

Contents

1	Present Status in the Development of III–V Multi-Junction Solar Cells	1
	Simon P. Philipps, Wolfgang Guter, Elke Welser, Jan Schöne, Marc Steiner, Frank Dimroth, and Andreas W. Bett	
1.1	Introduction	1
1.2	Research Status	4
1.2.1	Numerical Simulation	4
1.2.2	Device Fabrication	9
1.3	Next Steps	14
	References	19
2	The Interest and Potential of Ultra-High Concentration	23
	Carlos Algora and Ignacio Rey-Stolle	
2.1	Motivation of Ultra-High Concentration	23
2.2	Cost Calculation Update	28
2.3	Series Resistance	29
2.4	Tunnel Junctions for UHCPV	35
2.5	Increase of the MJSC Efficiency at Ultra-High Concentration	39
2.6	Advanced Characterisation	45
2.6.1	Quantum Efficiency Under Concentration	45
2.6.2	Electroluminescence Spectroscopy	47
2.6.3	Electroluminescence Intensity Mapping	49
2.7	Reliability	52
	References	56
3	The Sun Tracker in Concentrator Photovoltaics	61
	Ignacio Luque-Heredia, Goulven Quéméré, Rafael Cervantes, Olivier Laurent, Emmanuele Chiappori, and Jing Ying Chong	
3.1	Introduction	61
3.2	Requirements and Specifications	63
3.3	The Tracker Structure	67

3.4	Sun Tracking Control	74
3.4.1	Background	74
3.4.2	The Autocalibrated Sun Tracking Control Unit	79
3.5	Sun Tracking Accuracy Monitoring	83
3.5.1	The Tracking Accuracy Sensor	84
3.5.2	The Monitoring System	85
3.5.3	Accuracy Assessment: Example of the Autocalibrated Tracking Strategy	87
	References	91
4	Light Management in Thin-Film Solar Cell	95
	Janez Krč, Benjamin Lipovšek, and Marko Topič	
4.1	Introduction	95
4.2	Optical Properties of Thin-Film Photovoltaic Devices	97
4.2.1	Optical Modelling and Simulation	100
4.2.2	Importance of Light Management in Thin-Film Solar Cells	101
4.3	Advanced Light Management in Thin-Film Solar Cells	106
4.3.1	Efficient Light Scattering	106
4.3.2	Minimisation of Optical Losses	113
4.3.3	Enhanced Utilisation of the Solar Spectrum	121
4.4	Conclusion	124
	References	126
5	Surface Plasmon Polaritons in Metallic Nanostructures: Fundamentals and Their Application to Thin-Film Solar Cells	131
	Carsten Rockstuhl, Stephan Fahr, and Falk Lederer	
5.1	Introduction	131
5.2	Plasmon Polaritons and Their Use in Solar Cells	132
5.3	Fundamentals	134
5.3.1	Localized Surface Plasmon Polaritons	134
5.3.2	Propagating Surface Plasmon Polaritons	138
5.3.3	Simulation Techniques	142
5.4	Use of Localized Surface Plasmon Polaritons in Solar Cells	143
5.4.1	Thin-Film Solar Cells	145
5.4.2	Tandem Solar Cells	147
5.5	Use of Propagating Surface Plasmon Polaritons in Solar Cells	149
5.5.1	Thin-Film Solar Cells	150
5.6	Conclusions	152
	References	153
6	Non-Coherent Up-Conversion in Multi-Component Organic Systems	157
	Stanislav Balushev and Tzenka Miteva	
6.1	Comparison Between Up-Conversion Processes	157
6.2	Requirements of an Organic System for Observation of Efficient TTA-UC	165

6.3	Characterization of the TTA-UC	169
6.3.1	Replacement of the Volatile Organic Solvent	170
6.3.2	Materials and Methods	173
6.3.3	Transparency Window	173
6.3.4	Triplet Harvesting	175
6.3.5	Intensity Dependence.....	176
6.3.6	Dependence on the Beam Diameter and Viscosity of the Optically Inactive Solvent	177
6.3.7	Molar Concentration Dependence	179
6.3.8	Molar Concentration Dependence	180
6.3.9	Temperature Dependence in Solid-State Films	181
6.4	Sunlight UC and Its Application for Organic Solar Cells	183
6.4.1	Active UC-Media: The Molecular Couples	185
6.4.2	Active UC-Media: The Molecular Couples	186
6.5	Conclusion	188
	References.....	189
7	Next Generation Photovoltaics Based on Multiple Exciton Generation in Quantum Dot Solar Cells	191
	Arthur J. Nozik	
7.1	Introduction.....	192
7.2	Solar Cells Utilizing Hot Carriers for Enhanced Conversion Efficiency	193
7.3	Quantum Dots, Multiple Exciton Generation, and Third Generation Solar Cells	194
7.4	Configurations of QD Solar Cells	199
7.4.1	Photoelectrodes Composed of Quantum Dot Arrays	200
7.4.2	Quantum Dot-Sensitized Nanocrystalline TiO ₂ Solar Cells	201
7.4.3	Quantum Dots Dispersed in Organic Semiconductor Polymer Matrices	201
7.5	Schottky Junction and <i>p-n</i> Junction Solar Cells Based on Films of QD Arrays.....	202
7.6	Conclusions.....	203
	References.....	204
8	Fundamentals of Intermediate Band Solar Cells	209
	Antonio Martí and Antonio Luque	
8.1	Introduction.....	209
8.2	Intermediate Band Solar Cell Model	213
8.3	Quantum Dot Intermediate Band Solar Cells	216
8.4	Thin-Film Intermediate Band Solar Cells	219
8.5	InGaN Intermediate Band Solar Cells.....	220
8.6	Highly Mismatched Alloys	221
8.7	ZnTe:O Intermediate Band Solar Cells.....	222
8.8	Molecular Approach	223

8.9	In ₂ S ₃ :V Intermediate Band Material	223
8.10	Other Intermediate Band Solar Cell Systems	225
8.11	Conclusions	225
	References	226
9	Modelling of Quantum Dots for Intermediate Band Solar Cells	229
	Stanko Tomić	
9.1	Introduction	229
9.2	Theory of QD Array Electronic Structure	232
9.2.1	The k-p Theory	232
9.2.2	Plane Waves Implementation of QD Array Electronic Structure Solver	234
9.2.3	Model QD Arrays	234
9.2.4	Wavefunction Delocalization and Intermediate Band Formation in QD Arrays	235
9.2.5	Electronic Structure of QD Arrays	237
9.2.6	Absorption Characteristics of QD Arrays	239
9.3	Radiative and Non-Radiative Processes in QD Array	242
9.3.1	Radiative Processes in QD Arrays	242
9.3.2	Electron-Phonon Interaction in QD Arrays	244
9.3.3	Auger-Related Nonradiative Times in QD Arrays	246
9.4	Conclusions	247
	References	249
10	The Quantum Dot Intermediate Band Solar Cell	251
	Colin R. Stanley, Corrie D. Farmer, Elisa Antolín, Antonio Martí, and Antonio Luque	
10.1	Introduction	251
10.2	Molecular Beam Epitaxy of III-V Semiconductors	253
10.2.1	Introduction	253
10.2.2	MBE Growth Kinetics	254
10.2.3	The Utility of Reflection High Energy Electron Diffraction in MBE	255
10.3	MBE Growth of InAs Quantum Dots on (100)-GaAs	256
10.3.1	Introduction	256
10.3.2	MBE Growth of InAs Quantum Dots	256
10.3.3	Capping of InAs QDs	257
10.3.4	“Seeded” InAs QD Growth	259
10.3.5	Multi-Layer Stacks of InAs QDs	260
10.4	MBE Growth of InAs Quantum Dots for IBSCs	261
10.4.1	Introduction	261
10.4.2	Optimising the CB→IB Energy Separation	262
10.4.3	Multiple QD Layers	264
10.4.4	Populating the IB with Electrons	265

10.5	Manufacture of QD-IBSC Die	265
10.5.1	Introduction	265
10.5.2	Low Resistance Ohmic Metallisations to <i>n</i> - and <i>p</i> -Type Emitters	268
10.5.3	Definition of Diode Area	269
10.5.4	Exposure of AlGaAs Window Layer	269
10.5.5	Broad Band Anti-Reflection Coating	269
10.6	Characterisation of Quantum Dot Intermediate Band Solar Cells	270
10.7	Conclusions	272
	References	274
11	Thin-Film Technology in Intermediate Band Solar Cells: Advanced Concepts for Chalcopyrite Solar Cells	277
	David Fuenes Marrón	
11.1	Why Not Thin-Film Intermediate Band Solar Cells? Theoretical Aspects	278
11.2	The Impurity Approach	287
11.3	The Nanostructuring Approach	294
11.4	Conclusions and Outlook	298
	References	304
12	InGaN Technology for IBSC Applications	309
	C. Thomas Foxon, Sergei V. Novikov, and Richard P. Campion	
12.1	Introduction	309
12.2	Motivation and Theoretical Consideration for InGaN:Mn in IBSC Applications	310
12.3	Growth of Mn Doped In-Rich InGaN	312
12.4	Proposed IBSC Structures and Progress So Far	317
12.5	Future Plans and Options	318
12.6	Summary and Conclusions	318
	References	319
13	Ion Implant Technology for Intermediate Band Solar Cells	321
	Javier Olea, David Pastor, María Toledano Luque, Ignacio Mártel, and Germán González Díaz	
13.1	Introduction	321
13.2	Experimental	323
13.3	Results	324
	13.3.1 Structural Characterization	324
	13.3.2 Electrical Transport Properties	329
13.4	Discussion	343
13.5	Conclusions	344
	References	345
	Index	347