

CONTENTS

Preface	.	.	.	v
About the Authors	.	.	.	ix
Acknowledgements	.	.	.	xii
Structure of the Book	.	.	.	xiii
1 Mesoscopic Physics and Nanotechnologies	.	.	.	1
1.1. Outlook of the book	.	.	.	3
1.2. Trends in nanoelectronics and optoelectronics	.	.	.	4
1.3. Characteristic lengths in mesoscopic systems	.	.	.	8
1.4. Quantum mechanical coherence	.	.	.	11
1.5. Quantum wells, wires, and dots	.	.	.	12
1.6. Density of states and dimensionality	.	.	.	13
1.7. Semiconductor heterostructures	.	.	.	15
1.8. Quantum transport	.	.	.	17
References	.	.	.	17
Further Reading	.	.	.	18
Problems	.	.	.	18
2 Survey of Solid State Physics	.	.	.	21
2.1. Introduction	.	.	.	23
2.2. Short review of quantum mechanics	.	.	.	24
2.2.1. Wave-particle duality and the Heisenberg principle	.	.	.	24
2.2.2. Schrödinger wave equation. Applications	.	.	.	26
2.2.3. Fermi–Dirac and Bose–Einstein distributions	.	.	.	28
2.2.4. Perturbation methods	.	.	.	29
2.3. Free electron model of a solid. Density of states function	.	.	.	31
2.4. Bloch theorem	.	.	.	34
2.5. Electrons in crystalline solids	.	.	.	35
2.5.1. Nearly free electron model	.	.	.	35
2.5.2. Tight binding approximation	.	.	.	37
2.6. Dynamics of electrons in bands	.	.	.	40
2.6.1. Equation of motion	.	.	.	40
2.6.2. Effective mass	.	.	.	41
2.6.3. Holes	.	.	.	43

2.7. Lattice vibrations	45
2.7.1. One-dimensional lattice	45
2.7.2. Three-dimensional lattice	49
2.8. Phonons	50
References	51
Further Reading	51
Problems	51
3 Review of Semiconductor Physics	55
3.1. Introduction	57
3.2. Energy bands in typical semiconductors	57
3.3. Intrinsic and extrinsic semiconductors	60
3.4. Electron and hole concentrations in semiconductors	63
3.5. Elementary transport in semiconductors	69
3.5.1. Electric field transport. Mobility	69
3.5.2. Conduction by diffusion	71
3.5.3. Continuity equations. Carrier lifetime and diffusion length	72
3.6. Degenerate semiconductors	75
3.7. Optical properties of semiconductors	76
3.7.1. Optical processes in semiconductors	76
3.7.2. Interband absorption	77
3.7.3. Excitonic effects	80
3.7.4. Emission spectrum	82
3.7.5. Stimulated emission	84
References	87
Further Reading	87
Problems	87
4 The Physics of Low-Dimensional Semiconductors	89
4.1. Introduction	91
4.2. Basic properties of two-dimensional semiconductor nanostructures	92
4.3. Square quantum well of finite depth	96
4.4. Parabolic and triangular quantum wells	98
4.4.1. Parabolic well	98
4.4.2. Triangular wells	99
4.5. Quantum wires	100
4.6. Quantum dots	102
4.7. Strained layers	104
4.8. Effect of strain on valence bands	106
4.9. Band structure in quantum wells	109

4.10. Excitonic effects in quantum wells	111
References	113
Further Reading	113
Problems	114
5 Semiconductor Quantum Nanostructures and Superlattices	117
5.1. Introduction	119
5.2. MOSFET structures	120
5.3. Heterojunctions	123
5.3.1. Modulation-doped heterojunctions	123
5.3.2. SiGe strained heterostructures	126
5.4. Quantum wells	127
5.4.1. Modulation-doped quantum well	127
5.4.2. Multiple quantum wells (MQW)	129
5.5. Superlattices	131
5.5.1. The concept of a superlattice	131
5.5.2. Kronig–Penney model of a superlattice. Zone folding	132
5.5.3. Tight binding approximation of a superlattice	137
5.5.4. nipi superlattices	138
References	141
Further Reading	141
Problems	141
6 Electric Field Transport in Nanostructures	143
6.1. Introduction	145
6.2. Parallel transport	145
6.2.1. Electron scattering mechanisms	146
6.2.2. Experimental data on parallel transport	149
6.2.3. Hot electrons in parallel transport	151
6.3. Perpendicular transport	153
6.3.1. Resonant tunnelling	153
6.3.2. Electric field effects in superlattices	155
6.4. Quantum transport in nanostructures	159
6.4.1. Quantized conductance. Landauer formula	160
6.4.2. Landauer–Büttiker formula for multi-probe quantum transport	163
6.4.3. Coulomb blockade	165
References	169
Further Reading	169
Problems	169

7 Transport in Magnetic Fields and the Quantum Hall Effect	173
7.1. Introduction	175
7.2. Effect of a magnetic field on a crystal	176
7.3. Low-dimensional systems in magnetic fields	178
7.4. Density of states of a 2D system in a magnetic field	179
7.5. The Aharonov–Bohm effect	180
7.6. The Shubnikov–de Haas effect	183
7.7. The quantum Hall effect	185
7.7.1. Experimental facts and elementary theory of the integer quantum Hall effect (IQHE)	185
7.7.2. Edge states and the IQHE	186
7.7.3. Extended and localized states	189
7.7.4. Applications in metrology	191
7.7.5. The fractional quantum Hall effect (FQHE)	192
References	194
Further Reading	194
Problems	195
8 Optical and Electro-optical Processes in Quantum Heterostructures	197
8.1. Introduction	199
8.2. Optical properties of quantum wells and superlattices	199
8.3. Optical properties of quantum dots and nanocrystals	204
8.3.1. Growth techniques. Self-assembled quantum dots	204
8.3.2. Optical properties	206
8.4. Electro-optical effects in quantum wells. Quantum confined Stark effect	213
8.5. Electro-optical effects in superlattices. Stark ladders and Bloch oscillations	216
References	220
Further Reading	221
Problems	221
9 Electronic Devices Based on Nanostructures	223
9.1. Introduction	225
9.2. MODFETs	227
9.3. Heterojunction bipolar transistors	229
9.4. Resonant tunnel effect	232
9.5. Hot electron transistors	234
9.6. Resonant tunnelling transistor	237
9.7. Single electron transistor	240
References	242

Further Reading	243
Problems	243
10 Optoelectronic Devices Based on Nanostructures	245
10.1. Introduction	247
10.2. Heterostructure semiconductor lasers	247
10.3. Quantum well semiconductor lasers	251
10.4. Vertical cavity surface emitting lasers (VCSELs)	254
10.5. Strained quantum well lasers	256
10.6. Quantum dot lasers	258
10.7. Quantum well and superlattice photodetectors	262
10.8. Quantum well modulators	265
References	267
Further Reading	267
Problems	268
Index	271