

Contents

Preface *xi*

1	Lignin-Derived Materials for Supercapacitors	1
	<i>Jesús Muñiz, Ana K. Cuentas-Gallegos, Miguel Robles, Alfredo Guillén-López, Diego R. Lobato-Peralta, and Jojhar E. Pascoe-Sussoni</i>	
1.1	Lignocellulosic Biomass Conversion to Value-Added Products	1
1.1.1	Cellulose	1
1.1.2	Hemicellulose	2
1.1.3	Lignin	4
1.2	Production of Carbon Materials by Thermochemical Processes	6
1.2.1	Hydrothermal Processing	7
1.2.1.1	Hydrothermal Processing Mechanism	7
1.2.2	Gasification	7
1.2.2.1	Lignocellulosic Biomass Gasification Mechanism	8
1.2.3	Pyrolysis	9
1.2.3.1	Lignocellulosic Biomass Pyrolysis	9
1.2.3.2	Fast Pyrolysis	10
1.2.3.3	Intermediate Pyrolysis	11
1.2.3.4	Slow Pyrolysis	11
1.2.4	Solar Pyrolysis	12
1.3	Nanoporous Carbon Obtained from Biomass for SC Applications	13
1.3.1	Supercapacitors	13
1.3.1.1	Electric Double-Layer Capacitors (EDLCs)	14
1.3.2	Carbon Materials for EDLC	16
1.3.2.1	Physical Activation	16
1.3.2.2	Chemical Activation	17
1.3.2.3	Pseudocapacitors	18
1.3.2.4	Hybrid Supercapacitors	19
1.4	Computational Simulation of Nanocarbon Structures from Lignin-Derived Materials with Potential Application in Energy Storage Devices	19
1.4.1	Computational Study of Lignin from Different Computational Approaches	19

1.4.2	Computational Studies of Lignin Through Pyrolysis-Simulated Molecular Dynamics	26
1.5	Tailoring Nanocarbon Structures to Enhance the Performance of Electrodes in Supercapacitors	31
1.5.1	MD to Aid the Design of EDLCs	34
1.6	Perspectives for Future Development	35
	Acknowledgments	36
	References	36
2	Some Aspects of Preparations and Applications of Electrochemical Double-Layer Capacitors (Supercapacitors)	53
	<i>Aleksandr E. Kolosov, Volodymyr Y. Izotov, Elena P. Kolosova, Volodymyr V. Vanin, and Anish Khan</i>	
2.1	Introduction	53
2.2	Supercapacitors and Rechargeable Batteries	55
2.3	Combined Electrodes for Double Electrochemical Layer Capacitors	56
2.3.1	Brief State-of-the-Art Analysis Regarding the Technical Means of Manufacturing Electrodes for Electrochemical Double-Layer Capacitor	56
2.3.2	Electrode Fabrication Method for Electrochemical Double-Layer Capacitors	57
2.3.3	Combined Electrode for Double Electrochemical Layer Capacitors	60
2.3.4	Improved Composite Electrode for Supercapacitors	63
2.4	Prospective Carbon Nanomaterials for Manufacturing Electrodes of Supercapacitors: Nanotubes and Graphene	67
2.5	Using Ultrasound while Getting Supercapacitors	69
2.6	Some Perspective Applications for Supercapacitors	70
2.7	Conclusions	72
	References	72
3	Metal Hydroxides for Supercapacitors	79
	<i>Viresh Kumar, Rigved Samant, Abu Faizal, and Himanshu S. Panda</i>	
3.1	Introduction	79
3.2	Unary Metal Hydroxides	81
3.2.1	Nickel Hydroxide (NH)	81
3.2.2	Cobalt Hydroxide	86
3.2.3	Iron Hydroxide	89
3.2.4	Manganese Hydroxide	91
3.2.5	Cadmium Hydroxide	91
3.2.6	Copper Hydroxide	93
3.3	Binary and Ternary Hydroxides	96
3.4	Summary	101
	References	105

4	Polyaniline-Based Materials for Supercapacitors	113
	<i>Asim A. Yaqoob, Mohamad N. M. Ibrahim, Akil Ahmad, Asma Khatoon, and Siti H. M. Setapar</i>	
4.1	Introduction	113
4.2	Significant Conducting Mechanism for Polyaniline	114
4.3	Properties of PANI-Based Supercapacitors	116
4.3.1	High-Rate Supercapacitors	116
4.3.2	Electrolytic Capacitors	116
4.3.3	Smart Supercapacitors	116
4.3.4	Carbon Precursor	117
4.3.5	Elastic Supercapacitors	117
4.4	Significance and Role of PANI Supercapacitors	118
4.5	Conclusion and Future Perspectives	121
	Acknowledgment	122
	References	123
5	Perovskites for Supercapacitors	131
	<i>Ehsan Rezaie, Abdollah Hajalilou, and Yuanhai Su</i>	
5.1	Introduction	131
5.2	Classifications and Structures of Perovskite Materials	132
5.2.1	Stoichiometry Perovskite Structure	132
5.2.2	Halide Double Perovskites	134
5.2.3	Organic–Inorganic Hybrid Perovskites	137
5.2.4	Cation- and Anion-Deficient Perovskite Structures	137
5.3	Supercapacitance Performance of Perovskite Materials	141
5.3.1	Capacitance Performance of Simple ABO_3 Perovskites with Different Morphologies	142
5.3.2	Effect of Element Doping in A-site on Supercapacitance Performance of Perovskite Materials	152
5.3.3	Effect of Element Doping in B-site on Supercapacitance Performance of Perovskite Materials	162
5.3.4	Effect of Cation Leaching on Capacitance Stability	168
5.4	Summary	175
	Acknowledgment	175
	References	176
6	General Synthesis Methods of Inorganic Materials for Supercapacitors	187
	<i>Mehmet H. Calimli, Tugba G. Karahan, Anish Khan, and Fatih Sen</i>	
6.1	Introduction	187
6.2	Synthesis of Inorganic Supercapacitors	190
6.2.1	Metal Oxides	190
6.2.1.1	Synthesis of Electrode Materials	191
6.3	Conclusions	195
	References	195

7	Conducting Polymer Carbon-Based Binary Hybrid for Supercapacitors	205
	<i>Rini Jain and Satyendra Mishra</i>	
7.1	Introduction	205
7.2	Conducting Polymers	206
7.2.1	Polyaniline (PANI)	206
7.2.2	Polypyrrole (PPy)	206
7.2.3	Poly(3,4-ethylenedioxythiophene) (PEDOT)	206
7.3	CP Application in Supercapacitors	206
7.3.1	Limitations of CP Electrode Supercapacitors	207
7.4	Carbonaceous Materials Used as Fillers for Conducting Polymers	207
7.4.1	Carbon Nanotubes	207
7.4.2	Carbon Fibers (CFs)	208
7.4.3	Graphene and Graphene Oxide (GO)	209
7.4.4	Reduced Graphene Oxide (RGO)	209
7.5	Nanocomposite Supercapacitor Application/Hybrid Supercapacitors	209
7.5.1	CP/CNT Nanocomposites	210
7.5.2	CPs/Graphene Composites	212
7.5.2.1	CPs/Graphene Oxide	213
7.5.2.2	CPs/Chemically Modified Graphene	214
7.6	Conclusions, Future Prospects, and Challenges	218
	References	219
8	New Inorganic Nanomaterials for Supercapacitors	225
	<i>Mehmet H. Calimli, Gokcem Dasdemir, Anish Khan, and Fatih Sen</i>	
8.1	Introduction	225
8.2	Experimental	227
8.2.1	Synthesis of $\text{ZnCo}_2\text{O}_4/\text{NiO}/\text{NF}$	227
8.2.1.1	Preparation of Nickel Foam (NF) Substrate	227
8.2.1.2	Synthesis of 2D $\text{ZnCo}_2\text{O}_4/\text{NF}$ Nanoflake Structures	227
8.2.2	Fabrication ZnWO_4 Nanoparticles	229
8.2.3	Procedure of Fabrication of $\delta\text{-MnO}_2/\text{HCS}$	231
8.2.3.1	Fabrication of $\delta\text{-MnO}_2$	231
8.2.3.2	Synthesis of HCS	232
8.2.3.3	$\delta\text{-MnO}_2/\text{HCS}$ Synthesis	232
8.2.4	Procedure CoNi_2S_4 Ultrathin Nanosheets (Freestanding) Preparation	232
8.2.4.1	Preparation of $\text{Ni}_{0.75}\text{Co}_{0.25}(\text{OH})_2(\text{CO}_3)_{0.125}$ Exhibiting Free Nanoscaled Sheets	232
8.2.4.2	Fabrication of CoNi_2S_4 Ultrathin Freestanding Nanosheets	233
8.3	Electrochemical Performance	234
8.4	Conclusion	237
	References	239

9 Metal Oxides for Supercapacitors 245*Reza Ghaffari Adli, Yuanhai Su, Mir Ghasem Hosseini, and Abdollah Hajjalilou*

- 9.1 Introduction 245
- 9.2 Electrochemical Measurements 247
- 9.3 Characterization Methods of Electrode Materials 249
- 9.4 Electrode Materials 249
 - 9.4.1 Transition Metal Oxides 250
 - 9.4.1.1 RuO_2 250
 - 9.4.1.2 MnO_2 251
 - 9.4.1.3 NiO 253
 - 9.4.1.4 Co_3O_4 254
 - 9.4.1.5 $\text{MoO}_2/\text{MoO}_3$ 254
 - 9.4.1.6 SnO_2 256
 - 9.4.1.7 Iron Oxides 256
 - 9.4.1.8 V_2O_5 258
 - 9.4.1.9 WO_3 259
 - 9.4.1.10 Bi_2O_3 260
 - 9.4.2 Mixed Transition Metal Oxides 263
 - 9.4.2.1 Metal Cobaltite 263
 - 9.4.2.2 Metal Tungstate 266
 - 9.4.2.3 Metal Vanadates 266
 - 9.4.2.4 Metal Phosphate 270
 - 9.4.2.5 Metal Molybdates 270
- 9.5 Conclusion and Future Research 271
- Acknowledgment 272
- References 272

10 High-Surface Saccharum officinarum Based Materials for Supercapacitor Applications 285*Divya Velpula, Shilpa Chakra Chidurala, Rakesh Kumar Thida, and Shireesha Konda*

- 10.1 Introduction 285
- 10.2 Chemical Composition of SCB and SCBA 286
- 10.3 Advantageous Utilizations of SCB and SCBA 287
- 10.4 Applications of SCB and SCBA 287
- 10.5 Organism-Based Materials as Supercapacitors 289
 - 10.5.1 Synthesis of Carbon-Based Materials from Saccharum officinarum for Supercapacitor Applications 290
 - 10.5.1.1 Carbon Aerogel 290
 - 10.5.1.2 Activated Carbon 291
 - 10.5.1.3 Hydrothermally Treated and Activated Carbon 292
- 10.6 Conclusion and Future Research 295
- References 296

11	Microwave-Assisted Graphene-Based Conducting Polymer Materials for Supercapacitors	299
	<i>Senthil K. Kandasamy, Kavitha N. Singaram, Hemalatha Krishnamoorthy, Chandrasekaran Arumugam, Shanmugam Palanisamy, Kannan Kandasamy, Anish Khan, Abdullah M. Asiri, and Hurija D.-Cancar</i>	
11.1	Introduction	299
11.1.1	EDLCs	302
11.1.2	Pseudocapacitors	302
11.2	Composites	304
11.3	Microwave Annealing and Its Impacts	305
11.3.1	Graphene Oxide/Polyaniline Composite	306
11.3.1.1	Synthesis of Graphene Oxide/Polyaniline Composite	307
11.3.1.2	Microwave Annealing of Graphene Oxide/Polyaniline Composite	308
11.3.1.3	Effects of Microwave Treatment of Graphene Oxide/PANI and Feeding Ratio on Structural Properties	309
11.3.1.4	Effects of Microwave Treatment of Graphene Oxide/PANI and Feeding Ratio on Electrochemical Analysis	310
11.3.2	Graphene Oxide/Polypyrrole Composite	313
11.3.2.1	Synthesis of Graphene Oxide/Polypyrrole Nanocomposite	316
11.3.2.2	Microwave Annealing of Graphene Oxide/Polypyrrole Nanocomposite	317
11.3.2.3	Effects of Microwave Treatment of Graphene Oxide/PPy and Feeding Ratio on Structural Properties	317
11.3.2.4	Effects of Microwave Treatment of Graphene Oxide/PPy and Feeding Ratio on Electrochemical Analysis	318
11.4	Conclusions and Future Work	320
	References	321
	Index	327