

Contents

1	Building 3D Nanostructured Devices by Self-Assembly	1
	Steve Hu, Jeong-Hyun Cho, and David H. Gracias	
1.1	The Pressing Need for 3D Patterned Nanofabrication	1
1.2	Self-Assembly Using Molecular Linkages	3
1.2.1	Three-Dimensional Self-Assembly Using Protein Linkages	4
1.2.2	Three-Dimensional Self-Assembly with DNA Linkages	6
1.3	Three-Dimensional Self-Assembly Using Physical Forces	10
1.4	Three-Dimensional Patterned Nanofabrication by Curving and Bending Nanostructures	12
1.4.1	Curving Hingeless Nanostructures Using Stress	13
1.4.2	Three-Dimensional Nanofabrication by Bending Hinged Panels to Create Patterned Polyhedral Nanoparticles	20
1.5	Conclusions	22
	References	23
2	Bio-inspired 3D Nanoarchitectures	29
	Jian Shi and Xudong Wang	
2.1	Introduction	29
2.2	Historical Perspective	31
2.3	Bio-inspired Nanophotonics	31
2.3.1	Photonic Crystals	31
2.3.2	Color Mine in Nature	34
2.3.3	Natural Photonic Crystals	35
2.3.3.1	Spine of Sea Mouse	35
2.3.3.2	Diatom	37
2.3.3.3	Butterfly Wings	37
2.3.3.4	Beetles	40
2.3.3.5	Weevil	43
2.3.4	Other Natural Photonics	43
2.3.4.1	Brittle Star	43
2.3.4.2	Glass Sponge	45

2.4	Bio-inspired Fabrication of Nanostructures	47
2.4.1	Biom mineralization	47
2.4.2	Biological Fine Structure Duplication	48
2.4.2.1	Replication by Surface Coating	49
2.4.2.2	Replication by Atom Exchange	52
2.5	Bio-inspired Functionality	54
2.6	Conclusion	56
	References	57
3	Building 3D Micro- and Nanostructures Through Nanoimprint . .	59
	Xing Cheng	
3.1	Introduction to 3D Structure Fabrication Through Nanoimprint .	59
3.2	Overview of Nanoimprint Lithography	60
3.2.1	Fundamentals of Nanoimprint Lithography	60
3.2.2	Materials for Nanoimprint Lithography	61
3.3	Building 3D Nanostructures by Nanoimprint	63
3.3.1	Direct Patterning of 3D Structures in One Step	63
3.3.1.1	Replicating 3D Polymer Structures from 3D Templates	63
3.3.1.2	Applications of 3D Polymer Structures by One-Step Nanoimprint	65
	Dual Damascene Structure for Back-End Processing of Microelectronic Circuit Chips	66
	Advanced Optical Components Based on 3D Polymer Structures	67
3.3.2	Building 3D Nanostructures by Transfer Bonding and Sequential Layer Stacking	70
3.3.2.1	Principles of Transfer Bonding and Sequential Layer Stacking	70
3.3.2.2	3D Structures Built by Transfer Bonding and Sequential Layer Stacking	72
3.3.2.3	Defect Modes and Process Yield of Transfer Bonding and Sequential Layer Stacking	80
3.3.3	Building 3D Nanostructures by Two Consecutive Nanoimprints	82
3.4	Summary and Future Outlook	82
	References	84
4	Electrochemical Growth of Nanostructured Materials	89
	Jin-Hee Lim and John B. Wiley	
4.1	Magnetic Nanomaterials	90
4.2	Semiconductor Nanostructures	93
4.3	Thermoelectric Nanomaterials	95
4.4	Conducting Polymer Nanostructures	96

4.5	Nanotube and Core–Shell Nanostructures	98
4.6	Porous Au Nanowires	99
4.7	Modification of Nanowires	102
4.8	Functionalization of Nanowires	104
4.9	Nanostructure Arrays on Substrates	106
4.10	Patterning of Nanowires	107
	References	111
5	Three-Dimensional Micro/Nanomaterials Generated by Fiber-Drawing Nanomanufacturing	117
	Zeyu Ma, Yan Hong, Shujiang Ding, Minghui Zhang, Mainul Hossain, and Ming Su	
5.1	Introduction	117
5.2	Fiber Draw Tower	117
5.3	Materials Selections	119
5.4	Drawing Process	119
5.5	Size Design	120
5.6	Three-Dimensional Assembling	122
5.7	Metallic Nanowires	122
5.8	Semiconductor Nanowires	123
5.9	Glass Microchannel Array	125
5.10	Differential Etching of Glasses	125
5.11	Glass Microspike Array	126
5.12	Hybrid Glass Membranes	128
5.13	Textured Structure of Encapsulated Paraffin Wax Microfiber . .	130
5.14	Conclusions	131
	References	131
6	One-Dimensional Metal Oxide Nanostructures for Photoelectrochemical Hydrogen Generation	133
	Yat Li	
6.1	Introduction	133
6.1.1	Photoelectrochemical Hydrogen Generation	133
6.1.2	Challenges in Metal Oxide-Based PEC Hydrogen Generation	135
6.1.3	One-Dimensional Nanomaterials for Photoelectrodes . .	136
6.2	Pristine Metal Oxide Nanowire/Nanotube-Arrayed Photoelectrodes	138
6.2.1	Nanowire-Arrayed Photoelectrodes	138
6.2.1.1	Hematite (α -Fe ₂ O ₃)	138
6.2.1.2	Titanium Oxide (TiO ₂) and Zinc Oxide (ZnO)	139
6.2.1.3	Tungsten Trioxide (WO ₃)	142
6.2.2	Nanotube-Arrayed Photoelectrodes	143

6.3	Element-Doped Metal Oxide 1D Nanostructures	146
6.3.1	TiO ₂ Nanostructures	146
6.3.2	ZnO Nanostructures	149
6.3.3	Hematite (α -Fe ₂ O ₃) Nanostructures	149
6.4	Quantum Dot Sensitizations	152
6.4.1	Background	152
6.4.2	Quantum Dot-Sensitized ZnO Nanowires	153
6.4.3	Quantum Dot-Cosensitized Nanowires	154
6.4.4	Double-Sided Quantum Dot Sensitization	155
6.5	Synergistic Effect of Quantum Dot Sensitization and Elemental Doping	158
6.6	Concluding Remarks	160
	References	162
7	Helical Nanostructures: Synthesis and Potential Applications . . .	167
	Pu-Xian Gao and Gang Liu	
7.1	Introduction	167
7.2	Semiconductor Nanohelices	168
7.2.1	ZnO Nanohelices	168
7.2.1.1	Superlattice-Structured ZnO Nanohelices . .	168
7.2.1.2	Superelasticity, Nanobuckling, and Nonlinear Electronic Transport of Superlattice-Structured ZnO Nanohelices	170
	Superelasticity of Superlattice- Structured ZnO Nanohelix	171
	Nanobuckling and Fracture of Superlattice-Structured ZnO Nanohelix	172
	Nonlinear Electronic Transport of Superlattice-Structured ZnO Nanohelix	174
7.2.1.3	Other ZnO Nanohelices	176
7.2.2	SiO ₂ Nanohelices	178
7.2.3	CdS Nanohelices	183
7.2.4	InP Nanohelices	188
7.2.5	Ga ₂ O ₃ Nanohelices	190
7.3	Carbon-Related Nanohelices	191
7.3.1	Helical Carbon Nanoribbon/Nanocoil	192
7.3.2	Helical Carbon Nanotube	194
7.3.3	Tungsten-Containing Carbon (WC) Nanospring	195
7.4	Other Nanohelices	197
7.4.1	Helical SiC/SiO ₂ Core-Shell Nanowires and Si ₃ N ₄ Microcoils	197
7.4.2	MgB ₂ Nanohelices	198
7.4.3	Si Spirals	199
7.5	Potential Applications	201

7.6	Summary	202
	References	202
8	Hierarchical 3D Nanostructure Organization for Next-Generation Devices	205
	Eric N. Dattoli and Wei Lu	
8.1	Introduction	205
8.2	Fluidic Flow-Assisted Assembly	206
	8.2.1 Drop-Drying	207
	8.2.2 Channel-Confined Fluidic Flow	208
	8.2.3 Blown Bubble Film Transfer	210
8.3	Nematic Liquid Crystal-Induced Assembly	212
8.4	Langmuir–Blodgett Assembly	213
8.5	Dielectrophoresis Assembly	215
8.6	Chemical Affinity and Electrostatic Interaction-Directed Assembly	219
8.7	Contact Transfer	221
	8.7.1 Shear-Assisted Contact Printing	221
	8.7.2 Stamp Transfer	224
8.8	Directed Growth	226
	8.8.1 Horizontal Growth	226
	8.8.2 Vertical Growth	228
8.9	Device Applications	230
	8.9.1 Thin-Film Transistors	230
	8.9.1.1 Performance Considerations for NW- or NT-Based TFTs	230
	8.9.1.2 Transparent Nanowire-Based TFTs	233
	8.9.1.3 CNT-Based TFTs	235
	8.9.2 3D Multilayer Device Structures	237
	8.9.3 Sensors	240
	8.9.4 Vertical Nanowire Field-Effect Transistors (FETs)	242
8.10	Conclusion	243
	References	243
9	Strain-Induced, Self Rolled-Up Semiconductor Microtube Resonators: A New Architecture for Photonic Device Applications	249
	Xin Miao, Ik Su Chun, and Xiuling Li	
9.1	Introduction	249
9.2	Formation Process	250
9.3	Photonic Applications of Rolled-Up Semiconductor Tubes	252
	9.3.1 Spontaneous Emission from Quantum Well Microtubes: Intensity Enhancement and Energy Shift	252
	9.3.2 Optical Resonance Modes in Rolled-Up Microtube Ring Cavity	254
	9.3.3 Optically Pumped Lasing from Rolled-Up Microtube Ring Cavity	256
	References	258

10	Carbon Nanotube Arrays: Synthesis, Properties, and Applications	261
	Suman Neupane and Wenzhi Li	
10.1	Introduction	261
10.2	Carbon Nanotube Synthesis	262
10.2.1	Arc Discharge	262
10.2.2	Laser Ablation	262
10.2.3	Electrochemical Synthesis	263
10.2.4	Diffusion Flame Synthesis	264
10.2.5	Chemical Vapor Deposition	264
10.3	Carbon Nanotube Arrays	265
10.3.1	CNTA Synthesis Using Patterned Catalyst Arrays	266
10.3.1.1	Pulsed Laser Deposition	266
10.3.1.2	Anodic Aluminum Oxide (AAO) Templates	266
10.3.1.3	Reverse Micelle Method	266
10.3.1.4	Photolithography	267
10.3.1.5	Electrochemical Etching	268
10.3.1.6	Sputtering	268
10.3.1.7	Nanosphere Lithography	268
10.3.1.8	Sol–Gel Method	269
10.3.2	CNTA Synthesis by Other Methods	269
10.3.3	Horizontal Arrays of CNTs	270
10.4	Mechanical Properties	270
10.5	Thermal Properties	271
10.6	Electrical Properties	273
10.7	Applications of CNTs and CNTAs	276
10.7.1	Hydrogen Storage	276
10.7.2	CNTs as Sensors	278
10.7.3	CNTs for Battery and Supercapacitor Applications	279
10.7.4	CNTs for Photovoltaic Device	279
10.8	Conclusions	280
	References	281
11	Molecular Rotors Observed by Scanning Tunneling Microscopy . .	287
	Ye-Liang Wang, Qi Liu, Hai-Gang Zhang, Hai-Ming Guo, and Hong-Jun Gao	
11.1	Introduction	287
11.2	Solution-Based and Surface-Mounted Molecular Machines	289
11.3	Single Molecular Rotors at Surfaces	290
11.3.1	A Monomolecular Rotor in Supramolecular Network	290
11.3.2	Gear-Like Rotation of Molecular Rotor Along the Edge of the Molecular Island	292
11.3.3	Thermal-Driven Rotation on Reconstructed Surface Template	292
11.3.4	STM-Driven Rotation on Reconstructed Surface Template	301

11.3.5	Molecular Rotors with Variable Rotation Radii	303
11.3.6	Rolling Motion of a Single Molecule at the Surface . . .	305
11.4	Array of Molecular Motors at Surfaces	308
11.5	Outlook	310
11.6	Conclusion	311
	References	311
12	Nanophotonic Devices Based on ZnO Nanowires	317
	Qing Yang, Limin Tong, and Zhong Lin Wang	
12.1	Introduction	317
12.2	Pure Optical Devices Based on ZnO NWs	318
12.2.1	ZnO NW Subwavelength Waveguides and Their Applications	318
12.2.2	Optically Pumped Lasers in ZnO NWs	322
12.2.3	Nonlinear Optical Devices Based on ZnO NWs	330
12.3	Optoelectronic Devices Based ZnO NWs	333
12.3.1	ZnO NW Ultra-sensitive UV and Infrared PDs	333
12.3.2	Dye-Sensitized Solar Cells Based on ZnO NWs	339
12.3.3	Single ZnO NW and NW Array Light-Emitting Diodes	345
12.3.4	Electrically Pumped Random Lasing from ZnO Nanorod Arrays	350
12.4	Piezo-phototronic Devices Based on ZnO NWs	352
12.4.1	Optimizing the Power Output of a ZnO Photocell by Piezopotential	353
12.4.2	Enhancing Sensitivity of a Single ZnO Micro-/NW Photodetector by Piezo-phototronic Effect	354
12.5	Conclusions	356
	References	356
13	Nanostructured Light Management for Advanced Photovoltaics	363
	Jia Zhu, Zongfu Yu, Sangmoo Jeong, Ching-Mei Hsu, Shanui Fan, and Yi Cui	
13.1	Introduction	363
13.2	Fabrication of Nanowire and Nanocone Arrays	365
13.2.1	Method	366
13.2.2	Shape Control: Nanowires and Nanocones	366
13.2.3	Diameter and Spacing Control	368
13.2.4	Large-Scale Process	368
13.3	Photon Management: Antireflection	372
13.3.1	Nanowires	372
13.3.2	Nanocones	374
13.4	Photon Management: Absorption Enhancement	376
13.4.1	Different Mechanisms	376
13.4.2	Nanodome Structures	378
13.5	Solar Cell Performance	383

13.6	Fundamental Limit of Light Trapping in Nanophotonics	384
13.7	Summary and Outlook	388
	References	389
14	Highly Sensitive and Selective Gas Detection by 3D Metal Oxide Nanoarchitectures	391
	Jiajun Chen, Kai Wang, Baobao Cao, and Weilie Zhou	
14.1	Introduction	391
14.2	Highly Sensitive Gas Detection by Stand-alone 3D Nanosensors	394
14.2.1	Metal Oxide Nanowire/Nanotube Array Gas Sensors .	395
14.2.1.1	Nanowire Arrays	395
14.2.1.2	Nanotube Arrays	399
14.2.2	Gas Sensors Based on Opal and Inverted Opal Nanostructures	401
14.3	Sensor Arrays Based on 3D Nanostructured Gas Sensors	403
14.4	Conclusion Remarks	408
	References	409
15	Quantum Dot-Sensitized, Three-Dimensional Nanostructures for Photovoltaic Applications	413
	Jun Wang, Xukai Xin, Daniel Vennerberg, and Zhiqun Lin	
15.1	Introduction	413
15.2	Quantum Dot-Sensitized Solar Cells	415
15.2.1	Overview	415
15.2.2	Synthesis of Quantum Dots and Surface Functionalization	415
15.2.3	Quantum Dot-Sensitized Nanoparticle Films	419
15.2.4	Quantum Dot-Sensitized Nanowire Arrays	426
15.2.5	Quantum Dot-Sensitized Nanotube Arrays	428
15.2.6	Investigation of Charge Injection in Quantum Dot-Sensitized Solar Cells	432
15.2.6.1	Generation of Excited Electrons	432
15.2.6.2	Recombination and Transportation of Excited Electrons	434
15.3	Outlook	438
	References	439
16	Three-Dimensional Photovoltaic Devices Based on Vertically Aligned Nanowire Array	447
	Kai Wang, Jiajun Chen, Satish Chandra Rai, and Weilie Zhou	
16.1	Introduction	447
16.2	Photovoltaic Devices Based on Nanowire Array Integrated with the Substrate	448
16.3	Photovoltaic Devices Based on Nanowire Array with Axial Junctions	451

16.4	Photovoltaic Devices Based on Nanowire Array Embedded in Thin Film	452
16.5	Photovoltaic Devices Based on Nanowire Array with Core–Shell Structure	453
16.5.1	p–n Core–Shell Homojunction Photovoltaic Devices . .	453
16.5.2	Type II Core–Shell Heterojunction Photovoltaic Devices	456
16.5.2.1	Synthesis of ZnO/ZnSe and ZnO/ZnS Core–Shell Nanowire Array . . .	457
16.5.2.2	Structural and Optical Properties of ZnO/ZnSe Core–Shell Nanowire Array . . .	458
16.5.2.3	Photoresponse of ZnO/ZnSe Nanowire Array	461
16.5.2.4	Morphologies, Structure and Optical Properties of ZnO/ZnS Nanowire Array . . .	462
16.5.2.5	Photovoltaic Effect of ZnO/ZnS Nanowire Array	465
16.6	Summary and Perspectives	469
	References	471
17	Supercapacitors Based on 3D Nanostructured Electrodes	477
	Hao Zhang, Gaoping Cao, and Yusheng Yang	
17.1	Supercapacitors	478
17.2	Electrochemical Double Layer Capacitors Based on 3D Nanostructured Electrodes	479
17.2.1	Electrodes Based on Activated Carbons and Activated Carbon Fibers: Powdered Carbons with Disordered Pore Structures	480
17.2.2	Electrodes Based on Carbon Foams, Carbon Aerogels, and Other Monolithic Carbon: Monolithic Carbon with Disordered Micropores	483
17.2.3	Electrodes Based on Template Carbons, Graphene, Carbide-Derived Carbons, and Hierarchical Porous Carbons: Powdered Carbons with High Mesopore Ratios or Reasonable PSD	486
17.2.4	Electrodes Based on Carbon Nanotubes: Monolithic Carbons with Developed Mesoporous Structures	492
17.3	Pseudo-capacitors Based on 3D Nanostructured Electrodes . . .	497
17.3.1	Nanostructured Metal Oxide Electrode Materials . . .	498
17.3.2	Nanostructured Conducting Polymer Electrode Materials	500
17.4	Hybrid Capacitors Based on 3D Nanostructured Electrodes . . .	502

17.4.1	Nanostructured Electrodes Based on Metal Oxides/Carbon Composite	504
17.4.2	Nanostructured Electrodes Based on Polymers/Carbon Composites	508
17.5	Conclusions and Perspectives	513
	References	514
18	Aligned Ni-Coated Single-Walled Carbon Nanotubes Under Magnetic Field for Coolant Applications	523
	Haiping Hong, Mark Horton, and G.P. Peterson	
18.1	Introduction	523
18.2	Experiment	524
18.3	Results and Discussion	525
18.3.1	Thermal Conductivity of Nanofluids Containing Ni-Coated Nanotubes	525
18.3.2	Evidence of Magnetic Alignment of Ni-Coated Nanotubes	529
18.4	Conclusion	533
	References	534
	Index	535

<http://www.springer.com/978-1-4419-9821-7>

Three-Dimensional Nanoarchitectures

Designing Next-Generation Devices

Zhou, W.; Wang, Z.L. (Eds.)

2011, XVIII, 538 p. 359 illus., 238 illus. in color.,

Hardcover

ISBN: 978-1-4419-9821-7