Thiner Wires

Physicists develop optical fibers that will be able to connect circuits in the computers of the future

Marcos de Oliveira

No one notices and few know that any email sent out of Brazil, or access to an American website, for example, is done via fiber optic cables. These thin tubes made of purified silica sand carry information back and forth using laser light. Now, the same principle is beginning to be used to design future computers in a technological trend that advocates the use of circuits made entirely of light. The idea is to use optical micro- and nanofibers to connect future computer circuits. These devices are being studied in Brazil and were developed in the Special Fibers Laboratory (LaFE) of the Gleb Wataghin Institute of Physics (IFGW) at the State University of Campinas (Unicamp).

"In the future, these micro and small fibers may serve to connect or filter circuits in computers, where light from lasers can be used in place of the current chips," says Professor Cristiano Monteiro de Barros Cordeiro, coordinator of the project at the Optics and Photonics Research Center (CePOF) in Campinas, led by Professor Hugo Fragnito and funded by FAPESP's Program for Research, Innovation and Dissemination Centers (RIDC).

The new fibers are up to five hundred times thinner than a strand of hair, or 500 nanometers (1 nanometer equals 1 millimeter divided by 1 million). Commercial fibers are much larger, with a diameter of 125 microns, so a bit larger than a human hair. "This use of micro- and nanofibers is still futuristic, but researchers think that current communications between chips via electrons traveling through metals could be replaced by trails of light," says Cordeiro.

Small glass tubes that, when heated, are transformed into glass fibers

Although still considered a dream, micro- and nanofibers offer the prospect of lower power consumption and less system heating, an important characteristic for the main function for which they are candidates—to interconnect chips and other circuitry inside a computer. Some of the new fibers have a diameter of 1 micron and are therefore smaller than the wavelength of the laser beams typical of these devices—1.5 micron—used in current optical communications. Thus, part of the light is outside the fiber wall, but the light wave continues to travel along the length of the device. "Whether this portion of the light outside the fiber helps or hinders future optical interconnection is still an open question in groups studying these fibers all over the world," says Cordeiro, who has been studying this type of fiber since 2009. Among these groups are the University of Southampton, in the UK, and OFS Laboratories, in the United States, related to the company Furukawa, in Japan

These fibers can also be used as optical sensors, an aspect that was the subject of a patent filed with the Brazilian Industrial Property Institute (INPI) in late 2011. The group produced a fiber with a sensitivity to mechanical tension 50 times greater than existing fibers. They can be used in construction, for example glued along the length of a bridge to measure the deformation of the structure when a truck crosses based on the change in the light transmitted.

The study and design of optical fibers and other areas of laser communication is now a tradition in the IFGW laboratories at Unicamp. That is where the first optical fibers in Brazil were created, in the late 1970s, when they were still a novelty even in countries with advanced technology. The first was in 1977, developed by professors Rogério Cerqueira Leite, José Ripper Filho and Sergio Porto. They worked as researchers at Bell Labs in the United States, the research center where transistors and lasers were invented, and where the first optical fiber tests were performed. They saw the importance of the work being performed with lasers and fibers in telecommunications at Bell Labs and brought the innovative idea back to Unicamp.

The next steps in these studies included professors Hugo Fragnito, Carlos Henrique de Brito Cruz, now the scientific director of FAPESP, and Carlos Lenz, all researchers who had worked at Bell Labs. "At Bell Labs, we often discussed the future and determined what we had to study today and what would be important in the coming decades," says Fragnito.

Thus, fiber optics research at IFGW involved several areas, such as the study of photonic crystal fibers, a special type. They are also able to confine and carry light from one end of a fiber to the other, but not for long distances. Since their microstructure contains air holes, multiple cores, and new materials, they would be better employed in other applications, such as in industrial equipment, precision clocks, sensors, medical diagnostic equipment or in electronic devices.

Photonic crystal fibers—already manufactured by companies in Europe—are being used, for example, in new light sources and optical communication amplifiers to recover signals in transmission networks. IFGW research in the area of microstructured fibers includes a partnership with the University of Bath, in England, where the first photonic crystal fiber was created, the University of Sydney, in Australia, and the Max Planck Institute for the Science of Light in Erlangen, Germany.

In 2007, Unicamp researchers, in partnership with colleagues from other institutions, developed and filed three patents relating to photonic crystal fibers. The first deals with the structure of these thin tubes of glass. Contrary to traditional fibers, they contain holes,

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which run parallel to the axis of the fiber along its entire length. The microholes allow more efficient control of the direction the light travels, based on the characteristics one wants the fiber to have.

The researchers from Unicamp and the Photonics and Optical Communications Laboratory at Mackenzie Presbyterian University, in São Paulo, created new holes around the core to allow the fiber to act as a biological or chemical sensor. Thus, the light follows its traditional path and lets the gas or liquid to be analyzed enter into the fiber through the lateral holes. Analysis is based on the diffraction of the portion of the light that travels from the core to the shell of the fiber and encounters the material.

In the second patent, researchers from Unicamp and the University of Sydney, Australia, made tears several centimeters long along the fiber instead of holes. "This fiber will be good for chemical sensing of leaks in industry or even in oil wells," says Cordeiro, who, after his doctorate at Unicamp, held a post-doctoral position in the lab of the creator of photonic crystal fibers, the British researcher Philip Russell, at the University of Bath, England. Russell currently works at the Max Planck Institute in Germany.

The third patent, also developed in partnership with Mackenzie University, is about a photonic crystal fiber whose core and shell (the part of the fiber that surrounds the core) are filled with different liquids, such as water or ethanol. Researchers have used water in the shell and a mixture of water and glycerin in the core without them mixing. This fiber is intended for probing and sensing, for example, when performing spectroscopic analysis of liquids to measure the emission or absorption of electromagnetic radiation of a substance.

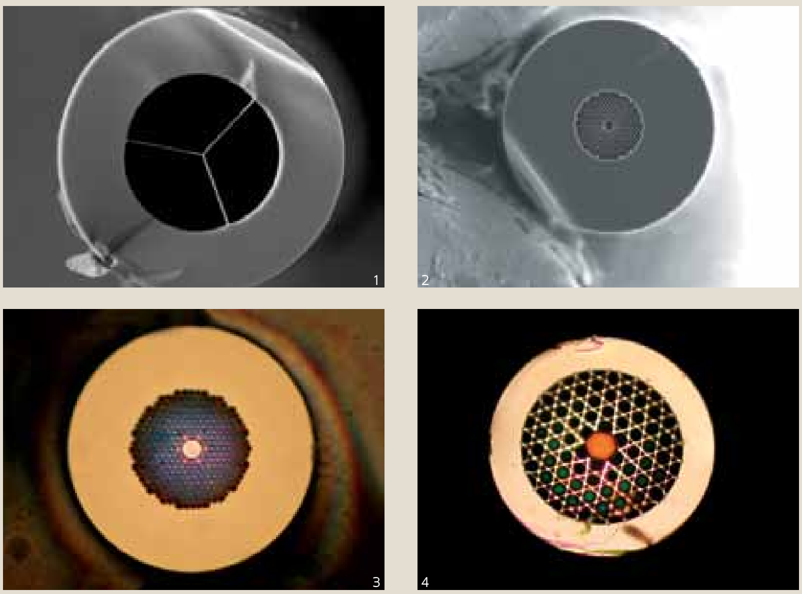
Another achievement in the area of photonic transmission research was the experiments with an amplifier for optical transmission lines. Between 2007 and 2009, Fragnito's group managed to beat world records for transmission bandwidth capacity using an amplifier developed at Unicamp. It was able to receive and transmit multiple laser signals at the same time in a wide spectrum of electromagnetic waves used for telephony and data transmission, which does not happen in conventional equipment.

The purpose of these amplifiers is to reinforce the light signal, which travels along the fibers, principally between cities and in international connections — a distance of 20 km to 100 km. It recovers the light wave, which loses strength over distance. The technological advances of the new amplifiers are essential to increasing the capacity and speed of the telecommunications system and reducing the cost of deploying new networks.

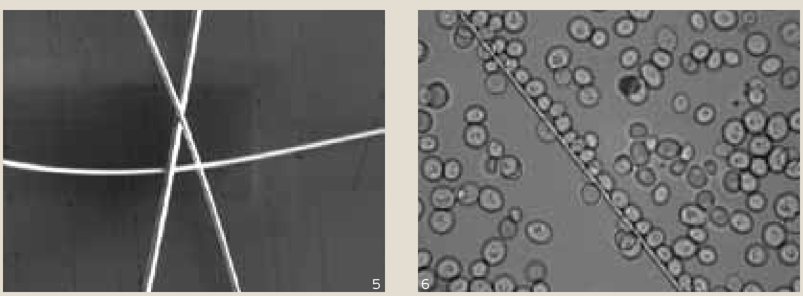
The new generation of optical amplifiers are called Fiber Optic Parametric

Functional Diversity

Properties of fibers vary depending on their structure



Tunnels in fiber microstructures regulate the passage of light in photonic crystal fibers



Experimental nanofibers (image 5) may become components of computer chips; some versions use bacteria (Fig. 6)

PHOTOS 1. IFGW-UNICAMP **2.** BATH UNIVERSITY **3.** IFGW-UNICAMP **4.** CRISTIANO CORDEIRO **5 AND 6.** CLAUDECIR BIAZOLI/IFGW-UNICAMP **7.** MARCELO GOUVEIA/IFGW-UNICAMP

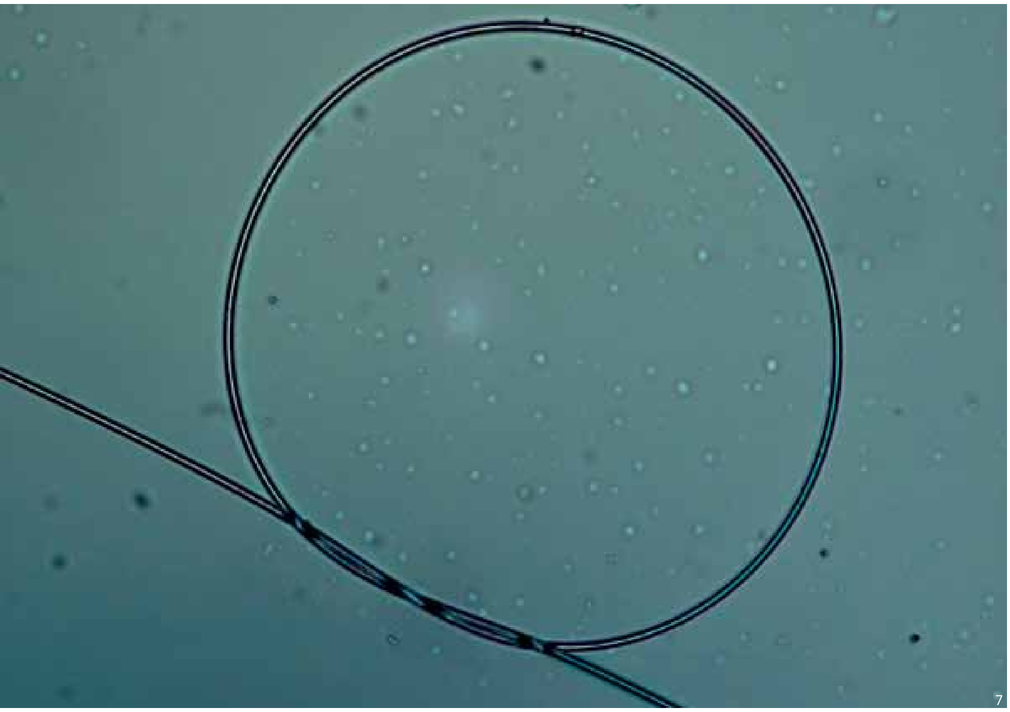


Image of a microfiber with a 3-micron diameter, obtained by electron microscopy at Unicamp

Amplifiers (FOPA), and are studied at Unicamp and other centers, such as Bell Labs, currently a part of the company Alcatel-Lucent, Stanford University and Cornell University, in the United States, and Chalmers Institute of Technology, in Sweden, in addition to Japanese and French companies. The knowledge embodied in the new amplifier can prevent future congestion of the Internet. According to Fragnito, no one knows for sure what applications will be needed in the future. "What we know is that television or movies with the highest resolution possible will need to be rapidly transmitted. In some situations, the current transmission capacity is reaching the limit. One idea circulating in optical communications research is that each fiber could have more independent cores, each with multiple wavelengths," says Fragnito, who, in addition to CePOF, coordinates the National Institute of Photonics Science and Technology for Optical Communications (Fotonicom), which receives funding from FAPESP and the National Council on Scientific and Technological Development (CNPq).

"With current technology, we can transmit 40 laser channels and each one can carry 100 gigabits per second (Gb/s) for a total of 4 terabits per second (Tb/s). Using FOPAs, we could transmit ten times more, i.e. 40 Tb/s per fiber or, to give an idea of what this means, practically all Internet traffic through a single fiber. Today this seems like a lot, but in a few years it will be insufficient to meet growth needs. If, instead of one core per fiber, we could have another six, for a total of seven, transmission capacity would be 280 Tb/s in one optical fiber," said Fragnito.

He believes the key challenges in enabling Internet growth over the next 15 to 20 years are increasing network capacity by a factor of 100 to 1000, and reducing the cost, size and power consumption of network equipment by the same factor. "To this end, at Fotonicom, in addition to FOPAs and multicore fibers, we are developing integrated optics incorporating hundreds of lasers, amplifiers, receivers and other devices in a small chip measuring just a few microns."

The area of optical communications is advancing to support new media and the Internet. Once electrical signals are converted into light, there will be no turning back, but this will only happen definitively when all transmissions and circuits use optical fibers or new optical waveguides. "We still have very difficult problems in the area of optical fibers, representing great scientific challenges," says Fragnito. ■

PROJECTS

1. Optics and Photonics Research Center at Unicamp (CePOF) – No. 2005/51689-2 (2006-2012)
2. Photonics for optical communications No. 2008/57857-2 (INCT) (2009-2014)

GRANT MECHANISM

1. Research, Innovation and Dissemination Centers (RIDC)
2. Thematic Project

COORDINATOR

1. and 2. Hugo Fragnito – Unicamp Institute of Physics

INVESTMENT

1. R$1 million a year to CePOF
2. R$2,950,799.01

SCIENTIFIC ARTICLES

1. Chavez Boggio, J. M. *et al.* Spectrally flat and broadband double-pumped fiber optical parametric amplifiers. **Optics Express**. v. 15, n. 9, p. 5288-309, 2007.

2. Chesini, G. *et al.* Analysis and optimization of an all-fiber device based on photonic crystal fiber with integrated electrodes. **Optics Express**. v. 18, nº 3, p. 2842-48, 2010.

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