Edited by
Herbert Gross

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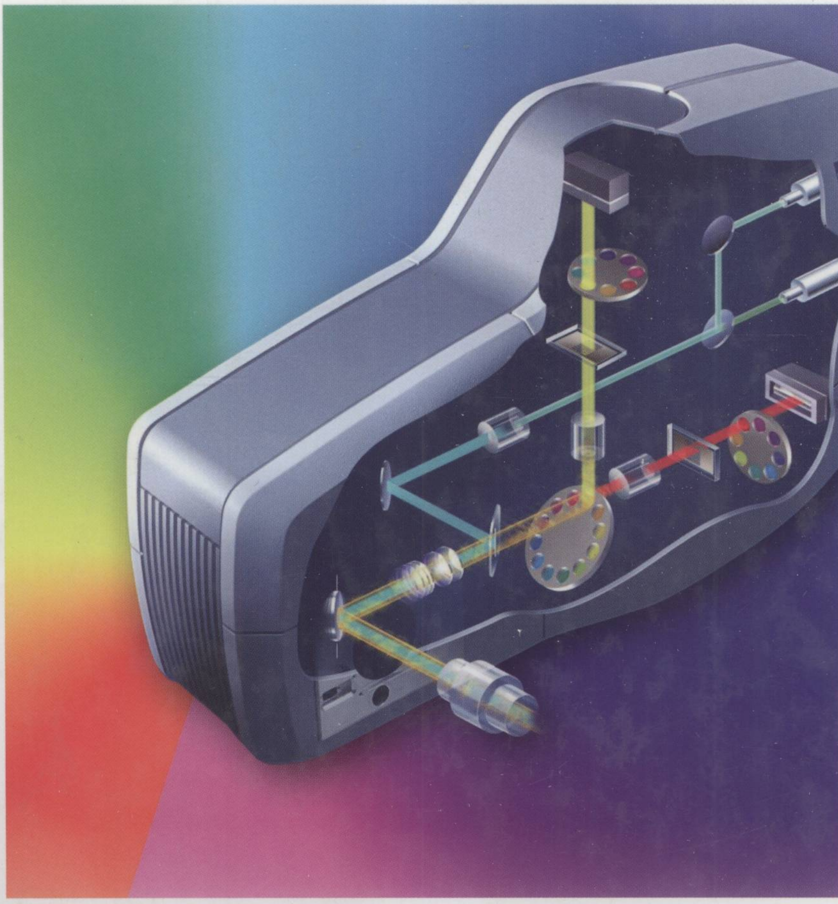
Handbook of Optical Systems

H. Gross, F. Blechinger, B. Achtner
Survey of Optical Instruments

Volume 4



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Volume 4: Survey of Optical Instruments
Herbert Gross, Fritz Blechinger, Bertram Achtner

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Volume 4:

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Volume 1: Fundamentals of Technical Optics
Volume 2: Physical Image Formation
Volume 3: Aberration Theory and Correction of Optical Systems
Volume 4: Survey of Optical Instruments
Volume 5: Metrology of Optical Components and Systems
Volume 6: Advanced Physical Optics

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Herbert Gross

Herbert Gross was born in 1955. He studied physics at the University of Stuttgart, Germany, and joined Carl Zeiss in 1982, where he has since been working in the department of optical design. His special areas of interest are the development of simulation methods, optical design software and algorithms, the modeling of laser systems and simulation of problems in physical optics, and the tolerance and the measurement of optical systems. Since 1995, he has been head of the central optical design department at Zeiss. In 1995, he received his PhD at the University of Stuttgart, Germany, on the modeling of laser beam propagation in the partial coherent region

Bertram Achtner

Bertram Achtner was born in 1960. He studied Applied Mathematics at the Fachhochschule Regensburg. Since 1985 he has been working as a lens designer at Carl Zeiss. There he worked for different departments. His areas of interest spread out over the whole scope of lens design. He has experience in infrared optics, telescopes, telescope systems, microscope objectives, endoscopes, zoom systems and photographic lenses. His special interest lies in the design process of optical systems, which is a mixture of exact science with art. He holds several patents and has held seminars in lens design at Carl Zeiss. He received the title of a Senior Scientist at Carl Zeiss in 2006.

Fritz Blechinger

Fritz Blechinger was born in 1954. He received his diploma in Feinwerktechnik in 1978 from the University of Applied Science in Munich. From 1978 until 1984 he worked at Optische Werke Rodenstock, where he developed medical systems, scanning systems, infrared optics, projection objectives and software solutions. Thereafter until 1995 he worked at MBB in Ottobrunn where he became the manager of the department of optical systems. His responsibilities included developments of high-resolution digital cameras, telescopes, spectrometers, interferometer systems, test optics and several other systems. From 1996 he was head of the optical design group at Linos Photonics, Munich, where he was concerned with special objectives, infrared systems, printing objectives, photosystems, among others. In 2006 he was the head of the optical design group at Leuze Elektronik. Since 2007 he has been heading the optical system design department at SwissOptic AG in Switzerland. He is also the prime developer of the optical design software OpTaliX, and the founder of Optenso for marketing this software. He has held many talks at conferences and published several papers.

Preface

The first two volumes of this handbook series on optical systems covered the basics of technical and physical optics. The third volume covered the understanding of aberration theory, performance evaluation and the fundamental layout of systems. Furthermore, the reader was introduced to the techniques used to improve and optimize optical systems and give them the right tolerances for manufacture. These topics provide the reader with the main framework for understanding the design and principle of optical systems.

Now in the current fourth volume, we give a summary of the well known optical system types which have been developed over the last approximately 150 years of system engineering. The content will not consist of a collection or an archive of proved system data, because compilations of this type are available in electronic form today. The goal of this volume is really to demonstrate and explain to the reader the various classes of system and the most important thoughts, principles and properties, which lie behind these successful solutions.

Two colleagues have helped me with this task and have therefore made a useful contribution to this volume. Chapter 40 on infrared systems, and also parts of chapter 45, were written by Bertram Achtner. The detailed chapters 37 on eyepieces and 43 on telescopes are the work of Fritz Blechinger. I would like to acknowledge both colleagues for their involvement, their helpful cooperation and their important contributions. Without their competence and special knowledge, it would be impossible for this volume to have a sufficiently comprehensive content.

Many colleagues and friends have helped me to collect, prepare and correct the text and have contributed important material to this volume. I would like to thank them all and apologise if I forget to mention any one of them by name. Dietmar Gängler provided several pictures for the stray light section in photographic lenses. Hannfried Zügge made substantial corrections and provided important hints in the chapters on photographic lenses and zoom systems. From Wolfgang Vollrath and Michael Kempe I received much material on microscopic objective lenses. Harald Schadwinkel and Richard Ankerhold contributed to the microscopic topic by means of several pictures. Lothar Schreiber, Michael Kempe and Peter Török corrected the chapter on microscopic systems and substantially improved it. Helmuth Beierl provided me with data on lithographic systems. Martin Peschka read and corrected

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the chapter on infrared systems. I thank Markus Seeßelberg for proof reading several parts of the text and for many helpful hints, corrections and suggestions. A special acknowledgement goes to Willi Ulrich and Wolfgang Singer, who helped me with the material on lithographic systems and also put a great deal of effort into the critical checking of this chapter.

At this point, I must thank Heike Höpcke from Wiley for her continual understanding and patience during the work on this volume. Without her experience, interest and competence, it would be impossible to finish this book within what can sometimes be rather complicated parameters. Also I want to acknowledge Linda Bristow for her fast and perfect language improvement, which has transformed the text into a readable and understandable form.

Last but not least I want to thank my family for their appreciation and endless patience.

Essingen,
October 2007

Herbert Gross

Introduction

If the basic knowledge of technical optics, as outlined in the first volume of this series, as well as the understanding of the physical optics principles, presented in volume two and also the special aspects and practical points of view contained in volume three are all put together, the readers will themselves be able to design, optimize and develop an optical system. In the current fourth volume, a survey of the different typical optical systems should give the reader an overview of the practical use and corresponding results of the principles and theories. This collection demonstrates the application of the more abstract methods used to obtain real solutions and should illustrate and consolidate the reader's knowledge.

The systematic sorting of optical systems into type classes or families is not unique, and other listings may be more understandable and comprehensive. It is possible to use the application, the typical correction, the complexity or other criteria to sort the various system types. One possibility, for example, is the use of a chart with the etendue of the systems versus the dependence on numerical aperture and field size. But the spectral difficulties cannot be addressed easily in this scheme and special aspects such as the overall size or moving components are not included. Furthermore, some dependencies usually exist between the different system types, and these must be taken into account. In some cases, it is necessary to refer the reader to a section in the book, which comes afterwards. So every sorting scheme has its own problems and undesirable features. I hope that the reader can accept the representation chosen in this survey.

The book starts with the optical properties of the human eye, which is the most important optical system. However, it is, in fact, quite difficult to understand the complete human optical perception system. Many classical optical instruments use visual observation, and therefore it is important to know the performance data of the eye and circumstances relating to different adaptation and accommodation stages as well as the effect of color perception and visual acuity. The problems with the optical system of the eye concern the combination of physical optics and the neuropsychological effects of light detection by the human eye and image processing in the brain. In particular, the three-dimensional stereoscopic vision of the eye is an important aspect. The basic eye defects and the principles of their correction are also considered in this chapter.

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The next part of the book is concerned with eyepieces, those systems which are close to the eye in the usual visually observing optical systems. Due to the special problems concerned with the remote pupil of the systems and the difficulties in correcting distortion, astigmatism, curvature and lateral chromatic aberrations, some principles are first outlined. After a historical review and an overview of the basic types of eyepiece, the various successful solutions are discussed in detail. Different classes of performance quality and size of the field of view are outlined. Finally some special aspects, such as zoom eyepieces and compensating systems, are explained.

The next chapter focuses on elementary systems, which mostly consist of only a few lenses or mirrors. Simple magnifier lenses, data disc systems, collimators and focusing lenses are discussed first. The special features and problems of plastic optical lenses are outlined and their limitations and options are considered. Some simple and also more complicated Mangin mirror systems and their properties are the topic of the next section. This follows a section, where the special mirror systems of Dyson and Offner are presented, which are popular due to their symmetry and correction features. Retro-reflecting components and systems are discussed as the next topic. Then telecentric systems and their properties are explained with special examples. Beam delivery systems for laser light beam guiding applications are the last topic in this chapter. The particular aspects of high energy density and coherent laser light are outlined here.

The next chapter is concerned with photographic lenses. This type of system has quite a long history of development. A special survey and the particular aspects of camera systems are discussed at the beginning, and then the various system types are presented. Starting with the simple singlets, the layout of the photographic systems becomes more and more complicated. The different classes of system needed to obtain a large field of view and a good performance at wide angles and also to improve the brightness and resolution with the help of higher numerical apertures are outlined here. Symmetrical layouts, quasi-symmetrical setups, telephoto- and retrofocus types of system are discussed as well as fish-eye systems. Special developments for compact camera systems, catadioptric systems and the design of cameras in the infrared or ultraviolet are explained with some sample setups. The chapter finishes with considerations of the special aspects of vignetting, stray light and internal focusing of photographic lenses.

The optical systems for the infrared spectral range have very special features and problems. This is due to the poor availability of materials and detectors and the disturbing influence of thermal radiation and stray light. These effects and the major system setups are outlined in the next chapter. The special waveband considerations and their material options are discussed, together with questions on cooling and stray light suppression. Special measures to athermalize systems in the infrared are outlined and the rare possibilities of achromatizing the spectral ranges are discussed. In particular, the design of zoom systems and the classical setup of the infrared application with re-imager and afocal modules are shown here.

In the next chapter, a general outline of zoom lenses and the underlying principles for this type of variable system is discussed in detail. The two major approaches, with optical and mechanical compensation of the systems, which are used to get a fixed image location are explained from different points of view together with several examples, which are extracted from the patent literature. The huge number of possible solutions is sorted according to the number of movable lens groups. In the case of zoom systems, an analytical predesign often helps in the understanding of the solution space. The chapter demonstrates some of the basic theories required to solve this task. The correction of aberrations and the final numerical work required to finalize high-performance zoom systems is outlined. There is no simple, complete and perfect scheme in existence, which will perform this task. The chapter closes with some special aspects on the behavior of the pupil in zoom systems, solid state setups with variable components, the combined action of focusing and zooming in camera lenses and the adjustment of zoom systems.

The following chapter deals with microscopic systems. For this system type, it is hard to separate the optical design from the special aspects of the application and the image and contrast mode. In this volume of the series, only the systems aspect is represented. All the questions on resolution, microscopic imaging modes and special applications are addressed in volume six. The chapter starts with some general considerations on the optical principle of a microscope. A special section on the various types of objective lenses and their properties then follows. This is one of the central aspects of the optical system of a microscope. Therefore this section is quite detailed and deals with simple lenses, high-numerical-aperture lenses, field-flattening aspects, catadioptric setups and systems for the ultraviolet range. The next section considers some particular points of defocusing, immersion microscopy, index mismatch and the role of the pupil. The tube optical system and conoscopic observation are also explained. As has been known for a long time, illumination is one of the key factors in obtaining high quality and highly resolved images in a microscope. Therefore the illumination principle of Köhler and the setups for collector and condenser optics are outlined here. Some special features of dark-field illumination and TIRF applications complete this section. Quite a different domain of microscopic imaging is the use of stereoscopic systems, where lower magnifications are used, but the observer obtains a stereoscopic image impression. This type of system is discussed in the following section. The special aspects of the, very popular, confocal imaging microscope is outlined as the next topic. The scan systems and the pinhole setup together with the special illumination relationships are discussed. In the last section, some particular aspects like autofluorescence, the adjustment of microscopic lenses and imaging with low Fresnel numbers is outlined.

The setup of mirror telescopic systems is the topic of the next chapter. This kind of system has a long history, even longer than that of photographic systems. The chapter begins with the major considerations of refractors and their chromatic aberrations and single reflector systems. The various types of two-reflector telescopes are discussed in detail, followed by the three-mirror setups. Systems with four or more mirrors and, in particular, Schiefspiegler setups are outlined in a systematic manner. Special layouts of anastigmatic telescopes and systems with two axes are shown. The next two sections cover the discussion of catadioptric systems of various types. The special use of field correctors and some considerations of the effect of central obscuration and spider diffraction complete this chapter.

Lithographic projection systems have been very important economically over the last thirty years. This kind of system is quite complicated and has very special applications. The next chapter deals with this type of lens. First, some physical aspects of resolution, coherence, polarization and the performance of materials in the ultraviolet are discussed to prepare the reader. The extreme high-performance properties of lithographic systems, due to a special application, are covered in the next section. Then an outline of the development evolution of projection lenses is shown. Refractive and catadioptric, as well as pure mirror systems, are discussed. The options due to the use of aspheres and the influence of immersion are discussed. In the final section of this chapter, the typical types of layout are illustrated by concrete examples of design studies and real systems.

The last chapter of this book is concerned with some special system types, which do not fit into the systems outlined above. First relay systems are discussed from a more general point of view. *4f* setups, endoscopic systems and periscopes are prominent examples of this system type. In the next section, the reader is familiarized with scan systems. The special f–θ setup, the resolution and performance criteria of scanners and general aspects of layout and correction are discussed and a large number of examples is given. A more general view on projection systems is given in the next section. Film projection, digital detectors, digital light modulators and special applications are also outlined here. As an example, the layout and problems of head-mounted display systems are discussed. The basic knowledge of interferometric lenses is outlined next. Collimators and null corrector systems form the major topics of this section. Refractive and diffractive null corrector systems are discussed with the help of special examples. The next section presents the basic principles and layouts of autofocus systems using quite different principles. The astigmatic sensor, confocal sensors and triangulation-based setups are outlined. Last but not least, spectroscopic systems are explained in the final section. Prism and grating spectrometers, the well known Rowland setup and some more sophisticated solutions are also discussed.

In every chapter, the final section contains a list of publications and patent references for further reading. With these suggestions, the reader is able to go into more detail and obtain concrete data from sample systems. Most of the data is also obtainable from the sample collection of the optical design software OpTaliX, which was introduced in volume three of this series.

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