Silicon-based metamaterials could bring photonic circuits

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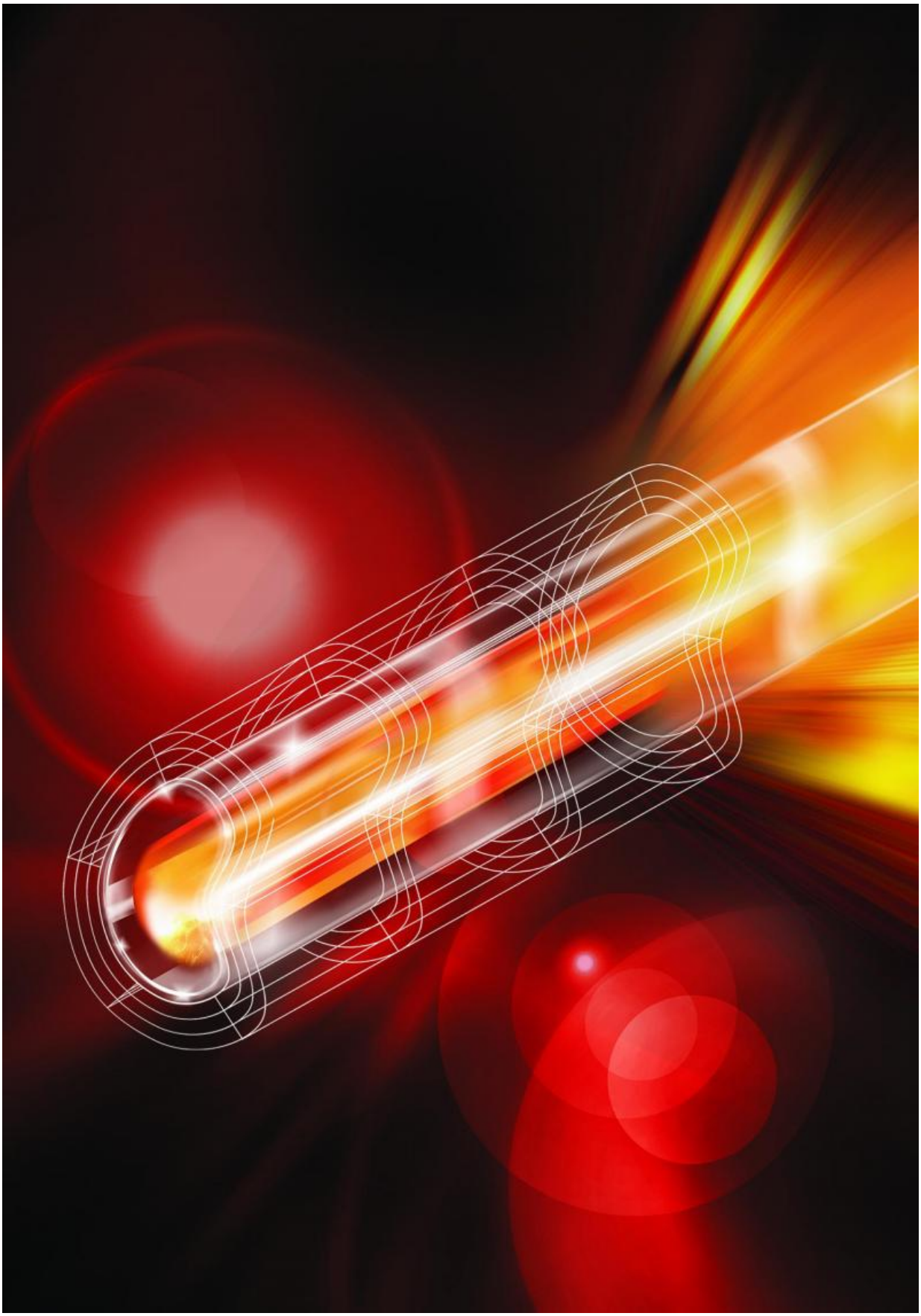

New transparent metamaterials under development could make possible computer chips and interconnecting circuits that use light instead of electrons to process and transmit data, representing a potential leap in performance. Credit: Purdue University image/Zubin Jacob

New transparent metamaterials under development could make possible computer chips and interconnecting circuits that use light instead of electrons to process and transmit data, representing a potential leap in performance.

Although optical fibers are now used to transmit large amounts of data over great distances, the technology cannot easily be miniaturized because the wavelength of light is too large to fit within the miniscule dimensions of microcircuits.

"The role of optical fibers is to guide light from point A to point B, in fact, across continents," said Zubin Jacob, an assistant professor of electrical and computer engineering at Purdue University. "The biggest advantage of doing this compared to copper cables is that it has a very high bandwidth, so large amounts of data can pass through these optical cables as opposed to copper wires. However, on our computers and consumer electronics we still use copper wires between different parts of the chip. The reason is that you can't confine light to the same size as a nanoscale copper wire."

Transparent metamaterials, nanostructured artificial media with transparent building blocks, allow unprecedented control of light and may represent a solution. Researchers are making progress in developing metamaterials that shrink the wavelength of light, pointing toward a

strategy to use light instead of electrons to process and transmit data in computer chips.

"If you have very high bandwidth communication on the chip as well as interconnecting circuits between chips, you can go to faster clock speeds, so faster data processing," Jacob said. Such an advance could make it possible to shrink the bulkiness of a high-performance computer cluster to the size of a standard desktop machine.

Unlike some of the metamaterials under development, which rely on the use of noble metals such as gold and silver, the new metamaterials are made entirely of dielectric materials, or insulators and non-metals. This approach could allow researchers to overcome a major limitation encountered thus far in the development of technologies based on metamaterials: using metals results in the loss of too much light to be practical for many applications.

A review article about all-dielectric metamaterials appeared online this month in the journal *Nature Nanotechnology*, highlighting the rapid development in this new field of research. The article was authored by doctoral student Saman Jahani and Jacob.

"A key factor is that we don't use metals at all in this metamaterial, because if you use metals a lot of the light goes into heat and is lost," Jacob said. "We want to bring everything to the silicon platform because this is the best material to integrate electronic and photonic devices on the same chip."

A critical detail is the material's "anisotropic velocity" – meaning light is transmitted much faster in one direction through the material than in another. Conventional materials transmit light at almost the same speed no matter which direction it is traveling through the material.

"The tricky part of this work is that we require the material to be highly anisotropic," he said. "So in one direction light travels almost as fast as it would in a vacuum, and in the other direction it travels as it would in silicon, which is around four times slower."

The innovation could make it possible to modify a phenomenon called "total internal reflection," the principle currently used to guide light in fiber optics. The researchers are working to engineer total internal reflection in optical fibers surrounded by the new silicon-based metamaterial.

"Our contribution has been basically the fact that we have been able to adapt this total internal reflection phenomenon down to the nanoscale, which was conventionally thought impossible," Jacob said.

Because the material is transparent it is suitable for transmitting light, which is a critical issue for practical device applications. The approach could reduce heating in circuits, meaning less power would be required to operate devices. Such an innovation could in the long run bring miniaturized data processing units.

"Another fascinating application for these transparent metamaterials is in enhancing light-matter coupling for single quantum light emitters," Jacob said. "The size of light waves inside a fiber are too large to effectively interact with tiny atoms and molecules. The transparent metamaterial cladding can compress the light waves to sub-wavelength values thus allowing light to effectively interact with quantum objects. This can pave the way for light sources at the single photon level."

More information: Saman Jahani et al. All-dielectric metamaterials, *Nature Nanotechnology* (2016). DOI: 10.1038/nnano.2015.304

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