

Contents

Preface ix

- 1 Introduction 1**
Peng Cai, Wentao Deng, Hongshuai Hou, Guoqiang Zou, and Xiaobo Ji
 - 1.1 A Brief Development of SICs 1
 - 1.2 Comparison Between Different Hybrid-Ion Capacitors 4
 - 1.3 SICs Energy Storage Mechanism Introduction 16
 - 1.4 Key Technologies of SICs 17
 - References 21

- 2 Characteristics of Sodium-Ion Capacitor Devices 27**
Peng Cai, Wentao Deng, Hongshuai Hou, Guoqiang Zou, and Xiaobo Ji
 - 2.1 Basic Features 27
 - 2.2 Working Principle 30
 - 2.3 Equations 32
 - References 42

- 3 Fundamental Understanding of Sodium-Ion Capacitors Mechanism 45**
Peng Cai, Wentao Deng, Hongshuai Hou, Guoqiang Zou, and Xiaobo Ji
 - 3.1 EDLC-Type Mechanism of SCs and Battery-Type Mechanism of SIBs 45
 - 3.2 Pseudocapacitance Mechanism 46
 - 3.2.1 Motivation for the Search for Pseudocapacitance 46
 - 3.2.2 Definition and Types of Pseudocapacitance 47
 - 3.2.3 Energy Storage Mechanism of Pseudocapacitors 50
 - 3.2.3.1 Adsorption Pseudocapacitance 50
 - 3.2.3.2 Redox Pseudocapacitance 50
 - 3.2.3.3 Intercalation Pseudocapacitance 50
 - 3.2.4 Pseudocapacitance Electrode Materials 51
 - 3.2.4.1 Conductive Polymer 51
 - 3.2.4.2 MXene 52
 - 3.2.4.3 Pseudocapacitive Materials for Comparison 53

3.2.5	Evolution of Pseudocapacitance	56
3.2.6	Electrochemical Features of Pseudocapacitance	57
	References	59
4	Classification of Sodium-Ion Capacitors Cell Configurations	63
	<i>Peng Cai, Wentao Deng, Guoqiang Zou, Hongshuai Hou, and Xiaobo Ji</i>	
4.1	Battery-Type Anode and EDLC Cathode SICs Cell Configurations	63
4.2	Battery-Type Anode and Pseudocapacitive Cathode SICs Cell Configurations	64
4.3	EDLC Anode and Battery-Type Cathode SICs Cell Configurations	66
4.4	Pseudocapacitive Anode and Battery-Type Cathode SICs Cell Configurations	66
4.5	Capacitive Anode and Hybrid Cathode SICs Cell Configurations	67
4.6	Summary	69
	References	73
5	Cathode Materials for Sodium-Ion Capacitors	75
	<i>Xiong Zhang, Wenjie Liu, Lei Wang, Chen Li, and Yanwei Ma</i>	
5.1	Introduction	75
5.2	EDLC Cathode Materials	77
5.2.1	0D Carbonaceous Cathodes	78
5.2.2	1D Carbonaceous Cathodes	78
5.2.2.1	Carbon Nanotubes	78
5.2.2.2	Carbon Nanofibers	79
5.2.3	2D Carbonaceous Cathodes	81
5.2.3.1	Reduced Graphene Oxide	81
5.2.3.2	Carbon Nanosheets	83
5.2.4	3D Carbonaceous Cathodes	84
5.2.4.1	Hollow Carbon Microspheres	84
5.2.4.2	Activated Hard Carbon	85
5.2.4.3	Disorder Carbon	86
5.2.4.4	Folded Carbon	89
5.3	Pseudocapacitive Cathode Materials	90
5.3.1	Adsorption Pseudocapacitive Materials	93
5.3.2	Redox Pseudocapacitive Materials	95
5.3.2.1	Conductive Polymers	95
5.3.2.2	Vanadium-Based Materials	96
5.3.3	Intercalation Pseudocapacitive Materials	98
5.4	Battery-Type Cathode Materials	102
5.4.1	$\text{NaMn}_{1/3}\text{Co}_{1/3}\text{Ni}_{1/3}\text{PO}_4$ Cathodes	102
5.4.2	$\text{Na}_3\text{V}_2(\text{PO}_4)_3$ Cathodes	104
5.4.3	$\text{Na}_3\text{V}_2\text{O}_2(\text{PO}_4)_2\text{F}$ Cathodes	105

- 5.4.4 Sodium Transition Metal Oxides Cathodes 107
- 5.4.4.1 $\text{Na}_{0.67}(\text{Mn}_{0.75}\text{Al}_{0.25})\text{O}_2$ 107
- 5.4.4.2 $\text{Na}_{0.67}\text{Co}_{0.5}\text{Mn}_{0.5}\text{O}_2$ 108
- 5.4.4.3 $\text{Na}_{0.5}\text{Mn}_{0.5}\text{Co}_{0.48}\text{Mg}_{0.02}\text{O}_2$ 109
- 5.4.4.4 $\text{Na}_{0.66}\text{Mn}_{0.54}\text{Ni}_{0.13}\text{Co}_{0.13}\text{O}_2$ 110
- References 110

6 Anode Materials for Sodium-Ion Capacitors 115

Kangyu Zou, Wentao Deng, Hongshuai Hou, Xiaobo Ji, and Guoqiang Zou

- 6.1 EDLC Anode Materials 120
- 6.2 Pseudocapacitive Anode Materials 123
- 6.3 Battery-Type Anode Materials 128
 - 6.3.1 Intercalation Materials 128
 - 6.3.1.1 Carbonaceous Anode 128
 - 6.3.1.2 Titanium-Based Compound 142
 - 6.3.1.3 Niobium-Based Compound 148
 - 6.3.1.4 Vanadium-Based Oxide 152
 - 6.3.1.5 Other New Intercalation Anodes 153
 - 6.3.2 Conversion Materials 154
 - 6.3.2.1 Metal Oxides 154
 - 6.3.2.2 Metal Sulfides 157
 - 6.3.2.3 Metal Selenides 162
 - 6.3.3 Alloying Materials 165
 - 6.3.3.1 Sn-Based Anode 165
 - 6.3.3.2 Sb Anode 168
 - 6.3.3.3 Bi Anode 169
- 6.4 Other Novel Materials 169
- References 176

7 Flexible Sodium-Ion Capacitor Devices 183

Taoqiu Zhang and Huanwen Wang

- 7.1 Flexible SICs Devices 183
 - 7.1.1 Flexible Battery-Type Anode and Capacitive Cathode SICs Cell Configurations 185
 - 7.1.1.1 Flexible Electrodes Based on Carbon Nanofiber 186
 - 7.1.1.2 Flexible Electrodes Based on Graphene Substrates 201
 - 7.1.1.3 Flexible Electrodes Based on Carbon Cloth 205
 - 7.1.1.4 Flexible Electrodes Based on MXenes 206
 - 7.1.1.5 Flexible Electrodes Based on Metal Foil 208
 - 7.2 Flexible Capacitive Anode and Battery-Type Cathode SICs Cell Configurations 211
 - 7.3 Electrolytes in Flexible SICs Devices 217
 - References 222

8	Pre-sodiation Technologies	225
	<i>Zirui Song, Chang Liu, and Xiaobo Ji</i>	
8.1	Introduction	225
8.2	Pre-lithiation in Lithium-Ion Batteries	226
8.2.1	Operation with Li Metal	227
8.2.2	Usage of Li-Based Alternatives	229
8.2.3	Supply of Extra Additives	232
8.3	Pre-sodiation in Sodium-Ion Batteries	236
8.3.1	Operation with Na Metal	236
8.3.2	Usage of Na-Based Alternatives	237
8.3.3	Supply of Extra Additives	237
8.4	Pre-sodiation in Sodium-Ion Capacitors	238
8.4.1	Electrochemical Method	239
8.4.2	Alternatives Method	239
8.4.3	Sacrificial Additives Method	241
	References	245
9	Conclusions and Future Perspective	249
	<i>Kangyu Zou, Wentao Deng, Hongshuai Hou, Guoqiang Zou, and Xiaobo Ji</i>	
9.1	Definitions and Mechanisms	249
9.2	Configurations	250
9.3	Electrode Materials	251
9.4	Key Technologies	251
9.5	Future Perspective	252
	Index	259