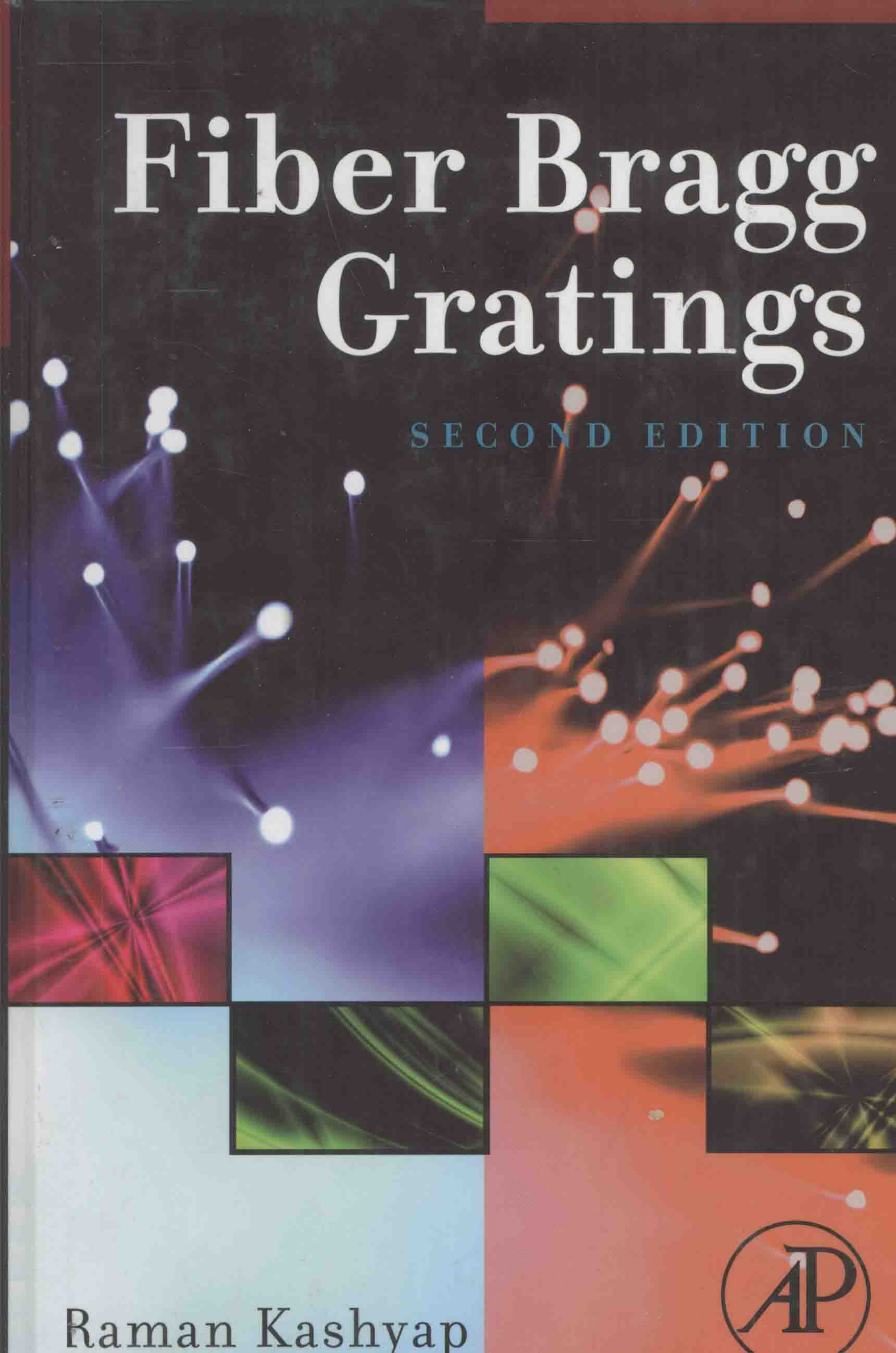
Fiber Bragg Gratings

SECOND EDITION



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Software Package

This book is accompanied by a special edition of the software, PicWave from Photon Design (www.photond.com/products/picwave.htm), provided to simulate live many of the examples found in this book. By showing the device structures in detail and providing additional results, it will help to gain additional insight into the examples presented in this book.

The software runs on any modern PC with Windows-2000 or later installed, with 1GB of memory or more. It can be downloaded from the books companion Web site, www.elsevierdirect.com/companions/9780123725790 free of charge to owners of this book.

PicWave takes a rather different time-domain travelling wave (TDTW) approach to the frequency-domain based theory presented in this book, and illustrates how similar results can be obtained in the time domain. PicWave is a circuit model and as such is capable of modelling not just linear fiber components but also complex fiber devices such as fiber couplers, splitters and amongst others.

Features illustrated by the software include:

- Behavior of a fiber-Bragg grating, including transmission, reflection, group delay, group velocity dispersion (after Chapter 4)
- Simulation of multi-mode effects, such as grating assisted co-directional coupling from a fiber core to a cladding mode (after Chapter 4)
- Effect of apodization on FBG characteristics (after Chapter 5)
- Simulation of fiber band pass filters, including devices based on single fibers, Mach-Zehnder interferometer circuits and in-coupler gratings (after Chapter 6)
- Behavior of chirped fiber Bragg gratings (after Chapter 7)
- Transmission of digital bit patterns through examples, showing the distortion of signals in the time domain (eye diagrams).

The user is able to run the chosen examples, inspecting all the results available within PicWave, including optical transmission and reflection spectra, group delay, dispersion, time signals and more.

This special version of Picwave is limited to modelling only the passive fibre devices covered in this book. However the full PicWave package is capable of modelling other non-linear and active devices such as laser diodes and SOAs as discussed in Chapter 8.

Photon Design®

Dedicated to the memory of my parents, Vimla and Kedar Nath Kashyap.

Preface

Despite the lapse of a decade since the previous edition of this book was published, fiber Bragg gratings continue to flourish and their applications expand. As has been the experience with optical fibers in the past, new discoveries have continued to remain a driver for technological developments. In this respect, the past decade has seen further activity in the poling of glass, fiber Bragg grating sensors, high-power fiber lasers, and the opening of a new research on femtosecond (fs) laser processing, which was just beginning to grow when the first edition came out in print. To reflect these developments, this edition has three new chapters that touch on the topics of sensing, fs laser writing of fiber Bragg gratings (FBGs), and poling of glass and optical fibers. It is hoped that these chapters will bring the book into the mainstream of topical research interest. The basis of the FBG, the refractive index change induced by ultraviolet or fs laser pulses, now stands around a record ~0.1, having met the prediction made in 1999. Truly broadband mirrors spanning 300 nm are now possible *in fiber* with high reflectivity (99%), challenging thin-film technology. In fact, some of the periodic nanostructured gratings formed by fs laser pulses have a glass-air boundary, which leads to the possibility of miniaturizing devices still further with the large refractive index contrast of 0.45. The fs laser has allowed the writing of strong gratings in materials that have traditionally been nonphotosensitive, such as pure silica and ZBLAN glass. The use of high-intensity pulses enables multiphoton absorption to occur, and these pulses also literally rip the electrons out of their orbits to the conduction band, inducing plasmas and carrier heating. The optical damage that results has interesting applications in strong gratings for high-temperature sensing. Indeed, sapphire fiber gratings for high-temperature turbine measurements would not have been possible without fs lasers. High-power lasers have suddenly become commonplace at unusual wavelength, fueled by the downturn in the telecommunications and the rise of the multibillion-dollar biophotonics and sensing industries. FBGs have found their place in peculiar applications such as in the investigation of strain in the human lumbar column. Glass poling, too, has evolved, even though the goal of the 10 pm-V^{-1} electrically induced nonlinearity remains elusive. New polarization controllers, fiber-based Q-switches, and other tunable FBG devices have come of age with optical fiber poling. The low-loss optical fibers for telecommunications made of a fused silica cladding and a germania-doped core still maintain their pride of place in optical fiber technology. Rare earth dopants in silica and other glasses have made many more applications possible. The advent of photonic crystal fibers are now demonstrating a way to increase the power-handling capacity of optical fibers, although high-quality gratings remain difficult to implement in these fibers. Gratings are being applied to reduce the impact of nonlinearities in fibers, pulse shaping and compression, and signal processing. The mechanisms contributing to photosensitivity continue to be debated, although major advances have been made in this area. There are a number of methods of the holographic inscription of Bragg gratings using ultraviolet radiation or infrared fs pulses, with the phase-mask technique holding a prominent position. These methods have multiplied, with several techniques demonstrated for the fabrication of ultralong gratings. New areas just on the brink of breakthroughs, such as random lasers, are highly compatible with the FBG. It is impossible to cover the massive advances made in this field in a book of this size (even though the second edition is now vastly expanded), a field in which the number of applications has exploded. The book therefore continues to be an introduction to the extremely rich area of the technology of fiber gratings, with a view to providing an insight to some of the exciting prospects, including the principles of fiber Bragg gratings, the photosensitization of optical fibers, Bragg grating fabrication, theory, properties of gratings, specific applications, sensing technology, glass poling, femtosecond processing of glass, and FBG measurement techniques.

Acknowledgments

Writing a book is like planting a tree. One sees it grow and develop branches and roots, leading to connections that permeate throughout the world, with the hundreds of researchers providing the nourishment. At the end, the tree should flourish to shade the ones who nourished it, and those yet to come. Therefore, I am grateful to the scientific community at large for providing the data for this book, now in its much-expanded form. The writing of the second edition poses some problems, as the written data are often still valid and the new must be integrated into the old. The choice has been a difficult one, as the field is now very large, and it is often based on the examples that provide the information required. The book is not therefore intended to be a bibliography of all the research and applications that have been published in the area of laser-induced fiber gratings, for there are too many. Instead, we focus on the technology with the goals of guiding the reader on how to fabricate, use, and implement systems with fiber gratings and shedding light on recent advances in the field.

I am deeply grateful to Walter Margulis for the major contribution he made by writing the chapter on glass poling. Choosing the right person to prepare that chapter was a difficult decision to make until I took the step of asking him, and since, it was to be the best decision I could have made. His dedication and lightening response is evident in the extremely thorough chapter he has written. Without his help, the book would still be somewhere in cyberspace.

I am grateful, too, to my students and researchers, in particular Runnan Liu, Irina Kostko, Mathieu Gagné, Jerome Poulin, Francis Guay, Julie Baron, Äissa Harhira, and the numerous others who spent time in my labs for their research in the several areas of FBGs. Included among these are Jessica Chauve, Cedric Pruche, Lucien Bojor, and John Machlecler. Galina Nemova's contribution on surface plasmons is most appreciated.

I am indebted to Jacques Albert, Réal Vallée, Sidarath Ramachandran, Ian Bennion, and numerous others who have all generously contributed material included in the new edition. James Brennan and Bertrand Poumellec are gratefully acknowledged for their painstaking review of sections of the first edition and their constructive comments, which I have tried to incorporate in this edition. *Fiber Bragg Gratings* may not have made such progress without the help of Dr. Jürgen Bartschke, who was instrumental in bringing to life the first CW intra-cavity 244 nm laser source in my lab at BT Laboratories in 1989.

His recent visit from Xiton Photonics has renewed an old friendship and perhaps new innovations in gratings. I hope that the theft of his passport did not spoil an otherwise good visit to Montréal!

Finally, I would like to thank Hannah and Monika, whose patience was not only tested to the limits of exasperation, but whose caring and infinite capacity to see the light at the end of the tunnel kept me on the straight and narrow.

Raman Kashyap
Montréal
August 2009

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