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Kamal Nain Chopra

Optoelectronic Gyroscopes

Design and Applications

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Foreword

It is a matter of great pleasure for me to express that Dr. Kamal Nain Chopra has made a tremendous and commendable effort in writing this book on optoelectronic gyroscopes and the related technologies, a topic, on which the availability of literature, especially at one place, is very much required for the DRDO scientists in particular and the researchers and academicians in general. Practically, all the concepts, including the novel evolving ones, characterization, and applications of photonic crystals along with the devices based on them, have been discussed briefly in this book, thereby making it very useful indeed for the scientific community in both India and abroad. It is clear from the literature that prior to this, very few attempts seem to have been made in presenting the different aspects of the subject from the research point of view, at one place, and therefore, this effort is expected to bridge the gaps between various types of research papers and literature on the subject at different places. The book should especially be useful for the designers and engineers of the optoelectronic gyroscopes, as the design aspects for the efficiency optimization have been presented and discussed.

In addition, the book is expected to be of great interest and utility for the budding researchers and scientists in the field, since it provides a large number of theoretical and experimental results available in the literature, for them to have a clear understanding of the subject and also to choose the direction in which to move for carrying out research in this fascinating field. It is my sincere wish that this book serves the researchers in enhancing their inputs on the topic and also their interest in making more concentrated efforts in carrying out research in this rapidly evolving field.

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Preface

A lot of literature, especially books on the concepts, technologies, and related phenomena of optoelectronic gyroscopes, is available. However, most of the books seem to have been written from the textbook point of view; not much effort seems to have been made on writing books for the researchers. Also, the premier books have been written a decade earlier or even before that. The literature for the studies conducted on the topic after that is quite scattered. This book is a sincere effort of the author to make available very useful information on this topic, especially from the research point of view, and also to bridge the gap between the information in the books and the research works done after that. A lot of emphasis has been laid on the research investigations carried out during the last decade, which makes this book very useful for the researchers to get an idea about the latest trends of research in this fascinating field. Also, the information has been presented in a brief and concise manner, making it easier for the researchers to understand the concepts quickly and go through the new papers after choosing the direction of interest.

In addition, the technical analysis of the theoretical aspects of concepts of the technologies used for making some of the components, especially ring laser mirrors, the substrates used and optical testing, and characterization of components has been presented.

In addition to the discussions regarding the theoretical modeling and designing of these devices, some related experimental results available in the literature have been presented to make the presentation clear and meaningful. All these devices are having many useful applications in various fields like sensors and industry, and in practical research applications in most of the scientific and engineering topics.

A number of important academic institutes like IITs, IISc, Bangalore, and universities, and scientific laboratories including National Physical Laboratory, other CSIR Laboratories, ISRO, and DRDO (in which LASTEC and IRDE have been quite active) are actively engaged in this subject. In view of such immense importance of the topic for so many institutes and scientific laboratories, a book on this topic is really needed, which will undoubtedly serve the purpose of understanding the complexities of this subject for the scientists of NPL, DRDO, and CSIR. It is also hoped that apart from being useful to these scientists and

technologists, this book will serve as the motivating force for the researchers entering this complicated and rapidly evolving field. Also, the discussions on the theoretical modeling and designing of these devices, along with some related experimental results, should be quite useful for the designers and engineers engaged in developing devices based on sensors, optical testing, and thin-film characterization for the newer applications and more importantly research purposes.

Chapter 1 gives the optimization and mathematical modeling of ring laser gyroscopes (RLGs), for enhancing their efficiency. In addition, the problems encountered in the fabrication and working of the RLGs and some of the techniques for solving them have been highlighted. A brief qualitative review of the recent novel investigations on RLGs has also been given. This chapter is expected to be very useful for the new entrants in this fascinating field and also for the designers and technologists already engaged in improving the design of RLGs.

Chapter 2 gives the optimization and mathematical modeling of fiber optical gyroscopes (FOGs), along with results of some of the computations of the important parameters considered for designing the FOG. The problems encountered in the fabrication and working of the FOGs and some of the techniques for solving these problems have been highlighted. The sources of error in the FOG, some of the important results reported in the literature, and the designing aspects of the FOG have been technically discussed. Apart from presenting a qualitative review of the novel investigations on FOG, the recent innovations in finding the alternatives to the FOG have been discussed. The chapter is expected to be useful to the researchers and the designers in this fascinating field.

Chapter 3 gives the evolution of the laser coating technology and the development of the dielectric laser mirrors, which have drawn the attention of various researchers and also commercial firms. However, not much work seems to have been done on the development of the dielectric mirrors with very low scattering loss ($\sim$5–10 ppm). This chapter presents the experimental results, which have been observed and verified during the course of research and development for designing and fabrication of such coatings. A technical discussion of all the important aspects—optics, materials (coatings and substrates), designs, cleanliness conditions, coating techniques, and optimization of the process control parameters for the successful development of such coatings, with applications in the ring laser gyroscope used as the inertial navigation system—has also been given. The experimental results in improving the scattering loss by different techniques given in the chapter are on the basis of the long-term experience of the designing and fabricating the low scattering loss dielectric laser mirrors.

Chapter 4 gives the evolution of the high-power laser coating technology and the development of high laser damage threshold coatings, which have drawn the attention of various researchers. The present chapter discusses technically all the important aspects—optics, materials (coatings and substrates), designs, and coating techniques for the development of such coatings—and presents the important points, which have been observed and verified during the course of research and development for designing and fabrication of such coatings for various types of

high-power lasers. The experimental results in improving the laser-induced damage threshold by different techniques have been presented in the paper.

Chapter 5 provides the technical analysis of the important techniques for optical testing of optical elements—Ronchi test, optical nondestructive testing (NDT), optical fiber NDT, laser speckle interferometry and speckle NDT, infrared thermography NDT, endoscopic NDT, terahertz (THz) NDT technology, improved interferometric optical testing, phase-shifting interferometry, phase-shifting single-shot interferometer technique, electronic speckle pattern interferometry (ESPI) technique, single-shot Fizeau interferometer technique, optical time-domain reflectometer, optical interferometry, and fiber-optic measurement technique. A brief discussion of the applications of optical testing has been given. A qualitative review of the recent novel studies on optical testing has also been included. The technical analysis and the overview should be of good utility to the new entrants in the field, and also the designers and engineers engaged in the design and development of high-quality optical elements and their testing.

Chapter 6 gives an overview of the important characterization techniques for optical thin films. Scientific analysis of various thin-film characterization techniques like X-ray photoelectron spectroscopy (XPS), secondary ion mass spectrometry (SIMS), scanning tunneling microscope, transmission electron microscope (TEM), reflection high-energy electron diffraction (RHEED), atomic force microscope (AFM), Fourier transform infrared (FTIR) technique, and differential interference contrast microscope has been given. Also, a brief discussion of the material characterization, structural features (macrostructure, mesostructure, microstructure, and nanostructure), and analytical characterization has been included. Some recent important studies on the scattering loss and the absorption loss of the optical thin films have also been briefly discussed. This overview should be of good utility to the new entrants in the development of high-quality optical thin films and their characterization.

New Delhi, India Kamal Nain Chopra

Acknowledgements

The author is grateful to DRDO in general and LASTEC in particular for providing an opportunity to work for many years with a number of scientists working on optoelectronic gyroscopes and the related technologies. Thanks are also due to the Photonics Group of the Indian Institute of Technology, Delhi, where the author got a very good exposure to the subject during the short period, working as Research Scientist in the group. A large number of presentations and discussions on the complexities and technicalities of some of the topics of optical gyroscopes and the related technologies have been immensely helpful in the writing of this book; most importantly, the urge to undertake this project was ignited during these meetings.

Thanks are due to Dr. Rambabu Kammili, Director, RCI, Hyderabad, for giving opportunities to give invited talks and attend review meetings on ring laser gyroscopes, thereby providing the chances to interact with the scientists of DRDO Laboratories of Hyderabad and also academicians of the Indian Institute of Science, Bangalore, the discussions with whom helped me in the final refinements of my ideas presented on the topic in the book. Finally, the author is grateful to Prof. Vipin Kumar Tripathi of the Department of Physics, Indian Institute of Technology, Delhi, for various suggestions and encouragement during the course of writing this book, which helped me not only in greatly improving the contents but also in the presentation and readability of the book. The author is thankful to Shri. G. Krishna Rao, Director, Electro Optical Instruments Research Academy (ELOIRA), Hyderabad, for useful discussions, suggestions, and encouragement while finalizing this book.

About This Book

The book is a serious attempt by the author for presenting some useful and important aspects of the optoelectronic gyroscopes: ring laser gyroscopes (RLGs) and fiber-optic gyroscopes (FOGs). The designing aspects for optimizing their performance have been analytically discussed in detail, besides explaining some of the related concepts and the new developments.

Some useful novel designs of RLG given in the literature have also been presented and discussed for the benefit of the optical engineers aiming to design and develop new types of RLG with a view to minimize the size and maximize the longevity of the RLG.

In addition, the related technologies like double ion beam sputtering for fabricating some of the required components like RLG mirrors on the high-quality optical substrates and the optical testing, and thin-film characterization techniques for their evaluation have been discussed in detail at one place. Since the literature about these topics is quite scattered, this book will be able to bridge the gap for the scientists and academicians engaged in working on these topics. Since the quality of the RLG mirrors determines to a large extent the performance of the RLGs, great emphasis has been laid on the design and technology for these mirrors, besides discussing their stringent specifications.

Since the author has hands-on experience on most of the topics presented in the book, he has been able to discuss the minute details and complexities of the subject. Another advantage for the readers is that the book also discusses at length some of the recent experimental results described in the literature and the designing aspects for optimizing the results. In view of this novel combination of concepts, the book is expected to be really useful for the researchers, designers, and engineers working in these high-technology areas of optical gyroscopes and the related technologies.

Contents

About the Author

Dr. Kamal Nain Chopra has done B.Sc. (University of Delhi), M.Sc. (Physics - IIT, Delhi), M.Tech. (Opto-Electronics - IIT, Delhi), and Ph.D. (Applied Physics - IIT, Delhi). He has served DRDO for a period of 33 years and superannuated as Scientist G, from Laser Science and Technology Centre (LASTEC), Delhi, in the year 2005. Subsequently, he has also served as Professor (Physics) in NSIT (DU) and MAIT(GGSIPU), and as Project Scientist in IIT, Delhi, in various Projects, on Topics including Photonics, Thin Films, and Optical Testing.

He has about 390 publications including about 300 in International journals (UK, USA, France, Germany, Italy, Netherland, and China) on various topics including Thin Films Optics, Lasers and Laser Components, Holography, and Modern Optics; 12 Invited talks; 15 Technical reports; and 30 papers in International Conference Proceedings (e.g. Taylor and Francis, UK; and Scientific Net, Switzerland).

Dr Kamal Nain Chopra has co-authored a book titled, "Thin Films and their Applications in Military and Civil Sectors", DESIDOC, DRDO, Ministry of Defence, INDIA, 2010. He has authored a book titled, "Unconventional Lasers: Design and Technical Analysis", DESIDOC, DRDO, Ministry of Defence, INDIA, 2017. He has also authored a Book titled, "Conventional and Unconventional Sources of Renewable Energy: Renewable Energy Sources", Lambert Academic Publishing, LAP, GERMANY, 2017. In addition, he has authored a book titled, "Spintronics Theoretical Analysis and Designing of Devices Based on Giant Magnetoresistance", DESIDOC, DRDO, Ministry of Defence, INDIA, 2019.

He has undertaken visits to foreign universities and industries including (i) School of Thin Film Coatings, Department of Physics, St. Jerome University, Marseille, FRANCE [5 months (1984-85)]; (ii) Department of Physics, Innsbruck University, Innsbruck, AUSTRIA, including 5 days in M/s. Balzers, Liechtenstein, SWITZERLAND [10 days (1995)]; and (iii) M/s. Elettrorava, Torino, ITALY [15 days (2000)].

He has vast experience of serving the Recruitment and Assessment Boards of DRDO (RAC and CEPTAM), as Chairman as well as Expert Board Member. He is a reviewer and editorial board member for some leading international journals.

His fields of specialisation are opto-electronis, unconventional lasers, optical gyroscopes, thin films designing, fabrication, and characterisation by modern techniques, and specialized optical testing techniques.