The digital future may rely on ultrafast optical electronics and computers

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The author’s lab’s ultrafast optical switch in action. Credit: Mohammed Hassan, University of Arizona, CC BY-ND

If you've ever wished you had a faster phone, computer or internet connection, you've encountered the personal experience of hitting a limit of technology. But there might be help on the way.

Over the past several decades, scientists and engineers like me have worked to develop faster transistors, the electronic components underlying modern electronic and digital communications technologies. These efforts have been based on a category of materials called semiconductors that have special electrical properties. Silicon is perhaps the best known example of this type of material.

But about a decade ago, scientific efforts hit the speed limit of semiconductor-based transistors. Researchers simply can't make electrons move faster through these materials. One way engineers are trying to address the speed limits inherent in moving a current through silicon is to design shorter physical circuits—essentially giving electrons less distance to travel. Increasing the computing power of a chip comes down to increasing the number of transistors. However, even if researchers are able to get transistors to be very small, they won't be fast enough for the faster processing and data transfer speeds people and businesses will need.

My research group's work aims to develop faster ways to move data, using ultrafast laser pulses in free space and optical fiber. The laser light travels through optical fiber with almost no loss and with a very low level of noise.

In our most recent study, published in February 2023 in *Science Advances*, we took a step toward that, demonstrating that it's possible to use laser-based systems equipped with optical transistors, which depend on photons rather than voltage to move electrons, and to transfer information much more quickly than current systems—and do so more effectively than previously reported optical switches.

Ultrafast optical transistors

At their most fundamental level, digital transmissions involve a signal switching on and off to represent ones and zeros. Electronic transistors use voltage to send this signal: When the voltage induces the electrons to flow through the system, they signal a 1; when there are no electrons flowing, that signals a 0. This requires a source to emit the electrons and a receiver to detect them.

Our system of ultrafast optical data transmission is based on light rather than voltage. Our research group is one of many working with optical communication at the transistor level—the building blocks of modern processors—to get around the current limitations with silicon.

Our system controls reflected light to transmit information. When light shines on a piece of glass, most of it passes through, though a little bit might reflect. That is what you experience as glare when driving toward sunlight or looking through a window.

We use two laser beams transmitted from two sources passing through the same piece of glass. One beam is constant, but its transmission through the glass is controlled by the second beam. By using the second beam to shift the properties of the glass from transparent to reflective, we can start and stop the transmission of the constant beam, switching the optical signal from on to off and back again very quickly.

With this method, we can switch the glass properties much more quickly than current systems can send electrons. So we can send many more on and off signals—zeros and ones—in less time.

How fast are we talking?

Our study took the first step to transmitting data 1 million times faster than if we had used the typical electronics. With electrons, the maximum speed for transmitting data is a nanosecond, one-billionth of a second, which is very fast. But the optical switch we constructed was able to transmit data a million times faster, which took just a few hundred attoseconds.

We were also able to transmit those signals securely so that an attacker who tried to intercept or modify the messages would fail or be detected.

Using a laser beam to carry a signal, and adjusting its signal intensity with glass controlled by another laser beam, means the information can travel not only more quickly but also much greater distances.

For instance, the James Webb Space Telescope recently transmitted stunning images from far out in space. These pictures were transferred as data from the telescope to the base station on Earth at a rate of one "on" or "off" every 35 nanosconds using optical communications.

A laser system like the one we're developing could speed up the transfer rate a billionfold, allowing faster and clearer exploration of deep space, more quickly revealing the universe's secrets. And someday computers themselves might run on light.

More information: Dandan Hui et al, Ultrafast optical switching and data encoding on synthesized light fields, *Science Advances* (2023). DOI: 10.1126/sciadv.adf1015