Contents

Preface xi

1 **Introduction and fundamentals** 1
- 1.1 Introduction to semiconducting materials . . . 1
- 1.2 Electrons in solids . . . 1
  - 1.2.1 The relaxation time model . . . 2
  - 1.2.2 Quantum model of the free electron gas . . . 4
  - 1.2.3 Electrons in periodic potentials: theorem of Bloch . . . 12
  - 1.2.4 Periodic crystal lattices: basic concepts . . . 15
- 1.3 Band structure . . . 17
  - 1.3.1 Brillouin zone boundary analysis . . . 18
  - 1.3.2 Band representation and classification of solids . . . 19
  - 1.3.3 The electronic hole . . . 24

Problems . . . 25

2 **Semiconductor statistics** 29
- 2.1 Statistics of charge carriers in solids . . . 29
  - 2.1.1 Some limitations . . . 31
  - 2.1.2 Intrinsic case . . . 32
  - 2.1.3 General aspects of the extrinsic case . . . 33
- 2.2 Defects and impurities in semiconductors . . . 35
  - 2.2.1 Hydrogenic or effective mass model . . . 35
  - 2.2.2 Deep impurities . . . 41
  - 2.2.3 Amphoteric impurities and isoelectronic impurities . . . 41
  - 2.2.4 Hydrogen: a particularly important impurity . . . 41
  - 2.2.5 Compensation, passivation and activation . . . 42
  - 2.2.6 Statistics of impurity levels . . . 43

Problems . . . 50

3 **Transport properties** 60
- 3.1 Introduction . . . 60
- 3.2 Transport phenomena . . . 60
  - 3.2.1 Electrical conduction and scattering mechanisms . . . 60
  - 3.2.2 Sources of dispersion . . . 64
  - 3.2.3 Conduction in the presence of magnetic fields . . . 65
  - 3.2.4 Conduction in high electric fields . . . 68

3.2.5 Negative differential resistivity 69
3.2.6 Diffusion 70
3.2.7 Continuity equations 73
3.2.8 Thermoelectric properties 74
Problems 76

4 Optical properties **79**
4.1 Introduction 79
4.2 Phenomenological description of absorption 81
4.3 Interband absorption 82
4.3.1 Direct bandgap and indirect bandgap 82
4.3.2 Transition rate for direct bandgap semiconductors . . 83
4.4 Excitons 85
4.4.1 Free excitons 86
4.5 Absorption by free charge carriers 87
4.5.1 Dependence with conductivity and frequency 88
4.6 Recombination 93
4.6.1 Interband recombination 93
4.6.2 Auger recombination 95
4.6.3 Recombination in the presence of defects/impurities . 96
4.6.4 Photoconductivity 97
4.6.5 Excess charge carrier profiles 98
Problems 101

5 Semiconducting junctions **108**
5.1 Bipolar junction 108
5.1.1 Introduction 108
5.1.2 Characterization of the depletion zone 112
5.1.3 I–V curve 115
5.2 Diodes 122
5.2.1 Photodiodes and solar cells 122
5.2.2 Photodiodes 122
5.2.3 Solar cells 123
5.3 Bipolar transistors 127
5.3.1 Minority charge carrier profiles 127
5.3.2 Emitter and collector currents 130
5.3.3 Current amplification 131
Problems 134

6 Nanostructures **140**
6.1 Heterostructures and nanostructures 140
6.1.1 Type I and type II heterostructures 141
6.1.2 Nanostructures 142
6.2 Quantum wells 144
6.3 Superlattices 147

6.4 Quantum Hall effect 148
6.4.1 Velocity components 149
6.4.2 Landau levels 151
6.4.3 Quantum Hall effect in two-dimensional systems . . . 153
Problems 158

Bibliography **161**

Index **165**