

# Contents

<b>1</b>	<b>Introduction to Quantum Mechanics</b> .....	1
1.1	Introduction .....	1
1.2	Matter Waves .....	10
1.3	Heisenberg's Uncertainty Principle .....	12
1.4	Schrödinger Equation .....	15
1.5	Electron Confinement.....	19
	1.5.1 Particle in a Box .....	20
	1.5.2 Density of States .....	22
	1.5.3 Particle in a Coulomb Potential .....	25
1.6	Tunnelling of a Particle Through Potential Barrier.....	27
	Further Reading .....	29
<b>2</b>	<b>Structure and Bonding</b> .....	31
2.1	Introduction .....	31
2.2	Arrangement of Atoms .....	33
2.3	Two Dimensional Crystal Structures.....	36
2.4	Three Dimensional Crystal Structures .....	36
2.5	Some Examples of Three Dimensional Crystals .....	38
	2.5.1 Body Centred Cube (bcc).....	38
2.6	Planes in the Crystals .....	38
2.7	Crystallographic Directions .....	38
2.8	Reciprocal Lattice.....	38
2.9	Quasi Crystals .....	41
2.10	Liquid Crystals .....	43
2.11	Bonding in Solids .....	44
	2.11.1 Covalent Bond .....	45
	2.11.2 Ionic Bond.....	46
	2.11.3 Metallic Bond .....	47
	2.11.4 Mixed Bonds .....	47
	2.11.5 Secondary Bonds .....	48

2.12	Electronic Structure of Solids .....	49
2.12.1	Free Electron Motion .....	50
2.12.2	Bloch's Theorem.....	50
2.12.3	Origin of Band Structure .....	51
	Further Reading .....	53
<b>3</b>	<b>Synthesis of Nanomaterials—I (Physical Methods)</b> .....	<b>55</b>
3.1	Introduction .....	55
3.2	Mechanical Methods.....	55
3.2.1	High Energy Ball Milling .....	55
3.2.2	Melt Mixing .....	57
3.3	Methods Based on Evaporation .....	59
3.3.1	Physical Vapour Deposition with Consolidation .....	61
3.3.2	Ionized Cluster Beam Deposition .....	63
3.3.3	Laser Vapourization (Ablation) .....	64
3.3.4	Laser Pyrolysis .....	65
3.4	Sputter Deposition .....	65
3.4.1	DC Sputtering .....	67
3.4.2	RF Sputtering .....	69
3.4.3	Magnetron Sputtering.....	69
3.4.4	ECR Plasma Deposition .....	70
3.5	Chemical Vapour Deposition (CVD) .....	71
3.6	Electric Arc Deposition.....	73
3.7	Ion Beam Techniques (Ion Implantation) .....	75
3.8	Molecular Beam Epitaxy (MBE).....	75
	Further Reading .....	76
<b>4</b>	<b>Synthesis of Nanomaterials—II (Chemical Methods)</b> .....	<b>77</b>
4.1	Introduction .....	77
4.2	Colloids and Colloids in Solutions .....	78
4.2.1	Interactions of Colloids and Medium .....	78
4.2.2	Colloids in Vacuum .....	83
4.2.3	Colloids in a Medium.....	84
4.2.4	Effect of Charges on Colloids .....	84
4.2.5	Stearic Repulsion .....	86
4.2.6	Synthesis of Colloids .....	87
4.3	Nucleation and Growth of Nanoparticles .....	87
4.4	Synthesis of Metal Nanoparticles by Colloidal Route .....	91
4.5	Synthesis of Semiconductor Nanoparticles by Colloidal Route ..	92
4.6	Langmuir-Blodgett (LB) Method .....	95
4.7	Microemulsions .....	98
4.8	Sol-Gel Method .....	103
4.9	Hydrothermal Synthesis .....	105
4.10	Sonochemical Synthesis .....	106

4.11	Microwave Synthesis .....	107
4.12	Synthesis Using Micro-reactor or Lab-On-Chip .....	107
	Further Reading .....	109
<b>5</b>	<b>Synthesis of Nanomaterials—III (Biological Methods)</b> .....	111
5.1	Introduction .....	111
5.2	Synthesis Using Microorganisms .....	116
5.3	Synthesis Using Plant Extracts .....	120
5.4	Use of Proteins, Templates Like DNA, S-Layers etc. ....	121
5.5	Synthesis of Nanoparticles Using DNA .....	123
	Further Reading .....	123
<b>6</b>	<b>Self Assembly</b> .....	125
6.1	Introduction .....	125
6.2	Mechanism of Self Assembly .....	127
6.3	Some Examples of Self Assembly .....	129
6.3.1	Self Assembly of Nanoparticles Using Organic Molecules .....	129
6.3.2	Self Assembly in Biological Systems .....	130
6.3.3	Self Assembly in Inorganic Materials .....	132
	Further Reading .....	133
<b>7</b>	<b>Analysis Techniques</b> .....	135
7.1	Introduction .....	135
7.2	Microscopes .....	135
7.2.1	Optical Microscopes .....	135
7.2.2	Confocal Microscope .....	140
7.3	Electron Microscopes .....	141
7.3.1	Scanning Electron Microscope .....	143
7.3.2	Transmission Electron Microscope (TEM) .....	146
7.4	Scanning Probe Microscopes (SPM) .....	148
7.4.1	Scanning Tunnelling Microscope .....	149
7.4.2	Atomic Force Microscope .....	152
7.4.3	Scanning Near-Field Optical Microscope (SNOM) ....	155
7.5	Diffraction Techniques .....	159
7.5.1	X-Ray Diffraction (XRD) .....	160
7.5.2	Atomic Scattering Factor .....	161
7.5.3	Bragg's Law of Diffraction .....	162
7.5.4	Diffraction from Different Types of Samples .....	165
7.5.5	Crystal Structure Factor .....	166
7.5.6	Diffraction from Nanoparticles .....	167
7.5.7	X-ray Diffractometer .....	170
7.5.8	Dynamic Light Scattering .....	171

7.6	Spectroscopies .....	173
7.6.1	Optical (Ultraviolet-Visible-Near Infra Red) Absorption Spectrometer .....	173
7.6.2	UV-Vis-NIR Spectrometer .....	175
7.6.3	Infra Red Spectrometers .....	176
7.6.4	Dispersive Infra Red Spectrometer .....	178
7.6.5	Fourier Transform Infra Red Spectrometer .....	179
7.6.6	Raman Spectroscopy .....	181
7.6.7	Luminescence .....	184
7.6.8	X-Ray and Ultra Violet Photoelectron Spectroscopies (XPS or ESCA and UPS) .....	186
7.6.9	Auger Electron Spectroscopy .....	190
7.7	Magnetic Measurements .....	192
7.7.1	Vibrating Sample Magnetometer (VSM) .....	192
7.8	Mechanical Measurements .....	194
7.8.1	Some Common Terminologies Related to Mechanical Properties .....	194
	Further Reading .....	197
<b>8</b>	<b>Types of Nanomaterials and Their Properties .....</b>	<b>199</b>
8.1	Introduction .....	199
8.2	Clusters .....	200
8.2.1	Types of Clusters .....	200
8.3	Semiconductor Nanoparticles .....	203
8.3.1	Excitons .....	204
8.3.2	Effective Mass Approximation .....	205
8.3.3	Optical Properties of Semiconductor Nanoparticles ...	208
8.4	Plasmonic Materials .....	214
8.4.1	Localized Surface Plasmon Resonance .....	215
8.4.2	Surface Plasmon Polariton .....	222
8.5	Nanomagnetism .....	225
8.5.1	Types of Magnetic Materials .....	227
8.6	Mechanical Properties of Nanomaterials .....	235
8.7	Structural Properties .....	237
8.8	Melting of Nanoparticles .....	238
	Further Reading .....	239
<b>9</b>	<b>Nanolithography .....</b>	<b>241</b>
9.1	Introduction .....	241
9.2	Lithography Using Photons (UV-VIS, Lasers and X-Rays).....	245
9.2.1	Lithography Using UV Light and Laser Beams .....	246
9.2.2	Use of X-rays in Lithography .....	246
9.3	Lithography Using Particle Beams .....	246
9.3.1	Electron Beam Lithography .....	247
9.3.2	Ion Beam Lithography .....	248

9.3.3	Neutral Beam Lithography .....	248
9.3.4	Nano Sphere Lithography .....	248
9.4	Scanning Probe Lithography .....	249
9.4.1	Mechanical Methods .....	249
9.4.2	Dip Pen Lithography .....	250
9.4.3	Optical Scanning Probe Lithography .....	251
9.4.4	Thermo-Mechanical Lithography .....	251
9.4.5	Electrical Scanning Probe Lithography .....	252
9.5	Soft Lithography .....	252
9.5.1	Microcontact Printing ( $\mu$ CP) .....	253
9.5.2	Replica Molding (REM) .....	254
9.5.3	Microtransfer Molding ( $\mu$ TM) .....	255
9.5.4	Micromolding in Capillaries (MIMIC) .....	255
9.5.5	Solvent-Assisted Micromolding (SAMIM) .....	255
	Further Reading .....	257
<b>10</b>	<b>Nanoelectronics</b> .....	259
10.1	Introduction .....	259
10.2	Coulomb Blockade .....	260
10.3	Single Electron Transistor (SET) .....	263
10.4	Spintronics .....	267
10.4.1	Giant Magneto Resistance .....	268
10.4.2	Spin Valve .....	270
10.4.3	Magnetic Tunnel Junction (MTJ) .....	271
10.4.4	Spin Field Effect Transistor (SFET) .....	271
10.5	Nanophotonics .....	272
	Further Reading .....	272
<b>11</b>	<b>Some Special Nanomaterials</b> .....	273
11.1	Introduction .....	273
11.2	Carbon Nanomaterials .....	273
11.2.1	Fullerenes .....	273
11.2.2	Carbon Nanotubes (CNTs) .....	274
11.2.3	Types of Carbon Nanotubes .....	279
11.2.4	Synthesis of Carbon Nanotubes .....	281
11.2.5	Growth Mechanism .....	283
11.2.6	Graphene .....	285
11.3	Porous Material .....	286
11.3.1	Porous Silicon .....	286
11.3.2	How to Make Silicon Porous? .....	288
11.3.3	Mechanism of Pores Formation .....	290
11.3.4	Properties of Porous Silicon Morphology .....	293
11.4	Aerogels .....	296
11.4.1	Types of Aerogels .....	298
11.4.2	Properties of Aerogels .....	302
11.4.3	Applications of Aerogels .....	302

11.5	Zeolites .....	303
11.5.1	Synthesis of Zeolites .....	304
11.5.2	Properties of Zeolites .....	305
11.6	Porosity Through Templates .....	306
11.6.1	Micelles as Templates .....	306
11.6.2	Metal Organic Frameworks (MOF) .....	307
11.7	Core-Shell Particles .....	308
11.7.1	Synthesis of Silica Cores .....	309
11.7.2	Core-Shell Assemblies .....	310
11.7.3	Properties of Core-Shell Particles .....	311
11.8	Metamaterials .....	311
11.9	Bioinspired Materials .....	313
11.9.1	Lotus Effect (Self Cleaning) .....	313
11.9.2	Gecko Effect (Adhesive Materials) .....	315
	Further Reading .....	315
<b>12</b>	<b>Applications .....</b>	<b>317</b>
12.1	Introduction .....	317
12.2	Energy .....	317
12.2.1	Dye Sensitized Photovoltaic Solar Cell (Grätzel Cell) .....	321
12.2.2	Organic (Polymer/Small Organic Molecules) Photovoltaic Cells .....	326
12.2.3	Fuel Cell .....	327
12.2.4	Hydrogen Generation and Storage .....	332
12.2.5	Hydrogen Storage (and Release) .....	334
12.2.6	Hybrid Energy Cells .....	335
12.3	Automobiles .....	336
12.4	Sports and Toys .....	338
12.5	Textiles .....	338
12.6	Cosmetics .....	339
12.7	Medical Field .....	339
12.7.1	Imaging .....	340
12.7.2	Drug Delivery .....	341
12.7.3	Cancer Therapy .....	343
12.7.4	Tissue Repair .....	344
12.8	Agriculture and Food .....	345
12.9	Domestic Appliances .....	346
12.10	Space, Defense and Engineering .....	347
	Further Reading .....	348
<b>13</b>	<b>Nanotechnology and Environment .....</b>	<b>349</b>
13.1	Introduction .....	349
13.2	Environmental Pollution and Role of Nanotechnology .....	350
13.3	Effect of Nanotechnology on Human Health .....	352
	Further Reading .....	354

<b>14</b>	<b>Practicals</b>	355
14.1	Introduction	355
14.2	Synthesis of Gold/Silver Nanoparticles	356
14.2.1	Chemicals	356
14.2.2	Equipments	357
14.2.3	Synthesis Procedure	357
14.2.4	Results	358
14.3	Synthesis of CdS Nanoparticles	359
14.3.1	Chemicals	359
14.3.2	Equipments	359
14.3.3	Synthesis Procedure	359
14.3.4	Results	360
14.4	Synthesis of ZnO Nanoparticles	360
14.4.1	Chemicals	361
14.4.2	Equipment	361
14.4.3	Synthesis Procedure	361
14.4.4	Results	361
14.5	Synthesis of TiO <sub>2</sub> Nanoparticles	362
14.5.1	Chemicals	363
14.5.2	Equipment	363
14.5.3	Synthesis Procedure	363
14.5.4	Results	363
14.6	Synthesis of Fe <sub>2</sub> O <sub>3</sub> Nanoparticles	364
14.6.1	Chemicals	364
14.6.2	Equipment	365
14.6.3	Synthesis Procedure	365
14.6.4	Results	365
14.7	Synthesis of Porous Silicon	366
14.7.1	Materials	366
14.7.2	Equipment	366
14.7.3	Experimental Procedure	367
14.7.4	Results	368
14.8	Introductory Photolithography	368
14.8.1	Background	368
14.8.2	Chemicals	371
14.8.3	Equipment	371
14.8.4	Experimental Procedure	372
14.9	Introductory Nano (Soft) Lithography Using PDMS	372
14.9.1	Chemicals	373
14.9.2	Equipment	373
14.9.3	Synthesis Procedure	373
14.9.4	Results	374
14.9.5	Materials and Equipments	375
14.9.6	Experimental Procedure	375

14.9.7	Experimental Set-Up .....	376
14.9.8	Results .....	376
14.10	Fabrication of Porous Alumina or Anodized Alumina (AAO) Template .....	376
14.10.1	Chemicals .....	376
14.10.2	Equipment .....	376
14.10.3	Fabrication Procedure .....	377
14.10.4	Results .....	378
	Further Reading .....	379
<b>Appendices</b> .....		381
Appendix I .....		381
	Periodic Table Symbols of Elements and Their Atomic Numbers .....	381
Appendix II .....		382
	Electromagnetic Spectrum .....	382
Appendix III .....		383
	List of Fundamental Constants .....	383
Appendix IV .....		383
	Vacuum Techniques .....	383
	Vacuum System .....	384
	Vacuum Pumps .....	385
	Rotary Vane Pump .....	385
	Diffusion Pump .....	386
	Sorption Pump .....	387
	Ion Pump .....	388
	Vacuum Gauges .....	389
	U-tube Manometer .....	389
	McLeod Gauge .....	390
	Pirani Gauge .....	390
	Thermocouple Gauge .....	391
	Cold Cathode Gauge (Penning Gauge) .....	391
	Hot Cathode Ion Gauge .....	392
	Bayerd-Alpert (B-A) Gauge .....	393
	Further Reading .....	393
Appendix V .....		394
	Properties of Some Semiconductors .....	394
Appendix VI .....		395
	Kronig Penney Model (1-D) .....	395
	Further Reading .....	398
<b>Index</b> .....		399



Nanotechnology: Principles and Practices

Kulkarni, S.K.

2015, XXIV, 403 p. 341 illus., 13 illus. in color.,

ISBN: 978-3-319-09171-6