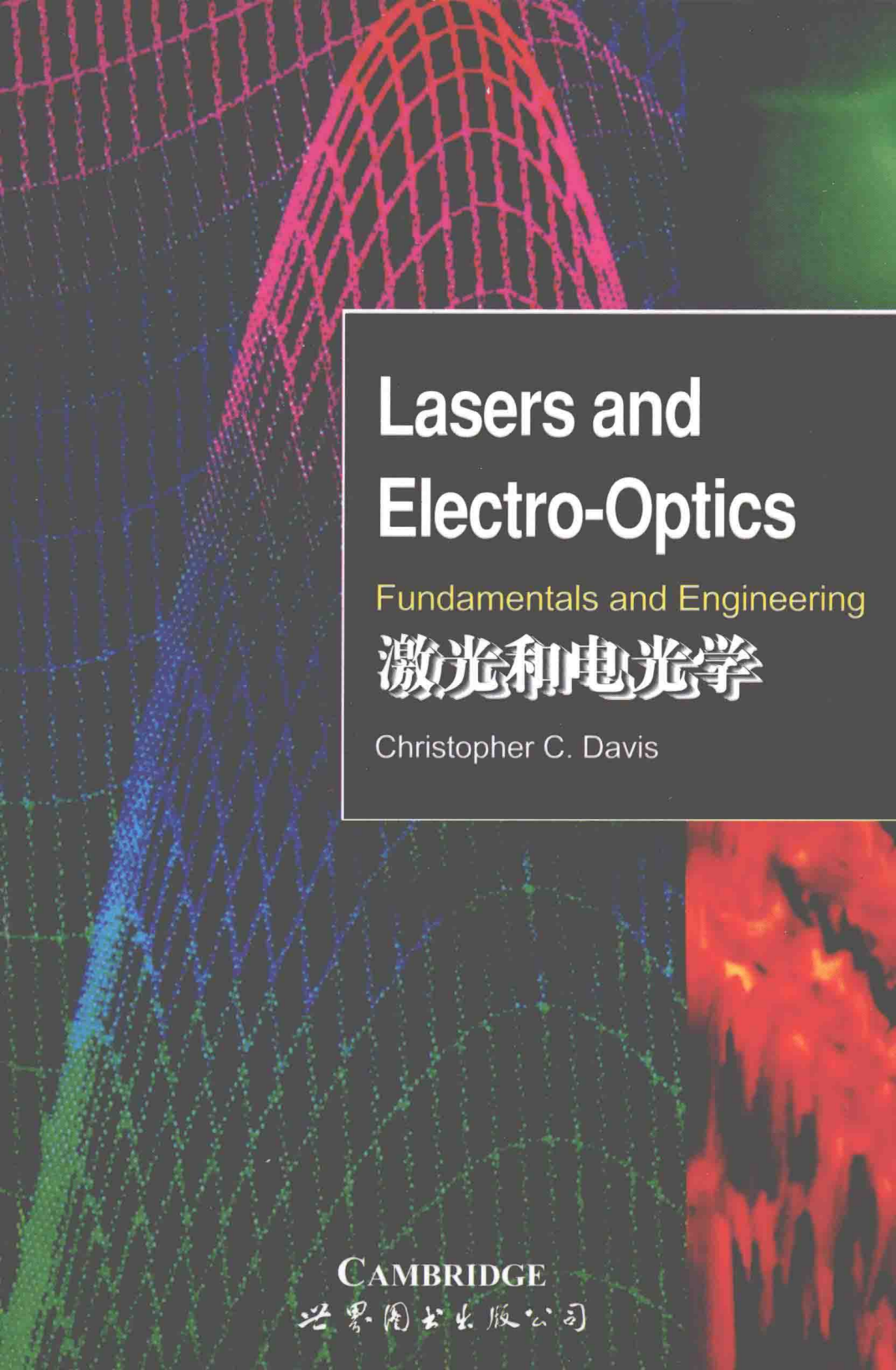
Lasers and
Electro-Optics
Fundamentals and Engineering
激光和电光学
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Lasers and Electro-Optics

Fundamentals and Engineering

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This comprehensive textbook provides a detailed introduction to the basic physics and engineering aspects of lasers, as well as to the design and operational principles of a wide range of optical systems and electro-optic devices. Throughout, full details of important derivations and results are given, as are many practical examples of the design, construction, and performance characteristics of different types of lasers and electro-optic devices.

The first half of the book deals with the fundamentals of laser physics, the characteristics of laser radiation, and discusses individual types of laser, including optically-pumped insulating crystal lasers, atomic gas lasers, molecular gas lasers, and semiconductor lasers. The second half deals with topics such as optical fibers, electro-optic and acousto-optic devices, the fundamentals of nonlinear optics, parametric processes, phase conjugation and optical bistability. The book concludes with chapters on optical detection, coherence theory, and the applications of lasers.

Covering a broad range of topics in modern optical physics and engineering, this book will be invaluable to those taking undergraduate courses in laser physics, optoelectronics, photonics, and optical engineering. It will also act as a useful reference for graduate students and researchers in these fields.

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Lasers and Electro-Optics

To my beloved wife, Mary, and our children:
Alex, Fiona and Mark.

Concordia res parvae crescunt

Preface

The author of a text generally feels obligated to explain the reasons for his or her writing. This is a matter of tradition as it provides an opportunity for explaining the development and philosophy of the text, its subject matter and intended audience, and acknowledges the help that the author has received. I hope to accomplish these tasks briefly here.

This text has grown over many years out of notes that I have developed for courses at the senior undergraduate and beginning graduate student level at the University of Manchester, Cornell University, and the University of Maryland, College Park. These courses have covered many aspects of laser physics and engineering, the practical aspects of optics that pertain to an understanding of these subjects, and a discussion of related phenomena and devices whose importance has grown from the invention of the laser in 1960. These include nonlinear optics, electro-optics, acousto-optics, and the devices that take practical advantage of these phenomena. The names given to the fields that encompass such subject matter have included laser physics, optical electronics, optoelectronics, photonics, and quantum electronics.

The last of these names is consistent with a treatment of the laser and associated phenomena as fundamentally quantum mechanical in nature. However, almost all aspects of laser operation and important related phenomena can be explained well classically. Therefore, this text requires no knowledge of quantum mechanics, although a background in electromagnetic theory at the undergraduate level is desirable for a greater understanding. Most electrical engineering majors do not take a course in quantum mechanics until they reach graduate level, and many physics majors will not have acquired sufficient quantum mechanics knowledge at the undergraduate level for this to make a meaningful contribution to better understanding in a study of lasers and electro-optics.

For all the above reasons this text should be suitable for senior undergraduate and beginning graduate students in electrical engineering or physics. It should also prove useful to mechanical engineers or chemists who use lasers and electro-optic devices in their research.

The text is broken up into two principal parts. Chapters 1–13 discuss the basic physics and engineering of lasers of all kinds, beginning with a discussion of the fundamental physics of the stimulated emission process and laser amplifiers. This is followed by chapters on laser resonators and the characteristics of laser radiation and methods for controlling it. There are succeeding chapters that cover optically-pumped insulating crystal lasers, atomic gas lasers, molecular gas lasers of various kinds including gas transport, gas dynamics and chemically-pumped varieties, and tunable lasers. The first section of the book concludes with a chapter

on semiconductor lasers that begins with a review of the basic physics necessary for their understanding.

The second part of the text covers various issues of relevance to lasers and electro-optics, including the optics of Gaussian beams, laser resonators and anisotropic crystalline materials. There are chapters on optical fibers, electro-optic and acousto-optic devices, the fundamentals of nonlinear optics, and application of nonlinear optics in harmonic generation, parametric processes, phase conjugation, and optical bistability. The text concludes with chapters on optical detectors and the detection process, coherence theory, and applications of lasers.

I have found that Chapters 1–13 provide sufficient material for a one semester course on lasers, with some applications from Chapter 24 included. Chapters 14–19, with Chapter 23 form the basis of a one semester course on optical design, electro-optic devices and optical detectors. I draw on the somewhat more difficult material in Chapters 20–22 as reference material in both the one semester courses just mentioned, and also as adjunct material in more advanced graduate courses.

I have been an experimentalist in the laser business for almost thirty years. I have always found the laser itself a fascinating device that provides a teaching vehicle for discussing many fundamental concepts and practical aspects of design. I have always tried to introduce practical details of real lasers into my classes as early as a treatment of some of the associated fundamentals permits. This should be apparent in the current text where I digress in Chapter 3 into a fairly detailed practical discussion of two important lasers, even though contextually a fuller discussion of these devices could be left until later. I believe that this makes pedagogical sense as students get a glimpse of where they are headed. Throughout the text I have attempted to provide full details of important derivations, and provide practical examples from the literature on the design, construction, and performance characteristics of lasers and electro-optic devices.

In developing a sound pedagogical approach to teaching the material in this text to many students over more than two decades I have drawn inevitably on the work of many others. There have been many other texts that cover material that is shared in common with the current one. What is different between this and related texts is not so much the analytic treatment of common subject matter, but the specific choice of material presentation sequence, and assorted explanations. As it is said, "there is nothing new under the sun," so it is not the intent of this author to claim that the treatment of particular topics in the current text is necessarily unique. Different authors impart their own slant to the same subject matter: sometimes their treatments converge, particularly when there is one especially good way of explanation that is valid. I have attempted in every case to provide reference to the original literature from which I have benefited in my writing, and I apologize for any inadvertent omissions.

Over the course of many years I have learned much from my contacts in the classroom, office, research laboratory, and at conferences. I am indebted to numerous past and present colleagues and students for their intellectual stimulation, advice, provision of material, and feedback on early versions of the current text that have contributed greatly to the finished product. I would like to thank especially my past and present faculty colleagues Mario Dagenais, Julius Goldhar, Ping-Tong Ho, Urs Hochuli, Terry King, Chi Lee, Ross McFarlane; and finally George Wolga who gave me valuable help at the very beginning of this work. My graduate students and post-doctoral research associates have over several years provided

help and advice that have helped me greatly. In particular, I appreciate their forebearance in tolerating a degree of benign neglect, especially during the latter stages of the completion of this work. I am particularly grateful to Walid Atia, Rob Bonney, Simon Bush, Ali Güngör, Pat Mead, Dave Mazzoni, Melody Owens, Saeed Pilevar, and Richard Wagreich for their current help with my research that has provided the time to complete this book. I am most grateful to Joan Hamilton and Nono Kusuma for drawing most of the diagrams and to Dave Mazzoni and Sarah Mulhall for help with additional diagrams.

I appreciate the patience of several editors at Cambridge University Press in waiting for completion of this text, and for accepting ongoing excuses as to why it was not completed earlier. I am most grateful to Patricia Keehn for her expert and careful computer typesetting work using TEX over enormous numbers of revisions of this document.†

Most of all, I am indebted to my family, especially my wife Mary, for their love and their tolerance of irregular hours at home, and "occasional" inattention to family matters.

College Park, Maryland
1995

Christopher C. Davis

† In most cases where curves showing the parametric variation of phenomena discussed in the text are given these have been calculated from scratch using Mathcad (©Mathsoft, Inc.) or by the use of Fortran subroutine available on the Unix network at the University of Maryland. Two- and three-dimensional graphics have been produced by Mathcad and Mongo (©John L. Tonry). The entire text has been typeset using Donald Knuth's TEX: *The TEXbook*, Addison-Wesley, Reading, MA, 1984. TEX is a trademark of the American Mathematical Society.

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