Nonlinear Fiber Optics

Fourth Edition

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In the memory of my mother and

for Anne, Sipra, Caroline, and Claire

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Preface

Since the publication of the first edition of this book in 1989, the field of *nonlinear fiber optics* has remained an active area of research and has thus continued to grow at a rapid pace. During the 1990s, a major factor behind such a sustained growth was the advent of fiber amplifiers and lasers, made by doping silica fibers with rare-earth materials such as erbium and ytterbium. Erbium-doped fiber amplifiers revolutionized the design of fiber-optic communication systems, including those making use of optical solitons, whose very existence stems from the presence of nonlinear effects in optical fibers. Optical amplifiers permit propagation of lightwave signals over thousands of kilometers as they can compensate for all losses encountered by the signal in the optical domain. At the same time, fiber amplifiers enable the use of massive wavelength-division multiplexing, a technique that led by 1999 to the development of lightwave systems with capacities exceeding 1 Tb/s. Nonlinear fiber optics plays an important role in the design of such high-capacity lightwave systems. In fact, an understanding of various nonlinear effects occurring inside optical fibers is almost a prerequisite for a lightwave-system designer.

Starting around 2000, a new development occurred in the field of *nonlinear fiber optics* that changed the focus of research and has led to a number of advances and novel applications in recent years. Several kinds of new fibers, classified as highly nonlinear fibers, have been developed. They are referred to with names such as microstructured fibers, holey fibers, or photonic crystal fibers, and share the common property that a relatively narrow core is surrounded by a cladding containing a large number of air holes. The nonlinear effects are enhanced dramatically in such fibers to the extent that they can be observed even when the fiber is only a few centimeters long. Their dispersive properties are also quite different compared with those of conventional fibers developed for telecommunication applications. Because of these changes, microstructured fibers exhibit a variety of novel nonlinear effects that are finding applications in fields as diverse as optical coherence tomography and high-precision frequency metrology.

The fourth edition is intended to bring the book up-to-date so that it remains a unique source of comprehensive coverage on the subject of nonlinear fiber optics. It retains most of the material that appeared in the third edition. However, an attempt was made to include recent research results on all topics relevant to the field of nonlinear fiber optics. Such an ambitious objective has increased the size of the book considerably. Two new chapters, Chapters 11 and 12, have been added to cover the recent research advances. Chapter 11 describes the properties of highly nonlinear fibers, and the novel nonlinear effects that have been observed since 2000 in such fibers are cov-

ered in Chapter 12. Although all other chapters have been updated, Chapters 8 to 10 required major additions because of the recent advances in the research areas covered by them. For example, polarization issues have become increasingly more important for stimulated Raman scattering and four-wave mixing, and thus they are discussed in detail in Chapters 8 and 10. It is important that students learn about such polarization effects in a course devoted to nonlinear fiber optics.

The potential readership is likely to consist of senior undergraduate students, graduate students enrolled in the M.S. and Ph.D. degree programs, engineers and technicians involved with the fiber-optics industry, and scientists working in the fields of fiber optics and optical communications. This revised edition should continue to be a useful text for graduate and senior-level courses dealing with nonlinear optics, fiber optics, or optical communications that are designed to provide mastery of the fundamental aspects. Some universities may even opt to offer a high-level graduate course devoted to solely nonlinear fiber optics. The problems provided at the end of each chapter should be useful to instructors of such a course.

Many individuals have contributed, either directly or indirectly, to the completion of the third edition. I am thankful to all of them, especially to my graduate students whose curiosity and involvement led to several improvements. Several of my colleagues have helped me in preparing the fourth edition. I especially thank F. Omenetto, Q. Lin, and F. Yaman for reading drafts of selected chapters and for making helpful suggestions. I am grateful to many readers for their occasional feedback. Last, but not least, I thank my wife, Anne, and my daughters, Sipra, Caroline, and Claire, for understanding why I needed to spend many weekends on the book instead of spending time with them.

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