Plastic Opto-Chips Offer Promise of Greater Communications Bandwidth

Government-funded academia team generates breakthrough that may help eliminate fiber bottlenecks and open new applications.

A new polymer-based electro-optic modulator may provide fiber optic networks with an order of magnitude increase in bandwidth that could clear the way for applications ranging from broadband Internet access to full-scale holographic projection currently found in science fiction television programs. Developed in a joint research effort by scientists at the University of Southern California (USC), Los Angeles, and the University of Washington, Seattle, the new technology also uses less power than present-generation modulators and features low noise disturbance.

Near-term benefits could be realized in systems such as large communications networks, electrically steered antennas and radar transmitters, and optical gyroscopes in airborne guidance systems. For the long term, the technology has the potential to open up as many new applications as emerged from the development of silicon semiconductors some 30 years ago.

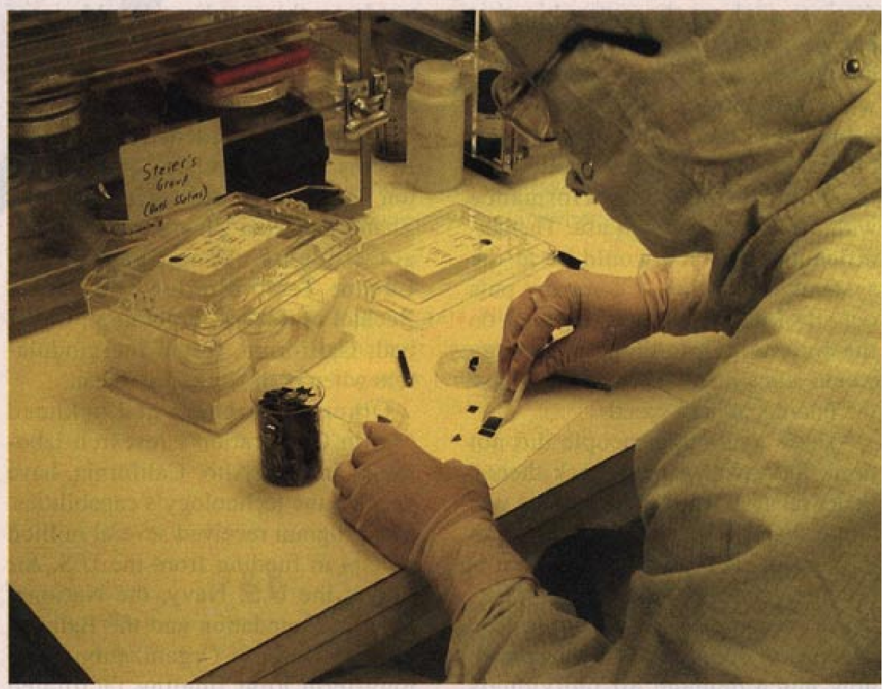
The niche technology can provide rapid results in very-high-bandwidth fiber optic communications. This type of modulator serves as the interface that places electronic data onto an optical carrier for transmission across a fiber optic network. As more telecommunications customers demand high-bandwidth links such as digital subscriber line (DSL) to the home, fiber optic systems increasingly are hard pressed to meet these demands. The new modulator moves this accumulated data from individual users onto fiber optic networks.

"The biggest problem in telecommunications is the I/O [input/output] problem," states Dr. Larry R. Dalton, professor of chemistry and engineering at both the University of Washington and USC, and head of the multisite team that developed the technology. "How do we go from the electrical domain to the appropriate transport domain?"

"It is a key component to enable fiber optic systems to go at much wider bandwidths and with much lower signal power required," says Dr. William H. Steier, professor of electrical engineering at USC. Steier, part of Dalton's team, explains that these types of modulators traditionally are mounted at the hub locations on a network where electronics are converted to optics. This technology will permit these modulators to be integrated on a single chip with the signal processing.

Preliminary tests indicate that a single modulator measuring about 1 micron can provide more than 300 gigahertz of bandwidth. Research program officials say that this would be enough to carry all of a major corporation's telecommunications, computer, television and satellite traffic.

Currently, most fiber optic networks employ wavelength division multiplexing, or WDM, technology. Each system accommodates large



Min-Cheol Oh, University of Southern California (USC) research associate in electrical engineering/electrophysics, works with recently developed polymeric electro-optic chips in the university clean room. These new chips have the potential to eliminate bottlenecks in optical links, which would vastly increase bandwidth over fiber.

Dr. Larry R. Dalton, professor of chemistry and engineering at both the University of Washington and USC, is the head of the multisite team that developed the polymer electro-optic modulator technology.

numbers of optical wavelengths, each of which is modulated and carrying data. To place even more optical wavelengths, each modulated and carrying data, on a fiber will require devices such as the opto-chip that allow modulating each wavelength component at a much wider bandwidth with lower signal power.

Individual users downloading pages off the Internet would not notice any real improvement in performance with these opto-chips in use. The significant difference would be at the systems level when a company puts out all of its DSL signals together on the Internet. Opto-chip technology would allow many more people to use the Internet at high speeds.

"Three years ago, people did not think there was a bottleneck there," Steier relates. "They thought there was ample bandwidth on fiber networks throughout the country. Suddenly, it is becoming apparent that there is a bottleneck because people did not realize, in terms of speed and data download, how much demand all individuals would need in their homes."

Steier relates that the modulator's evolution was a joint effort among chemists, electrical engineers and optical engineers to develop the new polymer materials and adapt them for use in high-speed optical devices. Bringing this diverse group together could have been a daunting task, but all of the participants were eager to work on this application. Many of the principals have been working together for about eight years. In addition to Dalton and Steier, other participants included Dr. Bruce H. Robinson, a University of Washington chemistry professor; and Cheng Zhang and Hua Zhang, USC graduate students. Yongqiang Shi of Lucent Technologies and James Bechtel of Tacan Corporation, Carlsbad, California, tested the modulators when both worked at Tacan.

Other researchers at Lockheed Martin Corporation's research laboratory in Palo Alto, California, have verified the technology's capabilities. The program received several million dollars in funding from the U.S. Air Force, the U.S. Navy, the National Science Foundation and the Ballistic Missile Defense Organization. This long-term joint funding facilitated the interdisciplinary interaction and was vital to the program's success, Steier states.

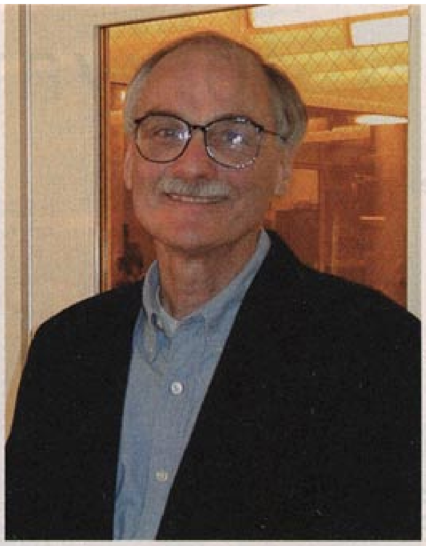
These researchers had to overcome several technological hurdles. First, according to Steier, came the development of effective electro-optic polymer material. The program's polymer chemists focused on designing and manufacturing these materials. These chemists, in turn, worked with the optical engineers to incorporate their advances into optical devices. This required developing the necessary clean room and fabrication methods to manufacture this optical waveguide technology.

The competing technology for these polymer devices currently is lithium niobate, a crystalline technology that has been in the works for several decades. Steier offers that lithium niobate modulators are limited to a speed of between 10 and 20 gigabits per second, and they each require an operating voltage of between 4 and 5 volts. The current polymer modulators have a drive requirement of less than 1 volt and can operate at from 40 to 80 gigabits per second. This lower power consumption also results in reduced heat, which usually comes from the drive electronics. The tests at Tacan Corporation employed modulators using less than 1 volt of electricity to translate cable television signals into optical signals.

Dalton notes that these polymer devices will not replace all lithium niobate systems, especially those in standard, single modulator device applications. Existing lithium niobate foundries can fabricate production quantities of these devices, while the polymer modulators have yet to achieve economic production. When the polymer units gain general acceptance and achieve economies of scale, then they can compete with the more traditional technology. The key cost may not be in the device's manufacturing but in how the technology is incorporated into a fiber system, he suggests.

Inventing the polymer technology required developing theoretical guidance on building the right system, Dalton explains. Lithium niobate and gallium arsenide are discrete materials with properties that cannot be changed substantially. Polymers, on the other hand, feature a modular approach to construction. They consist of a general class of materials made up of individual modules fitted together, offering a virtually infinite array of design possibilities. Determining the right combination of chromophores and lattices became an issue of quantum and statistical mechanics, he says.

The significant breakthrough came with the development of a better condensed matter theory of statistical mechanics, Dalton continues. This showed the researchers how to design the shape of the molecules as well as the individual electroactive components. For example, positioning inert material around electroactive material affected the electro-optic coefficient dramatically. "The driving force was actually a major breakthrough in theory," he warrants.



Dr. William H. Steier, professor of electrical engineering at USC, is focusing on integrating polymeric electro-optic modulators on silicon chips.

Dalton suggests that military applications could include guidance, radar and electronic countermeasures. In the commercial sector, both satellite and fiber optic telecommunications could be prime beneficiaries. "The exciting thing about these is that we can do so many things that you just couldn't do otherwise," he emphasizes. "With cleverness, you can produce so many devices that can realize possibilities that weren't realized before."

For example, phased array radar depends on extremely fast switching speeds to obtain good 360-degree instantaneous radar coverage. Dalton notes that prototype devices exploiting several different concepts have been demonstrated in this application. Even the commercial sector could employ these devices in telecommunications applications of phased arrays, especially in satellite links.

The U.S. Defense Department already is pursuing wideband optical applications that would require these types of modulators. The Defense Advanced Research Projects Agency's radio frequency (RF) photonics program aims to enable ships to collect the vast amounts of data accumulated by their many antennas by modulating their signals into a single optical carrier. That fiber, immune from electromagnetic interference, would carry this very wideband data back to a central processing location.

Steier offers that the first commercial customers of these modulators likely would be firms that operate fiber optic systems, such as the regional and international telecommunications companies. Even large corporations that run their own high-bandwidth optical networks could use the modulators. He notes that the demand for bandwidth on the nation's communication infrastructure is increasing much faster than experts envisioned. Many equipment providers have expressed enthusiasm for 80-gigabit modulators, he adds.

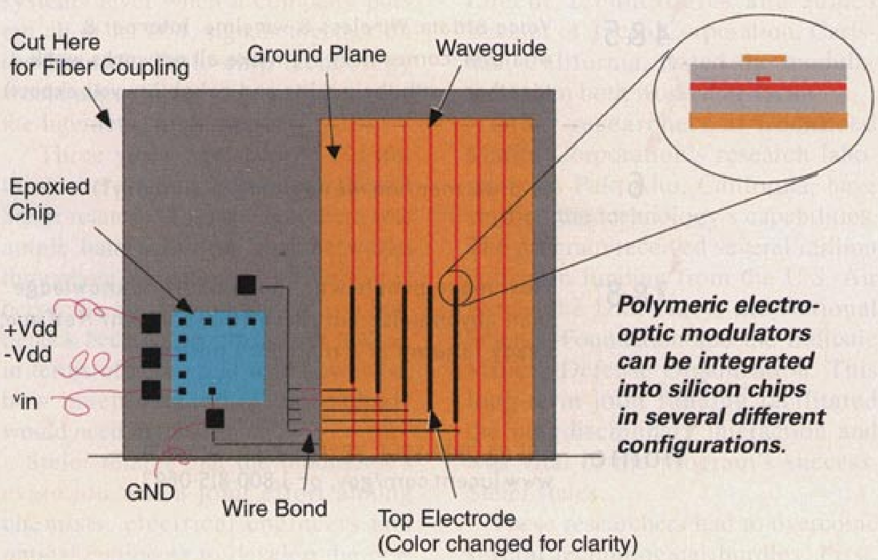
Dalton agrees that business-to-business applications are likely to be the first commercial uses. Individuals shortly thereafter may be able to benefit, however. Downloading a computer to fiber optic transmission requires a high signal transduction rate. Bringing optical fiber to the home could be enhanced by using these devices in signal transduction. This would permit a home computer user to download the contents of his or her computer onto the Internet instantly, Dalton says. "You have a 120-gigahertz bandwidth to play with, which is certainly orders of magnitude better than current download rates," he adds.

Homeowners also could use the devices as sensors. Installed as voltage sensors, the modulators could be connected to a computer as part of a home monitoring system.

Another application is for ultra-stable tunable oscillators. Incorporating this modulator technology, Dalton suggests, could introduce stabilities approaching those of atomic clocks. The optical devices also could serve in backplane interconnects between parallel processor boards in supercomputers.

"In the long term, the field will be truly impressive," he adds. "It will be just like silicon—it's just going to spin off so many different application areas, from analytical instrumentation to biomedical sensing."

One long-term development might be three-dimensional holographic projectors free of image flutter. These modulators would enable a holographic system to pump the vast amounts of bandwidth necessary for this type of image. This development lies some distance away in the future because the projection technology is not mature enough, Steier says. However, the development of these modulators that enables the easing of



Polymeric electro-optic modulators can be integrated into silicon chips in several different configurations.

bandwidth limitations might help spur the development of projectors.

The next step for the researchers is to move these modulators from the laboratory into the commercial marketplace. Commercializing the technology first will require significant long-term testing for temperature and photo-stability. This work is underway.

Several companies are actively pursuing this commercialization. These include Pacific Wave Industries, Los Angeles; Tacan Corporation; and Microvision, Seattle, as well as potentially larger companies. Steier predicts that the smaller firms will be sending commercial devices to other firms to begin long-term testing within six months.

While the materials are inexpensive, the cost of their engineering into a usable package is yet to be determined. Significant research remains to enable integrating the optical modulators on chips. Fabricating the interconnections between the high-speed electronics and the optical devices is a challenge. Another hurdle involves placing the polymer devices on the electronics without destroying either the polymer or the electronics during the fabrication process. Commercial-level success may not emerge from the laboratory for several years, Steier suggests.

Steier's laboratory team has succeeded in integrating polymeric materials with semiconductors. Dalton notes that this has been achieved in both horizontal and vertical integration, where polymeric electro-optic circuits have been produced on top of very-large-scale integration semiconductor chips. This involves placing a layer of planarizing polymer with an optical-quality surface on top of a chip. The fabrication process permits fabricating the electro-optic surface on that layer. Reactive ion etching techniques handle deep interconnections.

The same etching technology can be teamed with shadow ion etching or gray-scale etching to build three-dimensional, vertically integrated passive/active optical circuits. This permits constructing an optical waveguide that vertically links different chip layers. Dalton believes that the biggest challenge will be to make the necessary connections for alignment of a whole array of optical fibers coming into this three-dimensional circuit. These fibers must be positioned simultaneously so that they match all of the fabricated circuits.

The new modulator technology is not bound to its current polymer makeup, however. Chemists actively are pursuing development of even better materials, Steier reports. "The chemistry is pretty well understood. [The challenge] now is making these materials that have the proper optical effects in addition to the large electro-optical effect," he explains. "We have great hopes in the future that even better materials will come out of this."

Dalton focuses on the electro-optic coefficients as the real quantifiers for improvement in the technology. "They currently are about four times those of lithium niobate, but we are a long way from what theory tells us is the optimum material," he declares. *—RKA*

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