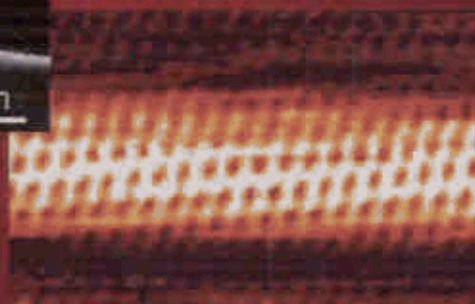
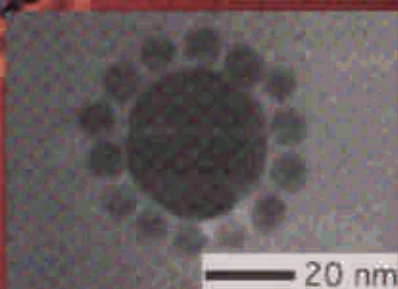


Introduction to NANOSCALE SCIENCE AND TECHNOLOGY

Edited by

Massimiliano Di Ventra, Stephane Evoy and James R. Heflin, Jr.



 Springer

Contents

Introduction	1
I. Nanoscale Fabrication and Characterization	5
1. Nanolithography	7
<i>L. R. Harriott and R. Hull</i>	
1.1. Introduction	7
1.2. Cross-Cutting Technologies: Resists and Masks	9
1.3. Photon-Based Nanolithography Techniques	13
1.4. Electron Beam Lithography	22
1.5. Focused Ion Beam Lithography	26
1.6. Emerging Nanolithographies	34
1.7. Summary	38
Questions	38
References	39
2. Self-Assembly and Self-Organization	41
<i>Roy Shenhar, Tyler B. Norsten, and Vincent M. Rotello</i>	
2.1. The Advantages of Self-Assembly	41
2.2. Intermolecular Interactions and Molecular Recognition	42
2.3. Self-Assembled Monolayers (SAMs)	44
2.4. Electrostatic Self-Assembly	55
2.5. Self-Organization in Block Copolymers	63
2.6. Summary	71
Questions	71
References	72
3. Scanning Probe Microscopes	75
<i>K.-W. Ng</i>	
3.1. Introduction	75
3.2. Basics of SPM	77
3.3. Scanning Tunneling Microscope	84
3.4. Other Scanned Probe Microscopes	91
3.5. Near-Field Scanning Optical Microscope (NSOM)	97

3.6. Summary	99
Questions	100
References	100
II. Nanomaterials and Nanostructures	101
4. The Geometry of Nanoscale Carbon	103
<i>Vincent Crespi</i>	
4.1. Bonding	103
4.2. Dimensionality	105
4.3. Topology	106
4.4. Curvature	109
4.5. Energetics	109
4.6. Kinetics	111
4.7. Other Rings	113
4.8. Surfaces	114
4.9. Holes ($G \neq 0$)	115
4.10. Conclusions	116
Questions	117
References	117
5. Fullerenes	119
<i>Harry C. Dorn and James C. Duchamp</i>	
5.1. Families of Fullerenes: From C_{60} to TNTs	119
5.2. Reactivity	128
5.3. Potential Applications	132
5.4. Further Reading	133
Questions	134
References	135
6. Carbon Nanotubes	137
<i>Brian W. Smith and David E. Luzzi</i>	
6.1. History	137
6.2. Molecular and Supramolecular Structure	138
6.3. Intrinsic Properties of Individual Single Wall Carbon Nanotubes	141
6.4. Synthesis and Characterization of Carbon Nanotubes	152
6.5. Modification	166
6.6. Applications of Nanotubes	172
6.7. Conclusions	180
Questions	180
References	181
7. Quantum Dots	183
<i>A. B. Denison, Louisa J. Hope-Weeks, Robert W. Meulenberg, and L. J. Terminello</i>	
7.1. Introduction	183

7.2. Quantum Mechanical Background	183
7.3. Quantum Confinement—3D Quantum Dot	185
7.4. Other Interactions	187
7.5. Colloidal Growth of Nanocrystals	188
7.6. Epitaxial Growth	192
7.7. Quantum Dots Formed by Ion Implantation	194
7.8. Further Reading	198
Questions	198
References	198
8. Nanocomposites	199
<i>Robert C. Cammarata</i>	
8.1. Introduction	199
8.2. Nanolayered Composites	202
8.3. Nanofilamentary and Nanowire Composites	206
8.4. Nanoparticulate Composites	208
8.5. Summary	211
References	212
III. Nanoscale and Molecular Electronics	215
9. Advances in Microelectronics—From Microscale to Nanoscale Devices	217
<i>Jan Van der Spiegel</i>	
9.1. Introduction	217
9.2. Brief History of Microelectronic Devices and Technology	218
9.3. Basics of Semiconductors	222
9.4. Structure and Operation of a MOS Transistor	229
9.5. Scaling of Transistor Dimensions	236
9.6. Small-Dimension Effects	238
9.7. Nanoscale MOSFET Transistors: Extending Classical CMOS Transistors	241
9.8. Beyond Traditional CMOS	251
9.9. Summary	254
Questions	255
Appendices	257
References	258
10. Molecular Electronics	261
<i>Michael Zwolak and Massimiliano Di Ventra</i>	
10.1. Tools and Ways to Build and Probe Molecular Devices	262
10.2. Conductance Measurements	267
10.3. Transport Mechanisms and Current-Induced Effects	275
10.4. Integration Strategies	279
10.5. Conclusions	280
10.6. Further Reading	281
Questions	281
References	282

11. Single Electronics	283
<i>Jia Grace Lu</i>	
11.1. Single Electron Tunneling	283
11.2. Superconducting Single Electron Transistor	294
11.3. Implementation of Single Electron Transistors	299
11.4. Application of Single Electron Transistors	300
11.5. Summary	303
Questions	304
Appendices	304
References	311
IV. Nanotechnology in Magnetic Systems	313
12. Semiconductor Nanostructures for Quantum Computation	315
<i>Michael E. Flatté</i>	
12.1. Nanostructures for Quantum Computation	315
12.2. Quantum Computation Algorithms	316
12.3. Superposition and Quantum Parallelism	317
12.4. Requirements for Physical Realizations of Quantum Computers	318
12.5. Spin as a Physical Realization of a Qubit	320
12.6. Quantum Computation with Electron Spins in Quantum Dots	321
12.7. Quantum Computation with Phosphorus Nuclei in Silicon	322
12.8. Conclusions	324
Questions	325
References	325
13. Magnetoresistive Materials and Devices	327
<i>Olle Heinonen</i>	
13.1. Introduction	327
13.2. Elements of Magnetoresistance	328
13.3. Read Heads and MRAM	338
13.4. Summary	351
Questions	352
References	352
14. Elements of Magnetic Storage	355
<i>Jordan A. Katine and Robert E. Fontana Jr.</i>	
14.1. Introduction to Magnetic Storage	355
14.2. Fundamentals of Magnetism and Their Application to Storage	358
14.3. Fabrication Technologies and Scaling	362
14.4. Summary	369
Questions	369
References	370

V. Nanotechnology in Integrative Systems	371
15. Introduction to Integrative Systems	373
<i>Michael Gaitan</i>	
15.1. Introduction	373
15.2. Review of MEMS and MST Fabrication Technologies	376
15.3. Integration of Micromachining with Microelectronics	380
15.4. Outlook	385
Questions	387
References	387
16. Nanoelectromechanical Systems	389
<i>Stephane Evoy, Martin Duemling, and Tushar Jarumar</i>	
16.1. Of MEMS and NEMS	389
16.2. Surface Machining and Characterization of NEMS	390
16.3. Dynamics of NEMS	391
16.4. Dissipative Processes in NEMS	405
16.5. Integration of NEMS with Quantum Electronic Devices	410
16.6. “Bottom-up” NEMS: Carbon Nanotube Nanomechanics	413
Questions	414
References	414
17. Micromechanical Sensors	417
<i>P. G. Datskos, N. V. Lavrik, and M. J. Sepaniak</i>	
17.1. Introduction	417
17.2. Mechanical Models	418
17.3. Fabrication and Readout	425
17.4. Performance of Micromechanical Sensors	429
17.5. Applications of Cantilevers Sensors	433
17.6. Summary	437
Questions	437
References	438
VI. Nanoscale Optoelectronics	441
18. Quantum-Confined Optoelectronic Systems	443
<i>Simon Fafard</i>	
18.1. Introduction	443
18.2. Size and Shape Engineering of Quantum Dots	445
18.3. Optical Properties of Self-Assembled Quantum Dots	448
18.4. Energy Level Engineering in Quantum Dots	454
18.5. Single Quantum Dot Spectroscopy	458
18.6. Quantum Dot Devices	460
18.7. Site Engineering of Quantum Dot Nanostructures	477
18.8. Summary	477

Questions	478
References	480
19. Organic Optoelectronic Nanostructures	485
<i>J. R. Hefflin</i>	
19.1. Introduction	485
19.2. Organic and Polymeric Light-Emitting Diodes	486
19.3. Photovoltaic Polymers	491
19.4. Self-Assembled Organic Nonlinear Optical Materials	497
19.5. Summary	502
Questions	503
References	503
20. Photonic Crystals	505
<i>Younan Xia, Kaori Kamata, and Yu Lu</i>	
20.1. Introduction	505
20.2. Photonic Band Structures and Band Gaps	506
20.3. Photonic Crystals by Microfabrication	509
20.4. Photonic Crystals by Self-Assembly	513
20.5. Photonic Crystals with Tunable Properties	523
20.6. Summary	525
Questions	526
References	526
VII. Nanobiotechnology	531
21. Biomimetic Nanostructures	533
<i>Dennis E. Discher</i>	
21.1. Introduction: Water, Cell Inspirations, and Copolymers	533
21.2. Worm Micelles and Vesicles from Block Copolymers	535
21.3. Solvent, Size, Energetics, and Fluidity	538
21.4. Polymersomes from Block Copolymers in Aqueous Solution	539
21.5. Stiffness and Stability Tuning of Worms and Membranes	542
21.6. Vesicles in Industry	543
21.7. Additional Polymer Interactions and Other Hollow Shells	543
21.8. Interfacing Biological Structures and Functions	544
21.9. Summary	546
Questions	546
References	547
22. Biomolecular Motors	549
<i>Jacob Schmidt and Carlo Montemagno</i>	
22.1. Introduction	549
22.2. Of MEMS and Biomolecular Motors	550
22.3. Operation and Function of Motor Proteins	552
22.4. Biotechnology of Motor Proteins	557

22.5. Science and Engineering of Molecular Motors	561
22.6. Enabling Molecular Motors in Technological Applications	568
22.7. Conclusion	571
Further Reading	572
Questions	572
References	572
23. Nanofluidics	575
<i>Jongyoon Han</i>	
23.1. Introduction	575
23.2. Fluids at the Micro- and Nanometer Scale	577
23.3. Fabrication of Nanoporous and Nanofluidic Devices	585
23.4. Applications of Nanofluidics	588
23.5. Summary	594
Questions	594
References	595
INDEX	599