loop construction but replaces the long central fiber coil with a circuit etched onto a semiconductor chip made from an alloy of indium, gallium, arsenide, and phosphide. The wavelength of the control pulse is tailored so that it excites negatively charged electrons and oppositely charged "holes" in the material to combine and give off photons. This elimination of charged particles changes the polarization of the material over a much shorter distance than the stretch needed by light to exert a similar effect in glass fibers. This in turn increases the semiconductor's index of refraction and slows the signal pulse.

This fast index of refraction change allows the device to switch extremely short pulses. But because the device can't switch again until the depleted electrons and holes are replaced—a comparatively slow process—it must wait longer than the fiber devices before it is ready to switch the next pulse coming down the line. The first device, for example, was able to switch light pulses at a rate of only 3 gigabits per second, says Prucnal. Since then, however, researchers led by Julian Lucek and David Cotter at British Telecom in Suffolk, U.K., have boosted the speed to 40 gigabits per second.

But instead of switching each pulse as it comes down the fiber, these devices can also be used to switch every 250th pulse, for example, in a common telecommunications task called demultiplexing. Such systems are currently used to reconstruct large signals that have been divided up into smaller chunks for ease of transmission; chunks from 250 of these large signals can be sent down a fiber in quick succession, and a TOAD can grab every 250th chunk, re-forming one original signal. In addition, Prucnal says, TOADs can pluck these chunks out at record speeds, when the main stream of data is moving at 250 gigabits per second. And semiconductor-based demultiplexers have the advantage over fiber-based systems, as they are smaller and should be easier to integrate with current semiconductor communications devices, says Prucnal. But before TOADs and their ilk make it to market, they will need to be integrated with other demultiplexing components on a single chip; Prucnal and others are currently pursuing this goal.

The performance of both the fiber-optic and semiconductor devices continues to improve, which is good, says Keith Blow, a physicist at British Telecom, because "the continued demand for bandwidth is not slowing." With electronics, he says, "you're probably going to run out of steam" to meet this demand. And that means the pull from the market, not only for optical switches but all the other NLO devices needed to create the information roadways of the future, is likely to get much stronger over time.

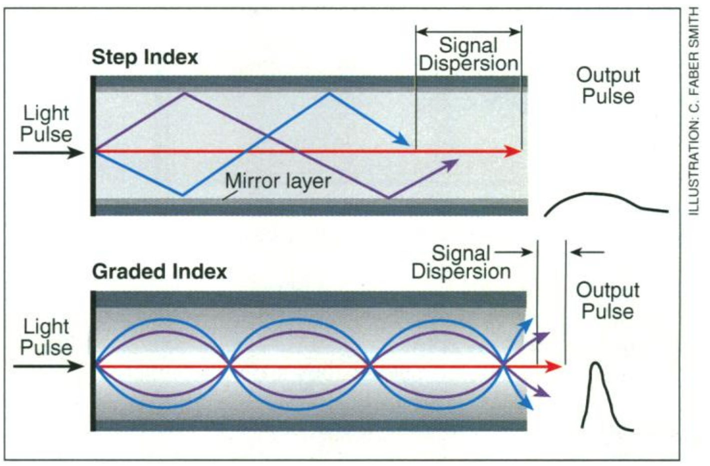
–Robert F. Service

TELECOMMUNICATIONS

Paving the Information Superhighway With Plastic

The deepest oceans and the highest mountains haven't stopped telecommunications companies from wiring the world with the latest in high-performance fiber-optic cables. But taking those fibers from the curb to your house—that's proven to be one tough trip. Now, a team of Japanese scientists has developed a new type of plastic cable that may overcome the roadblock.

While the glass optical fibers currently used for long-distance connections can transmit massive amounts of data in the form of pulses of light—theoretically up to trillions of bits of data, or terabits, per second—they are poorly suited to "short-hop" applications. Each is thinner than a hair, and expensive junction equipment is needed to precisely align an optical beam so it can jump from a "trunk" fiber into a local one. This makes the cost of wiring each and every home in a community prohibitive. In contrast, the copper wires that already feed movies to our televisions are cheap and simple to use. But they can't transmit nearly as much data as fibers do. For the technological visionaries who dream of sending 500 cable channels into each home simultaneously, "that's a bottleneck," says Edward Berman, president of Boston Optical Fiber Inc. in Marlborough, Massachusetts.



Making the grade. Graded-index plastic optical fibers *(bottom)* have faster lanes for photons near their perimeters, ensuring that—unlike step-index fibers—all the photons arrive closer together.

The solution, a group of Japanese researchers now says, can be found in one word: plastics. In a presentation last September at the European Conference on Optical Communication in Florence, Italy, materials scientist Yashuhiro Koike and his colleagues from Keio University in Yokohama described using a new type of plastic optical fiber to transmit light pulses from a red semiconductor laser at a blinding 2.5 billion bits per second—that's a transmission rate, or bandwidth, 25 times greater than that of the fastest copper cable. The performance is more than enough to handle the transmission demands of most short-hop applications for the foreseeable future, says Robert Steele, a plastic-fiber specialist with Delphi Packard Electric in Warren, Ohio. If a manufacturing process for producing large amounts of the plastic can be developed, it is "going to displace a lot of the copper going in," Steele says.

This is not the first time plastic optical fibers have been developed; they have been around for decades and used increasingly over the last 10 years for such applications as carrying information between sensors and processors in robots. And certainly the thought of using them to wire homes had crossed a number of researchers' minds. "Their diameter is larger [than glass fibers], which makes them more user-friendly to connect and install," says Berman.

But the traditional plastic fibers—known as step-index fibers—were not suitable for high-speed data transmission. One problem: Photons in each light pulse traveling down the fiber spread apart as they move. As a result, the pulses must be spaced far apart or they overlap, making it impossible to determine where one signal ends and the next begins. That limits bandwidth to 100 million bits per second over 100 meters of fiber.

The reason photons don't fly along in formation lies in the fiber makeup. Each is composed of a strand of solid plastic surrounded by a thin coating that acts like a mirror. As photons of light travel down these strands, they glance off the reflective walls. But different photons within a single light pulse glance off these walls at different angles. Those that bounce back and forth at steeper angles end up traveling a longer distance from one end of the fiber to the other, and as a result arrive at the other end well behind photons that took a more direct route. (This problem doesn't afflict long-distance glass fibers because their extremely narrow confines ensure that photons can only travel in one path.)

Since the early 1980s, Koike and other researchers around the world have been trying to get around this problem by experimenting with a type of plastic fiber known as graded index, whose composition changes to create slow lanes for photon travel in the core and high-speed lanes at the perimeter. Although photons that travel from side to side still cover longer distances, they also spend more time in the outer fast lanes than do the straight-flying photons, which plod down the middle. "As a result, there is less dispersion, [because] the different rays of light get to the end at the same time," says Steele. This allows light pulses to be spaced more closely together, boosting the amount of information the fiber can carry.

These fibers create this dead heat among photons because they are made of materials that transmit light at different speeds. This speed is given by each material's index of refraction; the higher the index, the more slowly light travels. In making their early graded-index fibers, Koike and his colleagues started with a hollow tube made from a common fiber polymer known as poly(methyl methacrylate), or PMMA. They then filled the tube with a mixture of two different polymer building blocks, or monomers: MMA, the singlet version of PMMA, and vinylbenzoate (VB), with a slightly higher index of refraction than MMA. When the researchers then shone ultraviolet (UV) light on the tube, the monomers absorbed energy and began to polymerize. And because the concentration of UV light was highest at the periphery, this polymerization progressed from the tube edges into the core. But the monomers polymerized at different rates. MMA polymerized first, producing PMMA, most of which ended up near the edges of the tube. Because PMMA formed first, it squeezed VB into the center before it too turned into a polymer. And VB's slower rate of light transmission created a slow lane for photons.

PLASTIC POWER

Carrier	Bandwidth over 100 m (megabits per second)
Copper wire	100
Step-index plastic fiber	100
Graded-index plastic fiber	2500

Wider wiring. The new plastic optical fibers can transmit huge amounts of data over short distances.

These early graded-index fibers had a serious drawback, however: They dispersed much of the light they were supposed to transmit. The problem, explains Koike, was that "the [polymerized] VB tended to agglomerate" inside the fiber, creating large unruly tangles of polymer chains that scattered most of the light coursing down the fiber. And as a result, the signals transmitted in these fibers quickly faded.

In 1992, however, Koike and his coworkers discovered a new technique for producing graded-index fibers that carry a signal down the line with less scattering. To make their new fibers, the Keio researchers started with the same hollow PMMA tube. But this time they did away with the VB and filled the tube with a mixture of MMA and so-called "dopant" molecules such as benzyl methacrylate and diphenyl sulfide, which have a higher refractive index than MMA. They also used heat instead of UV light to polymerize their monomer. In this case, heating the tube caused a gel layer to form at the interface between the tube wall and the MMA-dopant mixture. In the gel phase, the MMA molecules quickly began to connect themselves to the PMMA chains in the tube wall, pushing the gel layer farther into the core.

At the beginning of this polymerization process, a few of the dopant molecules were trapped in the polymer matrix near the edges, but most were pushed toward the core of the tube. As more polymers formed, they trapped atoms from this more concentrated region while pushing ever-higher concentrations of dopant molecules into the center. At the end, the researchers had a solid PMMA fiber with a continuously graded concentration of highly refractive dopants. And because these dopant molecules don't agglomerate, optical losses in the fibers were reduced.

The new fiber doesn't dispense with the signal degradation problem altogether. Optical signals "still get knocked down by a factor of around 30" after they pass through 100 meters of fiber, says Harry Lockwood, an optoelectronics consultant with the Lockwood Group in Newton, Massachusetts. "But it's still very usable," he adds, because 100 meters is ample for wiring most homes or local computer networks within offices.

Before the new fiber is ready for the market, companies must still work out how to ramp up production to industrial scale. That effort is already well under way among consortia members, such as NEC, Honeywell, Boeing, Sumitomo, Boston Optical Fiber, Packard Hughes Interconnect, and Mitsubishi. And with the new fibers commanding 25 times the bandwidth of both step-index fibers and the fastest copper wires, it's likely this scale-up will be moving fast as well.

–Robert F. Service

BIOPRESERVATION

Putting Proteins Under Glass

Remember Sea Monkeys? Advertised in comic books as a no-fuss, no-muss pet oddity, they come as a package of dried powder. In an aquarium, each powder grain grows within days into a live swimming creature—an embryonic brine shrimp, to be exact. As pets, the miniature shrimp aren't all that exciting, but their phoenixlike resurrection impresses a lot of kids.

And it isn't just kids who are impressed. Scientists and pharmaceutical companies that want to increase the shelf life of protein-based drugs are looking for better ways to store proteins and bring them back to life intact. Freeze-drying, the most widely used method, can bend proteins out of shape. Over the long term, this can lead to degradation of the protein's crucial active sites. "If we have 18 months on a product at room temperature we're delighted," says Michael Pikal, a pharmaceutical scientist with Eli Lilly in Indianapolis, Indiana.

To build a better shelf life, Pikal and other researchers are taking their cues from the Sea Monkeys. Brine shrimp—along with a variety of seeds and micro-organisms—appear to preserve themselves by transforming themselves into a glassy state. Sugars in their bodies encase their cells like sheaths of rock candy, holding proteins nearly immobile. In this "amorphous" condition, the molecules that make up the proteins exist somewhere between the disorder and mobility of a fluid and the orderly immobility of a crystalline solid.

Like the glassy states themselves, researchers' knowledge of these conditions is somewhat amorphous. There is great uncertainty, for instance, over just how the sugars preserve the proteins. In spite of the many unknowns, researchers have, through trial and error, recently found ways to use the glassy state to protect drugs. In the lab, Pikal has used it to keep human growth hormone twice as stable as does Lilly's current process. John Carpenter, a pharmaceutical scientist at the University of Colorado Health Sciences Center in Denver, reports that he and colleagues at Amgen in California have been able to maintain interleukin-1 receptor antagonist protein in a glassy form for 14 months at 50 degrees Celsius, with only 2% degradation. He was even able to bake it at 100 degrees Celsius for 5 minutes with no damage.

The allure of these findings is that phar-