

Contents

Preface — IX

Preface of 2nd Edition — XI

1 Introduction — 1

- 1.1 General Introduction — 1
- 1.2 Brief History — 4
 - 1.2.1 Inorganic Solar Cells — 4
 - 1.2.2 Organic and Hybrid Solar Cells — 5

2 Semiconductors and Junctions — 8

- 2.1 Introduction to Inorganic Semiconductors — 8
 - 2.1.1 Electronic States in Inorganic Semiconductors — 8
 - 2.1.2 Doping of Inorganic Semiconductors — 23
- 2.2 Introduction to Organic Semiconductors — 27
 - 2.2.1 Carbon Hybridization and Organic Molecules — 28
 - 2.2.2 Electronic States in Organic Semiconductors — 36
 - 2.2.3 Charge Transport in Organic Semiconductors — 67
- 2.3 Junctions — 80
 - 2.3.1 Inorganic p–n Homojunctions — 81
 - 2.3.2 Inorganic Heterojunctions — 88
 - 2.3.3 Schottky Junctions — 91
 - 2.3.4 Organic–Organic Heterojunctions — 92
 - 2.3.5 Organic–Inorganic Heterojunctions — 94

3 Working Mechanisms of Organic and Hybrid Solar Cells — 96

- 3.1 Basic Principles of Solar Cells — 96
 - 3.1.1 Energy Conversion and the Solar Spectrum — 96
 - 3.1.2 Shockley–Queisser Limit — 99
 - 3.1.3 Photocurrent and Spectral Response — 101
 - 3.1.4 Characteristics of a Solar Cell — 105
 - 3.1.5 Parasitic Resistances and the Generalized Shockley Model — 107
- 3.2 Inorganic Junction Solar Cells — 113
 - 3.2.1 p–n Junction Solar Cells — 113
 - 3.2.2 Inorganic Heterojunction Solar Cells — 116
- 3.3 General overview over Organic, Dye-sensitized, Hybrid and Perovskite Solar cells — 116
 - 3.3.1 Classification of solar cells — 116
 - 3.3.2 Organic Solar cells — 118

3.3.3	Hybrid Solar cells — 120
3.3.4	Perovskite Solar cells — 123
3.4	Other device applications — 127
3.4.1	Transistors — 127
3.4.2	Light emitting diode (LED) — 132
3.5	Novel device architectures — 137
3.5.1	Back-contacted solar cells — 138
3.5.2	Light management — 142
4	Organic Solar Cells — 146
4.1	Charge Separation in Organic Solar Cells — 146
4.1.1	Donor–Acceptor Junctions for Exciton Splitting — 146
4.1.2	Charge Transfer States — 147
4.1.3	Detailed Energetic Picture of Charge Transfer States — 152
4.2	Flat Heterojunctions — 158
4.3	Bulk Heterojunctions — 161
4.4	Mixing of Polymers and Fullerenes — 164
4.4.1	Pure Materials — 164
4.4.2	Mixed Films — 172
4.5	Non-fullerene-based organic solar cells — 178
5	Hybrid Junction Solar Cells — 180
5.1	Dye-Sensitized Solar Cells — 180
5.1.1	Liquid Electrolyte Dye-Sensitized Solar Cells — 180
5.1.2	Solid-State Dye-Sensitized Solar Cells — 187
5.2	Inorganic–Organic Hybrid Solar Cells — 188
5.2.1	Metal Oxide–Polymer Bulk Heterojunctions — 189
5.2.2	Dye-Sensitized Metal Oxide–Polymer Hybrid Solar Cells — 191
5.2.3	Hybrid Solar Cells with Inorganic Absorbers — 193
6	Perovskite Solar Cells — 197
6.1	A brief history of Perovskite Solar Cells — 197
6.1.1	Common Device Architectures for Perovskite Solar Cells — 198
6.2	Physico-chemical Properties of Hybrid Halide Perovskites — 200
6.2.1	Crystal Structure and Phase Transitions — 200
6.2.2	Electronic Properties and Band Engineering of Halide Perovskites — 201
6.2.3	Mixed Ionic-electronic Conductivity — 202
6.3	Layer Preparation Methods — 204
6.3.1	One-step Preparation — 205
6.3.2	Two-step Preparation — 209
6.3.3	Modern Trends in Film Preparation — 210
6.3.4	Perovskite film deposition via thermal evaporation — 210

6.4	Device Physics of Perovskite Solar Cells — 212
6.4.1	Photoexcited States and Relaxation Dynamics — 213
6.4.2	Excitons and Exciton Binding Energy — 214
6.4.3	Charge Transport, Carrier Lifetime and Diffusion Length — 215
6.4.4	Interfaces and Recombination in PSCs — 216
6.4.5	Ferroelectricity — 221
6.5	How to Correctly Measure Efficiency of PSCs? — 222
6.6	Pb-free Perovskite Solar Cells — 224
6.7	Flexible Perovskite Solar Cells — 226
6.8	Operational Stability of Perovskite Solar Cells — 227
7	Characterization Techniques — 230
7.1	Characterization of Solar Cell Components — 230
7.1.1	Absorption Spectra of Photoactive Materials — 230
7.1.2	Emission Spectra of Photoactive Materials — 232
7.1.3	Ellipsometry — 235
7.1.4	Quality of Transparent Contacts — 239
7.2	Steady-State Device Characterization — 244
7.2.1	Total Absorption Measurements — 244
7.2.2	Current Density–Voltage Measurements — 248
7.2.3	External Quantum Efficiency Measurements — 254
7.2.4	Light Intensity–Dependent Current–Voltage Measurements — 257
7.3	Time-Resolved Characterization Techniques — 262
7.3.1	Transient Photocurrent and Photovoltage Decay Measurements — 262
7.3.2	Photo-CELIV Measurements — 266
7.3.3	Impedance Spectroscopy — 269
7.3.4	Transient Absorption Spectroscopy — 273
7.3.5	Time-Resolved Photoluminescence Spectroscopy — 279
8	Fabrication and Device Lifetime — 284
8.1	Processing — 285
8.1.1	Processing Steps — 286
8.1.2	Coating Technologies — 293
8.1.3	Module Design — 298
8.2	Stability and Lifetime — 301
9	Conclusion and Outlook — 303
10	Questions and Exercises — 304
10.1	Exercises Chapter 1 — 304
10.2	Exercises Chapter 2 — 304
10.3	Exercises Chapter 3 — 309

VIII — Contents

10.4 Exercises Chapter 4-6 — **312**

10.5 Exercises Chapter 7 — **314**

10.6 Exercises Chapter 8 — **315**

10.7 Exercises Chapter 9 — **315**

Bibliography — 317