

Contents

1 Gain and Absorption: Many-Body Effects

<i>S. W. Koch, J. Hader, A. Thränhardt, J. V. Moloney</i>	1
1.1 Introduction	1
1.2 Theory	2
1.3 Simplified Models	7
1.3.1 General Features; Single-Particle Gain and Absorption ..	7
1.3.2 Fair Approximations	10
1.3.3 Poor Approximations	13
1.4 Commercial Applications	18
1.4.1 Gain Tables	18
1.4.2 On-Wafer Device Testing	19
1.5 Carrier Dynamics	23
References	24

2 Fabry–Perot Lasers: Temperature and Many-Body Effects

<i>B. Grote, E. K. Heller, R. Scarmozzino, J. Hader, J. V. Moloney,</i> <i>S. W. Koch</i>	27
2.1 Introduction	27
2.2 Theory	31
2.2.1 Transport	31
2.2.2 Optics	38
2.2.3 Gain	39
2.3 Temperature Sensitivity of InGaAsP Semiconductor Multi-Quantum Well Lasers	41
2.3.1 Laser Structure	42
2.3.2 Sample Characterization	42
2.3.3 Gain Spectra	44
2.3.4 Light-Current Characteristics and Model Calibration ...	47
2.3.5 Self-Heating	53
2.4 Summary	58
References	59

3 Fabry–Perot Lasers: Thermodynamics-Based Modeling

<i>U. Bandelow, H. Gajewski, and R. Hünlich</i>	63
3.1 Introduction	63

VIII Contents

3.2	Basic Equations	64
3.2.1	Poisson Equation	64
3.2.2	Transport Equations	64
3.2.3	State Equations	65
3.2.4	Optics	65
3.3	Heating	67
3.3.1	Free Energy, Entropy, Energy	67
3.3.2	Current Densities	69
3.3.3	Heat Equation	70
3.3.4	Entropy Balance	72
3.4	Boundary Conditions	74
3.5	Discretization	75
3.5.1	Time Discretization	75
3.5.2	Space Discretization	75
3.5.3	Discretization of the Currents	76
3.6	Solution of the Discretized Equations	78
3.6.1	Decoupling, Linearization	78
3.6.2	Solution of Linear Algebraic Equations	78
3.7	Example	78
3.7.1	Stationary Characteristics	79
3.7.2	Modulation Response	82
3.8	Conclusion	83
A	Temperature Dependence of Model Parameters	84
	References	85

4 Distributed Feedback Lasers: Quasi-3D Static and Dynamic Model

<i>X. Li</i>	87
4.1 Introduction	87
4.2 Governing Equations	89
4.2.1 Optical Wave Equations	89
4.2.2 Carrier Transport Equations	93
4.2.3 Optical Gain Model	95
4.2.4 Thermal Diffusion Equation	97
4.3 Implementation	98
4.3.1 General Approach	98
4.3.2 Solver for Optical Wave Equations	103
4.3.3 Solver for Carrier Transport Equations	104
4.3.4 Solver for Optical Gain Model	104
4.3.5 Solver for Thermal Diffusion Equation	104
4.4 Model Validation	106
4.5 Model Comparison and Application	107
4.5.1 Comparison among Different Models	107
4.5.2 1.3- μm InAlGaAs/InP BH SL-MQW DFB Laser Diode .	108
4.5.3 1.55- μm InGaAsP/InP RW SL-MQW DFB Laser Diode	110

4.6	Summary	117
	References	117

5 Multisection Lasers: Longitudinal Modes and their Dynamics

	<i>M. Radziunas, H.-J. Wünsche</i>	121
5.1	Introduction	121
5.2	Traveling Wave Model	122
5.3	Model Details and Parameters	123
	5.3.1 Model Details	123
	5.3.2 Parameters	125
5.4	Simulation of a Passive Dispersive Reflector Laser	126
5.5	The Concept of Instantaneous Optical Modes	129
5.6	Mode Expansion of the Optical Field	131
5.7	Driving Forces of Mode Dynamics	133
5.8	Mode-Beating Pulsations in a PhaseCOMB Laser	134
	5.8.1 Simulation	135
	5.8.2 Mode Decomposition	135
	5.8.3 Spatio-temporal Properties of Mode-beating Self-pulsations	137
5.9	Phase Control of Mode-beating Pulsations	139
	5.9.1 Simulation of Phase Tuning	139
	5.9.2 Mode Analysis	139
	5.9.3 Regimes of Operation	140
	5.9.4 Bifurcations	140
5.10	Conclusion	142
A	Numerical Methods	142
	A.1 Numerical Integration of Model Equations	142
	A.2 Computation of Modes	144
	A.3 Mode Decomposition	147
	References	149

6 Wavelength Tunable Lasers: Time-Domain Model for SG-DBR Lasers

	<i>D. F. G. Gallagher</i>	151
6.1	The Time-Domain Traveling Wave Model	151
	6.1.1 Gain Spectrum	153
	6.1.2 Noise Spectrum	155
	6.1.3 Carrier Equation	155
	6.1.4 Carrier Acceleration	156
	6.1.5 Extension to Two and Three Dimensions	156
	6.1.6 Advantages of the TDTW Method	158
	6.1.7 Limitations of the TDTW Method	159
6.2	The Sampled-Grating DBR Laser	159
	6.2.1 Principles	159

6.2.2	Reflection Coefficient	163
6.2.3	The Three-section SG-DBR Laser	164
6.2.4	The Four-section SG-DBR Laser	166
6.2.5	Results	169
6.3	The Digital-Supermode DBR Laser	178
6.3.1	Principle of Operation	178
6.3.2	Simulations	179
6.4	Conclusions	182
	References	184

7 Monolithic Mode-Locked Semiconductor Lasers

<i>E. A. Avrutin, V. Nikolaev, D. Gallagher</i>	185
7.1 Background and General Considerations	185
7.2 Modeling Requirements for Specific Laser Designs and Applications	187
7.3 Overview of Dynamic Modeling Approaches	189
7.3.1 Time-Domain Lumped Models	189
7.3.2 Distributed Time-Domain Models	192
7.3.3 Static or Dynamic Modal Analysis	198
7.4 Example: Mode-Locked Lasers for WDM and OTDM Applications	200
7.4.1 Background	200
7.4.2 Choice of Modeling Approach	200
7.4.3 Parameter Ranges of Dynamic Regimes: The Background	200
7.4.4 Choice of Cavity Design: All-Active and Active/Passive, Fabry–Perot and DBR Lasers	202
7.4.5 Passive Mode Locking	203
7.4.6 Hybrid Mode Locking	207
7.5 Modeling Semiconductor Parameters: The Absorber Relaxation Time	210
7.6 Directions for Future Work	213
7.7 Summary	214
References	214

8 Vertical-Cavity Surface-Emitting Lasers: Single-Mode Control and Self-Heating Effects

<i>M. Streiff, W. Fichtner, A. Witzig</i>	217
8.1 VCSEL Device Structure	217
8.2 Device Simulator	221
8.2.1 Optical Model	221
8.2.2 Electrothermal Model	222
8.2.3 Optical Gain and Loss	226
8.2.4 Simulator Implementation	227
8.3 Design Tutorial	230
8.3.1 Single-Mode Control in VCSEL Devices	231
8.3.2 VCSEL Optical Modes	232

8.3.3	Coupled Electrothermo-Optical Simulation	238
8.3.4	Single-Mode Optimization Using Metallic Absorbers and Anti-Resonant Structures	242
8.4	Conclusions	245
	References	246

9 Vertical-Cavity Surface-Emitting Lasers: High-Speed Performance and Analysis

	<i>J. S. Gustavsson, J. Bengtsson, A. Larsson</i>	249
9.1	Introduction to VCSELs	249
9.2	Important Characteristics of VCSELs	251
9.2.1	Resonance and Damping: Modulation Bandwidth	251
9.2.2	Nonlinearity	253
9.2.3	Noise	254
9.3	VCSEL Model	255
9.3.1	Current Transport	255
9.3.2	Heat Transport	259
9.3.3	Optical Fields	261
9.3.4	Material Gain	265
9.3.5	Noise	265
9.3.6	Iterative Procedures	268
9.4	Simulation Example: Fundamental-Mode-Stabilized VCSELs	270
9.4.1	Surface Relief Technique	271
9.4.2	Device Structure	275
9.4.3	Simulation Results	276
9.5	Conclusion	290
	References	291

10 GaN-based Light-Emitting Diodes

	<i>J. Piprek, S. Li</i>	293
10.1	Introduction	293
10.2	Device Structure	293
10.3	Models and Parameters	295
10.3.1	Wurtzite Energy Band Structure	295
10.3.2	Carrier Transport	298
10.3.3	Heat Generation and Dissipation	302
10.3.4	Spontaneous Photon Emission	303
10.3.5	Ray Tracing	304
10.4	Results and Discussion	306
10.4.1	Internal Device Analysis	306
10.4.2	External Device Characteristics	308
10.5	Summary	311
	References	311

11 Silicon Solar Cells

<i>P. P. Altermatt</i>	313
11.1 Operating Principles of Solar Cells	313
11.2 Basic Modeling Technique	315
11.3 Techniques for Full-Scale Modeling	318
11.4 Derivation of Silicon Material Parameters	319
11.5 Evaluating Recombination Losses	327
11.6 Modeling the Internal Operation of Cells	330
11.7 Deriving Design Rules for Minimizing Resistive Losses	334
References	339

12 Charge-Coupled Devices

<i>C. J. Wordelman, E. K. Banghart</i>	343
12.1 Introduction	343
12.2 Background	344
12.2.1 Principles of Operation of CCDs	344
12.2.2 CCD Architectures	345
12.3 Models and Methods	348
12.3.1 Process Models	349
12.3.2 Device Models	349
12.3.3 Solution Methods	352
12.4 Charge Capacity	353
12.5 Charge Transfer	357
12.5.1 Charge Transport Mechanisms	359
12.6 Charge Blooming	364
12.7 Dark Current	370
12.8 Charge Trapping	373
12.9 Summary	377
A Example Distribution	377
References	378

13 Infrared HgCdTe Optical Detectors

<i>G. R. Jones, R. J. Jones, W. French</i>	381
13.1 Introduction	381
13.2 Photon Detection	381
13.3 Summary of Simulation Tools	383
13.3.1 Introduction	383
13.3.2 Fundamentals of Device Simulation	384
13.3.3 Carrier Generation and Recombination Mechanisms	387
13.3.4 Shockley–Read–Hall Recombination	387
13.3.5 Auger Recombination	388
13.3.6 Recombination Through Photon Emission	388
13.4 Optoelectronic Simulation	389
13.4.1 Optical Beam Characteristics	389
13.4.2 Light Absorption and Photogeneration	390

13.5	Device Simulation	391
13.5.1	Material Parameters	391
13.5.2	Device Structure	393
13.5.3	Cross Talk Considerations	395
13.5.4	Photogeneration and Spectral Response	396
13.5.5	Recombination Studies	398
13.6	Temperature Studies	400
13.7	Variation of Composition	402
13.8	Conclusion	402
	References	403

14 Monolithic Wavelength Converters: Many-Body Effects and Saturation Analysis

	<i>J. Piprek, S. Li, P. Mensz, J. Hader</i>	405
14.1	Introduction	405
14.2	Device Structure	405
14.3	General Device Physics	406
14.3.1	Optical Waveguiding	406
14.3.2	Quantum Well Active Region	410
14.3.3	Carrier Transport	414
14.4	Simulation Results	415
14.4.1	Amplifier	416
14.4.2	Photodetector	420
14.4.3	Sampled-Grating DBR Laser	422
14.5	Summary	425
	References	425

15 Active Photonic Integrated Circuits

	<i>A. J. Lowery</i>	427
15.1	Introduction	427
15.2	Fundamental Requirements of a Simulator	428
15.2.1	Single-Mode Interfaces	428
15.2.2	Backward-Propagating Waves	428
15.2.3	Nonlinearities	429
15.2.4	Optical Time Delays	430
15.2.5	Time Domain versus Frequency Domain	430
15.2.6	Transmission Line Laser Models	431
15.3	The Simulation Environment	433
15.4	Simulation Example	434
15.4.1	Phase Discriminator	435
15.4.2	Internal Clock Source	437
15.4.3	External Clock Source	438
15.4.4	Phase Locking the Clock Sources	440
15.4.5	Optical AND Gate	443
15.4.6	Open Design Issues	446

XIV Contents

15.5 Conclusions	446
References	447
Index	449



<http://www.springer.com/978-0-387-22659-0>

Optoelectronic Devices
Advanced Simulation and Analysis
Piprek, J. (Ed.)
2005, XIV, 452 p., Hardcover
ISBN: 978-0-387-22659-0