

Contents

Preface	III
<hr/>	
CHAPTER 1	
<hr/>	
Introduction	1
1.1 Brief History of Primary and Secondary Batteries	6
1.2 General Information on Li-ion Batteries	9
Bibliography	11
<hr/>	
CHAPTER 2	
<hr/>	
Positive Electrode Materials for “Lithium-ion” Accumulators	13
2.1 Positive Electrode Materials of “Spinel” Structure	14
2.2 Positive Electrode Materials with Lithiated Layered Oxide Structure	20
2.3 Positive Electrode Materials with Olivine Structure	32
References	37
<hr/>	
CHAPTER 3	
<hr/>	
Negative Electrode Materials	45
3.1 Negative Electrode Materials: Several Solutions	45
3.1.1 Insertion-Intercalation	46
3.1.2 Conversion	47
3.1.3 Alloying	47
3.2 Carbon	48
3.2.1 Historical Background	48
3.2.2 Interest	49
3.2.3 Relationship between Structural Characteristics and Performance	50
3.3 Silicon	53
3.3.1 (De)lithiation Mechanisms	53
3.3.2 Degradation Mechanisms	54
3.3.3 Material Improvement Approaches	56
3.4 Lithium Metal	57
Bibliography	59

CHAPTER 4

Organic Electrode Materials	63
4.1 Different Types of Organic Electrode Materials	65
4.1.1 π -Extended System (Conducting Polymers)	65
4.1.2 Stable Radical	66
4.1.3 Organosulfides & Thioethers	67
4.1.4 Carbonyl Functions	67
4.1.5 Aromatic Amines	68
4.2 Implementation Strategies	68
4.2.1 Grafting on Inorganic or Organic Support	69
4.2.2 Polymeric Salt Formation	71
References	74

CHAPTER 5

Electrolytes and Separators	79
5.1 Liquid Electrolytes	80
5.1.1 Lithium Salts and Organic Solvents	80
5.1.2 Lithium Salts and Ionic Liquids	84
5.2 Separators	85
5.2.1 Properties of Separators	85
5.2.2 The Separator Market	86
5.2.3 Cost and Security	87
Bibliography	88

CHAPTER 6

Na-ion Batteries: Should/Can Lithium be Replaced?	89
6.1 General Aspects	89
6.1.1 Should Lithium be Replaced?	89
6.1.2 Can Lithium be Replaced? Towards a 100% Abundant Element-Based Battery	92
6.2 The Na-ion Technology	93
6.2.1 Brief History	93
6.2.2 Operating Principle	93
6.3 State of the Art	95
6.3.1 Negative Electrode Materials	95
6.3.2 Non-Carbon Materials	96
6.3.3 Positive Electrode Materials	98
6.3.4 Electrolytes and Interfaces	101
6.4 Full System Performance	102
6.5 Outlook	102
6.5.1 Low Cost Approach	102
6.5.2 High Power Approach	103
References	103

CHAPTER 7

Metal-Sulfur Batteries	107
7.1 The Metal-Sulfur Cell	107
7.1.1 Advantages and Comparison with Other Technologies	107
7.1.2 Working Mechanism of the Metal-Sulfur Cell	108
7.1.3 The (Li,Na)-ion Sulfur Cell	110
7.2 Technology State of the Art and Performances	110
7.2.1 Main Actors	110
7.2.2 Understanding the Complex Mechanism	110
7.2.3 Development Strategies	112
7.2.4 All-Solid-State Metal-Sulfur Batteries	119
7.2.5 Industrial Actors	119
7.3 Perspectives and Applications	121
Bibliography	122

CHAPTER 8

All Solid-State Batteries	125
8.1 Introduction and Overview	125
8.2 Main Families of Solid Ionic Conductors	127
8.2.1 Polymeric Solid Electrolytes	127
8.2.2 Inorganic Solid Electrolytes	130
8.2.3 Hybrid Solid Electrolytes	133
8.3 Electrochemical Stability of Solid Electrolytes	135
8.4 All-Solid-State Cells	137
8.5 Academic & Industrial Players	138
Bibliography	139

CHAPTER 9

Supercapacitors: From Material to Cell	145
9.1 Operating Principle	147
9.2 Carbon/Carbon Based Technology	152
9.2.1 Electrode Design and Components	152
9.2.2 Electrolyte	166
9.2.3 Separators	176
9.3 Hybrid Systems	179
9.3.1 Activated Carbon/MnO ₂ System	181
9.3.2 Lead Oxide/Activated Carbon System	182
9.3.3 NiOOH/Activated Carbon System	182
9.3.4 Graphite/Activated Carbon System	182
Bibliography	186

CHAPTER 10

Supercapacitors: Cells and Modules	199
10.1 Cell Design	199

10.1.1	Small Cells	200
10.1.2	High-Capacity Cells	200
10.2	Design of Modules and Systems	207
10.2.1	Modules Based on Hard Casing Cells	208
10.2.2	High Capacity Modules Based on Soft Packaging Cells (Pouch Cells)	213
10.2.3	High Capacity Modules Working in Aqueous Medium	216
	Bibliography	218

CHAPTER 11

	Characterization of the Electrical Performance of Li-ion Cells	221
11.1	Characterization of the Electrical Performance of Individual Cells	221
11.1.1	Acceptance Tests	221
11.1.2	Beginning of Life Performance Tests	223
11.1.3	Ageing Performance Tests	227
11.2	Resistance Measurements of Individual Cells	229
11.2.1	Introduction	229
11.2.2	How to Define an Internal Resistance?	229
11.2.3	Different Methods of Measuring Internal Resistance	231
11.2.4	Conclusion	243
	Bibliography	244

CHAPTER 12

	Microstructural and Physical and Chemical Characterizations of Battery Materials	245
12.1	Introduction: Characterization Methodology to Understand the Electrochemical Response of a Battery	245
12.2	Analysis of Mechanisms Associated with Exchangeable Lithium Loss	249
12.2.1	SEI Formation and Li Metal Precipitation on Negative Electrode	249
12.2.2	Loss of Lithium Content of Positive Electrode	252
12.3	Analysis of Phase Transformations that Limit Lithium Mobility	254
12.3.1	Microstructural Modification of a Positive Electrode	254
12.4	Mechanical Blocking, Obstruction, Disconnection and Loss of Electrical Contact	255
12.4.1	Loss of Graphite Electrode Capacity in Cycling at Low Temperatures	255
12.4.2	Exogenous Deposits	257
12.5	Electrolyte Degradation	258
12.6	Perspectives	259
	Bibliography	259

CHAPTER 13

Cells and Electrodes Manufacturing Process 263

13.1 General Principles 263

13.2 Cell Design 264

13.3 Electrode Manufacturing Process 268

 13.3.1 Electrode Formulation 268

 13.3.2 Slurry Preparation 269

13.4 Electrodes 270

 13.4.1 Calendering 272

13.5 Cell Fabrication Process 272

 13.5.1 Slitting 272

 13.5.2 Cell Assembly 273

 13.5.3 Electrolyte Filling 275

 13.5.4 Electrical Formation 275

13.6 Cells Bill of Materials and Cost Aspects 275

13.7 New Processes/Perspectives 276

13.8 Conclusion 277

Bibliography 277

CHAPTER 14

Battery System and Battery Management System (BMS) 279

14.1 Battery System Architecture 279

14.2 Battery System in Its Electrical Environment 281

14.3 Power Component Associated to Battery Pack 284

14.4 Multiples Functions of BMS 287

14.5 Design and Manufacture of Battery Packs 293

14.6 Examples of Innovation on Battery Systems 296

References 301

CHAPTER 15

Definition of the State Estimation Algorithms of a Battery System
and Associated Calculation Methods 303

15.1 Battery State Indicator Definition 303

 15.1.1 State of Charge 303

 15.1.2 State of Energy 304

 15.1.3 State of Health 304

 15.1.4 State of Function 305

 15.1.5 State of Safety 305

15.2 Battery Diagnosis Methods 306

 15.2.1 State of Charge Estimation 307

 15.2.2 Kalman Filter Exploitation for State of Charge Estimation . . . 312

 15.2.3 Battery Total Capacity Estimation 312

 15.2.4 Alternative Battery State Diagnosis Method 315

Bibliography 316

 CHAPTER 16

Standards and Safety	317
16.1 Phenomena Involved in Abusive Conditions	318
16.1.1 Phenomena at Cell Level	319
16.1.2 Phenomena at Module and Pack Level	323
16.2 Regulation	325
16.3 Standards	327
16.4 Tests and Additional Analysis	333
16.5 Solutions to Improve Safety at Different Levels	334
16.5.1 Improvement of the Components within the Cell	335
16.5.2 Safety Devices at Cell Level	340
16.5.3 Safety Devices at the Module and Battery System Level	342
16.6 Conclusions and Prospects	346
Bibliography	347

 CHAPTER 17

Li-ion Battery Recycling	351
17.1 Contextual Elements	351
17.2 Process Head	353
17.3 Process Core (Separation – Valorization)	354
17.3.1 Pyrometallurgy	354
17.3.2 Hydrometallurgy	355
17.4 Conclusion	363
References	364

 CHAPTER 18

Li-ion Batteries Environmental Impacts and Life Cycle Assessment (LCA)	369
18.1 Why a Focus on Battery Environmental Impacts?	369
18.2 How to Quantify Batteries Environmental Impacts?	370
18.3 What are the Main Impacts of Lithium-ion Batteries?	372
18.4 What are the Impact Sources?	379
18.5 Guidelines for Ecodesign	381
Bibliography	383

 CHAPTER 19

Applications and Markets – User Cost	385
19.1 General Elements of Market Analysis – Focus on the Electrified Vehicle Market	385
19.2 Issue of User Cost	388
References	389

Conclusion	391
Glossary	395
The Authors	407