

Far Future of Fibers

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Over the next century it seems likely that glass optical fibers, in many as-yet-uninvented forms, will continue to penetrate more and more deeply into science, technology, engineering and their applications.

Ultra-Low-Loss Fiber

Perhaps there will be hollow-core photonic crystal fibers, with specially treated ultra-smooth internal surfaces, that offer transmission losses of 0.001 dB/km in the mid-infrared. Such ultra-low loss will allow extremely long repeaterless communications spans (perhaps more than 20,000 km) and greatly simplify long-haul communications by rendering the ubiquitous Erbium-doped fiber amplifier, with its thirst for expensive pump lasers, largely redundant. All the world's oceans may then be spanned by single continuous lengths of such fiber: Sydney to Los Angeles, Auckland to Lima, or Sao Paolo to London. The resulting greatly reduced cost of long-haul communications will make access to the World Wide Web a realistic and cost-friendly possibility for all the world's populations. Of course, this may also entail the development of a range of new sources, modulators, and detectors for the mid-infrared, but semiconductor science and technology will certainly meet this challenge.

The extremely low loss of these fibers and the lack of optical damage in the empty core might also allow them to be used in power distribution systems. They will thus replace old-fashioned electrical power lines, which will vanish from the landscape in many countries, replaced by underground fiber optical power cables carrying light generated by the highly efficient laser “power stations” of the future. These high-power fibers will be so ultra-lightweight (a 100 km length with the newest high-strength carbon fiber coatings will weigh only 10 kg and have a transmission loss of 0.1 dB, i.e., a loss of 1%) that they could be suspended vertically in the atmosphere using computer-controlled balloons placed at regular intervals. Spiraling up into the sky, they will deliver megawatts of optical power to the Earth's surface from Sun- or fusion-driven lasers in space.

Domestic power outlets of the future may also be based on light, delivered via low-loss optical fibers. Such a power socket might consist of a low-loss optical fiber that, when a plug is inserted, sends a signal to a computer-controlled network specifying the amount of power required. Fiber power delivery to remote devices, using highly efficient laser diodes, will have become ubiquitous, providing an elegant and cost-effective replacement for awkward and often-unreliable electrical supply cables and batteries.

Sensing Systems

In an exotic sensor system of the future, a small “sensing” particle is picked up using laser tweezers and propelled into a length (which might be kilometers long) of hollow-core optical fiber. Enclosed and protected by the glass sheath, the particle can be propelled along a flexible path even through harsh environments. It can be held stationary or moved backward and forward by varying the power ratio between counterpropagating optical modes, and its position

monitored using time-domain reflectometry or (to interferometric precision) using laser Doppler velocimetry. It can also be optically addressed in many different ways, permitting sensitive measurements of external parameters with high spatial resolution. A further exotic particle type, made possible by future advances in semiconductor nanofabrication, is a micrometer-scale optoelectronic “microbot” that is powered by the propelling light and capable of sending signals back to the fiber input using light of a different wavelength or perhaps via a radio signal. It will be designed to sense many different physical quantities, including acting as a small microphone for detecting vibrations in inaccessible or harsh environments, as a point source for illumination or probing, as a light detector, or as a probe for local oscillating electric or magnetic fields. Perhaps the microbot could, by varying its orientation (if non-spherical) or its reflection coefficients against the incoming light, “swim” freely to and fro in the optical field upon instructions coded into the counterpropagating laser fields.

In the future it may be essential to monitor radiation levels and other parameters close to the core of a nuclear fusion reactor. Electronics cannot be used and solid-core fibers darken rapidly upon exposure to high levels of radiation. Flying particle sensors in hollow-core fibers will provide a solution: light generated by a radioluminescent particle is relayed back to the fiber input, providing a direct measure of radiation level, as well as other parameters.

Medicine

Endoscopy systems of the future will be multi-functional, enabling surgeons to carry out keyhole diagnosis, treatments, and surgery using a thin flexible cable containing a multi-core microstructured optical fiber with many advanced functions built into it. Such a fiber will be able to deliver drugs (perhaps photo-activated for treating all kinds of conditions including invasive cancer) in precise amounts through a hollow channel, transmit many different wavelengths of light appropriate for diagnosing the health of tissue, deliver selectable wavelengths of high-power laser light for tissue cutting and blood coagulation, and produce deep-UV light for killing cancerous cells. Each system is likely to have as standard a multi-mode fiber microscope for high-resolution “structured light” imaging of tissue at many different wavelengths. It will also have a built-in distributed electrically controllable transducer system (with feedback provided by optical bend and twist sensors) that will allow the fiber to be twisted, turned, coiled, and bent at the surgeon’s command.

So there you have it—a future where glass fibers will play an ever-increasing role in society and everyday life. Do some of these applications seem outrageous? Just think what has been achieved over the past half century in optical fiber communications. Maybe they are not outrageous enough . . .