In a first for wearable optics, researchers develop stretchy fiber to capture body motion

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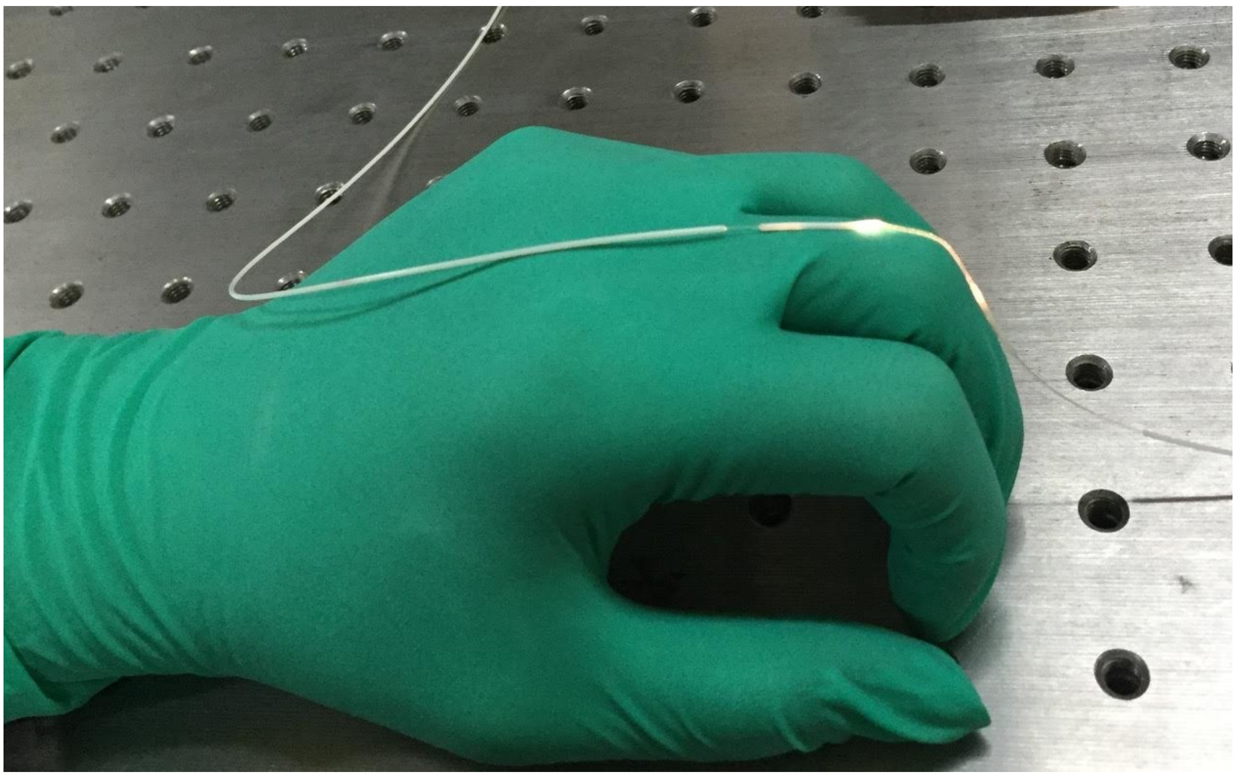

A silicone strain sensor glued to a rubber glove bends easily with the wearer's finger. The amount of light transmitted by the fiber changes with the bending. Credit: Changxi Yang, Tsinghua University

The exciting applications of wearable sensors have sparked a tremendous amount of research and business investment in recent years. Sensors attached to the body or integrated into clothing could allow athletes and physical therapists to monitor their progress, provide a more detailed level of motion capture for computer games or animation, help engineers build robots with a lighter touch or form the basis for new types of real-time health monitors.

In *Optica*, The Optical Society's journal for high impact research, a team led by Changxi Yang of the State Key Laboratory of Precision Measurement Technology and Instruments at Tsinghua University in Beijing offers the first demonstration of optical fibers sturdy enough to sense a wide range of human motion.

The new fiber is sensitive and flexible enough that it can detect joint movements, unlike currently used fiber sensors. "This new technique provides a fiber-optic approach for measuring extremely large deformations," said Yang. "It's wearable, mountable and also possesses intrinsic advantages of optical fibers such as inherent electrical safety and immunity to electromagnetic interference."

Trouble with stretching

Optical fibers have been used for strain sensing on bridges and buildings for years; stretch or bend the fiber a little and light going through it is shifted in a way that can be easily picked up by a monitor. Traditionally optical fibers haven't been the best choice for strain sensing on the human body because they are typically made of plastic or glass, which are stiff and don't bend well. A silica glass fiber, for example, can handle a maximum strain of less than 1 percent, while a bending finger joint would strain it by more than 30 percent.

This barrier has meant that most wearable sensor developments so far have been based on electronic sensors. These sensors detect movement by measuring changes in electrical properties such as resistance as the sensor bends. However, these systems are difficult to miniaturize, can lose their electrical charge and are sensitive to electromagnetic interference from devices such as cars and cell phones. A bendable optical fiber could avoid these problems and potentially create wearable devices that are more stable and sustainable than those based on electronics.

Simple silicone

When the researchers started looking for a fiber that could stand up to the amount of bending and stretching involved in human movements, they first tried fibers made of hydrogel, a soft, jelly-like substance that can hold strains of up to 700 percent. But hydrogel consists mostly of water, and therefore only worked in wet environments. When exposed to air, the fibers quickly dried out and shrank.

In a second attempt, Yang and his students, Jingjing Guo and Mengxuan Niu, developed a fiber made of silicone—specifically a soft polymer called polydimethylsiloxane (PDMS). They created the fiber by putting the liquid silicone into a tube-shaped mold and heating it to 80° C (176° F) for 40 minutes to get it to thicken, then used water pressure to push a thin fiber out of one end of the mold. They put the resulting fibers through an elaborate series of tests, such as repeatedly stretching them out to double their length. Even after 500 stretches, a fiber still returned to its original length.

"The fabricated PDMS fibers exhibited excellent mechanical flexibility, and could easily be tied and twisted," said Yang. What's more, when the team reduced the diameter of the fibers they produced, from 2 millimeters to 0.5 millimeters, the mechanical strength of the fibers actually increased.

To aid in sensing, the researchers mixed a fluorescent dye called

Rhodamine B into the silicone. When light shines through the fiber, some of the light is absorbed by the dye—the more the fiber stretches, the more light the dye absorbs. So simply measuring the transmitted light with a spectroscope provides a measurement of how much the fiber is being stretched or bent, which tells an observer about the movement of any body part it is attached to.

The glove test

The researchers tested that idea by gluing their fiber to a rubber glove with epoxy, and then monitoring it as a wearer flexed and extended his fingers. During that movement, they measured a strain in the fiber of 36 percent, in line with what others had measured using electronic sensors.

"The remarkable flexibility and stretchability of the PDMS fiber makes it especially attractive for sensing of large strains," said Yang, adding that this is the first time researchers have used an optical sensor to capture human motion.

The sensor also performed well in situations involving more subtle strains, such as the minute movements of neck muscles as a person breathes or speaks. "All the results show that the optical strain sensor can be used for monitoring of various human motions and may provide a new approach for exploration of human-machine interfaces," said Yang.

The team tested how well their fibers sensed strain over longer periods of time and in different environments, such as in water, glycerol and air. They learned that the fibers held up well, although the sensing accuracy did change in different environments, suggesting devices using the optical fiber-based sensors would need to be calibrated for the specific environment they'd be used in.

The team illuminated the fiber by attaching it to a halogen lamp, and measured the light passing through it with a spectrometer. To adapt the technology to create a wearable device, Yang said it should be possible to develop a compact light source and spectrometer that can be easily worn on the body.

More information: J. Guo, M. Niu, C. Yang, "Highly flexible and stretchable optical strain sensing for human motion detection," *Optica*, Volume 4, Issue 10, 1285-1288 (2017). DOI: 10.1364/OPTICA.49.001285

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