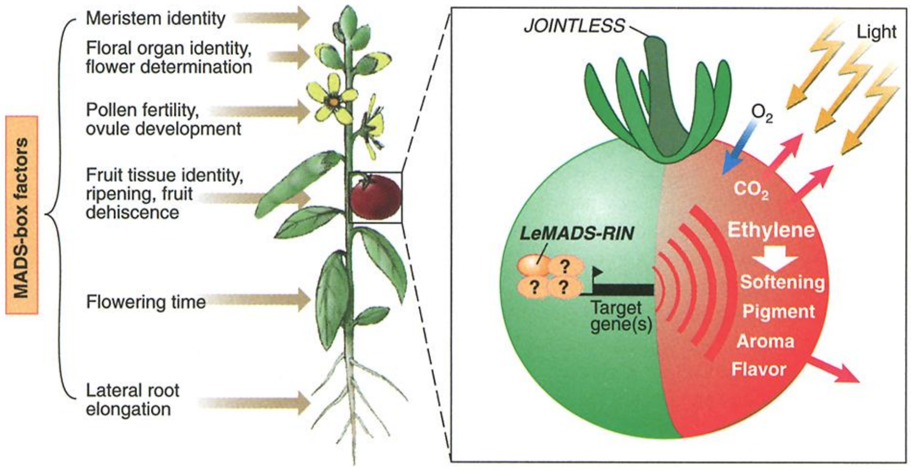

A MAD pathway from root to fruit. (Left) MADS-box transcription factors are involved in numerous steps in plant development (*6*). **(Right)** The LeMADS-RIN transcription factor directs ripening of the tomato fruit. LeMADS-RIN is depicted acting together with other unknown MADS-box factors. Members of the MADS-box family bind to DNA as dimers, heterodimers, or heteromultimers (*7*) to regulate the expression of target genes.

tomato genome, resulting in the fusion and inactivation of two adjacent genes. Remarkably, both genes belong to the MADS-box family of transcription factors. Loss of one of these transcription factors, *LeMADS-MC*, results in altered sepals and inflorescence, whereas loss of the other, *LeMADS-RIN*, results in a failure to produce ripe fruit. *LeMADS-RIN* is particularly interesting because it appears to act upstream of the earliest known steps in fruit ripening. This raises the possibility that a related gene might also regulate ripening in fruits such as the strawberry, which do not require the ethylene pathway to ripen. Indeed, these authors demonstrate the existence of such a gene in the strawberry. The possibility that these genes act as global regulators of fruit development can now be tested.

MADS-box factors are involved in many other aspects of plant development including the regulation of flowering time, fertility, organ and meristem identity, and even root architecture (see the figure), providing further opportunities for crop improvement. However, we still do not know what many MADS-box factors do. Functional analysis of this gene family will undoubtedly reveal additional targets for crop improvement and further insights into the control of plant development. Although the control of many developmental steps has been assigned to plant MADS-box factors, very little is known about the genes that are targeted by these transcriptional regulators. The way that MADS-box factors work to regulate plant development is still a mystery. In the case of *LeMADS-RIN* we have the first example of a MADS-box factor whose extensive biochemical and physiological downstream effects on ripening are already well documented (see the figure). Perhaps fruit ripening will provide an opportunity to forge the elusive connections between the regulator and the regulated.

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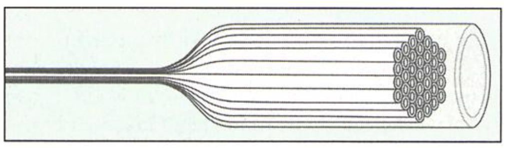
PERSPECTIVES: APPLIED OPTICS

New Ways to Guide Light

J. C. Knight and P. St. J. Russell

Silica-based optical fibers have been one of the engineering triumphs of the last few decades. Yet after an initial period of intense development that revolutionized telecommunications by massively increasing the information-carrying capability of cables, the rate of innovation in fiber design slowed to a crawl in the early 1980s as performance approached the fundamental limitations of the technology. Then, in the early 1990s, a new idea was formulated: Could an optical fiber be created that would guide light through a two-dimensional microstructure running along its length? Such a design would greatly extend the boundaries of fiber optics.



How to draw a photonoic fiber.

We now know that the answer is indeed yes. Around the world, the result has been a renaissance of fundamental research and development on optical fibers. The new fibers—variously called photonic crystal fibers or "holey" or microstructured fibers—have been used to demonstrate several useful effects and are approaching the performance levels required to be commercially viable.

Historically, optical fibers have been made from two materials with different refractive indices. The higher index material forms the fiber core, which "carries" the light. It is surrounded by a lower index cladding, which confines the light to the core by total internal reflection. Despite their remarkable transparency and low losses, such fibers are limited by the small refractive index contrasts attainable between the core and cladding materials (which need to be thermally compatible). Furthermore, the nonlinear optical response of the solid silica core limits the amount of light that the fiber can carry.

A conventional optical fiber is drawn from a macroscopic glass rod with the same transverse profile as the final, hair-thin fiber. Photonic crystal fibers are made in a similar way, but with one important difference: the preform contains a close-packed stack of silica capillaries (see the first figure) (*1*). A two-dimensional "crystal" of tiny air holes runs down the entire length of the fiber, reproducing the arrangement of the capillaries in the stack. By leaving out some capillaries or replacing them with solid canes, one can form a core that is embedded within the photonic crystal material. Light can be trapped in this core and guided along the fiber, producing unusual optical properties.

Because of their micrometer-scale regularity, the fibers can be modeled as "photonic crystals": composite materials that have a regular structure with a length scale of the order of optical wavelengths. Work on photonic crystal fibers was stimulated in part by the interest in photonic crystal ma-

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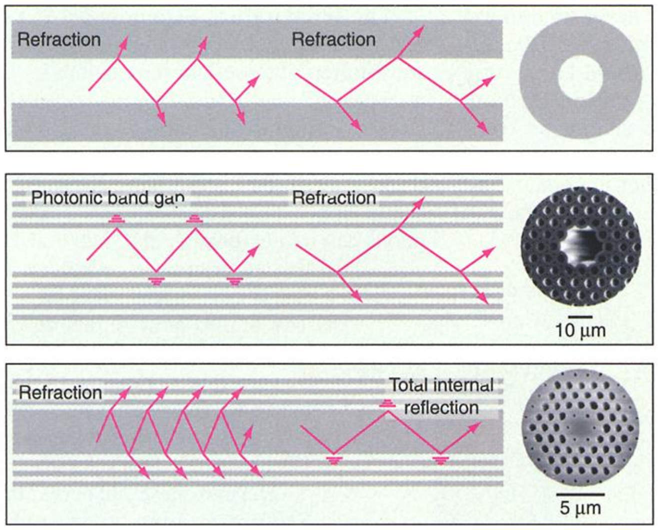

Guiding light. (Top) A hollow capillary refracts light at all angles of incidence. There is no angle at which light can be trapped in the hollow core, so capillaries cannot guide light under any circumstances. **(Middle)** A hollow-core photonic crystal fiber with an appropriately formed cladding (see scanning electron micrograph on the right) can guide light at angles of incidence where a photonic band gap operates (left), but otherwise refracts like a hollow-core capillary. **(Bottom)** A solid-core photonic crystal fiber (see scanning electron micrograph on the right) refracts light at steep angles of incidence on the core-cladding boundary (left). When the angle is shallow enough, light is trapped in the core and guided along the fiber.

terials in the early 1990s, driven largely by a remarkable possibility of these materials: the formation of photonic band gaps, light frequency ranges that cannot exist within the material, much like the electronic band gap in semiconductors.

It was predicted in 1995 (*2*) that a band gap in a photonic crystal fiber—if one could only be made—would enable light to be guided down a larger air hole embedded in the array. Light cannot normally be guided down an air hole (for example, a hollow glass capillary, see the second figure, top panel) because conventional guiding required cladding material with a lower refractive index than the core, and none lower than that of air exists. By surrounding the air hole with a photonic crystal, however, frequency ranges corresponding to the band gap of the crystal would be trapped within, and guided along, the air core (see the second figure, middle panel).

Such an air-core fiber enables new possibilities in optical telecommunications by overcoming some of the problems associated with the silica core that currently limit the performance of optical fibers. The air-guide concept has been verified experimentally (*3*), and efforts to design and make such structures continue (*4*, *5*). Air-core fibers are already useful in scientific applications, but optical losses due mainly to structural imperfections (*4*) currently limit large-scale commercial applications.

A light-guiding core can also be formed (*1*) by creating a local region of higher refractive index, for example, by embedding a solid silica cane within the photonic microstructure. This fiber (see the second figure, bottom panel) guides light by a mechanism analogous to total internal reflection, in that the guiding is confined in a region which has a higher refractive index than its surroundings. Reported optical losses in these fibers are relatively low (*6*) and continue to fall. These fibers have much in common with microstructured fibers developed in the earliest days of fiber optics (*7*), but the new insight afforded by designing them as photonic crystal fibers provides a massive advantage over those early structures (*8*).

Solid-core photonic crystal fibers, because of the two-dimensional nature of their cladding material, have some characteristics very different from conventional fibers. This has some advantages: It makes it practical to make a fiber with a very large core size, which can carry more optical power than its conventional counterpart. They can have a very large refractive index contrast, enabling spectacular nonlinear effects such as the generation of a broadband supercontinuum (*9*) that has led to a new generation of high-precision measurements in optical frequency metrology (*10*). Photonic crystal fibers also permit access to guided light in a way not possible in conventional optical fibers, providing new opportunities for fiber devices (*11*) and sensors.

Applications for photonic crystal fibers abound, and are presently being commercialized by a number of organizations. More exciting, the optics of these structures have not yet been fully explored, and the possibilities are limited only by the imagination. The renewed excitement in the field of optical fiber technology has led to a sea-change in our perception of what optical fibers can do.

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PERSPECTIVES: PALEOCLIMATE

Corals, Chemistry, and Climate

Daniel P. Schrag and Braddock K. Linsley

To most people, coral reefs are symbols of the extreme biodiversity of the undersea world. But to many geochemists, corals hold the key to understanding the recent temperature history of the tropical oceans. Certain coral species grow like trees, putting down layers of their skeletons every year, and can live for 300 years or more. By examining the chemistry of the coral skeleton, geochemists have been able to reconstruct the temperature history of the tropical oceans spanning the last several centuries, providing a better understanding of climate oscillations such as El Niño. The Sr/Ca ratio of corals has received particular attention, with claims of precision better than 0.5°C (*1*).

Such records are not without controversy. A coral skeleton is made of an inorganic mineral, aragonite (a form of calcium carbonate), but it is precipitated through a biological process that is not well understood. Furthermore, many corals used for paleotemperature reconstructions have algal symbionts that may affect the chemistry of the skeleton. This uncertainty has led some to question the reliability of these temperature reconstructions (*2*).

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