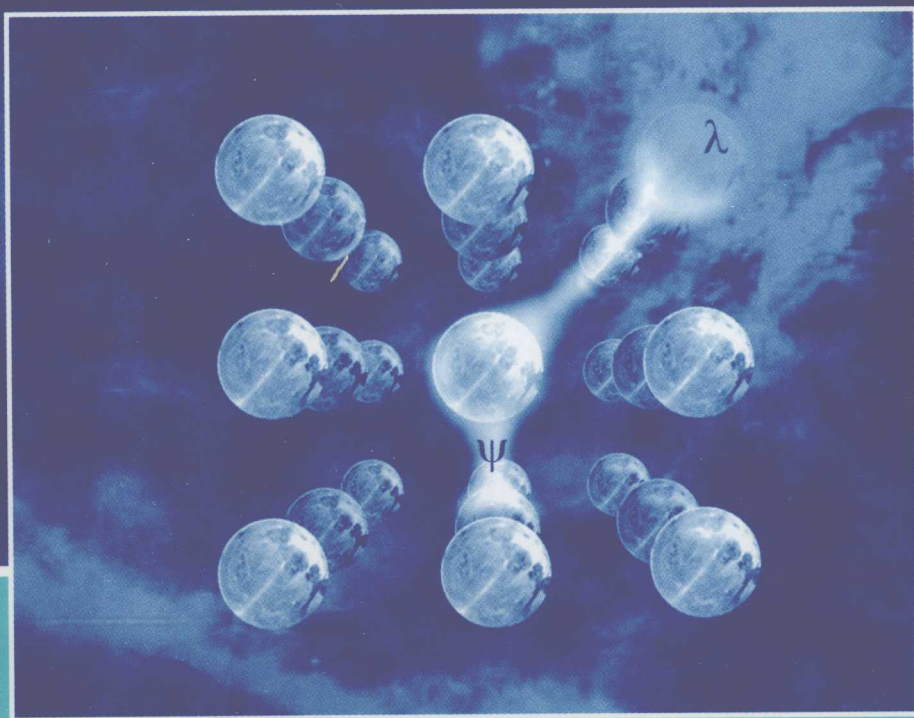


Physics of **OPTOELECTRONICS**



Michael A. Parker



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Preface

The study of optoelectronics examines matter, light and their interactions. The solid state and quantum theory provide fundamental descriptions of matter. The solid state shows the effect of crystal structure and departure from crystal structure on electronic transport. Classical and quantum electrodynamics describe the foundations of light and the interaction with matter.

The text introduces laser engineering physics in sufficient depth to make accessible recent publications in theory, experiment and construction. A number of well-known texts review present trends in optoelectronics while many others develop the theory. The *Physics of Optoelectronics* progresses from introductory material to that found in more advanced texts. Such a broad palette, however, requires the support of many sources as suggested by the reference sections after every chapter. The journal literature itself is dauntingly vast and best left to the individual texts for summary in any particular topical area. For this reason, the present text often overlaps many excellent references as a service to the reader to provide a self-contained account of the subject.

The *Physics of Optoelectronics* addresses the needs of students and professionals with a “standard” undergraduate background in engineering and physics. First- and second-year graduate students in science and engineering will most benefit, especially those planning further research and development. The textbook includes sufficient material for introducing undergraduates to semiconductor emitters and has been used for courses taught at Rutgers and Syracuse Universities over a period of six years. The students come from a variety of departments, but primarily from electrical and computer engineering. A subsequent course in optical systems and optoelectronic devices would be the most natural follow-up to the material presented herein.

The *Physics of Optoelectronics* focuses on the properties of optical fields and their interaction with matter. The laser, light emitting diode (LED) and photodetector perhaps represent the best examples of the interaction. For this reason, the book begins with an introduction to lasers and LEDs, and progresses to the rate equations as the fundamental description of the emission and detection processes. The rate equations exhibit the matter–light interaction through the gain terms. The remainder of the text develops the quantum mechanical expressions for gain and the optical fields. The text includes many of the derivation steps, and supplies figures to illustrate concepts in order to provide the reader with sufficient material for self-study.

The text summarizes and reviews the mathematical foundations of the quantum theory embodied in the Hilbert space. The mathematical foundations focus on the abstract form of the linear algebra for vectors and operators. These foundations supply the “pictures” often lacking in elementary studies of the quantum theory, that would otherwise make the subject more intuitive. A figure does not always accurately represent the mathematics but does help convey the meaning or “way of thinking” about a concept.

The quantum theory of particles and fields can be linked to the Lagrangian and Hamiltonian formulations of classical mechanics. A derivation of the field–matter interaction from first principles requires the electromagnetic field Lagrangian and Hamiltonian. A chapter on dynamics includes a brief summary and review of the formalism for discrete sets of particles and continuous media. The remainder of the discourse on dynamics covers topical areas in the quantum theory necessary for the study

of optical fields, transitions and semiconductor gain. The chapter includes the density operator, time-dependent perturbation theory, and the harmonic oscillator from the operator point-of-view.

The description of lasers and LEDS would not be complete without a discussion of the fundamental nature of the light that these devices produce. In the best of circumstances, the emission approximates the classical view of a coherent state with well-defined phase and amplitude. However, this often-found description of the optical fields originating in Maxwell's equations does not provide sufficient detail to describe the quantum light field, nor to understand recent progress in the areas of quantum optics and low-noise communications. The text develops the "quantized" electromagnetic fields and discusses the inherent quantum.

The later portions of the book develop the matter–light interaction, beginning with the time-dependent perturbation theory and Fermi's golden rule. After reviewing density-of-states and Bloch wave functions from the solid state, the text derives the gain from Fermi's golden rule. The gain describes the matter–light interaction in optical sources and detectors. However, Fermi's golden rule does not fully account for the effects of the environment. The theory typically implements the density operator and develops the Liouville equation (master equation) to describe collision broadening and saturation effects. The book briefly examines the origin of the fluctuation–dissipation theorem and applies it to the master equation. The book naturally leads to further study areas, including quantum optics, nanoscale emitters and detectors, nonlinear optics, and standard studies of q-switched and mode-locked lasers, parametric amplifiers, gas and solid state lasers.

The typical first-year graduate course (28 classes with approximately 1.5 hours each) covers the introduction (1.1–1.7), laser rate equations (2.1–2.5), the wave equations and transfer matrices (3.1–3.2, 3.5–3.7), a brief summary of waveguiding (3.8–3.9), linear algebra (4.1–4.6, 4.8–4.10), basic quantum theory (5.6–5.8), especially time dependent perturbation theory and density operators (5.10–5.11), quantum dipole and Fermi's golden rule (7.1–7.3), the Liouville equation and gain (7.9–7.13), and Fermi's golden rule approach to gain (Chapter 8). Usually some material must be sacrificed between the Liouville equation and the Fermi's golden rule approach for a one-semester course. A follow-up short course (8–12 classes) can cover the introduction to quantum electrodynamics (quantum optics — Chapter 6) with requisite material on quantum representations (5.9) and suggested material on noise from the beginning chapters (1.8, 2.6). Online lectures (with slides and audio) for a one-semester course are available free at www.crcpress.com. The topics for the one-semester course have been made independent of the other topics.

The author acknowledges the Rutgers, Cornell and Syracuse University programs in engineering and physics. The faculty, administration and staff at Rutgers have provided significant support for teaching and laboratory facilities. A number of individuals from the author's past have contributed to the author's view on semiconductor sources and detectors, especially C. L. Tang, P. D. Swanson, R. Liboff, E. A. Schiff, P. Kornreich, R. J. Michalak, S. Thai, K. Kasunic, and J. S. Kimmet. The author thanks his wife Carol, for her assistance and her patience during the weekends and evenings over the past several years while the author prepared the courses, compiled the material, and wrote the textbooks. Thanks also go to the staffs at Marcel Dekker, CRC Press, and Taylor & Francis for their advice and efforts to bring the text to publication. Most of all, the author thanks his students for attending the courses and for their challenging questions and suggestions.

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Contents

Preface.....	iii
 Chapter 1 Introduction to Semiconductor Lasers	
1.1 Basic Components and the Role of Feedback	2
1.2 Basic Properties of Lasers	4
1.2.1 Wavelength and Energy	5
1.2.2 Directionality	6
1.2.3 Monochromaticity and Brightness	6
1.2.4 Coherence Time and Coherence Length	7
1.3 Introduction to Emitter Construction	7
1.3.1 In-Plane and Edge-Emitting Lasers	7
1.3.2 VCSEL	8
1.3.3 Buried Waveguide Laser	9
1.3.4 Lateral Injection Laser	9
1.3.5 The Light Emitting Diode	9
1.3.6 Semiconductor Laser Amplifier	9
1.3.7 Gas Laser	9
1.3.8 The Solid State Laser	10
1.4 Introduction to Matter and Bonds	10
1.4.1 Classification of Matter	10
1.4.2 Bonding and the Periodic Table	12
1.5 Introduction to Bands and Transitions	14
1.5.1 Intuitive Origin of Bands	14
1.5.2 Indirect Bands, Light and Heavy Hole Bands	17
1.5.3 Introduction to Transitions	17
1.5.4 Introduction to Band Edge Diagrams	18
1.5.5 Bandgap States and Defects	20
1.5.6 Recombination Mechanisms	21
1.6 Introduction to the pn Junction for the Laser Diode	24
1.6.1 Junction Technology	24
1.6.2 Band-Edge Diagrams and the pn Junction	25
1.6.3 Nonequilibrium Statistics	26
1.7 Introduction to Light and Optics	28
1.7.1 Particle-Wave Nature of Light	28
1.7.2 Classical Method of Controlling Light	29
1.7.3 The Ridge Waveguide	31
1.7.4 The Confinement Factor	33
1.8 Introduction to Noise in Optoelectronic Components	34
1.8.1 Brief Essay on Noise for Systems	34
1.8.2 Johnson Noise	35
1.8.3 Low Frequency Noise	38
1.8.4 The Origin of Shot Noise	38
1.8.5 The Magnitude of the Shot Noise	41

1.8.6	Introduction to Noise in Optics	42
1.9	Review Exercises	43
1.10	Further Reading	45
 Chapter 2 Introduction to Laser Dynamics		
2.1	Introduction to the Rate Equations	47
2.1.1	The Simplest Rate Equations	48
2.1.2	Optical Confinement Factor	49
2.1.3	Total Carrier and Photon Rate	50
2.1.4	The Pump Term and the Internal Quantum Efficiency	50
2.1.5	Recombination Terms	51
2.1.6	Spontaneous Emission Term	53
2.1.7	The Optical Loss Term	54
2.2	Stimulated Emission—Absorption and Gain	56
2.2.1	Temporal Gain	56
2.2.2	Single Pass Gain	57
2.2.3	Material Gain	58
2.2.4	Material Transparency	60
2.2.5	Introduction to the Energy Dependence of Gain	60
2.2.6	The Phenomenological Rate Equations	61
2.3	The Power-Current Curves	64
2.3.1	Photon Density versus Pump-Current Number Density	64
2.3.2	Comment on the Threshold Density	67
2.3.3	Power versus Current	68
2.3.4	Power versus Voltage	69
2.3.5	Some Comments on Gain	70
2.4	Relations for Cavity Lifetime, Reflectance and Internal Loss	70
2.4.1	Internal Relations	70
2.4.2	External Relations	73
2.5	Modulation Bandwidth	74
2.5.1	Introduction to the Response Function and Bandwidth	74
2.5.2	Small Signal Analysis	76
2.6	Introduction to RIN and the Weiner–Khintchine Theorem	79
2.6.1	Basic Definition of Relative Noise Intensity	80
2.6.2	Basic Assumptions	80
2.6.3	The Fluctuation-Dissipation Theorem	82
2.6.4	Definition of Relative Intensity Noise as a Correlation	84
2.6.5	The Weiner–Khintchine Theorem	86
2.6.6	Alternate Derivations of the Weiner–Khintchine Formula	87
2.6.7	Langevin Noise Terms	89
2.6.8	Alternate Definitions for RIN	89
2.7	Relative Intensity Noise for the Semiconductor Laser	90
2.7.1	Rate Equations with Langevin Noise Sources and the Spectral Density	91
2.7.2	Langevin–Noise Correlation	94
2.7.3	The Relative Intensity Noise	97
2.8	Review Exercises	99
2.9	Further Reading	106

Chapter 3 Classical Electromagnetics and Lasers

3.1	A Brief Review of Maxwell's Equations and the Constituent Relations	108
3.1.1	Discussion of Maxwell's Equations and Related Quantities.....	108
3.1.2	Relation between Electric and Magnetic Fields in Vacuum.....	111
3.1.3	Relation between Electric and Magnetic Fields in Dielectrics	112
3.1.4	General Form of the Complex Traveling Wave.....	113
3.2	The Wave Equation	114
3.2.1	Derivation of the Wave Equation.....	114
3.2.2	The Complex Wave Vector	115
3.2.3	Definitions for Complex Index, Permittivity and Wave Vector.....	116
3.2.4	The Meaning of k_n	117
3.2.5	Approximate Expression for the Wave Vector.....	118
3.2.6	Approximate Expressions for the Refractive Index and Permittivity	119
3.2.7	The Susceptibility and the Pump	120
3.3	Boundary Conditions for the Electric and Magnetic Fields	122
3.3.1	Electric Field Perpendicular to an Interface.....	122
3.3.2	Electric Fields Parallel to the Surface	124
3.3.3	The Boundary Conditions for the General Electric Field	125
3.3.4	The Tangential Magnetic Field	125
3.3.5	Magnetic Field Perpendicular to the Interface (without Magnetization)	126
3.3.6	Arbitrary Magnetic Field	127
3.3.7	General Relations and Summary.....	127
3.4	Law of Reflection, Snell's Law and the Reflectivity	129
3.4.1	The Boundary Conditions.....	129
3.4.2	The Law of Reflection	131
3.4.3	Fresnel Reflectivity and Transmissivity for TE Fields.....	132
3.4.4	The TM fields.....	134
3.4.5	Graph of the Reflectivity Versus Angle	134
3.5	The Poynting Vector.....	135
3.5.1	Introduction to Power Transport for Real Fields	135
3.5.2	Power Transport and Energy Storage Mechanisms.....	137
3.5.3	Poynting Vector for Complex Fields.....	140
3.5.4	Power Flow Across a Boundary.....	141
3.6	Electromagnetic Scattering and Transfer Matrix Theory	144
3.6.1	Introduction to Scattering Theory	144
3.6.2	The Power-Amplitudes	146
3.6.3	Reflection and Transmission Coefficients	148
3.6.4	Scattering Matrices.....	151
3.6.5	The Transfer Matrix	154
3.6.6	Examples Using Scattering and Transfer Matrices	156
3.7	The Fabry-Perot Laser	160
3.7.1	Implications of the Transfer Matrix for the Fabry-Perot Laser.....	160
3.7.2	Longitudinal Modes and the Threshold Condition.....	164
3.7.3	Line Narrowing	168
3.8	Introduction to Waveguides	170
3.8.1	Basic Construction.....	171
3.8.2	Introduction to EM Waves for Waveguiding.....	171

3.8.3	The Triangle Relation.....	172
3.8.4	The Cut-off Condition from Geometric Optics.....	173
3.8.5	The Waveguide Refractive Index	175
3.9	Physical Optics Approach to Waveguiding.....	176
3.9.1	The Wave Equations	176
3.9.2	The General Solutions	178
3.9.3	Review the Boundary Conditions	179
3.9.4	The Solutions.....	179
3.9.5	An Expression for Cut-off	182
3.10	Dispersion in Waveguides	183
3.10.1	The Dispersion Diagram.....	184
3.10.2	A Formula for Dispersion.....	185
3.10.3	Bandwidth Limitations.....	186
3.11	The Displacement Current and Photoconduction	186
3.11.1	Displacement Current.....	187
3.11.2	The Power Relation.....	189
3.11.3	Voltage Induced by Moving Charge.....	189
3.12	Review Exercises.....	190
3.13	Further Reading	196

Chapter 4 Mathematical Foundations

4.1	Vector and Hilbert Spaces.....	197
4.1.1	Definition of Vector Space	198
4.1.2	Inner Product, Norm, and Metric	198
4.1.3	Hilbert Space	199
4.2	Dirac Notation and Euclidean Vector Spaces.....	199
4.2.1	Kets, Bras, and Brackets for Euclidean Space.....	200
4.2.2	Basis, Completeness, and Closure for Euclidean Space.....	201
4.2.3	The Euclidean Dual Vector Space	202
4.2.4	Inner Product and Norm	203
4.3	Hilbert Space	203
4.3.1	Hilbert Space of Functions with Discrete Basis Vectors.....	203
4.3.2	The Continuous Basis Set of Functions.....	205
4.3.3	Projecting Functions into Coordinate Space.....	206
4.3.4	The Sine Basis Set.....	210
4.3.5	The Cosine Basis Set.....	211
4.3.6	The Fourier Series Basis Set	211
4.3.7	The Fourier Transform	212
4.4	The Gram-Schmidt Orthonormalization Procedure.....	214
4.5	Linear Operators and Matrix Representations.....	215
4.5.1	Definition of a Linear Operator and Matrices	215
4.5.2	A Matrix Equation	216
4.5.3	Composition of Operators	217
4.5.4	Introduction to the Inverse of an Operator	217
4.5.5	Determinant.....	218
4.5.6	Trace.....	218
4.5.7	The Transpose and Hermitian Conjugate of a Matrix.....	219
4.5.8	Basis Vector Expansion of a Linear Operator	219
4.5.9	The Hilbert Space of Linear Operators	220

4.5.10 A Note on Matrices.....	221
4.6 An Algebra of Operators and Commutators	222
4.7 Operators and Matrices in Tensor Product Space.....	224
4.7.1 Tensor Product Spaces.....	224
4.7.2 Operators	225
4.7.3 Matrices of Direct Product Operators	226
4.7.4 The Matrix Representation of Basis Vectors for Direct Product Space.....	227
4.8 Unitary Operators and Similarity Transformations	229
4.8.1 Orthogonal Rotation Matrices.....	229
4.8.2 Unitary Transformations	230
4.8.3 Visualizing Unitary Transformations.....	231
4.8.4 Similarity Transformations	232
4.8.5 Trace and Determinant.....	233
4.9 Hermitian Operators and the Eigenvector Equation	234
4.9.1 Adjoint, Self-Adjoint and Hermitian Operators	234
4.9.2 Adjoint and Self-Adjoint Matrices	236
4.9.3 Eigenvectors and Eigenvalues for Hermitian Operators	236
4.9.4 The Heisenberg Uncertainty Relation	239
4.10 A Relation Between Unitary and Hermitian Operators.....	241
4.11 Translation Operators.....	242
4.11.1 The Exponential Form of the Translation Operator.....	242
4.11.2 Translation of the Position Operator.....	244
4.11.3 Translation of the Position-Coordinate Ket	244
4.11.4 Example Using the Dirac Delta Function	245
4.12 Functions in Rotated Coordinates	245
4.12.1 Rotating Functions	245
4.12.2 The Rotation Operator.....	246
4.13 Dyadic Notation.....	248
4.14 Minkowski Space.....	249
4.15 Review Exercises.....	252
4.16 Further Reading.....	256

Chapter 5 Fundamentals of Dynamics

5.1 Introduction to Generalized Coordinates	257
5.1.1 Constraints.....	258
5.1.2 Generalized Coordinates.....	258
5.1.3 Phase Space Coordinates	260
5.2 Introduction to the Lagrangian and the Hamiltonian.....	261
5.2.1 Lagrange's Equation from a Variational Principle.....	261
5.2.2 The Hamiltonian.....	264
5.2.3 Hamilton's Canonical Equations	264
5.3 Classical Commutation Relations	266
5.4 Classical Field Theory.....	268
5.4.1 Concepts for the Lagrangian and Hamiltonian Density.....	268
5.4.2 The Lagrange Density for 1-D Wave Motion.....	271
5.5 Schrodinger Equation from a Lagrangian	273
5.6 Linear Algebra and the Quantum Theory.....	275
5.6.1 Observables and Hermitian Operators	276