

Contents

About the Editor *xiii*

Preface *xv*

1 Research Developments on Lithium-Ion Batteries *1*

Lishan Yang, Da Xiong, Yangfan Li, Xiang Wang, Boyao Gan, and Xinkang Li

Outline *1*

1.1 Polyanion Cathodes *1*

1.1.1 Lithium Iron Phosphate *2*

1.1.2 Lithium Manganese Iron Phosphate *3*

1.2 Layered Oxide Cathodes *4*

1.3 Spinel Structure Cathodes *8*

1.4 Anode Materials *9*

1.5 Cell Technology *10*

1.5.1 Battery Cells *10*

1.5.2 Cell Integration Technology *13*

1.6 Electrolyte *13*

1.7 Binders *15*

1.8 Outlook *16*

References *18*

2 Evaluation of Sodium-Ion Battery: Fast-Charging Next Generation *25*

Muhammad Mamoor and Liqiang Xu

2.1 Motivation for Exploring Na-Ion Batteries *25*

2.2 Fundamental of SIBs *27*

2.3 Cathode Materials: Strategies for Improvement *29*

2.3.1 Layered Oxides *29*

2.3.1.1 Challenges – Structure Characteristic and Failure Mechanism *29*

2.3.1.2 Honeycomb-Ordered Superlattice Structure: Crystal Parameter Modulation *31*

2.3.2 Recent Progress of Phosphate-Based Polyanion *33*

2.3.2.1	Tuning Voltage and Capacity of NASICON	33
2.3.3	Optimizing Composition and Morphology: Prussian Blue Analog	37
2.3.4	Exploring Sustainable Alternatives: Organic Cathodes	38
2.4	Performance Optimization Strategies of Different Electrolytes for Fast Charging	40
2.4.1	Electrolyte Desolvation Strategies	41
2.4.2	Electrode–Electrolyte Interphase	43
2.4.3	Organic Electrolyte	48
2.5	Electrolyte Additives	51
2.5.1	Specific Groups of Additives	51
2.6	Performance Optimization Strategies for Fast-Charging Anode Materials	66
2.6.1	Porous Engineering	67
2.6.2	Nanostructuring	69
2.6.2.1	Templated-Assisted Strategies	71
2.6.3	Conductive Coating and Modification	75
2.6.4	Managing Volume Expansion: Alloy-Based Anodes	76
2.6.5	Conversion and Intercalation–Conversion Anode Materials: Balancing Capacity and Cyclability	78
2.6.6	2D Materials: Leveraging Unique Structures for Sodium Storage	81
2.7	Anode-Free SIBs: Design and Working Principle	84
2.7.1	Electrochemically Stable Electrolyte	85
2.8	All-Climates Sodium-Ion Batteries	87
2.8.1	Challenges for SIBs at Extreme Low Temperatures	88
2.8.2	Challenges for SIBs at High Temperatures	90
2.9	Na-Powered Progress: The Rise of Commercial Sodium-Ion Cells	91
2.9.1	Electrochemical Systems	92
2.9.2	The Price of Progress: SIB Baseline Cost Framework Study	93
2.9.3	SIB Cost Reduction: Aiming for $\$0.05 \text{ kWh}^{-1}$	94
2.10	Summary and Prospect	94
	References	97
3	Research Development on Potassium-Ion Batteries and Potassium–Sulfur Batteries	105
	<i>Yanyan He, Junhui Li, and Yuxin Dai</i>	
3.1	Introduction to Potassium-Ion Batteries	105
3.1.1	A Brief History of Potassium-Ion Battery Development	105
3.1.2	Aqueous Potassium-Ion Batteries	106

3.2	The Composition and Working Principle of Potassium-Ion Batteries	107
3.3	Cathode Materials for Potassium-Ion Batteries	109
3.3.1	Layered Metal Oxides	110
3.3.1.1	Challenges and Strategies	113
3.3.1.2	Chromium-Based Metal Oxide	113
3.3.1.3	Manganese-Based Metal Oxides	114
3.3.1.4	Cobalt-Based Metal Oxide	118
3.3.2	Polyanionic Compounds	120
3.3.2.1	Challenges and Strategies	121
3.3.2.2	Phosphates	121
3.3.2.3	Fluorophosphates	124
3.3.2.4	Pyrophosphates	127
3.3.2.5	Oxyphosphates	129
3.3.2.6	Sulfates and Fluorosulfates	132
3.3.3	Prussian Blue Analog	133
3.3.3.1	Challenges and Strategies	134
3.3.3.2	KFeFe-Prussian Blue Analogs	134
3.3.3.3	KMnFe-Prussian Blue Analogs	137
3.3.3.4	Other Prussian Blue Analogs	138
3.3.4	Organic Cathode Materials	139
3.3.4.1	Challenges and Strategies	139
3.3.4.2	Organic Small Molecules and Polymers	140
3.4	Anode Materials for Potassium-Ion Batteries	143
3.4.1	Intercalation-Type Anodes	144
3.4.1.1	Challenges and Strategies	144
3.4.1.2	Graphitic Carbon Materials	145
3.4.1.3	Non-graphitic Carbon Materials	146
3.4.1.4	Ti-Based Materials	149
3.4.2	Alloying Reaction-Type Anodes	151
3.4.2.1	Challenges and Strategies	152
3.4.2.2	P-Based Anodes	152
3.4.2.3	Sn-Based Anodes	153
3.4.2.4	Sb-Based Anodes	155
3.4.2.5	Bi-Based Anodes	157
3.4.2.6	Si-Based Anodes	160
3.4.2.7	Ge-Based Anodes	161
3.4.3	Conversion Reaction-Type Anodes	163
3.4.3.1	Challenges and Strategies	163
3.4.3.2	Metal Oxides	163

3.4.3.3	Metal Phosphides	164
3.4.3.4	Metal Chalcogenides	170
3.4.4	Organic Anode Materials	186
3.4.4.1	Challenges and Strategies	187
3.4.4.2	Carboxylate Organic Anode Materials	187
3.4.4.3	Organic Anode Materials Based on Framework Compounds	188
3.5	Electrolyte for Potassium-Ion Batteries	189
3.5.1	Challenges and Strategies	189
3.5.2	Water-Based Electrolyte	189
3.5.3	Organic Electrolyte	191
3.5.4	Ionic Electrolyte	192
3.5.5	Solid Electrolyte	193
3.6	Potassium–Sulfur Batteries	194
3.6.1	Composition, Working Mechanism, and Challenges of Potassium–Sulfur Batteries	194
3.6.2	Sulfur Cathodes	195
3.6.3	Anodes	197
3.6.4	Electrolytes	198
	References	201
4	The Electrocatalyst Design for Lithium–Sulfur Battery	225
	<i>Yueyue Kong, Bin Wang, Lu Wang, and Liqiang Xu</i>	
4.1	Background	225
4.2	Brief Introduction of Li–S Batteries	225
4.2.1	The Development History of Li–S Batteries	225
4.2.2	The Overview of Li–S Batteries	226
4.2.3	The Working Principle of Li–S Batteries	227
4.2.4	The Problems and Challenges of Li–S Battery	229
4.3	The Electrocatalyst Design Strategies	230
4.3.1	Micro/Nanostructure Design	230
4.3.2	Defect Engineering	234
4.3.3	Composition and Structural Manipulation	236
4.3.4	Heterojunction Construction	238
4.3.5	Alloy Electrocatalyst	242
4.3.6	Other Electrocatalysts	244
4.3.6.1	MOF Electrocatalysts	244
4.3.6.2	Polyoxometalate (POM) Electrocatalysts	245
4.3.6.3	Single-Atom (SA) Electrocatalysts	247
4.4	Lithium Anode Protection	249
4.4.1	Electrolyte Regulation	249
4.4.2	Artificial Modification Layer on Lithium Anode	252

4.5	<i>In situ</i> Characterization Method for Li-S Batteries	252
4.5.1	<i>In situ</i> Spectroscopy Characterization	253
4.5.1.1	<i>In situ</i> Raman Characterization	253
4.5.1.2	<i>In situ</i> Ultraviolet-Visible Spectroscopy (UV-vis) Characterization	254
4.5.1.3	<i>In situ</i> Fourier Transform Infrared Spectroscopy (FT-IR) Characterization	255
4.5.2	<i>In situ</i> X-Ray Characterization	256
4.5.2.1	<i>In situ</i> X-Ray Diffraction (XRD) Characterization	256
4.5.2.2	<i>In situ</i> X-Ray Absorption Spectroscopy (XAS) Characterization	257
4.5.3	<i>In situ</i> Electrochemical Impedance Spectroscopy (EIS) Characterization	258
4.5.4	<i>In situ</i> Transmission Electron Microscopy (TEM) Characterization	260
4.5.5	<i>In situ</i> Stress Monitoring Characterization	261
4.6	Practical Application Research of Li-S Batteries	262
4.6.1	Pouch-Type Li-S Battery	263
4.6.2	High- and Low-Temperature Electrochemical Performance	265
4.7	Conclusion and Prospect	266
	References	266

5 Room Temperature Sodium-Sulfur Batteries: Challenges and Progress 277

Mingyue Wang, Nana Wang, and Zhongchao Bai

5.1	Introduction	277
5.2	History of Na-S Batteries	278
5.3	Reaction Mechanism of Room Temperature Na-S Batteries	279
5.3.1	Reaction Mechanisms in Ether-Based Electrolytes	279
5.3.2	Reaction Mechanisms in Carbonate-Based Electrolytes	281
5.4	Challenges of Room Temperature Na-S Batteries	281
5.5	Progress on Room Temperature Na-S Batteries	283
5.5.1	Cathodes	283
5.5.1.1	Carbon-S Cathodes	283
5.5.1.2	Polymer-S Cathodes	284
5.5.1.3	Electrocatalyst-Enhanced S Cathode	285
5.5.2	Anodes	288
5.5.3	Separators	288
5.5.4	Electrolytes	290
5.5.4.1	Liquid Electrolytes (LEs)	290
5.5.4.2	Gel Polymer Electrolytes (GPEs)	292
5.5.4.3	Solid-State Electrolytes (SSEs)	292
5.6	Summary and Outlook	293
	References	295

6	Zinc-Ion Rechargeable Battery	297
	<i>Guangmeng Qu and Liqiang Xu</i>	
6.1	Overview of Aqueous Zinc-Ion Battery	297
6.2	Introduction	298
6.2.1	Development History	298
6.2.2	Structure and Components of AZIBs	299
6.2.3	Energy Storage Mechanism	301
6.3	Cathode Materials for AZIBs	305
6.3.1	Vanadium-Based Compound Cathode Materials	305
6.3.1.1	Layered Vanadium-Based Compound	306
6.3.1.2	Vanadium-Based Compounds with Tunnel Structure	308
6.3.1.3	Vanadium-Based Compounds with Spinel Structure	310
6.3.1.4	Polyanion-Type Vanadium-Based Compounds	310
6.3.1.5	Modification Strategy of Vanadium-Based Cathode Materials	311
6.3.2	Manganese-Based Oxide Cathode Materials	319
6.3.2.1	α -MnO ₂	319
6.3.2.2	β -MnO ₂	320
6.3.2.3	γ -MnO ₂	320
6.3.2.4	δ -MnO ₂	321
6.3.2.5	λ -MnO ₂	321
6.3.2.6	ϵ -MnO ₂	322
6.3.2.7	Other Manganese-Based Compounds	322
6.3.2.8	Modification Strategy of Mn-Based Oxide Cathode Materials	323
6.3.3	Prussian Blue Analogs (PBAs) Cathode Materials in Zinc-Ion Batteries	332
6.3.3.1	Synthesis Methods for PBA Cathode Materials	333
6.3.3.2	Optimization Strategy of PBA Cathode Materials	334
6.3.4	Halogen-Based (Iodine/Bromine) Cathode Materials for AZIBs	336
6.3.4.1	Iodine-Based Cathode Materials for AZIBs	336
6.3.4.2	Bromine-Based Cathode Materials for AZIBs	340
6.3.5	Organic Compounds Cathode Materials for AZIBs	343
6.3.5.1	Conductive Polymers	343
6.3.5.2	Carbonyl Compounds	346
6.3.5.3	Imine Compounds	347
6.3.5.4	Nitroxide Radicals Compounds	347
6.3.5.5	COFs and MOFs	348
6.4	Zinc Metal Anode Materials	349
6.4.1	Challenges and Issues of Zinc Anodes in Aqueous Zinc-Ion Batteries	350
6.4.1.1	Zinc Deposition and Dendrite Growth	350
6.4.1.2	Water-Induced Interface Side Reactions	352

6.4.2	Zinc Anode Protection Strategies	353
6.4.2.1	Surface-Coating Modification of Zinc Anodes	353
6.4.2.2	3D Structure Design of Zinc Metal Anode Materials	354
6.4.2.3	Zinc Alloy Anodes	355
6.4.2.4	Electrolyte Design to Optimize Zinc Anode	356
6.5	Summary and Future Outlook	358
	References	359
	Index	367

