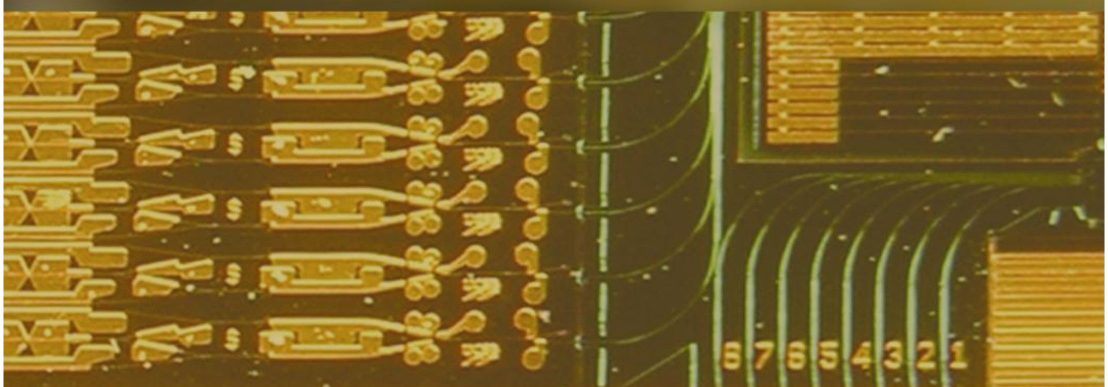
SECOND EDITION

Diode Lasers and Photonic Integrated Circuits



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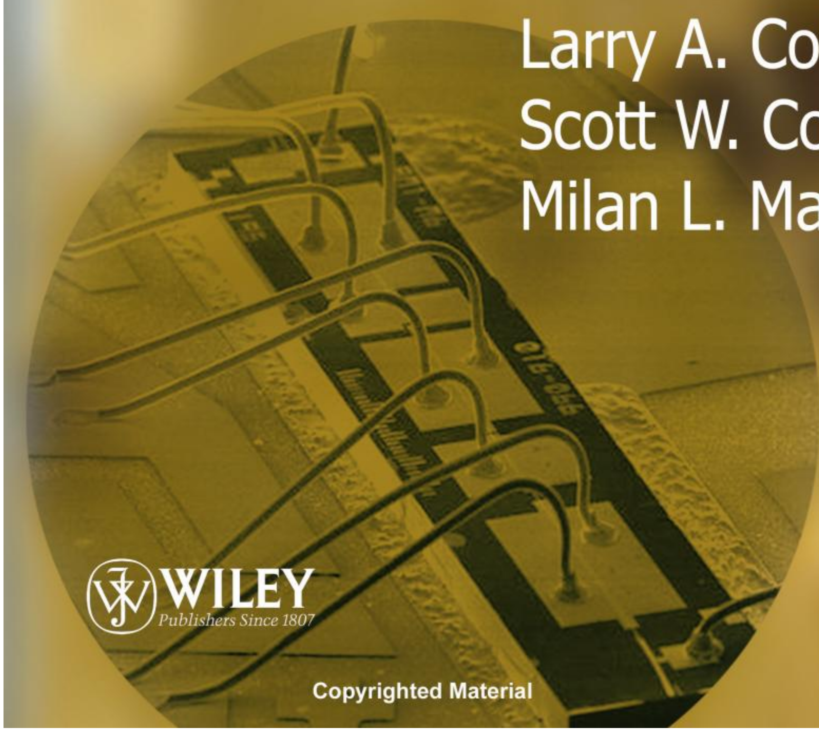

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Preface

Diode lasers and related photonic integrated circuits have become even more commercially important since the first edition of this book was published, in 1995. They are used in a wide variety of applications ranging from the readout sources in DVD and Blu-ray disk players, laser printers, mice and pointers, to the complex multiwavelength transmitters and receivers in optical fiber communication systems that carry hundreds of gigabits per second of information. New applications, such as solid-state lighting sources, or sources for high-spectral-efficiency telecommunications networks continue to emerge as the devices become more varied, reliable, manufacturable, and inexpensive.

In this edition, the GaN-based materials, which have become important in the UV/blue/green wavelength regions as well as for solid-state lighting, are included with equal emphasis to the GaAs and InP-based materials, which provide emission from the red to about 1 micron in wavelength on GaAs and over the 1.3–1.6 micron wavelength range on InP. Thus, the range of applications that can be addressed with a mastery contents of this edition is very broad.

This book has been written to be a resource for professors, graduate students, industry researchers, and design engineers dealing with the subject of diode lasers and related photonic integrated circuits for a range of applications. The depth of coverage is relatively advanced, but the initial chapters provide a working knowledge of semiconductor lasers before delving into much of the advanced material. Appendices are used both to provide a review of background material as well as some of the details of the more advanced topics. Thus, by appropriate use of the appendices, the text can support teaching the material at different academic levels, but it remains self-contained.

Significant new material has been added, to both improve on the original text, and to address important technology developments over the last decade. One of the key novel features is the addition of many worked examples throughout all the chapters to better illustrate how to apply the theory that is being covered. New homework problems have also been added to supplement the previous ones, some of which are less complex than the previous problems, because many found them too difficult for beginning students or casual reference readers.

New topics that are being covered in this second edition are more introductory material related to benefits, applications and basics of laser diodes and photonic ICs; additional methods for analytic calculation of S parameters based on Mason's rule; expanded treatment of DFB and VCSEL lasers; additional material on quantum dots, gain and other material parameters for both GaN, InP and GaAs based active regions and devices; treatment of the mode-locked lasers and injection locking; total internal reflection mirrors and beam splitters; a new appendix and section on mutimode interference effects and devices; treatment of star couplers and photonic multiplexers, demultiplexers and routers, and their design; expanded treatment of losses in dielectric waveguides; treatment of light propagation in curved waveguides; significantly expanded treatment of tunable and widely tunable laser diodes; expanded treatment of externally modulated lasers, including Mach-Zehnder modulators and semiconductor optical amplifiers; additional material on waveguide photodiodes, optical transceivers and triplexers; and a full section on basics and PICs for coherent communications.

Also available online with the second edition will be a number of password-protected tools, such as BPM and S and T matrix computation code, DFB laser code, mode solving code, as well as color versions of all figures, all of which should be useful for instructors and students, as well as other readers.

The full text is intended for use at the graduate level, although a fairly comprehensive introductory course on diode lasers at an advanced undergraduate level could be based around the material in Chapters 1 through 3 together with Appendices 1 through 7.

It is assumed that the readers have been exposed to elementary quantum mechanics, solid-state physics, and electromagnetic theory at the undergraduate level. It is also recommended that they have had an introductory optoelectronics course. Appendices 1 and 3 review most of the necessary background in just about all of the required detail. Thus, it is possible to use the book with less prior educational background, provided these review appendices are covered with some care.

For use in a more advanced graduate class, it would not be necessary to cover the material in the first seven appendices. (Of course, it would still be there for reference, and the associated homework problems could still be assigned to ensure its understanding. Nevertheless, it is still recommended that Appendix 5, which covers the definitions of modal gain and loss, be reviewed because this is not well understood by the average worker in the field.) The coverage could then move efficiently through the first three chapters and into Chapters 4 and 5, which deal with the details of gain and laser dynamics in a first course. For more focus on the gain physics some of Appendices 8 through 12 could be included in the coverage. In any event, their inclusion provides for a very self-contained treatment of this important subject matter.

Chapters 6 and 7 deal more with the electromagnetic wave aspects of photonic ICs and diode lasers. This material is essential for understanding the more advanced PIC type of devices used in modern fiber-optic links and networks.

However, keeping this material to last allows the student to develop a fairly complete understanding of the operation of diode lasers without getting bogged down in the mathematical techniques necessary for the lateral waveguide analysis. Thus, a working understanding and appreciation of laser operation can be gained in only one course. Chapter 6 deals with perturbation, coupled-mode theory and modal excitation while Chapter 7 deals with dielectric waveguide analysis. Putting Chapter 6 first emphasizes the generality of this material. That is, one really does not need to know the details of the lateral mode profile to develop these powerful techniques. Using the coupled-mode results, gratings and DFB lasers are again investigated. Historically, these components were primarily analyzed with this theory. However, in this text grating-based DFB and DBR lasers are first analyzed in Chapter 3 using exact matrix multiplication techniques, from which approximate formulas identical to those derived with coupled mode theory result. The proliferation of computers and the advent of lasers using complex grating designs with many separate sections has led the authors to assert that the matrix multiplication technique should be the primary approach taught to students. The advent of the vertical-cavity laser also supports this approach. Nevertheless, it should be realized that coupled-mode theory is very important to reduce the description of the properties of complex waveguide geometries to simple analytic formulae, which are especially useful in design work. Chapter 7 also introduces some basic numerical techniques, which have become indispensable with the availability of powerful personal computers and efficient software for solving complex numerical algorithms. The finite-difference technique is introduced for optical waveguide analysis, while the beam-propagation method is discussed as a key tool for analyzing real PIC structures.

Chapter 8 pulls together most of the material in the first seven chapters by providing a comprehensive overview of the development of photonic integrated circuits, with a series of design examples of relatively complex photonic integrated circuits.

Unlike many books in this field, this book is written as an engineering text. The reader is first trained to be able to solve problems on real diode lasers, based on a phenomenological understanding, before going into the complex physical details such as the material gain process or mode-coupling in dielectric waveguides. This provides motivation for learning the underlying details as well as a toolbox of techniques to immediately apply each new advanced detail in solving real problems. Also, attention has been paid to accuracy and consistency. For example, a careful distinction between the internal quantum efficiency in LEDs and injection efficiency in lasers is made, and calculations of gain not only illustrate an analysis technique, but they actually agree with experimental data. Finally, by maintaining consistent notation throughout all of the chapters and appendices, a unique self-contained treatment of all of the included material emerges.

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