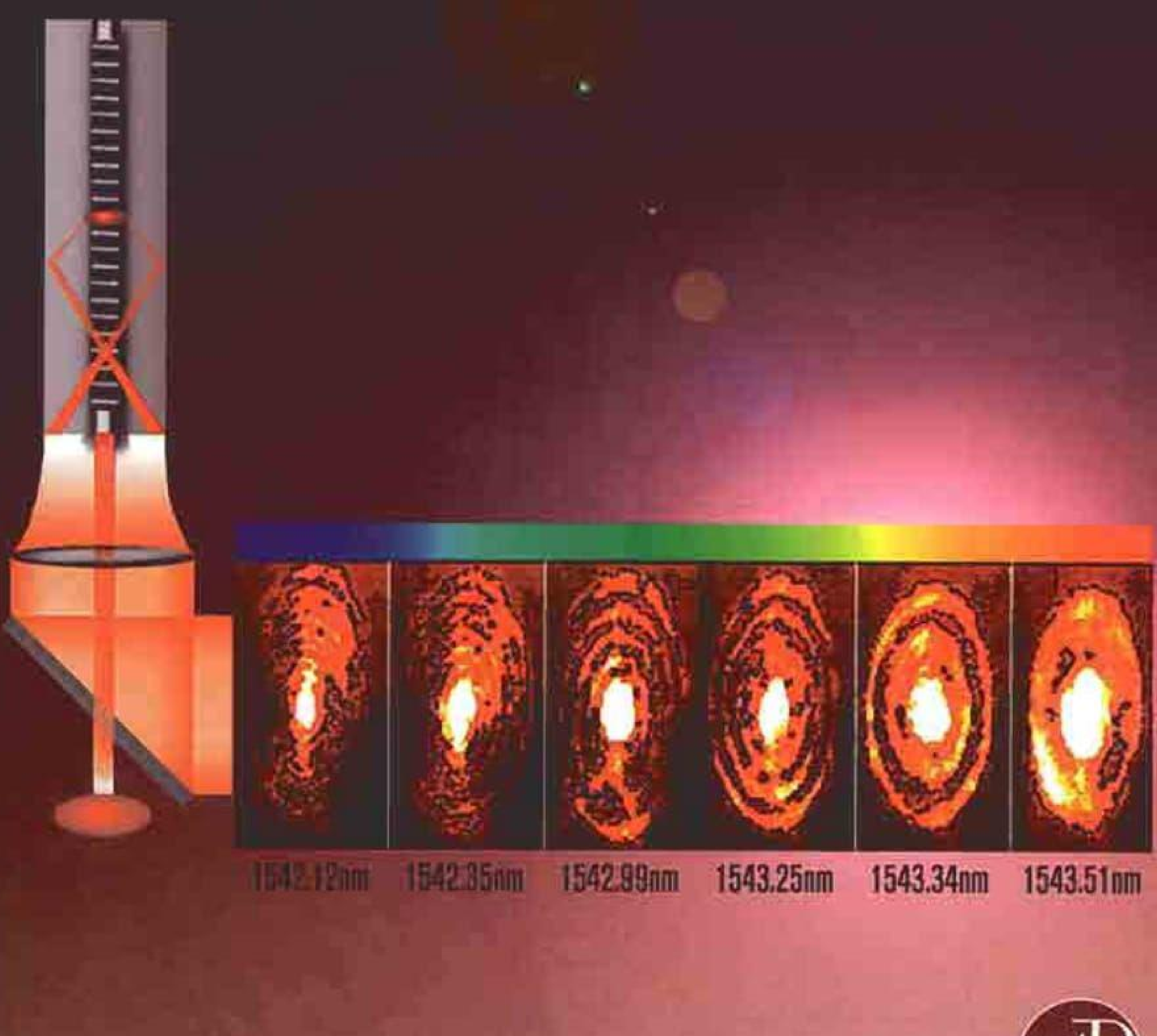
FIBER BRAGG GRATINGS

RAMAN KASHYAP



OPTICS AND PHOTONICS

Fiber Bragg Gratings

OPTICS AND PHOTONICS

(formerly Quantum Electronics)

EDITED BY

PAUL L. KELLY

Tufts University
Medford, Massachusetts

IVAN KAMINOW

Lucent Technologies
Holmdel, New Jersey

GOVIND AGRAWAL

University of Rochester
Rochester, New York

A complete list of titles in this series appears at the end of this volume.

Fiber Bragg Gratings

Raman Kashyap
BT Laboratories, Martlesham Heath
Ipswich, United Kingdom

ACADEMIC PRESS

San Diego London Boston
New York Sydney Tokyo Toronto

The cover picture shows the near-field photographs of radiation mode patterns of several low-order counterpropagating modes (LP_{0n}). These are excited by the forward propagating core mode in a 6-mm-long, side-tap grating with a 2° blaze angle, written into the core of a single mode fiber. *Artwork by Arjun Kashyap.*

This book is printed on acid-free paper. ♾

ACADEMIC PRESS
a division of Harcourt Brace & Company
525 B Street, Suite 1900, San Diego, CA 92101-4495, USA
http://www.apnet.com

ACADEMIC PRESS
24-28 Oval Road, London, NW1 7DX, UK
http://www.hbuk.co.uk/ao/

Library of Congress Catalog Card Number: 99-60954

International Standard Book Number: 0-12-400560-8

Printed in the United States of America
99 00 01 02 03 IP 9 8 7 6 5 4 3 2 1

For Monika, Hannah, and in memory of
Prof. Kedar Nath Kashyap

Contents

This page intentionally left blank

Preface

The field of fiber Bragg gratings is almost exactly twenty years old, dating back to its discovery by Ken Hill and co-workers in Canada. It grew slowly at first, but an important technological advance by Gerry Meltz and co-workers 10 years later, renewed worldwide interest in the subject. I was instrumental in setting up the first International Symposium on photosensitivity of optical fibers, jointly with Francois Ouellette in 1991, a meeting with 22 presentations and attended by approximately 50 researchers. Since, we have seen three further international conferences solely devoted to fiber Bragg gratings, the last of which was attended by approximately 300 researchers. As the applications of Bragg gratings are numerous, publications appear in widely differing conferences and journals. Surprisingly, apart from several review articles covering the most elementary aspects, no monograph is available on the subject and the quantity of available literature is spread across a number of specialist journals and proceedings of conferences. Thus, progress and the current state of the art are difficult to track, despite the approaching maturity of the field. More recently, poling of glass optical fibers has resulted in an electro-optic coefficient almost rivaling that of lithium niobate.

Germanium, the core dopant of low loss, fused silica optical fiber, is a rich defect former; ultraviolet radiation can strongly modify the nature of the defects causing large changes in the local refractive index. The mechanisms contributing to photosensitivity are complicated and still being debated. They depend on the types of defects present, dopants, and the presence of hydrogen whether in the molecular or in the ionic state. The lack of a thorough understanding has not, however, prevented the exploitation of the effect in a large number of applications. The very large index changes reported to date (~0.03) allow, for the first time, the fabrication of ultra-short (~100 μm long) broadband, high-reflectivity Bragg gratings in optical fibers. The maximum index change may be an order of magnitude larger still, leading to many more exciting possibilities. There are a number of methods of the holographic inscription of Bragg gratings, with the phase-mask technique holding a prominent position.

This book was born as a result of growing demands for yet more review articles on the subject. It aims to fill the gap by bringing together the fundamentals of fiber gratings, their specific characteristics, and many of the applications. The book covers much of the fundamental material on gratings and should be of interest to beginners, advanced researchers, as well as those interested in the fabrication of many types of gratings.

It is impossible to cover the massive advances made in this field in a book of this size, a field that continues to grow at an enormous rate despite recent commercialization. A large reference list is provided, to allow the interested reader to seek out specific topics in more detail. The purpose of this book is therefore to introduce the reader to the extremely rich area of the technology of fiber Bragg, with a view to providing insight into some of the exciting prospects. It begins with the principles of fiber Bragg gratings, photosensitization of optical fibers, Bragg grating fabrication, theory, properties of gratings, and specific applications, and concludes with measurement techniques.

BT Laboratories,
Ipswich IP5 3RE,
United Kingdom
July 1998

Raman Kashyap

Acknowledgments

I am grateful to many individuals who have either directly contributed to the book or so generously provided material for it. I thank the members of the European ACTS Program, PHOTOS, whose efforts have greatly contributed to the growing knowledge in this area. In particular, I am indebted to Marc Douay, Bertrand Poumellec, René Salathe, Pierre Sansonetti, Isabelle Riant, Fatima Bhakti, Hans Limberger, and Christian Bungarzaneau, for providing several original exemplary figures and simulations. I thank Ken Hill, Jacques Albert, Stanislav Chernikov, Turan Erdogan, Phillip Russell, Feodor Timofeev, Malin Permanante, Raoul Stubbe, Vince Handerek, Sotiris Kanellopoulos, Tom Strasser, Peter Krug, Takashi Mizuochi, Nadeem Rizvi, Doug Williams, Alistair Poustie, Steve Kershaw, and Mike Brierley for their assistance with figures, Arjun Kashyap for the arrangement on the front cover, and others who have also provided data for inclusion in the book.

Melanie Holmes's vast contribution on radiation mode coupling is humbly acknowledged. I especially thank her for the many philosophical discussions, fun arguments and Mars bars exchanged on the subject! Jenny Massicott has generously contributed and provided significant help with the section on gain controlled amplifiers. 'Thanks' must go to Richard Wyatt for reading the manuscript so quickly and Marcello Segatto for his many constructive comments.

A special thank you to Domenico Giannone for his painstaking and careful reading of parts of the manuscript, and to Hans Georg Fröhlich and Simon Wolting for undertaking fun experiments during their summer student-ships. Monica de Lacerda-Rocha provided numerous measurements on chirped gratings. Walter Margulis and Isabel Cristina Carvalho are acknowledged for the amusing times in the lab in Rio, proving that writing in-fiber gratings on a piece of Amazonian hardwood "optical bench" is easy, even late at night! Bernhard Lesche and Isabel Cristina Carvalho contributed to interesting discussions during the writing of the book. Martin Burley kept me amused with his music and sense of humor during the lulls in writing.

The IEEE, IEE, OSA and Elsevier Science are acknowledged for provision of copyright permission on several figures. I also gratefully acknowledge D. W. Smith of BT Laboratories for his generous support and provision of computer facilities for the production of the manuscript.

Finally, I am deeply appreciative of Monika and Hannah, whose unquestioning patience, support and provision of earthly comforts formed essential ingredients in the birth of this book.

Fiber Bragg Gratings

This page intentionally left blank