Contents

1. Introduction 1
1.1 Instabilities in Semiconductors 4
1.1.1 Negative Differential Conductivity 4
1.1.2 Mechanisms for NDC 7
1.1.3 Semiconductor Transport 12
1.2 Phase Transition Analogies 17
1.2.1 Equilibrium and Nonequilibrium Phase Transitions 18
1.2.2 Semiconductors as Nonequilibrium Systems 23
1.2.3 Bifurcation Phenomena 30

2. Bistability of Homogeneous Steady States 40
2.1 One-Carrier Models 40
2.1.1 Second-Order Phase Transitions 41
2.1.2 First-Order Phase Transitions 48
2.1.3 General M-Level Mechanisms 60
2.1.4 Critical Behavior 63
2.1.5 Cyclotron-Resonance Induced Phase Transitions 69
2.2 Two-Carrier Models 75
2.2.1 Models with Band-Band Impact Ionization 75
2.2.2 Models with Band-Trap Impact Ionization 77
2.2.3 Dynamics of Threshold Switching Transitions 88
2.2.4 Auger Recombination Induced Tristability 94
2.3 Excitonic Models 97
2.3.1 Stimulated Exciton Creation 98
2.3.2 Bound-Exciton Recombination and Optical Bistability 100

3. Small Fluctuations from the Homogeneous Steady State 103
3.1 Linear Modes of One-Carrier Models 103
3.1.1 Linearized Transport Equations 106
3.1.2 Stability and Differential Conductivity 111
3.2 Filamentary Instability 114
3.2.1 The Spectrum 114
3.2.2 Bifurcation of Layered or Filamentary Stationary Structures 117
3.3 Domain Instability 119
3.4 Electromagnetic Modes 122
3.4.1 Maxwell's Equations in Media with NDC 122
3.4.2 Transverse Modes ($k \perp \delta\varepsilon$) 126

3.4.3 Longitudinal Modes ($k||\delta\varepsilon$) 128
3.4.4 Mixed Modes 131
3.5 Oscillatory Instability 136
3.5.1 Two-Level Models 137
3.5.2 Single-Level Models 140

4. Stationary Transverse Spatial Structures 142
4.1 Plane Current Layers 142
4.1.1 Phase Portraits 143
4.1.2 Equal-Areas Rule 147
4.1.3 Electron-Density Profiles 150
4.1.4 Current-Voltage Characteristics 155
4.2 Cylindrical Current Filaments 157
4.2.1 Electron-Density Profiles 160
4.2.2 Equal-Areas Rule 163
4.3 Influence of Boundaries 168
4.3.1 Lateral Boundary Conditions 169
4.3.2 Neumann Boundary Conditions 174
4.3.3 Dirichlet Boundary Conditions 175
4.4 Filamentation in Two-Carrier Models 185
4.4.1 Ambipolar Diffusion and Trapping 186
4.4.2 Equal-Areas Rules for Current Layers and Filaments 191
4.5 Multiple Filaments 193

5. Stability of Transverse Spatial Structures 197
5.1 Plane Current Layers 197
5.1.1 General Results 199
5.1.2 Unstable Modes of Depletion Layers 204
5.1.3 Stable Modes of the Kink Profile 212
5.2 Cylindrical Current Filaments 213
5.2.1 General Results 213
5.2.2 Unstable Mode 214
5.3 Finite Boundary Conditions 216
5.3.1 Neumann Boundary Conditions 216
5.3.2 Dirichlet Boundary Conditions 217
5.4 Fluctuation-Induced Phase Transitions 218
5.4.1 Nucleation of Current Filaments 219
5.4.2 Transverse Solitary Waves 221

6. Self-Sustained Oscillations and Chaos 223
6.1 Mechanisms for Oscillatory Behavior 223
6.1.1 Survey of Mechanisms 223
6.1.2 Transit-Time Oscillations 227
6.2 Limit-Cycle Oscillations 230
6.2.1 Circuit-Induced Oscillations 231
6.2.2 Impact-Ionization Induced Oscillations 239
6.2.3 Exciton-Induced Oscillations 248

6.3 Chaos 252
6.3.1 Routes to Chaos 252
6.3.2 Single-Carrier Effects 259
6.3.3 Impact-Ionization Assisted Driven Chaos 266
6.3.4 Impact-Ionization Induced Self-Generated Chaos 270
6.3.5 Two-Carrier Effects 283

References 287

Subject Index 309