

Handbook of Optical Engineering

edited by

Daniel Malacara

*Centro de Investigaciones en Optica, A.C.
León, Mexico*

Brian J. Thompson

*University of Rochester
Rochester, New York*



MARCEL DEKKER, INC.

NEW YORK • BASEL

Copyright © 2001 by Marcel Dekker, Inc. All Rights Reserved.

Copyright © 2001 Marcel Dekker, Inc.

ISBN: 0-8247-9960-7

This book is printed on acid-free paper.

Headquarters

Marcel Dekker, Inc.
270 Madison Avenue, New York, NY 10016
tel: 212-696-9000; fax: 212-685-4540

Eastern Hemisphere Distribution

Marcel Dekker AG
Hutgasse 4, Postfach 812, CH-4001 Basel, Switzerland
tel: 41-61-261-8482; fax: 41-61-261-8896

World Wide Web

<http://www.dekker.com>

The publisher offers discounts on this book when ordered in bulk quantities. For more information, write to Special Sales/Professional Marketing at the headquarters address above.

Copyright © 2001 by Marcel Dekker, Inc. All Rights Reserved.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage and retrieval system, without permission in writing from the publisher.

Current printing (last digit):

10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA

Preface

This comprehensive and cohesive work includes all the relevant data to allow optical engineers worldwide to meet present and upcoming challenges in their day-to-day responsibilities. The thrust of the *Handbook of Optical Engineering* is toward engineering and technology rather than theoretical science.

The book has 26 chapters that cover most but not all topics in optics, beginning with a few chapters describing the principles of optics elements. These are followed by more technical and applied chapters.

All authors prepared their chapters with the following criteria in mind:

Descriptions are restricted to explaining principles, processes, methods, and procedures in a concise and practical way so that the reader can easily apply the topics discussed. Fundamental descriptions and a how-to-do-it approach are emphasized.

Useful formulas are provided wherever possible, along with step-by-step, worked-out examples, as needed, to illustrate applications and clarify calculation methods. Formulas are arranged in the best sequence for use on a computer or calculator.

The book is replete with tables, flow charts, graphs, schematics and line drawings in the tradition of useful reference books and major handbooks. National and ISO standards are included where appropriate, and permitted, in suitable abridgement for useful reference. Overlapping among different chapters has been avoided unless absolutely necessary.

*Daniel Malacara
Brian J. Thompson*

Contents

Preface

Contributors

1. Basic Ray Optics

Orestes Stavroudis

- 1.1 Introduction
- 1.2 Gaussian Optics à la Maxwell
- 1.3 The Eikonal Function and Its Antecedents
- 1.4 Ray Tracing and Its Generalization
- 1.5 The Paraxial Approximation and Its Uses
- 1.6 The Huygens' Principle and Developments
- 1.7 The Aberrations, Seidel and Otherwise
- References

2. Basic Wave Optics

Glenn D. Boreman

- 2.1 Diffraction
- 2.2 Interference
- 2.3 Coherence
- 2.4 Polarization
- References

3. Basic Photon Optics

Sofia E. Acosta-Ortiz

- 3.1 Nature of Quantum Optics
- 3.2 Nonlinear Optics
- 3.3 Multiphoton Processes
- 3.4 Phase Conjugate Optics

- 3.5 Ultrashort Optical Pulses
References
- 4. Prisms and Refractive Optical Components**
Daniel Malacara and Duncan T. Moore
 - 4.1 Prisms
 - 4.2 Lenses
 - 4.3 Gradient Index Optics
 - 4.4 Summary
References
- 5. Reflective Optical Components**
Daniel Malacara
 - 5.1 Mirrors
 - 5.2 Some Mirror Systems
 - 5.3 Reflective Coatings
 - 5.4 Beamsplitters
References
- 6. Diffractive Optical Components**
Cristina Solano
 - 6.1 Introduction
 - 6.2 Design Issues
 - 6.3 Fabrication Techniques
 - 6.4 Dynamic Diffractive Elements
 - 6.5 Applications
References
- 7. Some Lens Optical Devices**
Daniel Malacara, Jr.
 - 7.1 Introduction
 - 7.2 Principal and Meridional Rays
 - 7.3 Magnifiers
 - 7.4 Ophthalmic Lenses
 - 7.5 Achromatic Doublets and Collimators
 - 7.6 Afocal Systems
 - 7.7 Relay Systems and Periscopes
 - 7.8 Indirect Ophthalmoscopes and Fundus Camera
 - 7.9 Projectors
References
- 8. Telescopes**
Gonzalo Paez and Marija Strojnik
 - 8.1 Traditional Transmissive Telescopes
 - 8.2 Reflecting Telescopes

- 8.3 Filled-Aperture Telescope
- 8.4 Diluted-Aperture Telescope
- References

9. Spectrometers

William Wolfe

- 9.1 Introduction
- 9.2 Spectrometer Descriptions
- 9.3 Filter Spectrometers
- 9.4 Prism Spectrometers
- 9.5 Grating Spectrometers
- 9.6 The Fourier-Transform Spectrometer
- 9.7 Fabry–Perot Spectrometers
- 9.8 Laser Spectrometers
- 9.9 Unusual Spectrometers
- 9.10 Acousto-Optical Filters
- 9.11 Spectrometer Configurations
- 9.12 Comparisons
- References

10. Wavefront Slope Measurements in Optical Testing

Alejandro Cornejo-Rodriguez and Alberto Cordero-Davila

- 10.1 Introduction and Historical Review
- 10.2 Knife Test
- 10.3 Wire Test
- 10.4 Ronchi Test
- 10.5 Hartmann Test
- 10.6 Null Tests and the Ronchi and Hartmann Tests
- 10.7 Gradient Tests
- References

11. Basic Interferometers

Daniel Malacara

- 11.1 Introduction
- 11.2 Coherence of Light Sources for Interferometers
- 11.3 Young's Double Slit
- 11.4 Michelson Interferometer
- 11.5 Fizeau Interferometer
- 11.6 Newton Interferometer
- 11.7 Twyman–Green Interferometer
- 11.8 Common Path Interferometers
- 11.9 Lateral Shearing Interferometers
- 11.10 Talbot Interferometer and Moiré Deflectometry
- 11.11 Foucault Test and Schlieren Techniques
- 11.12 Multiple Reflection Interferometers
- 11.13 Cyclic Interferometers

11.14 Sagnac Interferometer
References

12. Modern Fringe Pattern Analysis in Interferometry

Manuel Servín and Malgorzata Kujawinska

- 12.1 Introduction
- 12.2 The Fringe Pattern
- 12.3 Smoothing Techniques
- 12.4 Temporal Phase-Measuring Methods
- 12.5 Spatial Phase-Measuring Methods
- 12.6 Phase Unwrapping
- 12.7 Extended Range Fringe Pattern Analysis
- 12.8 Applicability of Fringe Analysis Methods
- References

13. Optical Methods in Metrology: Point Methods

H. Zacarías Malacara and Ramón Rodríguez-Vera

- 13.1 Introduction
- 13.2 Linear Distance Measurements
- 13.3 Angular Measurements
- 13.4 Velocity and Vibration Measurement
- References

14. Optical Metrology of Diffuse Objects: Full-Field Methods

Malgorzata Kujawinska and Daniel Malacara

- 14.1 Introduction
- 14.2 Fringe Projection
- 14.3 Holographic Interferometry
- 14.4 Electronic Speckle Pattern Interferometry
- 14.5 Electronic Speckle Pattern Shearing Interferometry
- 14.6 In-Plane Grid and Moiré Methods
- References

15. Holography

Chandra S. Vikram

- 15.1 Introduction
- 15.2 Types of Holograms
- 15.3 Applications
- 15.4 Other Developments
- References

16. Fourier Optics and Image Processing

Francis T. S. Yu

- 16.1 Fourier Optics and Image Processing
- 16.2 Image Processing
- 16.3 Neural Networks

- 16.4 Wavelet Transform Processing
- 16.5 Computing with Optics
- References

17. Electro-Optical and Acousto-Optical Devices

Mohammad A. Karim

- 17.1 Introduction
- 17.2 Photoconductors
- 17.3 Photodiodes
- 17.4 Charge-Coupled Imagers
- 17.5 CRT and Imaging Tubes
- 17.6 Electro-Optic Modulation
- 17.7 Electro-Optic Devices
- 17.8 Acousto-Optic Modulation and Devices
- 17.9 Summary
- References

18. Radiometry

Marija Strojnik and Gonzalo Paez

- 18.1 Introductory Concepts
- 18.2 Standard Terminology for Radiometric Quantities
- 18.3 Photon-Based Radiometric Quantities
- 18.4 Photometric Quantities and Units
- 18.5 Radiative Power Transfer in a Three-Dimensional Space
- 18.6 Lambert's Law
- 18.7 Power Transfer Across a Boundary
- References

19. Incoherent Light Sources

H. Zacarías Malacara

- 19.1 Introduction
- 19.2 Tungsten Filament Sources
- 19.3 Arc Sources
- 19.4 Discharge Lamps
- 19.5 Fluorescent Lamps
- 19.6 Light-Emitting Diodes
- References

20. Lasers

Vicente Aboites

- 20.1 Types of Lasers, Main Operation Regimes, and Examples
- 20.2 Laser Medium
- 20.3 Resonators and Laser Beams
- 20.4 Gaussian Beams
- 20.5 Laser Applications and Instruments
- References

21. Spatial and Spectral Filters

Angus Macleod

- 21.1 Introduction
- 21.2 Some Fundamental Ideas
- 21.3 Spatial and Spectral Filtering
- 21.4 Spatial Filters
- 21.5 Spectral Filters
- References

22. Optical Fibers and Accessories

A. N. Starodumov

- 22.1 Introduction
- 22.2 Optical Fibers
- 22.3 Special Fibers
- 22.4 Fiber-Optic Components
- References

23. Isotropic Amorphous Optical Materials

Luis Efraín Regalado and Daniel Malacara

- 23.1 Introduction
- 23.2 Optical Glasses
- 23.3 Vitreous Silica
- 23.4 Mirror Materials
- 23.5 Optical Plastics
- 23.6 Infrared and Ultraviolet Materials
- 23.7 Optical Coatings and Other Amorphous Materials
- 23.8 Conclusions
- References

24. Anisotropic Materials

Dennis H. Goldstein

- 24.1 Introduction
- 24.2 Review of Concepts from Electromagnetism
- 24.3 Crystalline Materials and Their Properties
- 24.4 Crystals
- 24.5 Application of Electric Fields: Induced Birefringence and Polarization Modulation
- 24.6 Magneto Optics
- 24.7 Liquid Crystals
- 24.8 Modulation of Light
- 24.9 Concluding Remarks
- References

**25. Light-Sensitive Materials: Silver Halide Emulsions,
Photoresist and Photopolymers**

Sergio Calixto and Daniel J. Lougnot

- 25.1 Introduction
- 25.2 Commercial Silver Halide Emulsions
- 25.3 Silver Halide Emulsions for Holography
- 25.4 Photoresist
- 25.5 Photopolymer Holographic Recording Materials
- 25.6 Conclusion
- References

26. Optical Fabrication

David Anderson and Jim Burge

- 26.1 Introduction
- 26.2 Traditional Methods of Optical Fabrication
- 26.3 Fabrication of Aspheres and Nontraditional
Manufacturing Methods
- 26.4 Fabrication Issues for the Optical Designer
- 26.5 Conclusion
- References

Contributors

Vicente Aboites *Centro de Investigaciones en Optica, León, Mexico*

Sofia E. Acosta-Ortiz *Centro de Investigaciones en Optica, Aguascalientes, Mexico*

David Anderson *Rayleigh Optical Corporation, Tucson, Arizona*

Glenn D. Boreman *University of Central Florida, Orlando, Florida*

Jim Burge *The University of Arizona, Tucson, Arizona*

Sergio Calixto *Centro de Investigaciones en Optica, León, Mexico*

Alberto Cordero-Davila *Centro de Investigaciones en Optica, León, Mexico*

Alejandro Cornejo-Rodriguez *Centro de Investigaciones en Optica, León, Mexico*

Dennis H. Goldstein *Air Force Research Laboratory, Eglin AFB, Florida*

Mohammad A. Karim *The City College of the City University of New York, New York, New York*

Malgorzata Kujawska *Institute of Precise and Optical Instruments Technical University, Warsaw, Poland*

Daniel J. Lougnot *UMR CNRS, Mulhouse, France*

Daniel Malacara *Centro de Investigaciones en Optica, León, Mexico*

Daniel Malacara, Jr. *Centro de Investigaciones en Optica, León, Mexico.*

H. Zacarias Malacara *Centro de Investigaciones en Optica, León, Mexico*

Angus Macleod *Thin Film Center, Inc., Tucson, Arizona*

Duncan T. Moore *University of Rochester, Rochester, New York*

Gonzalo Paez *Centro de Investigaciones en Optica, León, Mexico*

Luis Efrain Regalado *Centro de Investigaciones en Optica, León, Mexico*

Ramon Rodriguez-Vera *Centro de Investigaciones en Optica, León, Mexico*

Manuel Servin *Centro de Investigaciones en Optica, León, Mexico*

Cristina Solano *Centro de Investigaciones en Optica, León, Mexico*

A. N. Starodumov *Centro de Investigaciones en Optica, León, Mexico*

Orestes Stavroudis *Centro de Investigaciones en Optica, León, Mexico*

Marija Strojnik *Centro de Investigaciones en Optica, León, Mexico*

Chandra S. Vikram *The University of Alabama in Huntsville, Huntsville, Alabama*

William Wolfe *The University of Arizona, Tucson, Arizona*

Francis T. S. Yu *The Pennsylvania State University, University Park, Pennsylvania*