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Chapter Author(s): Govind P. Agrawal

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13. Fiber Optics and Optical Communications

Govind P. Agrawal

The advent of the Internet during the decade of 1990s impacted our society in unforeseen ways. Addiction to cell phones, social media dominated by Facebook and Twitter, video streaming by companies such as Netflix and Hulu, and on-line shopping by the masses through Amazon are some of the things that were unimaginable in the 1980s, or even in the 1990s. What is seldom realized is that the Internet revolution would not have been possible without optical fibers and the optical communication technology developed for sending vast amounts of data over them.

The history of fiber optics has been traced by Jeff Hecht in his 1999 book.[1] He recounts an event in 1951 that we can take as the beginning of fiber optics at The Institute of Optics. It so happened that Prof. A. C. S. van Heel from the Technical University of Delft in the Netherlands visited The Institute's director Brian O'Brien in October 1951. He had been trying for some time, without success, to produce bundles of glass fibers capable of transmitting an image. He tried coating glass fibers with silver (and other materials), hoping that multiple internal reflections would confine a light beam to the fiber, but this approach failed. Over a dinner in his home, O'Brien suggested to van Heel that he use a dielectric cladding with a lower refractive index on top of the glass fiber to take advantage of total internal reflection. The Dutch guest took this advice, made cladded fibers, and was successful in transmitting images. He tried to make O'Brien coauthor in a paper he published in *Nature*, but his letter didn't reach O'Brien, who had moved to Boston to join the American Optical Company. O'Brien even tried to patent his idea, but his lawyer misinterpreted the date of publication of van Heel's paper, and a patent was never filed.

In 1953, optical fibers were also being made by Narinder Singh Kapany, a graduate student of Harold Hopkins at the Imperial College in London. In fact, it was Kapany who coined the term "fiber optics" for the first time. After he graduated in 1955, Kapany joined The Institute of Optics. He did not stay very long for he was interested in exploiting optical fibers for business opportunities. Indeed, Kapany founded several companies and had a successful career. Because of his departure,

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The Institute did not develop a research program in fiber optics. During the 1980s, Dennis Hall worked with Thomas Brown on optical waveguides, but they were mostly interested in semiconductor waveguides. Duncan Moore's group was involved with gradient-index materials, but did not make optical fibers from them. The Institute did try to have visibility in the field of fiber optics. Donald Keck, a well-known expert on fiber optics from Corning, was appointed on a part-time basis in 1985, but he discontinued his affiliation by 1988.

I joined the faculty of The Institute of Optics in January 1989. Before arriving, I was working at AT&T Bell Laboratories on various aspects of optical communication, and my research focused both on semiconductor lasers and on optical fibers. I had published in 1986 my first book on *Semiconductor Lasers* and had just completed another book entitled *Nonlinear Fiber Optics*.[2] My plan was to establish a research group working on all aspects of optical communication, including diode lasers and optical fibers.

The first thing I noticed at The Institute was the lack of any course in the area of optical communication. The Institute of Optics offered such a graduate-level course for the first time in 1989. I was surprised by the huge interest. The course was taught regularly during the 1990s and often had more than thirty students enrolled, which was not a common situation for graduate courses. Some students came from local industry, including Kodak and Corning. I decided in 1991 to write a book on optical communication systems, based on my course notes. This book was published in 1992 by Wiley.[3] It turned out to be a wise decision in retrospect. The field of optical communication was growing rapidly, and the book was adopted as a textbook by many universities worldwide, enhancing the reputation of The Institute. *Nonlinear Fiber Optics* also attracted considerable attention and became one of the most-cited books in physics. The front cover of the first editions of both books is shown in figure 13.1.

It was important to keep the momentum growing by adding additional faculty in the area of fiber optics. Turan Erdogan joined The Institute of Optics in 1995 from Bell Labs. He established a laboratory for studying fiber-based Bragg gratings and their diverse applications. A master's degree with specialization in optical communication was added to The Institute's MS program. I organized in 1997 a conference on "Advanced Concepts in High-Speed Optical Communications," which was held at the University of Rochester during May 25–27. Corning supported the research at The Institute through joint research projects. Several international collaborations were started during this time. My group was involved with the Ecole nationale supérieure des télécommunications (ENST), located in Paris. During a visit in June 1992, I was invited to make a presentation at the Centre national d'études des télécommunications (CNET) in Lannion, France. In addition, a multiyear collaboration was set up with the University of Rennes in France that was partly funded by the US National Science Foundation. Several faculty members of The Institute of Optics visited this university in 1999. As Rennes is a sister city of Rochester, the mayor of Rennes invited us to City Hall for a welcoming celebration.

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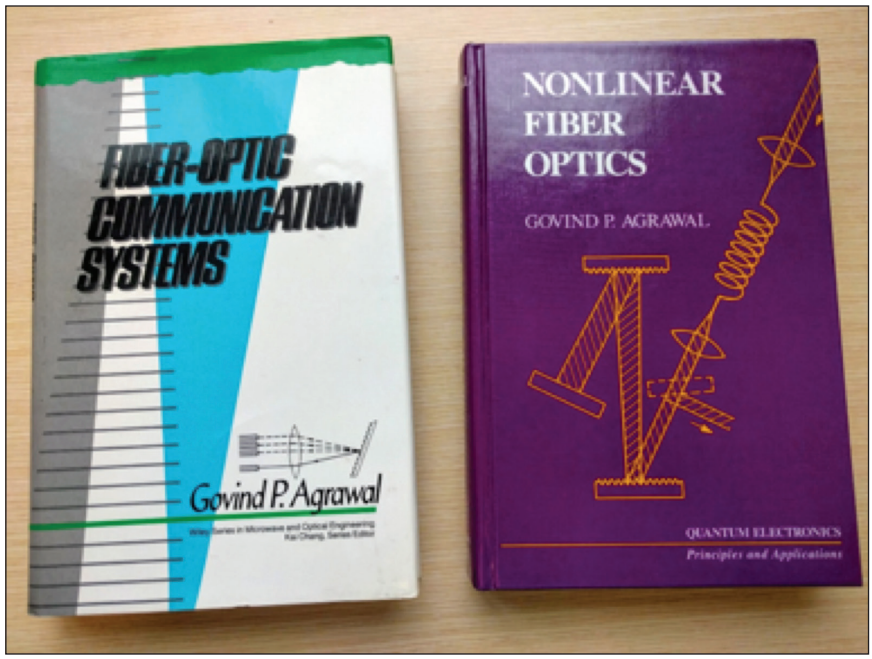

Figure 13.1. Covers of first editions of Fiber-Optic Communication Systems, a textbook first written in 1992, and Nonlinear Fiber Optics, one of the most-cited books in physics.

The field of optical communication exploded during the 1990s, soon after the telecom systems based on dense wavelength-division multiplexing (WDM) were developed. The capacity provided by such systems led to the tremendous growth of the Internet, as more and more businesses decided to set up websites. Eventually the growth became so rapid that it led to the dot.com bubble. The Institute of Optics was also affected by this boom-and-bust cycle. During the boom phase, several of my graduate students, including Clifford Headley, John Marciante, Stojan Radic, Rene Essiambre, Natasha Litchinister, and Drew Maywar, were hired by companies such as Corning and Lucent Bell Labs. Figure 13.2 shows several members of my group in the year 2000. The person on the right is Prof. Collin McKinstrie, with whom my group was collaborating at that time.

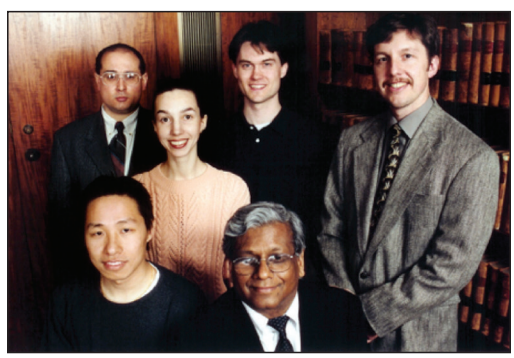

Figure 13.2. Agrawal group 2000: Back row: Fatih Yaman, Ekaterina Poutrina, Drew Maywar, Collin McKinstrie; front: Zhi M. Liao, Govind Agrawal.

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During the boom phase, several faculty members left The Institute to join one of the many new companies that were being founded at a rapid pace. I was also tempted but decided to remain at The Institute. Wayne Knox was hired from Lucent Bell Labs as the new director of The Institute, just as the bubble was bursting. His job was to build up the faculty and prepare The Institute for the twenty-first century. He hired several new faculty members and convinced the administration to expand The Institute into Georgen Hall, a new building that was completed in 2007. Several Institute alumni donated large sums of money for this project to succeed.

The field of optical communication did not recover for nearly ten years. I stopped teaching the optical communication course because the number of students declined to below five. I shifted to a new area known as silicon photonics where more external funding was available. One of my PhD students, Qiang Lin, worked in this area and is currently a professor of electrical engineering at UR, with a secondary appointment in The Institute of Optics. Another student, John Marciante, left Corning after the telecom downturn and is now a faculty member at The Institute. Because of a declining enrollment in the optical communication course, I began made of silica, silicon, or other semiconductor materials. The research on optical communication started growing again after 2010 as the focus shifted to a new technique, known as spatial-division multiplexing. It makes use of new kind of fiber known as multicore fibers and may even employ multimode fibers that have been known of since the 1970s. Both Corning and Lucent Bell Labs have supported my research in this emerging area.

Both fiber optics and optical communication constitute active areas of research and teaching in 2018. I taught the course on optical communication systems in Fall 2018. My research group is investigating nonlinear optical phenomena in multimode optical fibers and collaborating with companies such as Corning and Nokia Bell Labs. In recent years, The Institute of Optics has added three new faculty members. Jaime Cardenas came in 2016 as an expert on waveguide technology, especially in silicon photonics. William Renninger became an assistant professor in 2017 as an expert on fiber lasers and ultrafast technology. Scott Carney joined us in 2017 as the new director of The Institute. With these additions, The Institute of Optics is forging ahead with its mission of being at the forefront of the research and education in optical sciences and engineering.

Notes

1. J. Hecht, *City of light: The Story of Fiber Optics* (New York: Oxford University Press, 1999).
2. G. P. Agrawal and N. K. Dutta, *Semiconductor Lasers* (New York: Van Nostrand Reinhold, 1986; 2nd ed. 1993). G. P. Agrawal, *Nonlinear Fiber Optics* (San Diego: Academic Press, 1989; 5th ed. 2013).
3. G. P. Agrawal, *Fiber-Optic Communication Systems* (Somerset, NJ: Wiley, 1992; 4th ed. 2010).

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