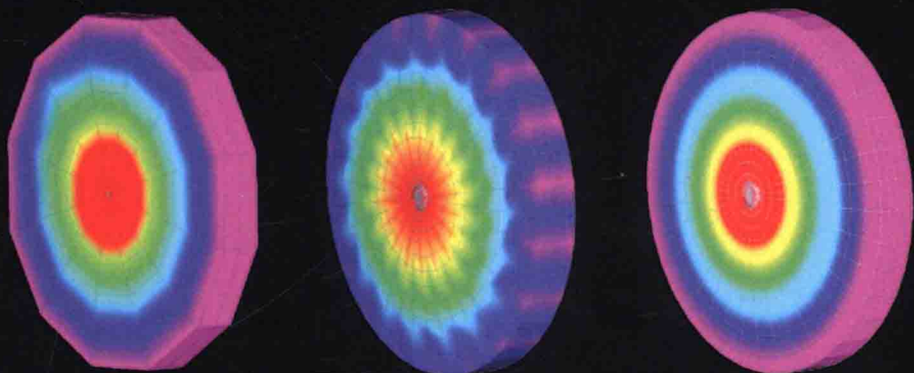
SECOND EDITION

Handbook of Optomechanical Engineering



Edited by

Anees Ahmad

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Electrical Engineering

SECOND EDITION

Handbook of Optomechanical Engineering

Optomechanical Engineering continues to play a key role in the design and development of major state of the art optical systems for space, military and medical applications. Most notable systems developed over the past decade include James Webb Space Telescope, cameras for Mars rovers, sensors and seekers for ballistic missile defense, and lasers systems for cosmetic surgery and industrial applications. The performance of such diversified optical systems depends on the selection of proper materials for optical elements and support structures, suitable design of optical mounts, and selection of correct fabrication methods to ensure long term stability at an affordable cost.

The **second edition** of **Handbook of Optomechanical Engineering** encompasses state of the art practical techniques that have been used successfully to produce many sophisticated optical systems over the past 15 years. This handbook is the result of collaboration of many well-known subject matter experts, who have successful track records of developing world's most sophisticated optical systems for space, military and industrial applications. In this handbook, these experts have generously shared their insights and practical knowledge in their areas of expertise for the benefit of young and less experienced optomechanical and optical engineers. This handbook is a single comprehensive collection of the latest optomechanical design and fabrication techniques that are scattered over hundreds of professional scholarly articles and papers published in professional society journals and conference proceedings.

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Ahmad

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Handbook of Optomechanical Engineering

2nd Edition

In Memory of

The late Paul R. Yoder Jr. who was a great mentor and an outstanding teacher and who introduced me to the art and science of Optomechanical Engineering at Perkin Elmer Corporation, Danbury, Connecticut in 1980.

Dedication

This book would not have been possible without the strong encouragement and full support of my lovely wife Rukhsana and my two very dear daughters Iram and Rabia. They have always been a true source of inspiration for all my professional accomplishments and humble contributions to the practice of Optomechanical Engineering.

Foreword

Optomechanical engineering is essential for the design of optical systems used in everyday life. There are many textbooks on optics and many textbooks on mechanical engineering, but few textbooks on the combination of optics and mechanics, and there are few universities that teach courses on optomechanical design. Unfortunately, it is impossible to design and build a high-quality optical system, whether it be a camera assembly for a smart phone, the James Webb Space telescope, the optical system for a military system, or the cameras for planetary exploratory missions, without truly understanding the relationship between the optics and the mechanics.

To build a high-quality optical system, it is important to understand the properties of the materials used to make the optics, whether it is glass, metal, plastic, low-expansion material, or material for lightweight optics. Thermal and structural analyses of the optics are extremely important. Mounts for holding the optics to within the required tolerances without distorting the optics are essential. The design of flexures used to control the location of the optical elements is very important. Understanding analytic methods for predicting changes in the position, orientation, and size of an image is important. So how do we learn both the necessary optical design and the necessary mechanical design to design and build a high-quality optomechanical system?

Most optomechanical engineers start their career by getting a good technical background in optics or mechanical engineering, and then through on-the-job training, they become high-quality optomechanical engineers. They learn from colleagues; they learn by making mistakes; and most importantly, they learn from books such as this handbook on optomechanical engineering that can tremendously help in giving the optical or mechanical engineers the information they need to design a good optomechanical system. This handbook covers all key optomechanical engineering topics such as International Organization for Standardization standards, material selection criteria, tolerancing, design of lens and mirror mounts and adjustment mechanisms, fabrication and heat treatment methods for long-term stability, etc. All chapters have been authored by the subject matter experts with highly successful track records of developing sophisticated optical systems for space, military, and medical applications.

James C. Wyant
Professor Emeritus of Optical Sciences
Founding Dean of the College of Optical Sciences
University of Arizona
SPIE Past President
OSA Past President

Preface

The discipline of optomechanical engineering continues to play a key role in the design and development of sophisticated optical systems for space, military, and commercial applications. Such systems include the James Webb telescope, high-resolution cameras for Mars rovers and other planetary missions; seekers and sensors for ballistic missile interceptors; and laser systems for surgical and cosmetic procedures such as hair and tattoo removal.

This second edition of *Handbook of Optomechanical Engineering* is the result of collaboration of many subject-matter experts from top optical engineering organizations across the United States and Canada. We have attempted to cover the latest optomechanical engineering knowledge, practice, and art that has been developed over the last 15 years at the leading optical engineering organizations across the world. All original chapters in the first editions have been extensively updated in this second edition. Moreover, four new chapters have been added in this edition: plastic optics (Chapter 5), optomechanical tolerancing and error budgets (Chapter 7), analysis and design of flexures (Chapter 10), and optomechanical constraint equations (Chapter 11). Plastic optics are increasingly being used in commercial and military applications. The chapter on plastic optics covers the materials, fabrication, and optomechanical design aspects of refractive and diffractive optical elements.

The new chapter on optomechanical tolerancing and error budgets addresses the important topic of tolerancing of optical elements and mechanical components. This chapter describes the tolerancing process and methods to consolidate optical and optomechanical tolerance analyses and covers the interaction between lenses and mounts in terms of manufacturing errors. Also described is the optomechanical statistical tolerancing method and guidelines to efficiently allocate tolerances for achieving the desired performance requirements while minimizing the manufacturing costs.

The chapter on analysis and design of flexures covers important kinematic and kinetic aspects of flexure design for many types of flexures that are commonly used to control the position and orientation of optical elements. Equations for quantifying permissible kinetic loads and for designing the structural members to meet the permissible load requirements are presented in this chapter. The limitations of elastic theory as applicable to flexures are also discussed.

The chapter on the optomechanical constraint equations covers the analytic methods to predict changes to the position, orientation, and size of the image of an optical system. Changes in these image properties may be caused by manufacturing tolerances, elastic structural deformations, or changes in operating temperature acting either independently or collectively. These equations may be used by an optomechanical engineer to ensure acceptable optical system performance of the as-built configuration in stressing service environments.

Many peers and colleagues have provided invaluable advice and ideas to ensure this new edition of the book. Provides detailed coverage of the latest optomechanical design practices. The authors would like to gratefully acknowledge the advice, support, and contributions of Tony Hull of New Mexico State University, Antoine Leys of Schott AG, Huub Janssen of Janssen Precision Engineering, and Richard Juergens and David Markason of Raytheon Missile Systems. Hopefully, this book will inspire the next generation of optomechanical engineers to enhance the practice of optomechanical engineering with new ideas and inventions.

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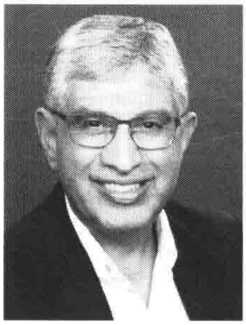

Dr. Anees Ahmad is a senior principal systems engineer at Raytheon Missile Systems and an adjunct professor at the College of Optical Sciences, University of Arizona in Tucson, Arizona. Dr. Ahmad has extensive and diversified experience in various engineering disciplines at Fortune 100 aerospace companies (Raytheon, Lockheed Martin, and United Technologies). His expertise includes the system design and development of electro-optical (EO) imaging sensors and seekers for space and military applications, remote sensing imagers, telescopes and visible and infrared (IR) detectors, and focal plane arrays. Dr. Ahmad has led the successful development and deployment of several visible, mid-wave IR and long-wavelength IR sensors, seekers, and cameras at Raytheon Missile Systems since 1997.

Dr. Ahmad's research interests include affordable advanced EO systems and solid-state lasers for space, medical, chemical sensing, and astronomy applications. He also teaches graduate- and senior-level optical engineering courses at the College of Optical Sciences, University of Arizona. He has five US patents in various areas of optical and optomechanical engineering and over 60 publications in refereed journals and *SPIE Proceedings*, including several invited papers. He is a member of the Society of Photo-Optical Instrumentation Engineers (SPIE) and the Optical Society (OSA) and serves as member of the program committee and session chair of SPIE optomechanical engineering conferences. He obtained his PhD in mechanical engineering from the University of Houston, Texas.