

# 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 defects .....	289
7.1.1	Electronic states due to point defects .....	291
7.1.2	Shallow levels .....	295
7.1.3	Depth of intrinsic defects .....	299
7.1.4	Ionization of defects .....	300
7.1.5	Point defect densities .....	302
7.1.6	Vacancies and dopant diffusivity .....	308
7.2	Line defects .....	311
7.3	Strain relief in heterostructures .....	320
7.3.1	Energetics of strain relief .....	322
7.3.2	Misfit dislocations .....	328
7.3.3	Dislocation dynamics .....	329
7.3.4	Reducing problems due to strain relief .....	336
7.4	Planar and volume defects .....	337
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 faults .....	344
7.6	Summary points .....	349
7.7	Homework .....	352
7.8	Suggested readings & references .....	355

## 8. AMORPHOUS SEMICONDUCTORS 357

8.1	Structure and bonding .....	358
8.2	Hydrogenated amorphous Si .....	364
8.3	Deposition methods for a-Si .....	366
8.4	Electronic properties .....	367
8.4.1	Carrier transport and mobility .....	367
8.4.2	Mobility measurements .....	370
8.4.3	Doping .....	372
8.4.4	Short-range order .....	373
8.5	Optical properties .....	374
8.6	Amorphous semiconductor alloys .....	377
8.7	Applications .....	380
8.7.1	Thin film transistors .....	380
8.7.2	Solar cells .....	383
8.8	Summary points .....	389
8.9	Homework .....	391
8.10	Suggested readings and references .....	392

---

## 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**



<http://www.springer.com/978-0-387-25653-5>

The Materials Science of Semiconductors

Rockett, A.

2008, XVIII, 622 p., Hardcover

ISBN: 978-0-387-25653-5