.2.3	Constructing 3D Graphene by Template Method	225
9.2.2.4	Introducing Composition on Graphene	226
9.2.3	Advanced Graphene-Based Supercapacitors	230
9.2.3.1	Electrolyte Design	230
9.2.3.2	Asymmetric Supercapacitors	230
9.2.3.3	Metal-Ion Capacitor	232
9.2.3.4	Flexible Supercapacitor	233
9.2.3.5	Microsupercapacitor	236
9.3	Future Prospects	237
	References	239
10	Graphene-Based Materials for Electrocatalysis	245
	<i>Lechen Diao and Chunlian He</i>	
10.1	Introduction	245

10.2	Preparation of Graphene-Based Materials for Electrocatalysis	246
10.2.1	Heteroatom Doping Graphene-Based Materials	247
10.2.1.1	Single Doping Graphene	249
10.2.1.2	Multidoping Graphene	252
10.2.2	Edge and Defect Sites	253
10.2.3	Graphene as Supports	256
10.2.4	Template Method Synthesis of Graphene-Based Electrocatalysts	259
10.3	Application of Graphene-Based Electrocatalysts	260
10.3.1	Graphene-Based Electrocatalysts for Water Splitting	260
10.3.2	Graphene-Based Electrocatalysts for ORR	262
10.3.3	Graphene-Based Electrocatalysts for CO ₂ RR	264
10.3.4	Graphene-Based Electrocatalysts for NRR	266
10.4	Outlook	268
	References	268

Index 275