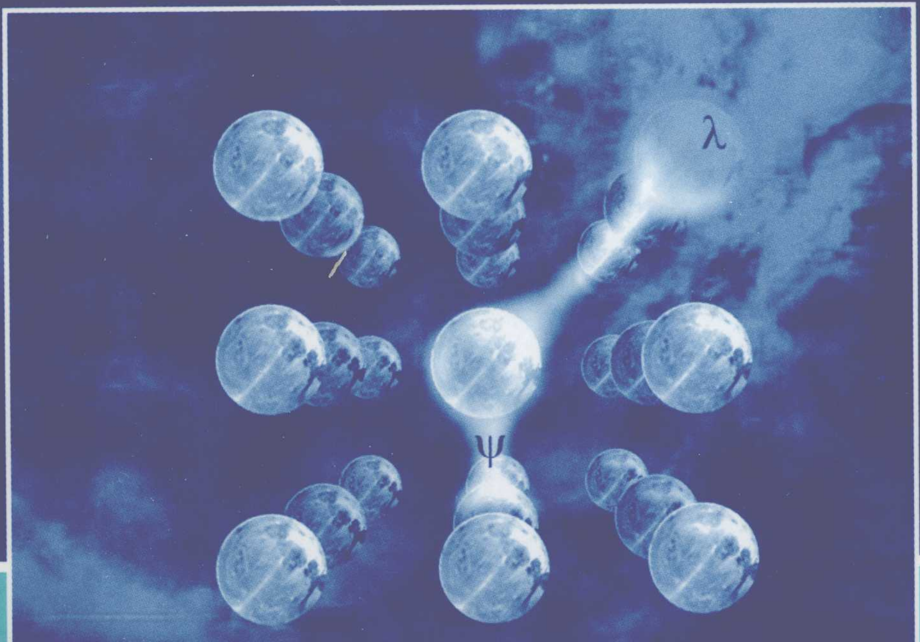
Physics of OPTOELECTRONICS



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

Chapter 3 Classical Electromagnetics and Lasers

Chapter 5 Fundamentals of Dynamics