

TABLE OF CONTENTS

PREFACE VII

Objectives	vii
Topics and use of the book	viii
Acknowledgements.....	ix

1. AN ENVIRONMENT OF CHALLENGES 1

1.1 Overview	1
1.2 A history of modern electronic devices	2
1.3 An issue of scale	7
1.4 Defining electronic materials	11
1.5 Purity.....	13
1.6 Performance.....	14
1.7 Summary points.....	17
1.8 Homework problems	18
1.9 Suggested readings & references.....	19

2. THE PHYSICS OF SOLIDS 21

2.1 Electronic band structures of solids.....	21
2.1.1 Free electrons in solids.....	23
2.1.2 Free electrons in a periodic potential	24
2.1.3 Nearly free electrons	25
2.1.4 Energy vs. momentum in 3d	28
2.1.5 Electrons and holes	32
2.1.6 Direct and indirect semiconductors.....	35
2.1.7 Effective mass	37
2.1.8 Density of states	38
2.2 Intrinsic and extrinsic semiconductors	40
2.2.1 Intrinsic semiconductors	40
2.2.2 Extrinsic semiconductors	42
2.3 Properties and the band structure	44
2.3.1 Resistance, capacitance, and inductance.....	44
2.3.2 Optical properties	53
2.3.3 Thermal properties	54
2.4 Quantum wells and confined carriers	59

2.5 Summary points	67
2.6 Homework	69
2.7 Suggested readings & references.....	71

3. OVERVIEW OF ELECTRONIC DEVICES 73

3.1 Diffusion and drift of carriers	74
3.1.1 Chemical potential	74
3.1.2 Carrier motion in a chemical potential gradient.....	74
3.2 Simple diodes	75
3.2.1 The junction contact potential.....	77
3.2.2 Biased junctions	81
3.2.3 Non-ideal diode behaviors	88
3.3 Schottky barriers and ohmic contacts.....	96
3.3.1 Ideal metal/semiconductor junctions	96
3.3.2 Real schottky diodes	101
3.4 Semiconductor heterojunctions	102
3.4.1 Heterojunctions at equilibrium.....	103
3.4.2 Heterojunctions as diodes	109
3.5 Transistors	111
3.5.1 Bipolar junction transistors	111
3.5.2 Field-effect transistors.....	114
3.6 Light-emitting devices.....	119
3.6.1 Light-emitting diodes	120
3.6.2 Laser diodes.....	124
3.7 Summary.....	134
3.8 Homework problems	136
3.9 Suggested readings & references.....	139

4. ASPECTS OF MATERIALS SCIENCE 141

4.1 Structures of materials	141
4.1.1 Crystal lattices	142
4.1.2 The reciprocal lattice.....	148
4.2 Basic thermodynamics of materials.....	151
4.3 Phase diagrams	155
4.4 Kinetics	163
4.4.1 Reaction kinetics	164
4.4.2 Nucleation	166
4.4.3 Atomic transport.....	170
4.5 Organic molecules	172
4.6 Applications.....	178
4.6.1 A basis for phase transformations.....	178

4.6.2 Silicon crystal fabrication	180
4.6.3 Rapid thermal processing.....	187
4.7 Summary points.....	189
4.8 Homework	191
4.9 Suggested Readings and References	194
5. ENGINEERING ELECTRONIC STRUCTURE	195
5.1 Linking atomic orbitals to bands	196
5.1.1 Homopolar semiconductors	197
5.1.2 Heteropolar compounds	201
5.2 LCAO: from atomic orbitals to bands	206
5.3 Common semiconductor energy bands	215
5.4 Pressure and temperature dependence.....	223
5.5 Applications.....	226
5.5.1 Experimental band structures.....	226
5.5.2 Gunn diodes	228
5.6 Summary points.....	232
5.7 Homework	233
5.8 Suggested readings & references.....	235
6. SEMICONDUCTOR ALLOYS	237
6.1 Alloy selection.....	238
6.1.1 Overview.....	238
6.1.2 Choosing alloy constituents	241
6.2 Semiconductor alloy thermodynamics	245
6.2.1 Regular solution theory revisited	245
6.2.2 Ternary and quaternary solutions.....	249
6.2.3 More mechanisms for alloy ordering.....	252
6.3 Band gap bowing.....	255
6.3.1 Binary and pseudobinary alloys.....	255
6.3.2 Bowing in quaternary alloys	260
6.4 Silicon-germanium alloys.....	261
6.4.1 Structure and solubility	262
6.4.2 Band gap engineering.....	264
6.4.3 Alloying and carrier mobility.....	267
6.5 Metastable semiconductor alloys	268
6.6 Applications.....	272
6.6.1 Heterojunction bipolar transistors.....	272
6.6.2 Solar cells	276
6.7 Summary points.....	280
6.8 Homework	282
6.9 Suggested readings & references.....	285

7. DEFECTS IN SEMICONDUCTORS 289

- 7.1 Point defects289
 - 7.1.1 Electronic states due to point defects291
 - 7.1.2 Shallow levels295
 - 7.1.3 Depth of intrinsic defects299
 - 7.1.4 Ionization of defects300
 - 7.1.5 Point defect densities.....302
 - 7.1.6 Vacancies and dopant diffusivity308
- 7.2 Line defects.....311
- 7.3 Strain relief in heterostructures320
 - 7.3.1 Energetics of strain relief322
 - 7.3.2 Misfit dislocations328
 - 7.3.3 Dislocation dynamics329
 - 7.3.4 Reducing problems due to strain relief336
- 7.4 Planar and volume defects337
 - 7.4.1 Twins and stacking faults.....337
 - 7.4.2 Surfaces, interfaces, grain boundaries.....340
 - 7.4.3 Volume defects.....343
- 7.5 SiC: a case study in stacking faults344
- 7.6 Summary points.....349
- 7.7 Homework352
- 7.8 Suggested readings & references.....355

8. AMORPHOUS SEMICONDUCTORS 357

- 8.1 Structure and bonding.....358
- 8.2 Hydrogenated amorphous Si364
- 8.3 Deposition methods for a-Si366
- 8.4 Electronic properties.....367
 - 8.4.1 Carrier transport and mobility.....367
 - 8.4.2 Mobility measurements370
 - 8.4.3 Doping372
 - 8.4.4 Short-range order373
- 8.5 Optical properties374
- 8.6 Amorphous semiconductor alloys377
- 8.7 Applications.....380
 - 8.7.1 Thin film transistors380
 - 8.7.2 Solar cells383
- 8.8 Summary points.....389
- 8.9 Homework391
- 8.10 Suggested readings and references392

9. ORGANIC SEMICONDUCTORS 395

9.1	Materials overview	395
9.1.1	Conjugated organic materials.....	396
9.1.2	Ionized organic molecular structures	403
9.2	Overview of organic devices	407
9.2.1	Light emitting devices.....	408
9.2.2	Transistors	411
9.3	Molecular optoelectronic materials	414
9.3.1	Molecular electron transporters.....	415
9.3.2	Molecular hole transporters.....	417
9.3.3	Dye molecules.....	420
9.3.4	Molecules for thin film transistors	427
9.4	Polymer optoelectronic organics	428
9.4.1	Polymers for organic light emitting devices	429
9.4.2	Polymers for transistors.....	434
9.5	Contact to organic materials	436
9.5.1	The cathode contact.....	436
9.5.2	The anode contact	439
9.6	Defects in organic materials	440
9.7	Patterning organic materials	442
9.8	Summary points	446
9.9	Homework	448
9.10	Suggested readings & references.....	450

10. THIN FILM GROWTH PROCESSES 455

10.1	Growth processes	455
10.2	Gas phase transport	460
10.3	Adsorption.....	461
10.4	Desorption.....	464
10.5	Sticking coefficient & surface coverage	466
10.6	Nucleation & growth of thin films.....	468
10.7	Surface diffusion.....	474
10.8	Surface energy	477
10.9	Morphology determined by nucleation.....	481
10.10	Microstructure evolution.....	484
10.11	Residual stress and adhesion.....	485
10.12	Applications	488
10.12.1	Adsorption, desorption and binding of H to Si	488
10.12.2	Surface processes in GaAs epitaxial growth.....	491
10.13	Summary points	496
10.14	Homework problems.....	499
10.15	Suggested readings & references.....	502

11. PHYSICAL VAPOR DEPOSITION	505
11.1 Evaporation.....	505
11.1.1 Basic system geometries	506
11.1.2 Sources	508
11.1.3 Vapor pressure	516
11.2 Monitoring deposition rates.....	517
11.2.1 Simple rate monitoring methods	518
11.2.2 Reflection high-energy electron diffraction.....	520
11.3 Sputtering.....	526
11.3.1 Sputtering yield	527
11.3.2 Energetic particles	533
11.3.3 Sputtering systems	539
11.3.4 Glow discharge basics.....	542
11.4 Fast particle modification of films	553
11.5 Application	560
11.6 Summary points	564
11.7 Homework problems	567
11.8 Suggested readings & references.....	570
12. CHEMICAL VAPOR DEPOSITION	573
12.1 Overview.....	574
12.2 CVD apparatus	578
12.3 Gas flow in CVD reactors	581
12.4 Reactant selection and design.....	584
12.5 Stimulated CVD	587
12.6 Selective CVD	591
12.7 Atomic layer deposition.....	594
12.8 Sample CVD and ALD processes	597
12.9 Summary points	604
12.10 Homework problems.....	606
12.11 Suggested readings & references	608
APPENDIX	611
Useful constants.....	611
Units	612
Unit conversions	612
INDEX	615