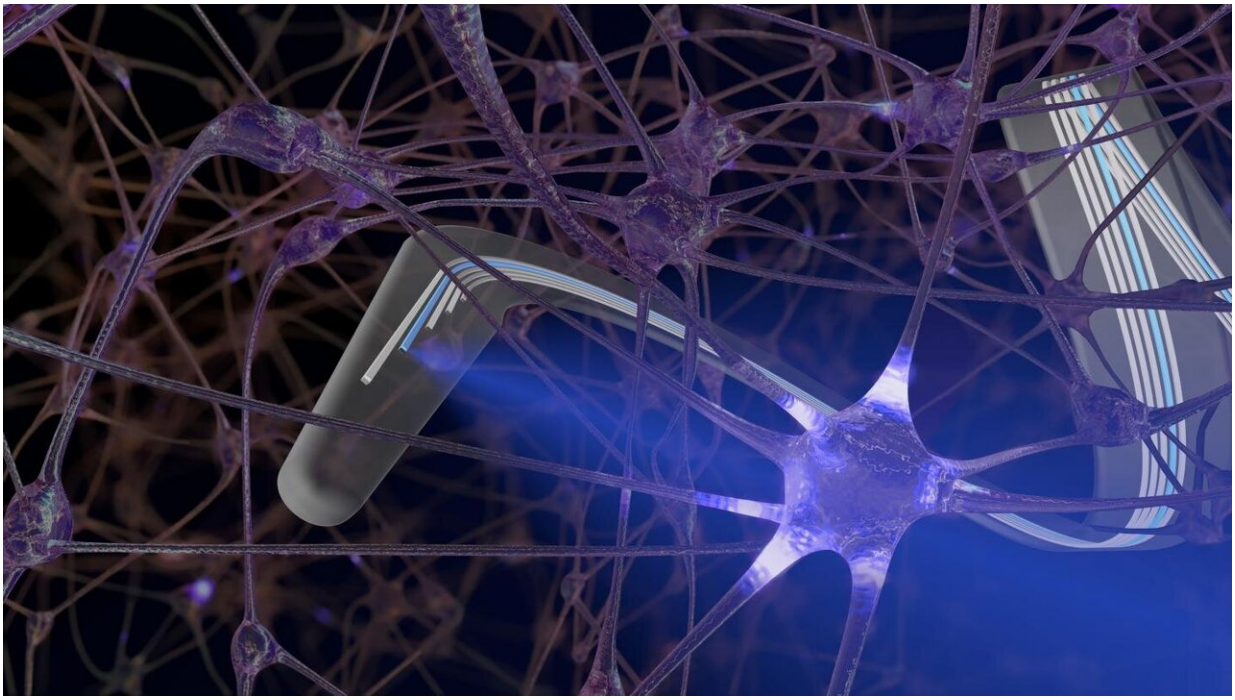
Parylene photonics enable future optical biointerfaces

September 22 2020, by Dan Carroll



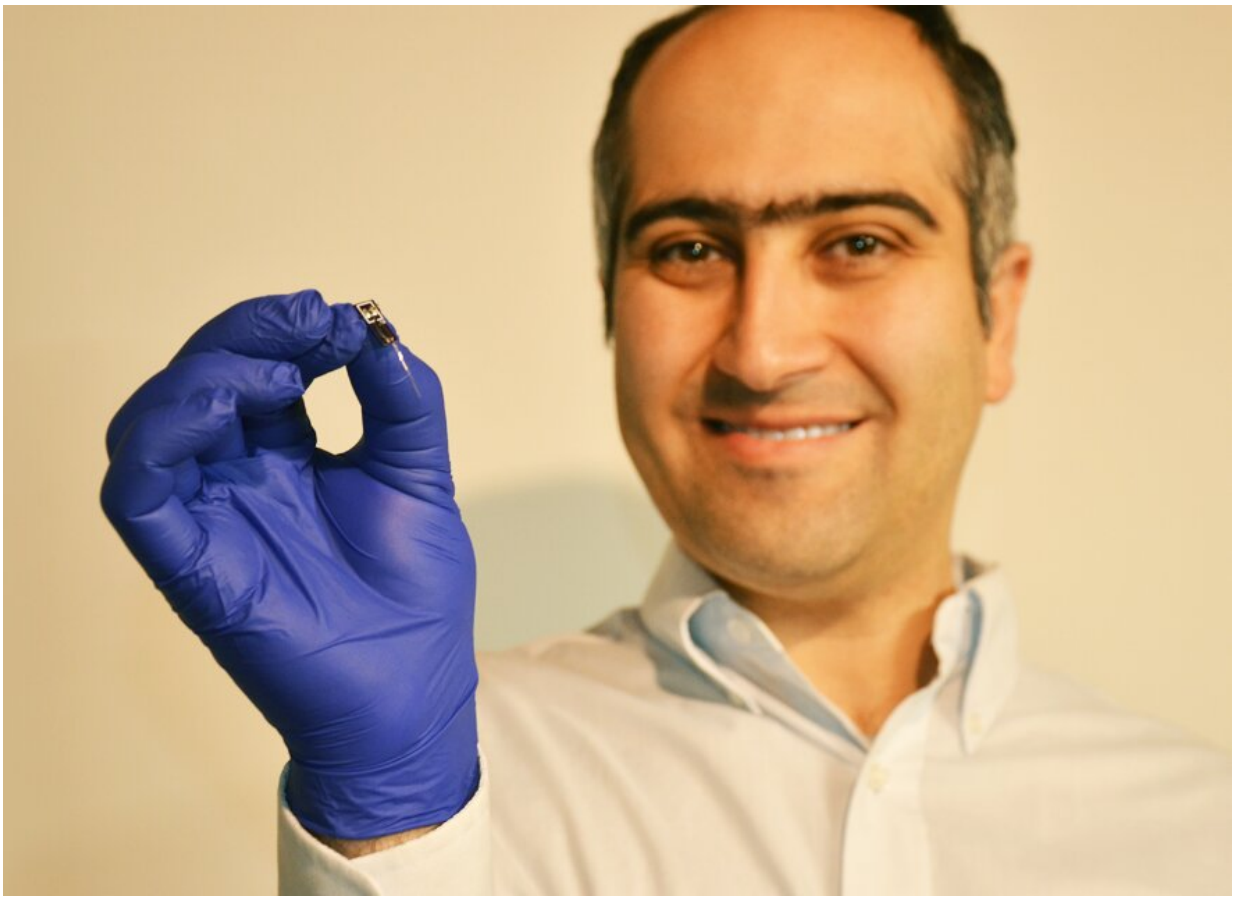
A Parylene photonic waveguide surrounded by neurons. Credit: Carnegie Mellon University College of Engineering

Carnegie Mellon University's Maysam Chamanzar and his team have invented an optical platform that will likely become the new standard in optical biointerfaces. He's labeled this new field of optical technology "Parylene photonics," demonstrated in a recent paper in *Nature Microsystems and Nanoengineering*.

There is a growing and unfulfilled demand for optical systems for biomedical applications. Miniaturized and flexible optical tools are needed to enable reliable ambulatory and on-demand imaging and manipulation of biological events in the body. Integrated photonic technology has mainly evolved around developing devices for optical communications. The advent of silicon photonics was a turning point in bringing optical functionalities to the small form-factor of a chip.

Research in this field boomed in the past couple of decades. However, silicon is a dangerously rigid material for interacting with soft tissue in biomedical applications. This increases the risk for patients to undergo tissue damage and scarring, especially due to the undulation of soft tissue against the inflexible device caused by respiration and other processes.

Chamanzar, an Assistant Professor of Electrical and Computer Engineering (ECE) and Biomedical Engineering, saw the pressing need for an optical platform tailored to biointerfaces with both optical capability and flexibility. His solution, Parylene photonics, is the first biocompatible and fully flexible integrated photonic platform ever made.

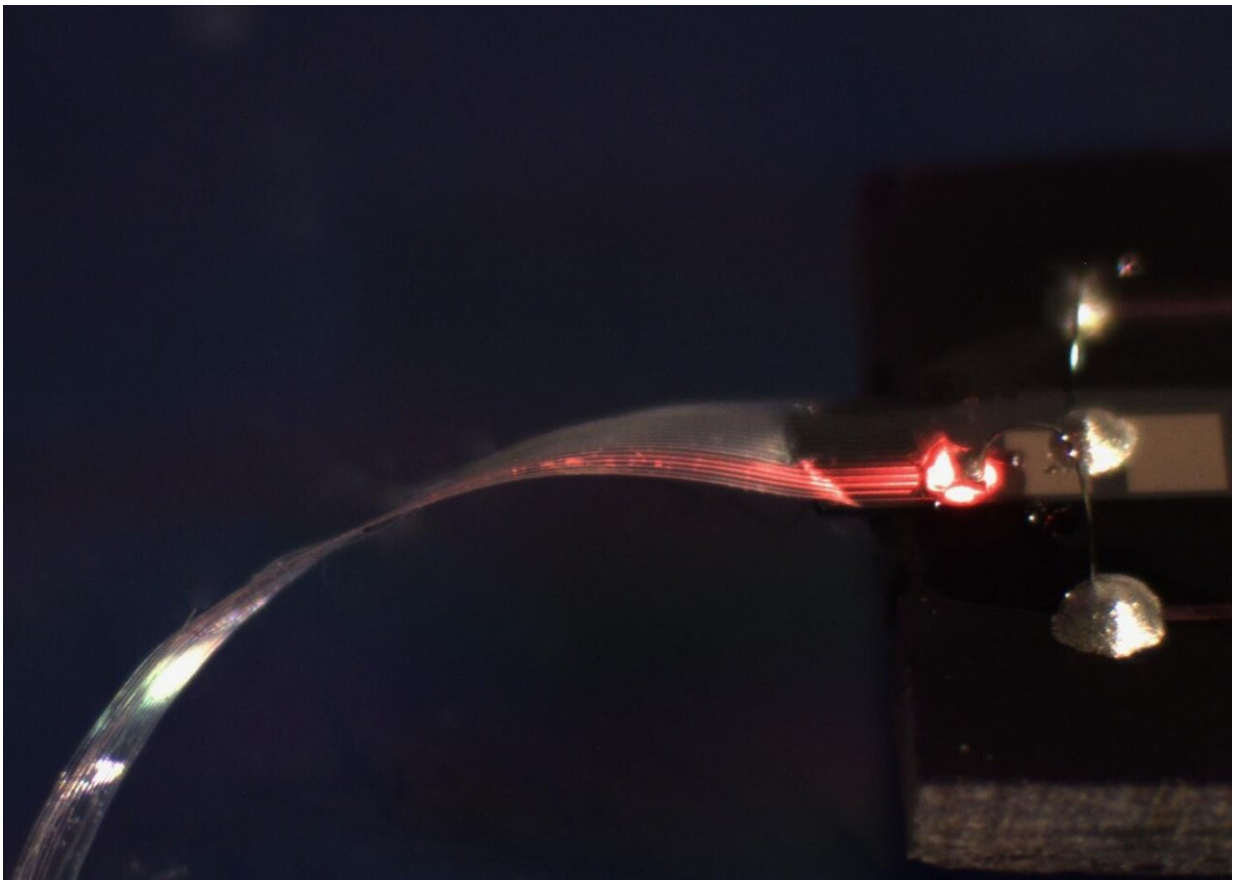


Chamanzar holding his team's device. Credit: Carnegie Mellon University College of Engineering Source: College of Engineering

To create this new photonic material class, Chamanzar's lab designed ultracompact optical waveguides by fabricating silicone (PDMS), an organic polymer with a low refractive index, around a core of Parylene C, a polymer with a much higher refractive index. The contrast in refractive index allows the waveguide to pipe light effectively, while the materials themselves remain extremely pliant. The result is a platform that is flexible, can operate over a broad spectrum of light, and is just 10 microns thick—about 1/10 the thickness of a human hair.

"We were using Parylene C as a biocompatible insulation coating for electrical implantable devices, when I noticed that this polymer is optically transparent. I became curious about its optical properties and did some basic measurements," said Chamanzar. "I found that Parylene C has exceptional optical properties. This was the onset of thinking about Parylene photonics as a new research direction."

Chamanzar's design was created with neural stimulation in mind, allowing for targeted stimulation and monitoring of specific neurons within the brain. Crucial to this, is the creation of 45-degree embedded micromirrors. While prior optical biointerfaces have stimulated a large swath of the brain tissue beyond what could be measured, these micromirrors create a tight overlap between the volume being stimulated and the volume recorded. These micromirrors also enable integration of external light sources with the Parylene waveguides.



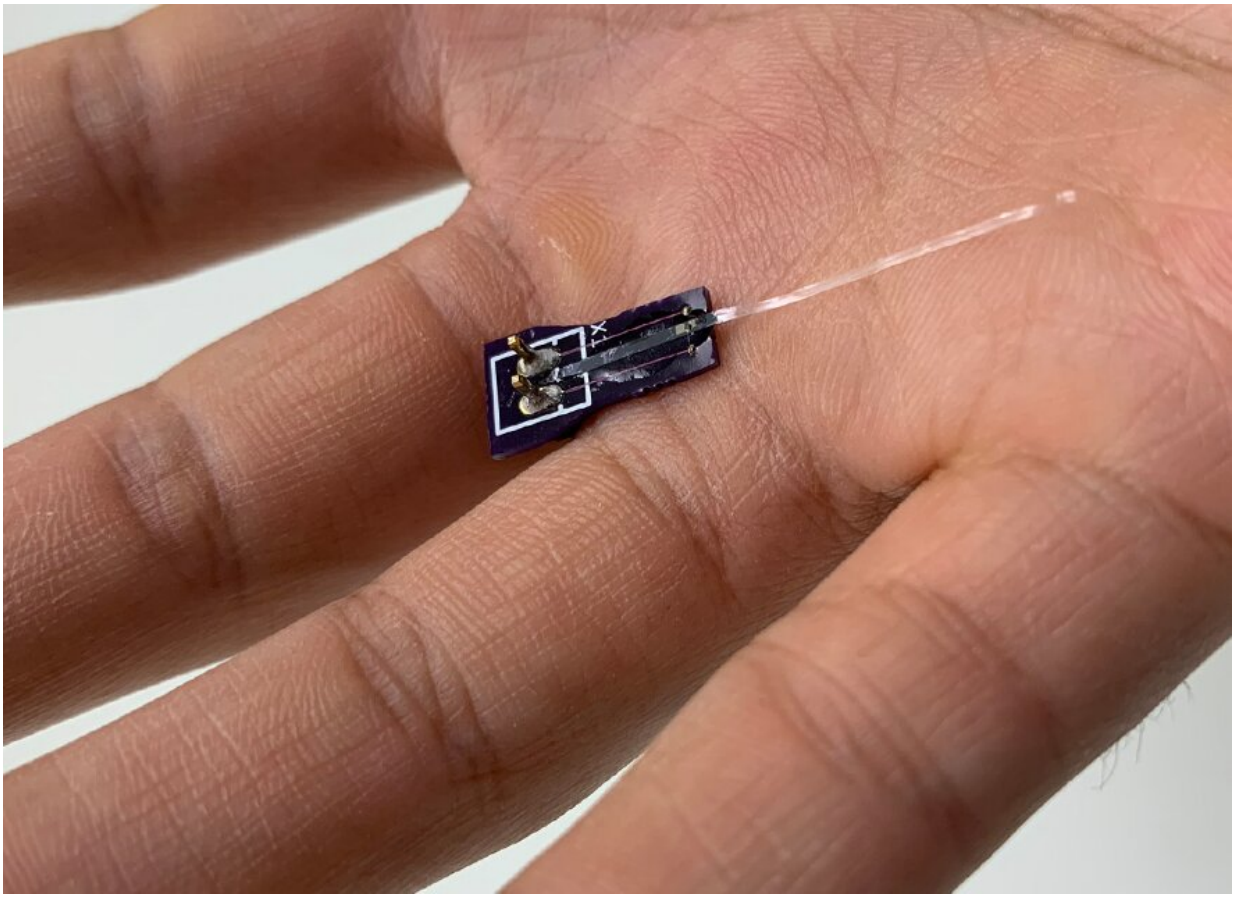
A powered waveguide under magnification. Credit: Carnegie Mellon University College of Engineering

ECE alumna Maya Lassiter (MS, '19), who was involved in the project, said, "Optical packaging is an interesting problem to solve because the best solutions need to be practical. We were able to package our Parylene photonic waveguides with discrete light sources using accessible packaging methods, to realize a compact device."

The applications for Parylene photonics range far beyond optical neural stimulation, and could one day replace current technologies in virtually every area of optical biointerfaces. These tiny flexible optical devices

can be inserted into the tissue for short-term imaging or manipulation. They can also be used as permanent implantable devices for long-term monitoring and therapeutic interventions.

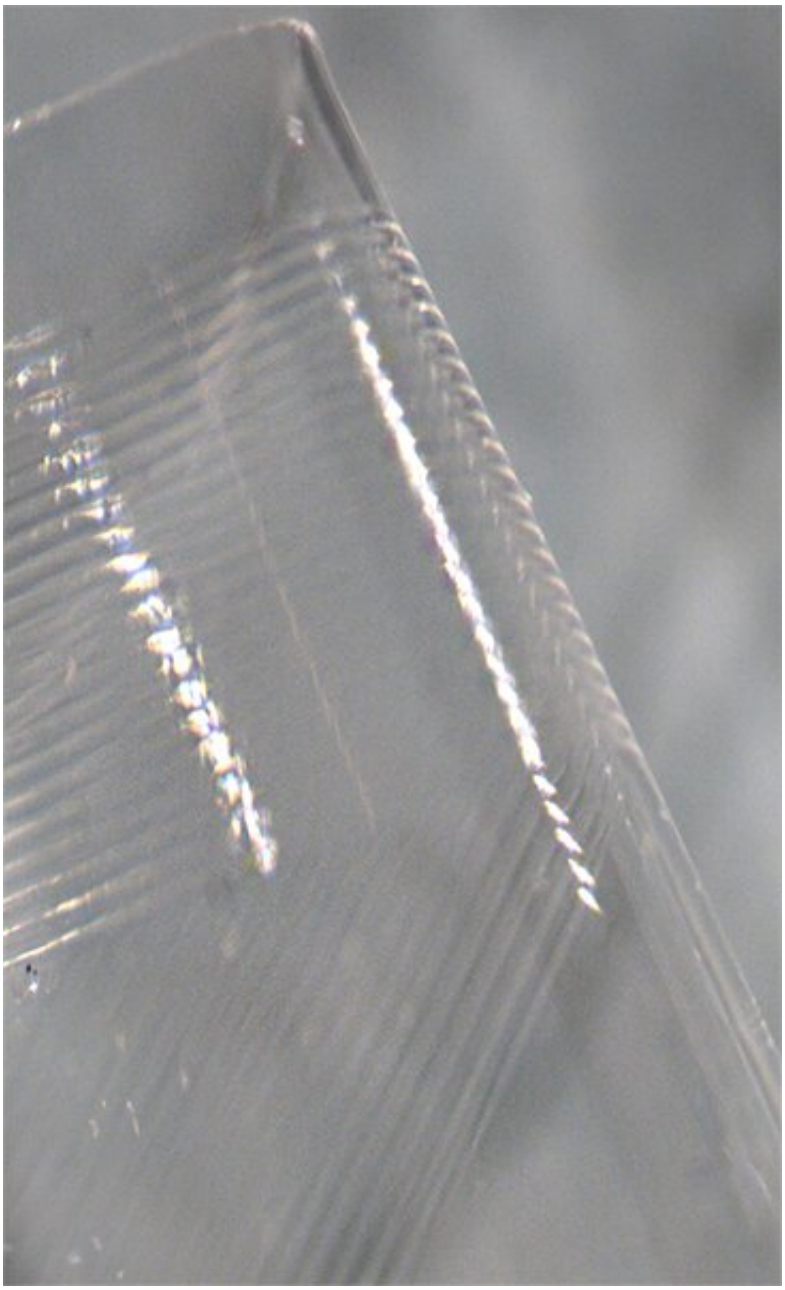
Additionally, Chamanzar and his team are considering possible uses in wearables. Parylene photonic devices placed on the skin could be used to conform to difficult areas of the body and measure pulse rate, oxygen saturation, blood flow, cancer biomarkers, and other biometrics. As further options for optical therapeutics are explored, such as laser treatment for cancer cells, the applications for a more versatile optical biointerface will only continue to grow.



A Parylene photonic waveguide held in the palm for scale. Credit: Carnegie

"The high index contrast between Parylene C and PDMS enables a low bend loss," said ECE Ph.D. candidate Jay Reddy, who has been working on this project. "These devices retain 90% efficiency as they are tightly bent down to a radius of almost half a millimeter, conforming tightly to anatomical features such as the cochlea and nerve bundles."

Another unconventional possibility for Parylene photonics is actually in communication links, bringing Chamanzar's whole pursuit full circle. Current chip-to-chip interconnects usually use rather inflexible optical fibers, and any area in which flexibility is needed requires transferring the signals to the electrical domain, which significantly limits bandwidth. Flexible Parylene photonic cables, however, provide a promising high bandwidth solution that could replace both types of optical interconnects and enable advances in optical interconnect design.



The waveguides are flexible and bend easily. Credit: College of Engineering

"So far, we have demonstrated low-loss, fully flexible Parylene photonic waveguides with embedded micromirrors that enable input/output light coupling over a broad range of optical wavelengths," said Chamanzar. "In the future, other optical devices such as microresonators and

interferometers can also be implemented in this platform to enable a whole gamut of new applications."

With Chamanzar's recent publication marking the debut of Parylene photonics, it's impossible to say just how far reaching the effects of this technology could be. However, the implications of this work are more than likely to mark a new chapter in the development of optical biointerfaces, similar to what silicon photonics enabled in optical communications and processing.

More information: Jay W. Reddy et al, Parylene photonics: a flexible, broadband optical waveguide platform with integrated micromirrors for biointerfaces, *Microsystems & Nanoengineering* (2020). DOI: 10.1038/s41378-020-00186-2

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