Table of Contents

1. INTRODUCTION 1

2. PHYSICAL MODELS 7

2.1 NOMENCLATURE 9
2.1.1 Fundamental Variables 9
2.1.2 Specified Variables 9
2.1.3 Computed Variables 10
2.1.4 Constants 12
2.2 CHARGE 12
2.2.1 Charge-neutral 15
2.2.2 Equilibrium 17
2.2.3 Non-equilibrium 17
2.2.3.1 Rate Equations 18
2.2.3.2 Current 18
2.2.3.3 Recombination/Generation 27
2.2.4 Boundary Conditions 28
2.3 PHOTONS 29
2.3.1 Interface Reflections 30
2.3.2 External Optical Generation 32
2.3.3 Stimulated Emission 36
2.4 ENERGY 43
2.4.1 Three Temperature Model 44
2.4.1.1 Rate Equations 44
2.4.1.2 Energy Flux 45
2.4.1.3 Recombination/Generation 55
2.4.1.4 Boundary Conditions 58
2.4.2 Single Temperature Model 59
2.4.3 Hot Electron Model 60
2.5 QUANTUM WELL ISSUES 61
2.6 MATERIAL MODELS 64

3. DEVICE EXAMPLES 69

3.1 MODEL CONFIRMATION 69
3.2 VERTICAL CAVITY SURFACE EMITTING LASER 69
3.2.1 Standard VCSEL Design 70
3.2.2 DBR Design 78
3.2.3 Improved VCSEL Design 85
3.3 QUANTUM-WELL SOLAR CELL 89

4. CONCLUSIONS 98

5. REFERENCES 101

6. APPENDIX A - MODEL CONFIRMATION 107

6.1 TEST 1 - DEPLETION REGION FIELD 107
6.2 TEST 2 - SHORT CIRCUIT CURRENT 108
6.3 TEST 3 - LATTICE TEMPERATURE 109

7. APPENDIX B - DEVICE FILES 110

7.1 LISTING 1 - MULTI-QUANTUM WELL SOLAR CELL 110

7.2 LISTING 2 - STANDARD DELTA DOPED VCSEL 111
7.3 LISTING 3 - 1.5 PERIODS OF AN N-TYPE DBR 114
7.4 LISTING 4 - 1.5 PERIODS OF A P-TYPE DBR 115
7.5 LISTING 5 - IMPROVED N-TYPE DBR 115
7.6 LISTING 6 - IMPROVED P-TYPE DBR 116
7.7 LISTING 7 - IMPROVED VCSEL 117
7.8 LISTING 8 - TEST PN DIODE 120
7.9 LISTING 9 - TEST PN PHOTODETECTOR 120
7.10 LISTING 10 - TEST RESISTOR 120

8. APPENDIX C - USER'S MANUAL VERSION 1.4.2 121

8.1 INTRODUCTION 121
8.1.1 Conventions for this manual 123
8.2 GETTING STARTED 124
8.2.1 The SimWindows Desktop 125
8.2.2 Loading a Device 126
8.2.3 Performing Simulations 128
8.2.4 Generating Output 129
8.2.5 Summary 131
8.3 SIMWINDOWS FILE TYPES 132
8.3.1 User Functions 132
8.3.1.1 Constant 133
8.3.1.2 Polynomial 133
8.3.1.3 General Function 134
8.3.2 Material Parameters Files 135
8.3.2.1 Format 136
8.3.2.2 Example Material Section 144
8.3.3 Device Files 146
8.3.3.1 Keywords 147
8.3.3.2 Overriding Material Parameters 150
8.3.3.3 Example Device Files 151
8.3.4 State Files 152
8.3.5 Data Files 152
8.4 BUG REPORT 154
8.5 CLASS DIAGRAMS 156

9. APPENDIX D - NOMENCLATURE 160

9.1 FUNDAMENTAL VARIABLES 160
9.2 SPECIFIED VARIABLES 160
9.3 COMPUTED VARIABLES 161
9.4 CONSTANTS 163

10. APPENDIX E - CONTINUOUS EQUATIONS 164

10.1 AUXILIARY EQUATIONS 164
10.2 RATE EQUATIONS 169
10.3 VECTOR EQUATIONS 170
10.4 BOUNDARY CONDITIONS 174
10.5 NORMALIZATION CONSTANTS 175

11. APPENDIX F - DISCRETE EQUATIONS 176

11.1 AUXILIARY EQUATIONS 176
11.2 RATE EQUATIONS 176
11.3 VECTOR EQUATIONS 177

12. APPENDIX G - SPECIAL DERIVATIONS 179

12.1 Derivation 1 - Free Carrier Quantum Well Concentration 179
12.2 Derivation 2 - Fermi-Dirac Thermionic Emission Current 179
12.3 Derivation 3 - Boltzmann Thermionic Emission Energy Flux 181
12.4 Derivation 4 - Fermi-Dirac Thermionic Emission Energy Flux 182

13. APPENDIX H - SPECIAL FUNCTIONS 185

13.1 Incomplete Gamma Function 185
13.2 Gamma Function 185
13.3 Fermi-Dirac Distribution Function 185
13.4 Fermi Integral 185
13.5 Dilogarithm 186
13.6 Trilogarithm 186
13.7 Bernoulli Function 186