

Contents

<i>Preface to the Second Edition</i>	v
Chapter 1 Introduction	1
1.1. Introduction	1
1.2. Emergence of Nanotechnology	4
1.3. Bottom-Up and Top-Down Approaches	8
1.4. Challenges in Nanotechnology	10
1.5. Scope of the Book	13
References	15
Chapter 2 Physical Chemistry of Solid Surfaces	19
2.1. Introduction	19
2.2. Surface Energy	21
2.3. Chemical Potential as a Function of Surface Curvature	32
2.4. Electrostatic Stabilization	38
2.4.1. Surface charge density	38
2.4.2. Electric potential at the proximity of solid surface	39
2.4.3. Van der Waals attraction potential	43
2.4.4. Interactions between two particles: DLVO theory	45
2.5. Steric Stabilization	50
2.5.1. Solvent and polymer	51
2.5.2. Interactions between polymer layers	53
2.5.3. Mixed steric and electric interactions	57
2.6. Summary	57
References	57

Chapter 3 Zero-Dimensional Nanostructures: Nanoparticles	61
3.1. Introduction	61
3.2. Nanoparticles Through Homogeneous Nucleation	63
3.2.1. Fundamentals of homogeneous nucleation	63
3.2.2. Subsequent growth of nuclei	69
3.2.2.1. Growth controlled by diffusion	70
3.2.2.2. Growth controlled by surface process	71
3.2.3. Synthesis of metallic nanoparticles	75
3.2.3.1. Influences of reduction reagents	80
3.2.3.2. Influences by other factors	83
3.2.3.3. Influences of polymer stabilizer	86
3.2.4. Synthesis of semiconductor nanoparticles	93
3.2.5. Synthesis of oxide nanoparticles	102
3.2.5.1. Introduction to sol–gel processing	102
3.2.5.2. Forced hydrolysis	106
3.2.5.3. Controlled release of ions	108
3.2.6. Vapor phase reactions	110
3.2.7. Solid-state phase segregation	112
3.3. Nanoparticles Through Heterogeneous Nucleation	116
3.3.1. Fundamentals of heterogeneous nucleation	116
3.3.2. Synthesis of nanoparticles	118
3.4. Kinetically Confined Synthesis of Nanoparticles	119
3.4.1. Synthesis inside micelles or using microemulsions	121
3.4.2. Aerosol synthesis	123
3.4.3. Growth termination	124
3.4.4. Spray pyrolysis	126
3.4.5. Template-based synthesis	126
3.5. Epitaxial Core–Shell Nanoparticles	127
3.6. Summary	130
References	131
Chapter 4 One-Dimensional Nanostructures: Nanowires and Nanorods	143
4.1. Introduction	143
4.2. Spontaneous Growth	145

4.2.1.	Evaporation (dissolution)-condensation growth	146
4.2.1.1.	Fundamentals of evaporation (dissolution)-condensation growth	146
4.2.1.2.	Evaporation-condensation growth	154
4.2.1.3.	Dissolution-condensation growth	159
4.2.2.	Vapor (or solution)-liquid-solid (VLS or SLS) growth	164
4.2.2.1.	Fundamental aspects of VLS and SLS growth	164
4.2.2.2.	VLS growth of various nanowires	170
4.2.2.3.	Control of the size of nanowires	172
4.2.2.4.	Precursors and catalysts	177
4.2.2.5.	Solution-liquid-solid growth	180
4.2.3.	Stress-induced recrystallization	183
4.3.	Template-Based Synthesis	183
4.3.1.	Electrochemical deposition	184
4.3.2.	Electrophoretic deposition	196
4.3.3.	Template filling	204
4.3.3.1.	Colloidal dispersion filling	204
4.3.3.2.	Melt and solution filling	206
4.3.3.3.	Chemical vapor deposition	207
4.3.3.4.	Deposition by centrifugation	207
4.3.4.	Converting through chemical reactions	208
4.4.	Electrospinning	213
4.5.	Lithography	215
4.6.	Summary	219
	References	219
	Chapter 5 Two-Dimensional Nanostructures: Thin Films	229
5.1.	Introduction	229
5.2.	Fundamentals of Film Growth	230
5.3.	Vacuum Science	235
5.4.	Physical Vapor Deposition (PVD)	240
5.4.1.	Evaporation	240
5.4.2.	Molecular beam epitaxy (MBE)	243

5.4.3. Sputtering	245
5.4.4. Comparison of evaporation and sputtering	247
5.5. Chemical Vapor Deposition (CVD)	248
5.5.1. Typical chemical reactions	248
5.5.2. Reaction kinetics	251
5.5.3. Transport phenomena	251
5.5.4. CVD methods	254
5.5.5. Diamond films by CVD	258
5.6. Atomic Layer Deposition	260
5.7. Superlattices	265
5.8. Self-Assembly	267
5.8.1. Monolayers of organosilicon or alkylsilane derivatives	270
5.8.2. Monolayers of alkanethiols and sulfides	273
5.8.3. Monolayers of carboxylic acids, amines, and alcohols	276
5.9. Langmuir–Blodgett Films	277
5.10. Electrochemical Deposition	282
5.11. Sol–Gel Films	284
5.12. Summary	289
References	289

Chapter 6 Special Nanomaterials	297
6.1. Introduction	297
6.2. Carbon Fullerenes and Nanotubes	297
6.2.1. Carbon fullerenes	298
6.2.2. Fullerene-derived crystals	300
6.2.3. Carbon nanotubes	300
6.3. Micro and Mesoporous Materials	308
6.3.1. Ordered mesoporous structures	308
6.3.2. Random mesoporous structures	320
6.3.3. Crystalline microporous materials: Zeolites	324
6.4. Core–Shell Structures	333
6.4.1. Metal–oxide structures	334

6.4.2. Metal–polymer structures	336
6.4.3. Oxide–polymer nanostructures	338
6.5. Organic-Inorganic Hybrids	339
6.5.1. Class 1 hybrids	340
6.5.2. Class 2 hybrids	341
6.6. Intercalation Compounds	344
6.7. Nanocomposites and Nanograined Materials	346
6.8. Inverse Opals	350
6.9. Bio-Induced Nanomaterials	353
6.10. Summary	354
References	354

Chapter 7 Nanostructures Fabricated by Physical Techniques 369

7.1. Introduction	369
7.2. Lithography	371
7.2.1. Photolithography	371
7.2.2. Phase-shifting photolithography	375
7.2.3. Electron beam lithography	377
7.2.4. X-ray lithography	379
7.2.5. Focused ion beam (FIB) lithography	381
7.2.6. Neutral atomic beam lithography	384
7.3. Nanomanipulation and Nanolithography	386
7.3.1. Scanning tunneling microscopy (STM)	387
7.3.2. Atomic force microscopy (AFM)	389
7.3.3. Near-field scanning optical microscopy (NSOM)	391
7.3.4. Nanomanipulation	394
7.3.5. Nanolithography	400
7.4. Soft Lithography	405
7.4.1. Microcontact printing	405
7.4.2. Molding	408
7.4.3. Nanoimprint	408
7.4.4. Dip-pen nanolithography	411
7.5. Assembly of Nanoparticles and Nanowires	412
7.5.1. Capillary forces	413
7.5.2. Dispersion interactions	416

7.5.3.	Shear-force-assisted assembly	417
7.5.4.	Electric-field-assisted assembly	418
7.5.5.	Covalently linked assembly	418
7.5.6.	Gravitational-field-assisted assembly	419
7.5.7.	Template-assisted assembly	419
7.6.	Other Methods for Microfabrication	420
7.7.	Summary	422
	References	422

Chapter 8 Characterization and Properties of Nanomaterials 433

8.1.	Introduction	433
8.2.	Structural Characterization	434
8.2.1.	X-ray diffraction (XRD)	435
8.2.2.	Small angle X-ray scattering (SAXS)	436
8.2.3.	Scanning electron microscopy (SEM)	441
8.2.4.	Transmission electron microscopy (TEM)	444
8.2.5.	Scanning probe microscopy (SPM)	445
8.2.6.	Gas adsorption	450
8.3.	Chemical Characterization	452
8.3.1.	Optical spectroscopy	452
8.3.2.	Electron spectroscopy	457
8.3.3.	Ion spectrometry	459
8.4.	Physical Properties of Nanomaterials	461
8.4.1.	Melting points and lattice constants	462
8.4.2.	Mechanical properties	467
8.4.3.	Optical properties	472
8.4.3.1.	Surface plasmon resonance	473
8.4.3.2.	Quantum size effects	478
8.4.4.	Electrical conductivity	483
8.4.4.1.	Surface scattering	483
8.4.4.2.	Change of electronic structure	488
8.4.4.3.	Quantum transport	488
8.4.4.4.	Effect of microstructure	492
8.4.5.	Ferroelectrics and dielectrics	493
8.4.6.	Superparamagnetism	496

8.5. Summary	498
References	499
Chapter 9 Applications of Nanomaterials	509
9.1. Introduction	509
9.2. Molecular Electronics and Nanoelectronics	510
9.3. Nanobots	512
9.4. Biological Applications of Nanoparticles	514
9.5. Catalysis by Gold Nanoparticles	516
9.6. Bandgap Engineered Quantum Devices	518
9.6.1. Quantum well devices	518
9.6.2. Quantum dot devices	521
9.7. Nanomechanics	522
9.8. Carbon Nanotube Emitters	524
9.9. Energy Applications of Nanomaterials	527
9.9.1. Photoelectrochemical cells	527
9.9.2. Lithium-ion rechargeable batteries	530
9.9.3. Hydrogen storage	535
9.9.4. Thermoelectrics	538
9.10. Environmental Applications of Nanomaterials	540
9.11. Photonic Crystals and Plasmon Waveguides	542
9.11.1. Photonic crystals	542
9.11.2. Plasmon waveguides	544
9.12. Summary	546
References	546
Appendices	561
<i>Index</i>	569