Optoelectronic Devices
Design, Modeling, and Simulation

With a clear application focus, this book explores optoelectronic device design and modeling through physics models and systematic numerical analysis.

By obtaining solutions directly from the physics-based governing equations through numerical techniques, the author shows how to design new devices and how to enhance the performance of existing devices. Semiconductor-based optoelectronic devices such as semiconductor laser diodes, electro-absorption modulators, semiconductor optical amplifiers, superluminescent light-emitting diodes and their integrations are all covered.

Including step-by-step practical design and simulation examples, together with detailed numerical algorithms, this book provides researchers, device designers, and graduate students in optoelectronics with the numerical techniques to solve their own structures.

Xun Li is a Professor in the Department of Electrical and Computer Engineering at McMaster University, Hamilton. Since receiving his Ph.D. from Beijing Jiaotong University in 1988, he has authored and co-authored over 160 technical papers and co-founded Apollo Photonics, Inc., developing one of the company’s major software products, “Advanced Laser Diode Simulator”. He is a Member of the OSA and SPIE, and a Senior Member of the IEEE.
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XUN LI
Department of Electrical and Computer Engineering
McMaster University
Hamilton, Ontario
## Contents

**Preface**

page xi

1 **Introduction**  
1.1 The underlying physics in device operation 1  
1.2 Modeling and simulation methodologies 1  
1.3 Device modeling aspects 3  
1.4 Device modeling techniques 3  
1.5 Overview 5

2 **Optical models**  
2.1 The wave equation in active media 6  
2.1.1 Maxwell equations 6  
2.1.2 The wave equation 8  
2.2 The reduced wave equation in the time domain 9  
2.3 The reduced wave equation in the space domain 11  
2.4 The reduced wave equation in both time and space domains — the traveling wave model 12  
2.4.1 The wave equation in fully confined structures 12  
2.4.2 The wave equation in partially confined structures 17  
2.4.3 The wave equation in periodically corrugated structures 21  
2.5 Broadband optical traveling wave models 31  
2.5.1 The direct convolution model 32  
2.5.2 The effective Bloch equation model 34  
2.5.3 The wavelength slicing model 37  
2.6 Separation of spatial and temporal dependences — the standing wave model 40  
2.7 Photon rate and phase equations — the behavior model 47  
2.8 The spontaneous emission noise treatment 48

3 **Material model I: Semiconductor band structures**  
3.1 Single electron in bulk semiconductors 54  
3.1.1 The Schrödinger equation and Hamiltonian operator 54  
3.1.2 Bloch’s theorem and band structure 57
### Contents

3.1.3 Solution at $\vec{k} = 0$: Kane's model 65  
3.1.4 Solution at $\vec{k} \neq 0$: Luttinger–Kohn’s model 71  
3.1.5 Solution under $4 \times 4$ Hamiltonian and axial approximation 76  
3.1.6 Hamiltonians for different semiconductors 80  

3.2 Single electron in semiconductor quantum well structures 80  
3.2.1 The effective mass theory and governing equation 80  
3.2.2 Conduction band (without degeneracy) 84  
3.2.3 Valence band (with degeneracy) 85  
3.2.4 Quantum well band structures 87  

3.3 Single electron in strained layer structures 91  
3.3.1 A general approach 91  
3.3.2 Strained bulk semiconductors 93  
3.3.3 Strained layer quantum well structures 95  
3.3.4 Semiconductors with the zinc blende structure 96  

3.4 Summary of the $k$–$p$ theory 98  

4 Material model II: Optical gain 102  
4.1 A comprehensive model with many-body effect 102  
4.1.1 Introduction 102  
4.1.2 The Heisenberg equation 103  
4.1.3 A comprehensive model 104  
4.1.4 General governing equations 109  
4.2 The free-carrier model as a zeroth order solution 122  
4.2.1 The free-carrier model 122  
4.2.2 The carrier rate equation 123  
4.2.3 The polariton rate equation 126  
4.2.4 The susceptibility 127  
4.3 The screened Coulomb interaction model as a first order solution 128  
4.3.1 The screened Coulomb interaction model 128  
4.3.2 The screened Coulomb potential 129  
4.3.3 Solution under zero injection and the exciton absorption 133  
4.3.4 Solution under arbitrary injection 137  
4.4 The many-body correlation model as a second order solution 140  
4.4.1 The many-body correlation model 140  
4.4.2 A semi-analytical solution 141  
4.4.3 The full numerical solution 144  

5 Carrier transport and thermal diffusion models 151  
5.1 The carrier transport model 151  
5.1.1 Poisson and carrier continuity equations 151  
5.1.2 The drift and diffusion model for a non-active region 152  
5.1.3 The carrier transport model for the active region 154  
5.1.4 Simplifications of the carrier transport model 158
Contents

5.1.5 The free-carrier transport model 160
5.1.6 Recombination rates 162
5.2 The carrier rate equation model 164
5.3 The thermal diffusion model 165
  5.3.1 The classical thermal diffusion model 165
  5.3.2 A one-dimensional thermal diffusion model 168

6 Solution techniques for optical equations 172
  6.1 The optical mode in the cross-sectional area 172
  6.2 Traveling wave equations 173
    6.2.1 The finite difference method 173
    6.2.2 The split-step method 183
    6.2.3 Time domain convolution through the digital filter 188
  6.3 Standing wave equations 191

7 Solution techniques for material gain equations 200
  7.1 Single electron band structures 200
  7.2 Material gain calculations 200
    7.2.1 The free-carrier gain model 200
    7.2.2 The screened Coulomb interaction gain model 205
    7.2.3 The many-body gain model 205
  7.3 Parameterization of material properties 211

8 Solution techniques for carrier transport and thermal diffusion equations 214
  8.1 The static carrier transport equation 214
    8.1.1 Scaling 215
    8.1.2 Boundary conditions 216
    8.1.3 The initial solution 218
    8.1.4 The finite difference discretization 218
    8.1.5 Solution of non-linear algebraic equations 228
  8.2 The transient carrier transport equation 231
  8.3 The carrier rate equation 232
  8.4 The thermal diffusion equation 233

9 Numerical analysis of device performance 236
  9.1 A general approach 236
    9.1.1 The material gain treatment 236
    9.1.2 The quasi-three-dimensional treatment 238
  9.2 Device performance analysis 240
    9.2.1 The steady state analysis 240
    9.2.2 The small-signal dynamic analysis 243
    9.2.3 The large-signal dynamic analysis 245
  9.3 Model calibration and validation 246
## Contents

### 10 Design and modeling examples of semiconductor laser diodes

10.1 Design and modeling of the active region for optical gain
   - The active region material
   - The active region structure

10.2 Design and modeling of the cross-sectional structure
   for optical and carrier confinement
   - General considerations in the layer stack design
   - The ridge waveguide structure
   - The buried heterostructure
   - Comparison between the ridge waveguide structure and buried heterostructure

10.3 Design and modeling of the cavity for lasing oscillation
   - The Fabry–Perot laser
   - Distributed feedback lasers in different coupling mechanisms through grating design
   - Lasers with multiple section designs

### 11 Design and modeling examples of other solitary optoelectronic devices

11.1 The electro-absorption modulator
   - The device structure
   - Simulated material properties and device performance
   - Design for high extinction ratio and low insertion loss
   - Design for polarization independent absorption

11.2 The semiconductor optical amplifier
   - The device structure
   - Simulated semiconductor optical amplifier performance
   - Design for performance enhancement

11.3 The superluminescent light emitting diode
   - The device structure
   - Simulated superluminescent light emitting diode performance
   - Design for performance enhancement

### 12 Design and modeling examples of integrated optoelectronic devices

12.1 The integrated semiconductor distributed feedback laser and electro-absorption modulator
   - The device structure
   - The interface
   - Simulated distributed feedback laser performance
   - Simulated electro-absorption modulator performance

12.2 The integrated semiconductor distributed feedback laser and monitoring photodetector
   - The device structure
Contents

12.2.2 Simulated distributed feedback laser performance 325
12.2.3 Crosstalk modeling 326

Appendices
A Lowdin’s renormalization theory 332
B Integrations in the many-body gain model 334
C Cash–Karp’s implementation of the fifth order Runge–Kutta method 347
D The solution of sparse linear equations 348
   D.1 The direct method 349
   D.2 The iterative method 351

Index 356
Preface

Over the past 30 years, the world has witnessed the rapid development of optoelectronic devices based on III-V compound semiconductors. Past effort has mainly been directed to the theoretical understanding of, and the technology development for, these devices in applications in telecommunication networks and compact disk (CD) data storage. With the growing deployment of such devices in new fields such as illumination, display, fiber sensor, fiber gyro, optical coherent tomography, etc., research on optoelectronic devices, especially on those light emitting components, continues to expand with the pursuit of many experimental explorations on new materials such as group-III nitride alloys and II-VI compounds and novel structures such as quantum wires, dots, and nanostructures.

As the manufacturing technology becomes mature and standardized and few uncertainties are left, design and simulation become the major issue in the performance enhancement of existing devices and in the development of new devices. Recent progress in numerical techniques as well as computing hardware has provided a powerful platform that makes sophisticated computer-aided design, modeling, and simulation possible. So far, the development of optoelectronic devices seems to replicate the history of electronic devices: from discrete to integrated, from technology intensive to design intensive, from trial-and-error experiments to computer-aided simulation and optimization.

The purpose of this book is to bridge the gap between the theoretical framework and the solution to real-world problems, or, more specifically, to bridge the gap between our knowledge acquired on electromagnetic field theory, quantum mechanics, and semiconductor physics and optoelectronic device design and modeling through advanced numerical tools.

Advanced optoelectronic devices are built on compound semiconductor material systems with complicated geometrical structures; they are also operated under varying conditions. For this reason, we can find hardly any easy, intuitive, and analytical solutions to the first-principle-based governing equations that accurately describe the closely coupled physical processes inside such devices. Although solutions are relatively easy to obtain from the equations derived from the phenomenological model, assumptions have to be made in such a model, which often ignores some important effects and fails to achieve quantitative agreement between theoretically predicted and practically measured results.

Therefore, obtaining the solution directly from the physics-based governing equations through numerical techniques seems to be a promising approach to bridge the gap as mentioned above, as not only a qualitative, but also a quantitative matching between
the theory and experiment is achievable. This book is intended for readers who want to link their understanding of the device physics through the theoretical framework they have already acquired to the design, modeling and simulation of real-world devices and innovative structures.

This book will focus on semiconductor-based optoelectronic devices such as laser diodes (LDs), electro-absorption modulators (EAMs), semiconductor optical amplifiers (SOAs), and superluminescent light emitting diodes (SLEDs) in various applications. Numerical methods will be used throughout the analysis of these devices.

Derived from physics-based first principles, governing equations will be given for the description of different physical processes, such as light propagation, optical gain generation, carrier transport and thermal diffusion, and their interplays inside the devices. Different numerical techniques will be discussed in detail along with the process of seeking the solution to these governing equations. Discussions on device design optimizations will also be followed, based on the interpretation of the numerical solutions.

The methodology introduced in this book hopefully will help its readers to learn (1) how to extract the governing equations from first principles for the accurate description of their devices; and more importantly, (2) how to obtain the numerical solution to those governing equations once derived. Practical design and simulation examples are also given to support the approaches used in this book.

I am in debt to my colleague and friend, Professor W.-P. Huang, who showed me the prospect of computer-aided design, modeling and simulation in this field 15 years ago, and with whom I had countless stimulating discussions on almost every topic involved in this book, from the material physics to waveguide theory, from the model establishment to result interpretation, and from the modeling methodology to numerical algorithm. I would like to thank Dr. T. Makino (former Nortel), Dr. K. Yokoyama (former NTT), Dr. T. Yamanaka (NTT), Dr. C.-L. Xu (RSOFT Inc.), Dr. J. Hong (Oplink Inc.), Dr. A. Shams (former Photonami Inc.), Professor S. Sadeghi (University of Alabama at Huntsville), Professor W. Li (University of Wisconsin at Platteville), Professor Y. Luo (Tsinghua University), Professor Y.-H. Zhang (Arizona State University), Ms. T.-N. Li (InPhenix Inc.), Ms. N. Zhou (AcceLink Co.), Mr. M. Mazed (IP Photonics Inc.), Professor T. Luo (University of Minnesota), Professor C.-Q. Xu (McMaster University), Professor M. Dagenais (University of Maryland at College Park), Dr. J. Piprek (former University of California at Santa Barbara), and many other colleagues and friends in this field, for numerous insightful and inspiring discussions and interactions on various subjects in this book, during and after our research collaborations. I am grateful to Ms. Y.-P. Xi, who helped me with the simulation of SOAs and SLEDs, and Mr. Q.-Y. Xu, who helped me with the simulation of crosstalks in the integrated DFB laser and monitoring photodetector. I am also grateful to Professor S.-H. Chen (Huazhong University of Sci. and Tech.) and her graduate students, who helped me to create most of the schematic diagrams in the first eight chapters and all the three-dimensional device structure drawings in Chapters 10 and 12. I would also like to thank my graduate students and many other graduate students in the Department of Electrical and Computer Engineering at McMaster University who took my course on this subject, for their valuable comments and suggestions. Finally, I appreciate the constant help and great patience of Dr. J. Lancashire and Ms. S. Koch.