

Second Edition

# Optoelectronics and Photonics: Principles and Practices

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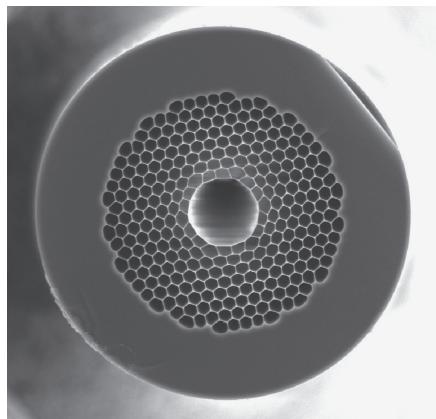
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*We have a habit in writing articles published in scientific journals to make the work as finished as possible, to cover up all the tracks, to not worry about the blind alleys or describe how you had the wrong idea first, and so on. So there isn't any place to publish, in a dignified manner, what you actually did in order to get to do the work.*

—RICHARD P. FEYNMAN  
NOBEL LECTURE, 1966



Philip Russell led a team of researchers at the University Bath in the 1990s where photonic crystal fibers were drawn. Thin hollow capillary tubes were stacked together and then fused to make a preform as shown on the left. A photonic crystal fiber was then drawn at a high temperature from this preform. Photonic crystal fibers have the ability to guide light endlessly in a single mode, and have highly desirable nonlinear properties for various photonics applications in the manipulation of light, such as the generation of supercontinuum light. (Courtesy of Professor Philip Russell.)



Peter Schultz, Donald Keck, and Bob Maurer (left to right) at Corning were the first to produce low-loss optical fibers in the 1970s by using the outside vapor deposition method for the fabrication of preforms, which were then used to draw fibers with low losses.  
*(Courtesy of Corning.)*

*To Nicolette, who brightens my every day  
and makes me smile with joy every time I see her.*

# PREFACE

The first edition of this book was written more than 12 years ago. At the time it was meant as an easy-to-read book for third-year engineering or applied physics undergraduate students; it emphasized qualitative explanations and relied heavily on intuitive derivations. As things turned out, the first edition ended up being used in fourth-year elective classes, and even in graduate courses on optoelectronics. Many of the instructors teaching at that level rightly needed better derivations, more rigor, better explanations, and, of course, many more topics and problems. We have all at one time or another suffered from how wrong some intuitive short-cut derivations can be. The second edition was therefore prepared by essentially rewriting the text almost from scratch with much better rigor and explanations, but without necessarily dwelling on mathematical details. Many new exciting practical examples have been introduced, and numerous new problems have been added. The book also had to be totally modernized given that much had happened in the intervening 12 years that deserved being covered in an undergraduate course.

## FEATURES, CHANGES, AND REVISIONS IN THE SECOND EDITION

The second edition represents a total revision of the first edition, with numerous additional features and enhancements.

- All chapters have been totally revised and extended.
- Numerous modern topics in photonics have been added to all the chapters.
- There are Additional Topics that can be covered in more advanced courses, or in courses that run over two semesters.
- There are many more new examples and solved problems within chapters, and many more practical end-of-chapter problems that start from basic concepts and build up onto advanced applications.
- Nearly all the illustrations and artwork in the first edition have been revised and redrawn to better reflect the concepts.
- Numerous new illustrations have been added to convey the concepts as clearly as possible.
- Photographs have been added, where appropriate, to enhance the readability of the book and to illustrate typical modern photonic/optoelectronic devices.
- The previous edition's Chapter 7 on photovoltaics has been incorporated into this edition's Chapter 5 as an Additional Topic, thus allowing more photonics-related topics to be covered.
- Advanced or complicated mathematical derivations are avoided and, instead, the emphasis is placed on concepts and engineering applications.
- Useful and essential equations in photonics are given with explanations and are used in examples and problems to give the student a sense of what typical values are.
- Cross referencing in the second edition has been avoided as much as possible, without too much repetition, to allow various sections and chapters to be skipped as desired by the reader.
- There is greater emphasis on practical or engineering examples; care has been taken to consider various photonics/optoelectronics courses at the undergraduate level across major universities.

- The second edition is supported by an extensive PowerPoint presentation for instructors who have adopted the book for their course. The PowerPoint slides have all the illustrations in color, and include additional color photos. The basic concepts and equations are also highlighted in additional slides. There are also numerous slides with examples and solved problems. Instructors should contact the publisher to access the PowerPoint.
- The second edition is also supported by an extensive Solutions Manual for instructors only. This is available from the publisher.

The second edition continues to represent a first course in optoelectronic materials and devices suitable for a half- or one-semester course at the undergraduate level either at the third- or fourth-year level in *electrical engineering*, *engineering physics*, and *materials science and engineering* departments. With its additional topics, it can also be used as an introductory textbook at the graduate level. Normally the students would not have covered Maxwell's equations. Although Maxwell's equations are mentioned in the text to alert the student, they are not used in developing the principles. It is assumed that the students would have taken a basic first- or second-year physics course, with modern physics, and would have seen rudimentary concepts in geometrical optics, interference, and diffraction, but not Fresnel's equations and concepts such as group velocity and group index. Typically an optoelectronics course would be given either after a semiconductor devices course or concurrently with it. Students would have been exposed to elementary quantum mechanics concepts, perhaps in conjunction with a basic semiconductor science course.

Most topics are initially introduced through qualitative explanations to allow the concept to be grasped first before any mathematical development. The mathematical level is assumed to include vectors, complex numbers, and partial differentiation but excludes reliance on Fourier transforms. On the one hand, we are required to cover as much as possible and, on the other hand, professional engineering accreditation requires students to solve numerical problems and carry out "design calculations." In preparing the text, I tried to satisfy engineering degree accreditation requirements in as much breadth as possible. Obviously one cannot solve numerical problems, carry out design calculations, and at the same time derive each equation without expanding the size of the text to an intolerable level. I have missed many topics but I have also covered many, though, undoubtedly, it is my own very biased selection.

I would like to thank two very special colleagues, whom I have known for a very long time, for their comments and help: Harry Ruda (University of Toronto) and Raman Kashyap (École Polytechnique de Montréal)—two perfect gentlemen who read some of the manuscript and made valuable criticisms toward this final version.

No textbook is perfect and I can only improve the text with your input. Please feel free to write to me with your comments. Although I may not be able to reply to each individual comment and suggestion, I do read all my email messages and take good note of suggestions and comments. Many instructors did, in fact, write to me on the first edition, pointed out how things could have been done better, and various mistakes one never seems to be able to eliminate totally. I hope that the second edition will at least go far in satisfying some of their criticisms. There is an important old adage that goes something like this (somewhat paraphrased), "a good diagram is worth a thousand words, but a bad diagram takes a thousand words to explain." I used a software package called Canvas to draw nearly all the line-art in the second edition as clearly as possible, and errors are all *mea culpa*; feel free to email me the errors you notice in the figures. All third-party artwork and photographs have been used with permission; and I'm grateful to

Pearson Education for meticulously obtaining permission from copyright holders. If you like the second edition, and cannot wait for the third, you can always write your comments and recommendations directly to the Sponsoring Editor for Electrical Engineering, Pearson Higher Education, One Lake Street, Upper Saddle River, NJ 07458, USA. This is the best way to have your input heard.

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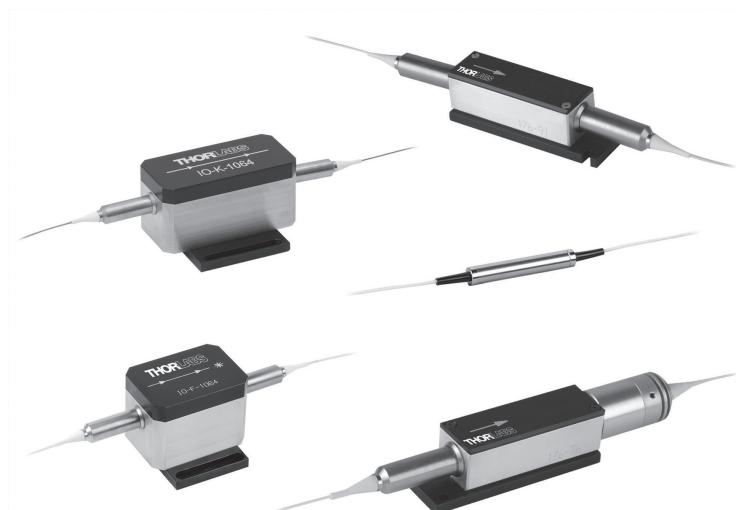
Saskatoon (March 2012)



Gordon Gould (1920–2005) obtained his BSc in Physics (1941) from Union College in Schenectady and MSc from Yale University. Gould came up with the idea of an optically pumped laser during his PhD work at Columbia University around 1957—he is now recognized for the invention of *optical pumping* as a means of exciting masers and lasers. He has been also credited for collisional pumping as in gas lasers, and a variety of application-related laser patents. After nearly three decades of legal disputes, in 1987, he eventually won rights to the invention of the laser. Gould's laboratory logbook even had an entry with the heading “Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation,” which is the first time that this acronym appears. Union College awarded Gould an honorary Doctor of Sciences in 1978 and the Eliphalet Nott Medal in 1995. (*Courtesy of Union College Alumni Office.*)



Fiber-coupled phase and amplitude modulators. The Pockels effect in lithium niobate is used to modulate the refractive index and hence the phase of an optical signal. In amplitude modulators, the Pockels effect is used to modulate the refractive indices of the two arms of a Mach–Zehnder interferometer, and hence the optical output. (© JENOPTIK Optical System GmbH.)



Fiber-coupled optical isolators: fiber isolators. The signal is allowed to propagate in one direction only, along the arrow shown on the device. The principle is based on Faraday rotation. (Courtesy of Thorlabs.)