

Fiber Bragg Gratings

Theory, Fabrication, and
Applications

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Fiber Bragg Gratings

Theory, Fabrication, and Applications

**Marcelo M. Werneck, Regina C. Allil,
and Fábio V. B. de Nazaré**

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Introduction to the Series

Since its inception in 1989, the Tutorial Texts (TT) series has grown to cover many diverse fields of science and engineering. The initial idea for the series was to make material presented in SPIE short courses available to those who could not attend and to provide a reference text for those who could. Thus, many of the texts in this series are generated by augmenting course notes with descriptive text that further illuminates the subject. In this way, the TT becomes an excellent stand-alone reference that finds a much wider audience than only short course attendees.

Tutorial Texts have grown in popularity and in the scope of material covered since 1989. They no longer necessarily stem from short courses; rather, they are often generated independently by experts in the field. They are popular because they provide a ready reference to those wishing to learn about emerging technologies or the latest information within their field. The topics within the series have grown from the initial areas of geometrical optics, optical detectors, and image processing to include the emerging fields of nanotechnology, biomedical optics, fiber optics, and laser technologies. Authors contributing to the TT series are instructed to provide introductory material so that those new to the field may use the book as a starting point to get a basic grasp of the material. It is hoped that some readers may develop sufficient interest to take a short course by the author or pursue further research in more advanced books to delve deeper into the subject.

The books in this series are distinguished from other technical monographs and textbooks in the way in which the material is presented. In keeping with the tutorial nature of the series, there is an emphasis on the use of graphical and illustrative material to better elucidate basic and advanced concepts. There is also heavy use of tabular reference data and numerous examples to further explain the concepts presented. The publishing time for the books is kept to a minimum so that the books will be as timely and up-to-date as possible. Furthermore, these introductory books are competitively priced compared to more traditional books on the same subject.

When a proposal for a text is received, each proposal is evaluated to determine the relevance of the proposed topic. This initial reviewing process has been very helpful to authors in identifying, early in the writing process, the need for additional material or other changes in approach that would serve to strengthen the text. Once a manuscript is completed, it is peer reviewed to ensure that chapters communicate accurately the essential ingredients of the science and technologies under discussion.

It is my goal to maintain the style and quality of books in the series and to further expand the topic areas to include new emerging fields as they become of interest to our reading audience.

*James A. Harrington
Rutgers University*

Contents

<i>Foreword</i>	<i>xi</i>
<i>Preface</i>	<i>xiii</i>
1 Introduction	1
1.1 Initial Concepts	1
2 History of FBG Device Development	9
2.1 Introduction	9
2.2 Historical Perspective	9
2.3 A Glimpse of Applications	12
2.4 Conclusions	15
References	16
3 Fiber Bragg Grating Theory and Models	19
3.1 Introduction	19
3.2 Fiber Bragg Grating Models	21
References	30
4 How to Set Up a Fiber Bragg Grating Laboratory	33
4.1 Introduction	33
4.2 Taking the First Step: The Laser	33
4.3 Cooling System	36
4.4 Nitrogen and Hydrogen	37
4.5 Optical Parts and Mounts	40
4.6 Instruments and Measurement Devices	43
4.7 Conclusions	48
References	49
5 Inscribing Fiber Bragg Gratings in Optical Fibers	51
5.1 Introduction	51
5.2 Inscribing Fiber Bragg Gratings with Phase Masks in Close Proximity to the Optical Fiber	51
5.2.1 The +1/−1 configuration	54
5.2.2 The 0/−1 configuration	57
5.3 Inscribing Fiber Bragg Gratings with Phase Masks and Mirrors	58

5.4	Conclusions	62
	References	63
6	Interrogation Techniques of Fiber Bragg Gratings	65
6.1	Introduction	65
6.2	Basic Demodulation Scheme for Laboratories	65
6.3	Commercial Equipment for Fiber Bragg Grating Demodulation	67
6.4	Edge Filter Technique	68
6.5	Twin FBG Technique	72
6.6	Tunable Laser Approach	73
6.7	WDM Demodulation Scheme	74
	References	76
7	Calibrating Fiber Bragg Gratings for Temperature and Strain	77
7.1	Introduction	77
7.2	First Steps	78
7.3	Temperature Calibration	79
7.4	Calibration in Strain	84
	References	88
8	Encapsulation and Bonding	89
8.1	Introduction	89
8.2	Properties of Silica Optical Fibers	90
8.3	FBG Properties	91
8.4	FBG Protection and Encapsulation	92
8.5	Bonding	95
	References	97
9	Compensation of Induced Thermal Effects	99
9.1	Introduction	99
9.2	Using an Additional Fiber Bragg Grating for Temperature Compensation	100
9.3	Applying Two Fiber Bragg Gratings in Opposite Conditions	102
9.4	Passive Compensation	102
9.5	Dynamic Temperature Compensation	109
	References	114
10	Structural Health Monitoring with Fiber Bragg Gratings	115
10.1	Introduction	115
10.2	Hull Monitoring	117
10.3	FBGs in Railway Monitoring	118
10.4	Dam Monitoring	120
10.5	Dyke Monitoring	122
10.6	Monitoring Pipelines	123
10.7	FBGs in Bridge Monitoring	125

10.8 Monitoring the Condition of Rotating Machinery	126
References	132
11 Temperature Measurements	133
11.1 Introduction	133
11.2 Samuel Hydroelectric Power Plant	134
11.3 Installation of FBG Sensors to Measure Temperature in a Hydroelectric Generator	134
11.4 Temperature Monitoring Results	140
11.5 Local Recalibration of the FBG Temperature Sensors	146
11.6 Conclusion	149
References	150
12 Measurement of the Coefficient of Thermal Expansion of Materials	151
<i>Leandro Alves Garção and Marcell Nunes Gonçalves</i>	
12.1 Introduction	151
12.2 FBG Bonding Procedure	151
12.3 Experimental Procedure	152
12.4 Experimental Results	154
12.5 Discussion	156
12.6 General CTE Measurement	157
12.7 Conclusion	160
References	161
13 Measuring Strain and Displacement	163
13.1 Introduction	163
13.2 The Spring Method	164
13.3 The Cantilever Method	166
13.4 Conclusion	174
References	175
14 Voltage Measurement	177
14.1 Introduction	177
14.2 Bragg Wavelength Displacement as a Function of Mechanical Strain	177
14.3 DC Measurements	178
14.3.1 Electric setup	178
14.3.2 Theoretical model of FBG displacement as a function of voltage application	179
14.4 Mechanical Setups for FBG-PZT DC Measurements	182
14.4.1 FBG wound around a PZT tube	182
14.4.2 FBG fixed laterally to the PZT tube	183
14.4.3 Mechanical amplifier	184
14.4.4 Tests with a PZT stack	188
14.4.5 Conclusions of the DC experiments	191

14.5	AC Measurements	191
14.5.1	Temperature compensation	191
14.5.2	Maximum voltage	192
14.5.3	Capacitive divider	194
14.5.4	Theoretical model of the transducer sensitivity	195
14.5.5	Results for the application of 13.8 kVrms	196
14.6	Conclusion	198
	References	199
15	Current Measurements	201
15.1	Introduction	201
15.2	Optical Fibers in Current-Measurement Systems: A Preliminary Approach	201
15.3	Fiber Bragg Gratings in Current-Measurement Systems: The Use of Magnetostrictive Materials	204
15.4	Designing an Opto-magnetostrictive Current-Measurement Device	207
15.4.1	The first approach concerning the opto-magnetostrictive current-measurement device	208
15.4.2	An optimized opto-magnetostrictive current sensor	214
15.4.3	Discussing the results	220
15.5	Conclusion	221
	References	222
16	Gas Measurements	225
	<i>Bruno Cerqueira Rente Ribeiro</i>	
16.1	Introduction	225
16.2	Nanostructures in Gas-Measurement Systems	226
16.3	Fiber-Optic-Based Gas Measurement	227
16.4	Preparing Fiber Bragg Gratings for Gas Sensing	228
16.4.1	Chemical etching	228
16.4.2	Tapering	230
16.4.3	D-shaped fiber	231
16.5	FBG Gas-Sensing Case Studies	231
16.6	Coated and Etched FBG Optical Effects in Fiber Sensors	234
16.7	Conclusion	235
	References	236
	<i>Index</i>	239

Foreword

The confluence of two significant events—on one hand, the discovery of photosensitivity in glass optical fibers in 1978 by Ken Hill; and the other, the side inscription of gratings into fibers by laser holographic means by Meltz and co-workers in 1989—has led the way to over thirty years of strong interest, continuous research, and a myriad of developments and innovations in the field of optical fiber-Bragg-grating technology.

Fiber Bragg gratings (FBGs) are one of the most useful, versatile, practical, and attractive passive devices in the fields of optical fiber communications and fiber optic sensors. This prominence is the result of their simplicity of operation coupled with their attractive and unique features, such as all-fiber construction, self-wavelength-value referencing, absolute encoding, capability for multi-point cascading, and batch fabrication, to name a few. A multitude of FBG devices are commonly used in different optical communication applications, such as dispersion compensators, gain lockers, spectral filters, wavelength references, and several more. Similarly, there is a broad variety of different sensors based on FBG elements that allow for the measurement of temperature, pressure, strain, acceleration, moisture, bio-chemical agents, and many other parameters in diverse civil and defense applications that range from aerospace structural health monitoring, to oil- and gas-well sensing, to miniature intra-aortic pressure and temperature probes.

Furthermore, despite over three decades of R&D activity and a mature FBG industry, there still remains a vast group of engineers, scientists, students, and new end-users engaged in the research and utilization of FBGs in novel applications. This process can be exemplified by the new femtosecond-IR-laser writing techniques; the advent of regenerated gratings for high-temperature operation; and the inscription of FBGs in novel, specialty optical fibers—from polymer to microstructural versions. Such technology advancements demand that students and researchers remain informed and up-to-date in the field, which makes the availability of a suitable textbook that can provide to the reader (in a simple and succinct fashion) the technology's basics, its applications, and recent innovations all the more necessary and valuable both to the expert as well as to the neophyte in the field.

This new book fills such a knowledge gap. As the name implies, it is a practical manual that provides the reader with basic but concrete and useful information on the fundamentals and key practical aspects of the operating principles, design, fabrication, and simple use of FBGs in general.

The book authors are well known in the fields of fiber optics and optical fiber sensors, and they have over 70 years of combined experience. Their experience in academia and applied research affords them a unique insight as well as the ability to strike a nice balance—between theory and practical guidelines—and they have done an excellent job in covering the material in an easy-to-understand way without sacrificing technical soundness. In addition, the material covered is extensive and reviews many of the potential areas of interest to any reader, from the operating basics of FBGs, its fabrication methods, measurement techniques, and their utilization as light-wave-tailoring devices and sensors.

In my opinion, this tutorial appeals to a broad and diverse audience, especially to nontechnical individuals and those becoming familiar with FBGs for the first time. It should be a “must have” reference book for anyone working in the field of fiber Bragg gratings.

Alexis Méndez
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Preface

The development of optical fibers has revolutionized not only telecommunications but also the way monitoring and sensing is conducted, particularly in remote or harsh environments. In this context, the discovery of photosensitivity in optical fibers led to the establishment of fiber Bragg gratings (FBGs), optical filters that have been widely employed in telecom and as measurement elements.

This Tutorial Text discusses these optical devices directly, focusing on the practical aspects and applications. It addresses the fundamental aspects of FBG operation to quickly introduce the subject to students, engineers, and laboratory technicians. Due to their inherent advantages in instrumentation, sensing, and automation systems, FBGs play an important role not only for industry professionals but also for academics. Thus, this book is primarily intended for scientists, professors, researchers, students, photonics technicians, and engineers involved in optical-fiber projects.

The chapters follow a logical sequence: after a discussion of the primary concepts, practical aspects regarding the development of a FBG laboratory and how these components are manufactured and used in practical applications are presented. The following chapters outline the operation of Bragg gratings and, for instance, discuss how measurement information can be retrieved (interrogation techniques), calibration methods, and how to prepare and deploy the devices in real monitoring conditions. The final chapters present several successful, real-world applications of the technology.

Fiber Bragg Gratings: Theory, Fabrication, and Applications delivers essential information concerning FBGs to professionals and researchers with an approach based on rules of thumb and practical aspects, enabling quick access to the main principles and techniques, and allowing readers to set up their own laboratory or application. It provides detailed information about how to operate and use these novel sensors, particularly with respect to the required infrastructure, daily operation, and possible applications. Dense physical aspects and the associated refined mathematical models are not thoroughly presented because this information can be found in other publications.

Many of the applications in this book reflect our own experience in courses, M.S. dissertations, D.S. theses, and projects at the Laboratório de

Instrumentação e Fotônica (LIF) of the Universidade Federal do Rio de Janeiro. Therefore, we acknowledge our former and present students who made it possible to accomplish all of work that went into this book. We also acknowledge the contributions of the following D.S. students: Marcell Nunes Gonçalves and Leandro Alves Garção for writing Chapter 12, and Bruno Cerqueira Rente Ribeiro for writing Chapter 16.

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