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Optical Devices in Ophthalmology and Optometry: Technology, Design Principles and Clinical Applications

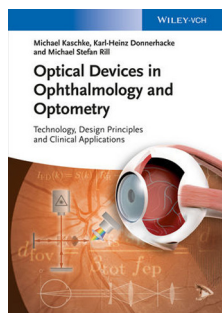
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Optical Devices in Ophthalmology and Optometry: Technology, Design Principles and Clinical Applications

Michael Kaschke, Karl-Heinz Donnerhacke, and Michael Stefan Rill, 619 pages, ISBN: 978-3-527-41068-2, Wiley-VCH, Weinheim (2014) US\$190.00, hardcover.

Reviewed by Barry R. Masters, Fellow of AAAS, OSA, and SPIE



Optical Devices in Ophthalmology and Optometry is a highly recommended textbook that explains the physical principles of optics, photonics, metrology, and lasers, and proceeds with the design principles and instrument construction of medical devices that are most often used in diagnosis and treatment. The textbook is based on the lectures that two of the authors taught to graduate students with backgrounds in physics,

electrical, and mechanical engineering. The author's aim in their courses is to bridge the physics and engineering with the development of medical devices for ophthalmology and optometry. But this textbook's intended audience consists of engineers and physicists who work in academic or industrial research. Together the authors built upon their expertise in optics, medical technology, laser development and laser applications in medicine, and medical devices to produce a comprehensive textbook that is physically rigorous, clearly written, well illustrated with clear, colored figures, and enhanced by extensive footnotes, problem sets, critical references, a summary of all the used mathematical variables and abbreviations, and an index.

There are several previous books in this genre: Alfred Vogt's *Lehrbuch und Atlas der Spaltlampenmikroskopie des Lebenden Auges* (1921), Thilo von Haugwitz's *Ophthalmologisch-optische Untersuchungsgeräte* (1981), and Bernhard Rassow's *Ophthalmologisch-optische Instrumente* (1987). In 1990 I edited the book *Noninvasive Diagnostic Techniques in Ophthalmology*, which was based on similar aims and focused on a similar interdisciplinary audience as the current book in this review. It is interesting that many of the inchoate medical devices that were described in the 1990 book are now mature diagnostic commercial products; for example, scanning laser ophthalmoscopes (independently developed in the United States by Robert H. Webb and his colleagues, and in Germany by Josef F. Bille and his colleagues), confocal microscopes, the prescient development of adaptive optics for wavefront correction, retinal blood flow measurements, specular microscopes, measurements of corneal topography, and Scheimpflug microscopes.

The authors of *Optical Devices in Ophthalmology and Optometry* are physicists who work or worked at Carl Zeiss in Oberkochen and Jena: two are professors of medical technology and one is a product manager for cataract surgery systems. The authors directly state their connection with Carl Zeiss; however, I commend them for their efforts to include the instruments from a variety of manufacturers and to provide a comparison of

the various medical devices that are available for diagnosis and treatment of eye diseases.

Within this book are several valuable lessons that are connected with the development of biomedical optics. If we think of medical devices that are prevalent and important and are the outcome of research and development in biomedical optics, there are several major success stories; I discuss three of them. First, the development of the pulse oximeter. Second, the development of lasers which were built for non-medical applications, and subsequently integrated into medical devices that were used for diagnosis and treatment of eye disease. Third, the development of optical low-coherence medical devices for the evaluation of eye disease. The pulse oximeter indirectly and noninvasively measures the oxygen saturation of hemoglobin in a person's arterial blood. Glenn Allan Millikan invented the medical device in 1942. It was originally used on the ear lobe to measure oxygen saturation of pilots during World War II. Today the pulsed oximeter is placed on the fingertip and this simple medical device is widely used in hospitals. The laser is based on the principle of stimulated emission that Albert Einstein described in his 1919 publication. Ophthalmic devices that incorporate lasers are widespread in clinics for the diagnosis and treatment of retinal diseases and refractive errors.

The principles and the development of ophthalmic medical devices that are based on optical low-coherence tomography (OCT) is an astonishing and instructive success story in the history of biomedical optics. The technology was originally used to locate faults in fiber optics used in the telecommunications industry, and it was first developed by a number of academic research groups to measure the axial eye length. In the early 1990s OCT was demonstrated *in vitro*, and then the first *in vivo* images of the retina were obtained. From the original academic research the projects progressed to clinical research with a series of prototypes. In the year 2012, an OCT medical device produced by Carl Zeiss reached 10,000 installations. The process from the original academic research, to multicenter clinical trials, to the demonstrated clinical efficacy, to the regulatory approval, to significant sales occurred over a 24-year time period.

The authors point out that there are significant milestones to be reached before the medical profession accepts new optical technology. There are major steps in the transformation of a laboratory device into a commercial medical device. The advances in the design, manufacturing, safety, maintenance, calibration, software, clinical studies, ease of use, prior regulatory approval, and subsequent and physician and patient acceptance are all important for the acceptance of a new biomedical device. This remarkable success story of the use of OCT in ophthalmology contains some lessons for the aspiring inventor. First, consider the limitations of the current technologies; i.e. optical imaging of the retina. Second, can technology from one sphere of physics and optical engineering be modified to solve a

limitation of current biomedical devices? Third, the human eye is part of the optical system and the optimal development of a new biomedical technology must consider the optical properties of the human eye, both in health and in disease. Finally, the early development of OCT was greatly enhanced by the successful collaboration of physicists and ophthalmologists.

In fact, success in the development of new biomedical optical devices often requires an interdisciplinary team to develop a viable product. Alternatively, the inventor must develop expertise in several fields. Think back to the invention of the first ophthalmoscope for imaging the *in vivo* human retina. In 1850 Hermann von Helmholtz invented his *Augenspiegel*, a direct ophthalmoscope, which was rapidly accepted in clinical practice and resulted in remarkable advances in the diagnosis and treatment of diseases of the posterior eye. Why did Helmholtz succeed in inventing the ophthalmoscope when his colleagues failed? Perhaps because he studied both physics and medicine, and he applied his knowledge of geometric optics and ray tracing to understand the problem of constructing a device to illuminate the retina through the pupil and to observe the scattered and reflected light from the retina.

Today scientists and engineers with expertise in physics, ophthalmology, laser-tissue interactions, optical and mechanical engineering, software development, manufacturing, intellectual property, regulatory affairs, sales, and marketing are all indispensable for success. The OCT success story emphasizes the importance of individuals with interdisciplinary expertise and a deep understanding of the human eye and its diseases in the development of new medical devices for ophthalmology and optometry.

A common problem in the development of new medical devices with ophthalmic applications is that the physicists and engineers involved in the project have insufficient knowledge of the human eye. This results in an asymmetric collaboration with ophthalmologists and limits innovation. *Optical Devices in Ophthalmology and Optometry* correctly addresses this potential problem in the first part of the book which offers a concise but comprehensive review of the structure and the function of the human eye, the optics of the human eye, and a survey of visual disorders and major eye diseases. The associated references can serve for more advanced study on these subjects.

The second part of the textbook, which is the major portion of the book, offers a detailed exposition of ophthalmic diagnosis and imaging, devices for the measurement of the refractive status of the eye, and ophthalmic imaging of the anterior and the posterior segments of the human eye. The chapter on the theory,

instrumentation, and clinical applications of low-coherence optical tomography is illustrative of the book's pedagogical quality. Each aspect of the physics is clearly developed and there is a good comparison of the time-domain and frequency-domain OCT. The limitations of each type of OCT are evaluated.

The third part of the book describes the physics of laser-tissue interactions. Each major type of laser that functions as the light source in ophthalmic medical devices is fully described, and its operating principles are explained. A section on safety includes a discussion of laser classes and the safe use of ophthalmic laser systems; the physician is warned not to wear any reflective items such as watches or rings! The section on laser systems for treatment of ocular disease and refractive errors illustrates the book's balance between theory and the design and operation of the various medical devices. Safety is always an issue for both the patient, the physician, and others in the vicinity of the medical device; it should be integral to the design and the operation of the medical device. Ophthalmic lasers are used to measure blood flow, to image the various structures of the eye, for photodynamic therapy, for photoablation of structures within the eye, for surgical ablation of corneal tissue to mitigate refractive errors, and for photocoagulation of the retina. Each of these types of ophthalmic lasers and their diagnostic and treatment modalities are comprehensively described in terms of the basic physics, the instrument designs, and the limitations of the medical applications. Since the prior knowledge of the intended audience is variable with respect to geometric and physical optics, and the basics of laser system the author included two extensive appendices on these subjects.

Optical Devices in Ophthalmology and Optometry sets a very high standard for biomedical optics textbooks. I am impressed with the integration of the mathematical physics, the explanations of the fundamental physics with the emphasis on physical insights, the instrument design principles and their relation to the function of resulting medical device, and the clear explanations of the coupling between the optical properties of the eye and the coupling with the optical devices. The use of well-designed color diagrams and clinical images is extremely helpful for the reader. The mathematics are developed as the relevant physics is introduced; for example ABCD matrices for ray tracing, the explicit form of the Zernike polynomials to express the wave aberration function, and Fourier transformations in the discussion of wave optics. Finally, the problems serve to reinforce the learning and stimulate innovative thinking, which is to be expected from an excellent textbook and reference work.