

## Table of Contents

- Preface to the Second Edition p. v
- Chapter 1 Introduction p. 1
  - 1.1 Introduction p. 1
  - 1.2 Emergence of Nanotechnology p. 4
  - 1.3 Bottom-Up and Top-Down Approaches p. 8
  - 1.4 Challenges in Nanotechnology p. 10
  - 1.5 Scope of the Book p. 13
  - References p. 15
- Chapter 2 Physical Chemistry of Solid Surfaces p. 19
  - 2.1 Introduction p. 19
  - 2.2 Surface Energy p. 21
  - 2.3 Chemical Potential as a Function of Surface Curvature p. 32
  - 2.4 Electrostatic Stabilization p. 38
    - 2.4.1 Surface charge density p. 38
    - 2.4.2 Electric potential at the proximity of solid surface p. 39
    - 2.4.3 Van der Waals attraction potential p. 43
    - 2.4.4 Interactions between two particles: DLVO theory p. 45
  - 2.5 Steric Stabilization p. 50
    - 2.5.1 Solvent and polymer p. 51
    - 2.5.2 Interactions between polymer layers p. 53
    - 2.5.3 Mixed steric and electric interactions p. 57
  - 2.6 Summary p. 57
  - References p. 57
- Chapter 3 Zero-Dimensional Nanostructures: Nanoparticles p. 61
  - 3.1 Introduction p. 61
  - 3.2 Nanoparticles Through Homogeneous Nucleation p. 63
    - 3.2.1 Fundamentals of homogeneous nucleation p. 63
    - 3.2.2 Subsequent growth of nuclei p. 69
      - 3.2.2.1 Growth controlled by diffusion p. 70
      - 3.2.2.2 Growth controlled by surface process p. 71
    - 3.2.3 Synthesis of metallic nanoparticles p. 75
      - 3.2.3.1 Influences of reduction reagents p. 80
      - 3.2.3.2 Influences by other factors p. 83
      - 3.2.3.3 Influences of polymer stabilizer p. 86
    - 3.2.4 Synthesis of semiconductor nanoparticles p. 93
    - 3.2.5 Synthesis of oxide nanoparticles p. 102
      - 3.2.5.1 Introduction to sol-gel processing p. 102
      - 3.2.5.2 Forced hydrolysis p. 106
      - 3.2.5.3 Controlled release of ions p. 108
    - 3.2.6 Vapor phase reactions p. 110
    - 3.2.7 Solid-state phase segregation p. 112
  - 3.3 Nanoparticles Through Heterogeneous Nucleation p. 116
    - 3.3.1 Fundamentals of heterogeneous nucleation p. 116
    - 3.3.2 Synthesis of nanoparticles p. 118

- 3.4 Kinetically Confined Synthesis of Nanoparticles p. 119
- 3.4.1 Synthesis inside micelles or using microemulsions p. 121
- 3.4.2 Aerosol synthesis p. 123
- 3.4.3 Growth termination p. 124
- 3.4.4 Spray pyrolysis p. 126
- 3.4.5 Template-based synthesis p. 126
- 3.5 Epitaxial Core-Shell Nanoparticles p. 127
- 3.6 Summary p. 130
- References p. 131
- Chapter 4 One-Dimensional Nanostructures: Nanowires and Nanorods p. 143
- 4.1 Introduction p. 143
- 4.2 Spontaneous Growth p. 145
- 4.2.1 Evaporation (dissolution)-condensation growth p. 146
- 4.2.1.1 Fundamentals of evaporation (dissolution)-condensation growth p. 146
- 4.2.1.2 Evaporation-condensation growth p. 154
- 4.2.1.3 Dissolution-condensation growth p. 159
- 4.2.2 Vapor (or solution)-liquid-solid (VLS or SLS) growth p. 164
- 4.2.2.1 Fundamental aspects of VLS and SLS growth p. 164
- 4.2.2.2 VLS growth of various nanowires p. 170
- 4.2.2.3 Control of the size of nanowires p. 172
- 4.2.2.4 Precursors and catalysts p. 177
- 4.2.2.5 Solution-liquid-solid growth p. 180
- 4.2.3 Stress-induced recrystallization p. 183
- 4.3 Template-Based Synthesis p. 183
- 4.3.1 Electrochemical deposition p. 184
- 4.3.2 Electrophoretic deposition p. 196
- 4.3.3 Template filling p. 204
- 4.3.3.1 Colloidal dispersion filling p. 204
- 4.3.3.2 Melt and solution filling p. 206
- 4.3.3.3 Chemical vapor deposition p. 207
- 4.3.3.4 Deposition by centrifugation p. 207
- 4.3.4 Converting through chemical reactions p. 208
- 4.4 Electrospinning p. 213
- 4.5 Lithography p. 215
- 4.6 Summary p. 219
- References p. 219
- Chapter 5 Two-Dimensional Nanostructures: Thin Films p. 229
- 5.1 Introduction p. 229
- 5.2 Fundamentals of Film Growth p. 230
- 5.3 Vacuum Science p. 235
- 5.4 Physical Vapor Deposition (PVD) p. 240
- 5.4.1 Evaporation p. 240
- 5.4.2 Molecular beam epitaxy (MBE) p. 243
- 5.4.3 Sputtering p. 245
- 5.4.4 Comparison of evaporation and sputtering p. 247
- 5.5 Chemical Vapor Deposition (CVD) p. 248

- 5.5.1 Typical chemical reactions p. 248
- 5.5.2 Reaction kinetics p. 251
- 5.5.3 Transport phenomena p. 251
- 5.5.4 CVD methods p. 254
- 5.5.5 Diamond films by CVD p. 258
- 5.6 Atomic Layer Deposition p. 260
- 5.7 Superlattices p. 265
- 5.8 Self-Assembly p. 267
  - 5.8.1 Monolayers of organosilicon or alkylsilane derivatives p. 270
  - 5.8.2 Monolayers of alkanethiols and sulfides p. 273
  - 5.8.3 Monolayers of carboxylic acids, amines, and alcohols p. 276
- 5.9 Langmuir-Blodgett Films p. 277
- 5.10 Electrochemical Deposition p. 282
- 5.11 Sol-Gel Films p. 284
- 5.12 Summary p. 289
- References p. 289
- Chapter 6 Special Nanomaterials p. 297
  - 6.1 Introduction p. 297
  - 6.2 Carbon Fullerenes and Nanotubes p. 297
    - 6.2.1 Carbon fullerenes p. 298
    - 6.2.2 Fullerene-derived crystals p. 300
    - 6.2.3 Carbon nanotubes p. 300
  - 6.3 Micro and Mesoporous Materials p. 308
    - 6.3.1 Ordered mesoporous structures p. 308
    - 6.3.2 Random mesoporous structures p. 320
    - 6.3.3 Crystalline microporous materials: Zeolites p. 324
  - 6.4 Core-Shell Structures p. 333
    - 6.4.1 Metal-oxide structures p. 334
    - 6.4.2 Metal-polymer structures p. 336
    - 6.4.3 Oxide-polymer nanostructures p. 338
  - 6.5 Organic-Inorganic Hybrids p. 339
    - 6.5.1 Class 1 hybrids p. 340
    - 6.5.2 Class 2 hybrids p. 341
  - 6.6 Intercalation Compounds p. 344
  - 6.7 Nanocomposites and Nanograined Materials p. 346
  - 6.8 Inverse Opals p. 350
  - 6.9 Bio-Induced Nanomaterials p. 353
  - 6.10 Summary p. 354
  - References p. 354
- Chapter 7 Nanostructures Fabricated by Physical Techniques p. 369
  - 7.1 Introduction p. 369
  - 7.2 Lithography p. 371
    - 7.2.1 Photolithography p. 371
    - 7.2.2 Phase-shifting photolithography p. 375
    - 7.2.3 Electron beam lithography p. 377
    - 7.2.4 X-ray lithography p. 379

- 7.2.5 Focused ion beam (FIB) lithography p. 381
- 7.2.6 Neutral atomic beam lithography p. 384
- 7.3 Nanomanipulation and Nanolithography p. 386
- 7.3.1 Scanning tunneling microscopy (STM) p. 387
- 7.3.2 Atomic force microscopy (AFM) p. 389
- 7.3.3 Near-field scanning optical microscopy (NSOM) p. 391
- 7.3.4 Nanomanipulation p. 394
- 7.3.5 Nanolithography p. 400
- 7.4 Soft Lithography p. 405
- 7.4.1 Microcontact printing p. 405
- 7.4.2 Molding p. 408
- 7.4.3 Nanoimprint p. 408
- 7.4.4 Dip-pen nanolithography p. 411
- 7.5 Assembly of Nanoparticles and Nanowires p. 412
- 7.5.1 Capillary forces p. 413
- 7.5.2 Dispersion interactions p. 416
- 7.5.3 Shear-force-assisted assembly p. 417
- 7.5.4 Electric-field-assisted assembly p. 418
- 7.5.5 Covalently linked assembly p. 418
- 7.5.6 Gravitational-field-assisted assembly p. 419
- 7.5.7 Template-assisted assembly p. 419
- 7.6 Other Methods for Microfabrication p. 420
- 7.7 Summary p. 422
- References p. 422
- Chapter 8 Characterization and Properties of Nanomaterials p. 433
- 8.1 Introduction p. 433
- 8.2 Structural Characterization p. 434
- 8.2.1 X-ray diffraction (XRD) p. 435
- 8.2.2 Small angle X-ray scattering (SAXS) p. 436
- 8.2.3 Scanning electron microscopy (SEM) p. 441
- 8.2.4 Transmission electron microscopy (TEM) p. 444
- 8.2.5 Scanning probe microscopy (SPM) p. 445
- 8.2.6 Gas adsorption p. 450
- 8.3 Chemical Characterization p. 452
- 8.3.1 Optical spectroscopy p. 452
- 8.3.2 Electron spectroscopy p. 457
- 8.3.3 Ion spectrometry p. 459
- 8.4 Physical Properties of Nanomaterials p. 461
- 8.4.1 Melting points and lattice constants p. 462
- 8.4.2 Mechanical properties p. 467
- 8.4.3 Optical properties p. 472
- 8.4.3.1 Surface plasmon resonance p. 473
- 8.4.3.2 Quantum size effects p. 478
- 8.4.4 Electrical conductivity p. 483
- 8.4.4.1 Surface scattering p. 483
- 8.4.4.2 Change of electronic structure p. 488

- 8.4.4.3 Quantum transport p. 488
- 8.4.4.4 Effect of microstructure p. 492
- 8.4.5 Ferroelectrics and dielectrics p. 493
- 8.4.6 Superparamagnetism p. 496
- 8.5 Summary p. 498
- References p. 499
- Chapter 9 Applications of Nanomaterials p. 509
- 9.1 Introduction p. 509
- 9.2 Molecular Electronics and Nanoelectronics p. 510
- 9.3 Nanobots p. 512
- 9.4 Biological Applications of Nanoparticles p. 514
- 9.5 Catalysis by Gold Nanoparticles p. 516
- 9.6 Bandgap Engineered Quantum Devices p. 518
  - 9.6.1 Quantum well devices p. 518
  - 9.6.2 Quantum dot devices p. 521
- 9.7 Nanomechanics p. 522
- 9.8 Carbon Nanotube Emitters p. 524
- 9.9 Energy Applications of Nanomaterials p. 527
  - 9.9.1 Photoelectrochemical cells p. 527
  - 9.9.2 Lithium-ion rechargeable batteries p. 530
  - 9.9.3 Hydrogen storage p. 535
  - 9.9.4 Thermoelectrics p. 538
- 9.10 Environmental Applications of Nanomaterials p. 540
- 9.11 Photonic Crystals and Plasmon Waveguides p. 542
  - 9.11.1 Photonic crystals p. 542
  - 9.11.2 Plasmon waveguides p. 544
- 9.12 Summary p. 546
- References p. 546
- Appendices p. 561
- Index p. 569