Michael Kaschke,
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Optical Devices in Ophthalmology and Optometry

Technology, Design Principles, and Clinical Applications

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To Sylvia without her support nothing would have been possible.

Michael Kaschke

To Christel for her abundance of understanding all the time.

Karl-Heinz Donnerhacke

To my family and friends for their steady support.

Michael Stefan Rill

Contents

Preface

This book is based on lectures "Optical Systems in Medical/Ophthalmic Technology" held by two of the authors since 2007 at the Karlsruhe Institute of Technology (Germany) and since 2003 at the Ernst Abbe University of Applied Sciences in Jena (Germany). The idea behind these lectures was to create a link between fundamental physical methods in optics, photonics, and measurement technology on the one hand, and to communicate their applications in medical sciences, in particular ophthalmology and optometry, to graduate students in physics and in electrical and mechanical engineering on the other. As this book is essentially based on these lectures, the structure, motivation, and target group of readers for this is quite similar. However, this book is intended as a textbook and compendium for the engineer and physicist in academic and industrial research and development. It will also be useful for the teaching and practicing ophthalmologist and optometrist with an interest in optical technology. To cover the broad spectrum of readers, we have not only described the application of optical methods to the design of ophthalmic diagnostic and laser treatment systems, but have also discussed clinical applications in such a way that the advantage of using a particular optical system and design becomes evident.

A large number of excellent reference books and textbooks exist on ophthalmology and optometry. The same applies to applied and technical optics. However, most of these books focus on a certain aspect (e.g., disease diagnosis, treatment procedures, etc.) or distinct optical and photonics techniques (e.g., OCT, aberrometry, etc.). Consequently, they often address experts with a certain scientific background. Students looking for a systematic and relatively complete introduction to the topic of optical methods and systems in ophthalmology and optometry are thus confronted with a number of books from which the necessary information has to be extracted with considerable effort. The situation is actually very similar for engineers and scientists of academic and research institutions, who often look for a compendium or reference book which gives them a general overview of available solutions in medical technology associated with their area of expertise. To close this gap, we provide an interdisciplinary overview of the currently most relevant (and most often used) techniques and technologies in ophthalmology and optometry, their underlying optical principles, as well as their corresponding diagnostic and therapeutic application.

The eye is our most important sensory organ and any reduction or loss of vision is a major impairment of our quality of life. Although the eye is quite accessible for optical examination methods, the diagnostic options available to the ophthalmologist were very limited until the middle and end of the nineteenth century. It was not until 1850 that Herrmann von Helmholtz invented the ophthalmoscope affording a view of the inside of the living eye for the very first time. This can be considered as the advent of modern ophthalmology and the birth of ophthalmic equipment making. Over the years, it has been demonstrated that no other organ necessitates the use of as many different optical-medical devices as the eye. It is also no surprise that ophthalmology has become by far the most successful application area of lasers in medicine since the invention of the laser in the 1960s. Ophthalmic and optometric methods and technologies have rapidly grown and matured during the last couple of decades and have actually seen an acceleration, but this is still a very active field of research today. Presenting an in-depth coverage of all the ongoing activities is certainly beyond the scope of this book. Consequently, we will try to walk the line between covering the more general and principal approaches in design, development and application of ophthalmic systems, and providing detailed background information on exciting current research topics.

As this book is intended to bridge technology and clinical domains, we will discuss modern optical technologies alongside their clinical deployment. In this way, it addresses graduate and postgraduate students in physics, electrical, mechanical, and biomedical engineering who want to gain a general insight into the principles and concepts of ophthalmic systems. We have also added some topic-related application-oriented "Problems" at the end of each chapter. The problems are presented with fully elaborated solutions, which can be downloaded from the reserved website of Wiley (http://www.wiley.com). These problems demonstrate how basic design parameters of an ophthalmic device are calculated.

Ophthalmologists and optometrists who want to gain a profound understanding of how the diagnostic and therapy systems work will also greatly benefit from the application oriented approach used in our book. We also give references to the most current and relevant literature throughout the chapters and in corresponding "Recommended Reading" sections. These references might be particularly useful for specialists or students who want to acquire further expertise in a special subject.

The book has a modular structure so that it can be used by readers with different backgrounds and interests. In the first part, a basic introduction to key aspects of ophthalmology and optometry is given, including a brief introduction to anatomy, optical properties, as well as refractive errors and diseases of the human eye. The second part is dedicated to ophthalmic diagnosis and imaging devices and techniques. Within this part, Chapter 4 gives as an overview of the link-up between common eye diseases and clinical conditions as well as relevant ophthalmic devices and methods. In the third part of this book, we focus on the therapeutic aspects of ophthalmology in which the use of laser systems is of particular importance. The appendix of this book provides the basics of optics and lasers, which are relevant to understanding the physical concepts of the presented ophthalmic and optometric systems. Here, the intention was not to present the entire content of textbooks on

Table 1 Examples of structured courses.

Background	Electrical Engineer	Biomedical Engineer	Physicist	Engineer/Scientist in practice	Ophthalmologist/ Optometrist
Chapter 1	2	R	1	R	R
Chapter 2	3	R	2	R	R
Chapter 3	4	R	3	R	R
Chapter 4	5	2	4	R	1
Chapter 5	6	3	5	1	2
Chapter 6	7	4	6	2	3
Chapter 7	8	5	7	3	4
Chapter 8	9	6	8	4	5
Chapter 9	11	8	9	5	6
Chapter 10	12	9	10	6	7
Appendix A	1	1	R	R	X
Appendix B	10	7	R	R	X

optics and lasers, but rather to focus on the topics relevant to ophthalmic devices and to provide a consistent reference base and notation.

The chapters of this book may be combined in various ways for use in semester courses. Representative examples of such structured courses are shown in Table 1 in which we also suggest a potentially beneficial sequence for reading the chapters of this book. Topics which should have already been treated during a previous course or are considered to be already known are marked with an "R", standing for "revision".

Commonly accepted notation and symbols have been used whenever possible. However, as this book covers a number of different topics, a number of symbols exist that have multiple meanings. To avoid confusion, we have added an overview of abbreviations and symbols to the Appendix C.

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The book would not have been possible without the encouragement, support and interest of our families and friends. We therefore also see it as their book.