

Contents

Preface XV

List of Contributors XVII

1	Electronic Process in Organic Solids	1
	<i>Hongzhen Lin, Fenglian Bai</i>	
1.1	Introduction	1
1.2	Structure Characteristics and Properties of Organic Solids	3
1.2.1	Organic Solids	4
1.2.2	Molecular Geometries	7
1.2.3	Aggregations and Assemblies	7
1.3	Electronic Processes in Organic Small Molecules	8
1.3.1	Photophysics of Small Molecules	8
1.3.1.1	Molecular Orbital Model	8
1.3.1.2	Jablonski Diagram	9
1.3.1.3	Frank–Condon Principle	10
1.3.1.4	Electronic Absorption	11
1.3.1.5	Fluorescence and Phosphorescence	13
1.3.2	Excitation for Charge and Energy Transfer in Small Molecules	15
1.3.2.1	Photoinduced Electron Transfer	15
1.3.2.2	Excitation Energy Transfer	18
1.4	Some Basic Concepts of Electronic Process in Conjugated Polymers	22
1.4.1	Excited States in Conjugated Polymers	24
1.4.1.1	Soliton	24
1.4.1.2	Polaron	25
1.4.1.3	Bipolaron	26
1.4.1.4	Exciton	27
1.4.2	Interactions between Conjugated Polymer Chains	30
1.4.2.1	Bound Polaron Pairs	30
1.4.2.2	Excimers	31
1.4.2.3	Ground-State Complexes	32
1.4.3	Photoinduced Charge Transfer between Conjugated Polymers and Electron Acceptors	32

1.5	Carriers Generation and Transport	35
1.5.1	Charge Carriers	35
1.5.2	Carrier Mobility and Its Measurement	36
1.5.3	Mobility-Influencing Factors	37
	References	38
2	Organic/Polymeric Semiconductors for Field-Effect Transistors	43
	<i>Qing Meng, Huanli Dong, Wenping Hu</i>	
2.1	Introduction	43
2.1.1	Features of Organic/Polymeric Semiconductors	44
2.1.2	Classification of Semiconductors for Organic Field-Effect Transistors	44
2.1.3	Main Parameters for the Characterization of Organic/Polymeric Semiconductors	46
2.2	Small-Molecular Semiconductors	47
2.2.1	P-type Small-Molecular Semiconductors	47
2.2.1.1	Polycyclic Aromatic Hydrocarbons	47
2.2.1.2	Chalcogen-Containing Semiconductors	53
2.2.1.3	Nitrogen-Containing Semiconductors	63
2.2.2	n-Type Small-Molecule Semiconductors	65
2.2.2.1	Fluorine-Containing Semiconductors	65
2.2.2.2	Cyano-Containing Semiconductors	67
2.2.2.3	Carbonyl and Imide Semiconductors	68
2.2.2.4	Fullerenes	70
2.3	Polymer Semiconductors	71
2.3.1	p-Type Polymer Semiconductors	72
2.3.1.1	Polythiophenes	72
2.3.1.2	Thiophene–Heteroacene Copolymers	73
2.3.1.3	Other Copolymers	74
2.3.2	n-Type Polymer Semiconductors	75
2.4	Normal Synthetic Methods for Organic Semiconductors	76
2.4.1	Diels–Alder Cycloaddition	77
2.4.2	Aldol Reaction	77
2.4.3	Stille Reaction	78
2.4.4	Suzuki Reaction	78
2.4.5	Sonogashira Crosscoupling	79
2.4.6	Ullmann Reaction	79
2.4.7	Heck Reaction	79
2.5	Purification of Organic Semiconductors	80
2.6	Outlook	81
	References	81
3	Organic/Polymeric Field-Effect Transistors	95
	<i>Chengliang Wang, Lang Jiang, Wenping Hu</i>	
3.1	Introduction	95

3.1.1	Configurations of Organic Field-Effect Transistors	96
3.1.2	Working Principle of Organic Field-Effect Transistors	97
3.2	Carriers Transport in Organic Field-Effect Transistors	101
3.2.1	Molecular Arrangement in Organic Semiconductors	101
3.2.2	Charge Transport Models in Organic Semiconductors	104
3.2.3	Factors Influencing Charge Transport in the Conducting Channel of Organic Transistors	108
3.3	Electrodes, Insulators, and Interfaces of Organic Field-Effect Transistors	109
3.3.1	Electrodes	109
3.3.2	Insulators	113
3.3.2.1	Oxides	113
3.3.2.2	Polymers	114
3.3.2.3	Self-Assembled Layers	116
3.3.2.4	Air Dielectric	116
3.3.3	Interfaces	117
3.3.3.1	Energy Level Alignment	117
3.3.3.2	Interface Compatibility	119
3.4	Organic/Polymeric Thin Film Field-Effect Transistors	121
3.4.1	Techniques for Thin Film Preparation	121
3.4.2	Effect of Thin-Film Microstructure on the Performance of Transistors	122
3.4.3	High-Performance Transistors of Small Molecules	126
3.4.4	High-Performance Transistors of Conjugated Polymers	133
3.4.5	New Techniques for Organic/Polymeric Thin Film Field-Effect Transistors	135
3.4.5.1	Self-Assembly	135
3.4.5.2	Printing	137
3.5	Organic/Polymeric Single Crystal Field-Effect Transistors	140
3.5.1	Organic/Polymeric Single Crystals	140
3.5.2	Growth of Organic/Polymeric Crystals	140
3.5.2.1	Vapor Process for the Growth of Organic Crystals	140
3.5.2.2	Solution Process for the Growth of Organic/Polymeric Crystals	142
3.5.3	Fabrication Techniques for Organic Field-Effect Transistors of Single Crystals	144
3.5.3.1	Electrostatic-Bonding Technique	144
3.5.3.2	Drop-Casting Technique	144
3.5.3.3	Deposition Parylene Dielectric Technique	146
3.5.3.4	Shadow Mask Technique	147
3.5.3.5	Gold Layer Glue Technique	148
3.5.4	Performance of Organic/Polymeric Single Crystals in Field-Effect Transistors	148
3.5.4.1	Organic/Polymeric Crystals	148
3.5.4.2	Structure–Property Relationship of Organic/Polymeric Single Crystals	153

3.6	Outlook	155
	References	156
4	Organic Circuits and Organic Single-Molecule Transistors	171
	<i>Qinxin Tang, Yanhong Tong, Wenping Hu</i>	
4.1	Introduction	171
4.1.1	Ambipolar Transistors	171
4.1.2	Inverter Circuits	173
4.1.3	Ring Oscillator Circuits	176
4.2	Circuits of Organic Thin Films	178
4.2.1	Circuits of Organic Thin Films Based on Ambipolar Transistors	178
4.2.2	Circuits of Organic Thin Films Based on Unipolar Transistors	184
4.2.3	Complementary Circuits of Organic Thin Films	187
4.2.4	Complex Circuits of Organic Thin Films	192
4.2.5	Performance Modulation of Organic Thin-Film Circuits	199
4.2.6	Analog Circuit Based on Organic Thin-Film Transistors	209
4.3	Self-Assembled and Printed Organic Circuits	210
4.3.1	Self-Assembled Organic Circuits	210
4.3.2	Printed Organic Circuits	213
4.4	Circuits of Organic Crystals	216
4.5	Single-Molecule Transistors	221
4.5.1	Fabrication of Single-Molecule Transistors	222
4.5.1.1	Fabrication of Single-Molecule Prototype Devices	222
4.5.1.2	Fabrication of Single-Molecule Transistors by Nanogap Electrodes	225
4.5.2	Behavior of Single-Molecule Transistors	244
4.5.2.1	Temperature- and Length-Variable Transport of Single Molecules	245
4.5.2.2	Inelastic Electron Tunneling Spectroscopy of Single Molecules	247
4.5.2.3	Transition Voltage Spectroscopy of Single Molecules	251
4.5.3	Quanta and Theories of Single-Molecule Transistors	253
4.6	Challenges and Outlooks	259
	References	259
5	Polymer Light-Emitting Diodes (PLEDs): Devices and Materials	277
	<i>Xiong Gong</i>	
5.1	Introduction	277
5.2	PLEDs Fabricated from Conjugated Polymers	278
5.2.1	Device Architecture	278
5.2.2	Device Fabrication	278
5.3	Accurate Measurement of PLED Device Parameters	279
5.3.1	Photopic Luminosity	279
5.3.2	Measurement of PLEDs	281
5.4	Devices Physics of PLEDs	283

5.4.1	Elementary Microscopic Process of PLEDs	283
5.4.1.1	Injection	283
5.4.1.2	Carrier Transport	284
5.4.1.3	Carrier Recombination	284
5.4.1.4	Photon Emission	284
5.4.1.5	Photon Extraction	285
5.4.2	Carrier Transport in PLEDs	285
5.4.3	Electronic Characteristic of PLEDs	286
5.4.3.1	Current–Voltage Characteristics	286
5.4.3.2	Space–Charge-Limited Currents	286
5.4.3.3	Injection-Limited Currents	288
5.4.3.4	Diffusion-Controlled Currents	288
5.4.4	Fowler–Nordheim Tunneling in Conjugated Polymer MIM Diodes	289
5.4.4.1	Single Carrier Devices	292
5.4.4.2	LED Operating Voltage and Efficiency	293
5.4.4.3	Limits of the Model	294
5.4.5	Approaches to Improved Carrier Injection	295
5.5	Materials for PLEDs	296
5.5.1	Conjugated Polymers for PLEDs	296
5.5.1.1	Poly(p-phenylenevinylene)s (PPVs)	297
5.5.1.2	Polyphenylenes (PPPs)	297
5.5.1.3	Polyfluorenes (PFs)	297
5.5.1.4	Polythiophenes (PTs)	299
5.5.2	Anode and Cathode	300
5.5.2.1	Anodes	300
5.5.2.2	Cathodes	301
5.5.3	Hole-Injection/Transporting Materials	302
5.5.3.1	Hole-Injection Materials	302
5.5.3.2	Hole-Transporting Materials	302
5.5.4	Electron-Transporting Materials	302
5.6	Electrophosphorescent PLEDs	303
5.6.1	Energy Transfer	303
5.6.2	Electrophosphorescent PLEDs	306
5.6.3	Nonconjugated Polymer-Based Electrophosphorescent PLEDs	309
5.6.4	Conjugated Polymer-Based Electrophosphorescent PLEDs	316
5.7	White-Light PLEDs	323
5.7.1	Solid-State Lighting	323
5.7.2	Characterization of White Light	324
5.7.3	Fabrication of White-Light PLEDs	325
5.7.4	Efficient Excitation Energy Transfer from PFO to the Fluorenone Defect	326
5.7.5	White Electrophosphorescent PLEDs	328
5.7.6	Outlook of White PLEDs	330

5.8	Summary	331
	References	331
6	Organic Solids for Photonics	337
	<i>Hongbing Fu</i>	
6.1	Introduction	337
6.2	Size Effects on the Optical Properties of Organic Solids	338
6.2.1	Exciton Confinement Effect	338
6.2.2	Size-Tunable Emission	339
6.2.3	Multiple Emissions	341
6.3	Aggregation-Induced Enhanced Emission	342
6.4	Composite Solid	344
6.5	Outlook	347
	References	348
7	Organic Photonic Devices	351
	<i>Hongbing Fu</i>	
7.1	Introduction	351
7.2	Crystalline One-Dimensional (1-D) Organic Nanostructures	352
7.2.1	Self-Assembly in Liquid Phase	352
7.2.2	Template-Induced Self-Assembly in Liquid Phase	353
7.2.3	Morphology Control with Molecular Design	355
7.2.4	Physical Vapor Deposition (PVD)	355
7.3	Organic Nanophotonics	357
7.3.1	Electroluminescence and Field Emission	358
7.3.2	Tunable Emission from Binary Organic Nanowires	358
7.3.3	Organic 1-D Optical Waveguides	362
7.3.4	Lasing from Organic Nanowires	368
7.3.5	Organic Photonic Circuits	369
7.4	Outlook	371
	References	373
8	Organic Solar Cells Based on Small Molecules	375
	<i>Yuze Lin, Xiaowei Zhan</i>	
8.1	Introduction	375
8.1.1	Solar Energy and Solar Cells	375
8.1.2	Materials Features for Solar Cells	376
8.1.3	Device Configurations of Solar Cells	377
8.1.3.1	Hamburger Structure	377
8.1.3.2	Tandem Structure	378
8.2	Small-Molecule Donors	378
8.2.1	Dyes	379
8.2.2	Oligothiophenes	384
8.2.3	Triphenylamine Derivatives	387
8.3	Small-Molecule Acceptors	391

8.3.1	Rylene Diimides	391
8.3.2	Other Nonfullerene Acceptors	393
8.4	Donor–Acceptor Dyad Molecules for Single-Component OPVs	395
8.5	Conclusions and Outlook	396
	References	397
9	Polymer Solar Cells	407
	<i>Huitao Bai, Qinqin Shi, Xiaowei Zhan</i>	
9.1	Introduction	407
9.2	Polymer Donor Materials	408
9.2.1	Polyphenylenevinylene (PPV) Derivatives	408
9.2.2	Polythiophene Derivatives	410
9.2.3	Polyfluorene Derivatives	413
9.2.4	Polycarbazole Derivatives	416
9.2.5	Polybenzodithiophene Derivatives	417
9.2.6	Polycyclopentadithiophene Derivatives	419
9.2.7	Metallic Conjugated Polymers	421
9.3	Polymer Acceptor Materials	423
9.4	Conclusions and Outlook	428
	References	429
10	Dye-Sensitized Solar Cells (DSSCs)	437
	<i>Lanchao Ma, Xiaowei Zhan</i>	
10.1	Introduction	437
10.2	Small-Molecule Dyes in DSSCs	442
10.2.1	Coumarin Dyes	442
10.2.2	Triphenylamine Dyes	444
10.2.3	Bisfluorenylaniline Dyes	448
10.2.4	Other Dyes	450
10.3	Polymer Dyes in DSSCs	453
10.4	Dyes in p-Type DSSCs	454
10.5	Summary and Outlook	457
	References	459
11	Organic Thermoelectric Power Devices	467
	<i>Martin Leijnse, Karsten Flensberg, Thomas Bjørnholm</i>	
11.1	Introduction	467
11.2	Basic Thermoelectric Principles	468
11.2.1	The Thermoelectric Effect	468
11.2.2	Thermoelectric Efficiency and Figure of Merit	472
11.2.3	Optimizing the Figure of Merit	474
11.3	Thermoelectric Materials and Devices	476
11.3.1	Inorganic Nanostructured Materials	476
11.3.2	Single-Molecule Devices	477
11.3.3	Devices Based on Polymers	480

11.3.4	Devices Based on Small Molecules	482
11.3.5	Hybrid and Composite Materials	482
11.4	Conclusions and Outlook	483
	References	484

Glossary of the book	487
-----------------------------	-----

Index	497
--------------	-----