Optical fiber innovation could make future optical computers a 'SNAP'

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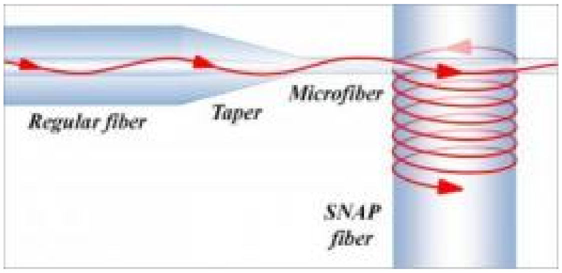


This figure shows the propagation of light in a SNAP fiber coupled to a tapered regular optical fiber. Credit: Courtesy OFS Laboratories

Optics and photonics may one day revolutionize computer technology with the promise of light-speed calculations. Storing light as memory, however, requires devices known as microresonators, an emerging technology that cannot yet meet the demands of computing. The solution, described in a paper published today in the Optical Society's (OSA) journal *Optics Letters*, may lie in combining light's eerie quantum properties with a previously unknown quality of optical fiber.

Researchers from OFS Laboratories in Somerset, N.J., have developed a precise and efficient way to create microresonators by making nanoscale changes to the diameter of normal optical fiber. These narrow sections are able to confine light, sending it on a back-and-forth corkscrew path inside a length of optical fiber and creating a microresonator.

Though trapping light in this so-called "Whispering Gallery" mode is a well-known phenomenon, the researchers have discovered a quick, efficient, and accurate way to manufacture long chains of these new microresonators, all based on a never-before-recognized characteristic of optical fiber. This is a new technology path and an essential step toward designing a practical optical computer, as described in the Optics Letters paper.

"Optical computers, which use light particles—photons—in place of electrons to process and store information, have the potential to be much faster than today's electronic computers," said Misha Sumetsky, a researcher at OFS Laboratories and lead author on the study. "Unfortunately, manufacturing microresonators that meet the demands of optical computing has been a long and, until now, unsuccessful pursuit."

Microresonator Design

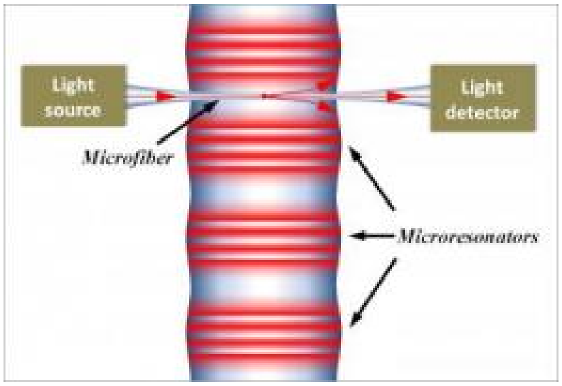
Designing a practical microresonator has been something of a "Holy Grail" on the path to optical computers. The current microresonator manufacturing technology is based on the well-established process of silicon lithography, which etches extremely precise features onto silicon wafers. For microresonators the most promising design appeared to be a long series of microscopic loops, which bottle up photons in whirling circles and then pass them from one ring to the next. The longer the chain, the longer the signal could be stored as memory. Unfortunately, even the most precise manufacturing processes still produce tiny imperfections in the rings. These bumps on the road slowly weaken the signal, attenuating the light, and allowing the memory held in the buffer to fade away.

Sumetsky and his colleagues at OFS Laboratories, formerly part of the famous Bell Labs, pursued a path that abandoned the silicon wafer in favor of the silica strand of optical fiber.

In conventional applications, optical fiber—a very pure form of glass—uses the fundamental properties of light and refraction to keep light from slipping out and diffusing. The core and cladding of optical fiber have slightly different indexes of refraction, giving the fiber the ability to bend the path of light without causing scattering. Light traveling through the fiber bounces back and forth inside the core, keeping it traveling along the fiber for many kilometers with very little signal loss.

Coaxing Light into a Whispering Gallery

This sends the light careening through the fiber at extremely high speed, but just as cars barreling down the highway sometimes get directed onto "cloverleaf" off ramps, so too can light be coaxed from the fiber and into a spiral path. Unlike cars, however, light doesn't need to slow down on the off ramp.



This figure is an illustration of SNAP microresonators formed by nanoscale variation of the optical fiber diameter. Credit: Courtesy OFS Laboratories.

In this case, the off ramp is created by narrowing the fiber to a small diameter to coax the light out of the core and into a fiber aligned perpendicularly and positioned very close to, or actually touching the first. Because they are so close, and the original fiber narrows down to a mere fraction of its original size, a portion of the light is able to make a literal "quantum leap" to the other fiber. This is an effect known as "evanescent coupling" and it enables an electromagnetic wave – light – to connect (or couple) from one fiber to another.

The light now finds itself not traveling down a straight path but rather racing around the fiber surface in very tight circles. Even though the light maintains its original pace within the glass, because it's really taking the long way around, corkscrewing along the new fiber's surface, it propagates down the fiber at a fraction of its original speed (figure 1).

This special redirection of light is known as the "Whispering Gallery" effect, named after the phenomenon that takes place in certain architectures, such as the St. Paul's Cathedral in London and Grand Central Station in New York, where someone whispering along the wall would hear their whisper coming from behind them as the sound traveled around the edge of the room and returned to its original spot (figure 2).

Optical Fiber Microresonators

Sumetsky and his colleagues were able to vary the optical fiber diameter by several nanometers. They did this with unprecedented precision, on the order of a hundredth of a nanometer.

This dimpling or narrowing of the fiber effectively changes the properties of the Whispering Gallery and has the effect that light traveling along the surface of the fiber would turn around and head back the way it came. If it were traveling between two of these narrowed portions of fiber, the light would continue to resonate back and forth with very little loss of signal. This is, in fact, the microresonator.

These optical fiber microresonators currently are able to retain light two orders of magnitude longer than lithographic microresonators – and the researchers say it's possible to push that number even higher.

If sufficient number of optical fiber microresonators were coupled together, again taking advantage of evanescent coupling, then any information contained in the light pulses could be stored long enough for computational purposes. The researchers have so far been able to couple 10 optical fiber microresonators, an important proof-of-concept step.

Manufacturing is a 'SNAP'

It's possible to create these nanoscale changes to the radius of the fiber by exploiting a property inherent in the fiber created during manufacturing and discovered at OFS Laboratories several years ago. Optical fiber is made by heating a much thicker rod of glass with a precise chemical makeup and stretching and drawing it out into extremely fine and flexible fibers. When the fiber is drawn out, the process introduces certain tension, and this tension is frozen in, creating a predetermined amount of stress.

The researchers harnessed this fixed stress by directing a laser beam at the fiber to heat it. By raising the fiber's temperature, but keeping it well below the melting point, it was possible to release this intrinsic pressure, changing the diameter and refractive index of the fiber without deforming it any further. As long as the fiber is produced under the same conditions and it is heated below the melting point, the same effect is always achieved. This process enables a technology that the researchers call Surface Nanoscale Axial Photonics (SNAP).

"We heated it to a temperature lower than the melting temperature," said Sumetsky. "This annealing allows us to change the radius in this nanoscale range. In the new system, the accuracy of the fiber radius variation is about 0.1 angstrom – orders of magnitude better than achieved before."

Previous attempts have been made at harnessing optical fiber for microresonators, but these relied on polishing or melting the fiber to change its diameter. This produced very uneven results and could not achieve nanoscale dimensions. To enable evanescent coupling, it's vital that the circumference of the microresonators be controlled to sub-angstrom accuracy. The SNAP process ensures this accuracy and that each microresonator is nearly identical.

This is the crucial point the researchers believe will enable the technology to move from laboratory studies to manufacturing. As long as the optical fiber is produced under the same conditions, it will always produce the same effect when heated, changing its properties in the same precise manner. "We can faithfully reproduce these resonators. There's a real, robust way of fabricating these, and this is the first paper that actually shows that," Sumetsky said.

According to the researchers, it's possible these microresonators could be used in specialized devices in about two to three years. However, their greatest potential may be in pioneering optical computing and in enabling fundamental physics research.

More information: "Surface nanoscale axial photonics: Robust fabrication of high quality factor microresonators," *Optics Letters*, Vol. 36, Issue 24, pp. 4824-4826 (2011). www.opticsinfobase.org/ol/abst … fm?uri=ol-36-24-4824

Provided by Optical Society of America

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