Electro-optical switch transmits data at record-low temperatures

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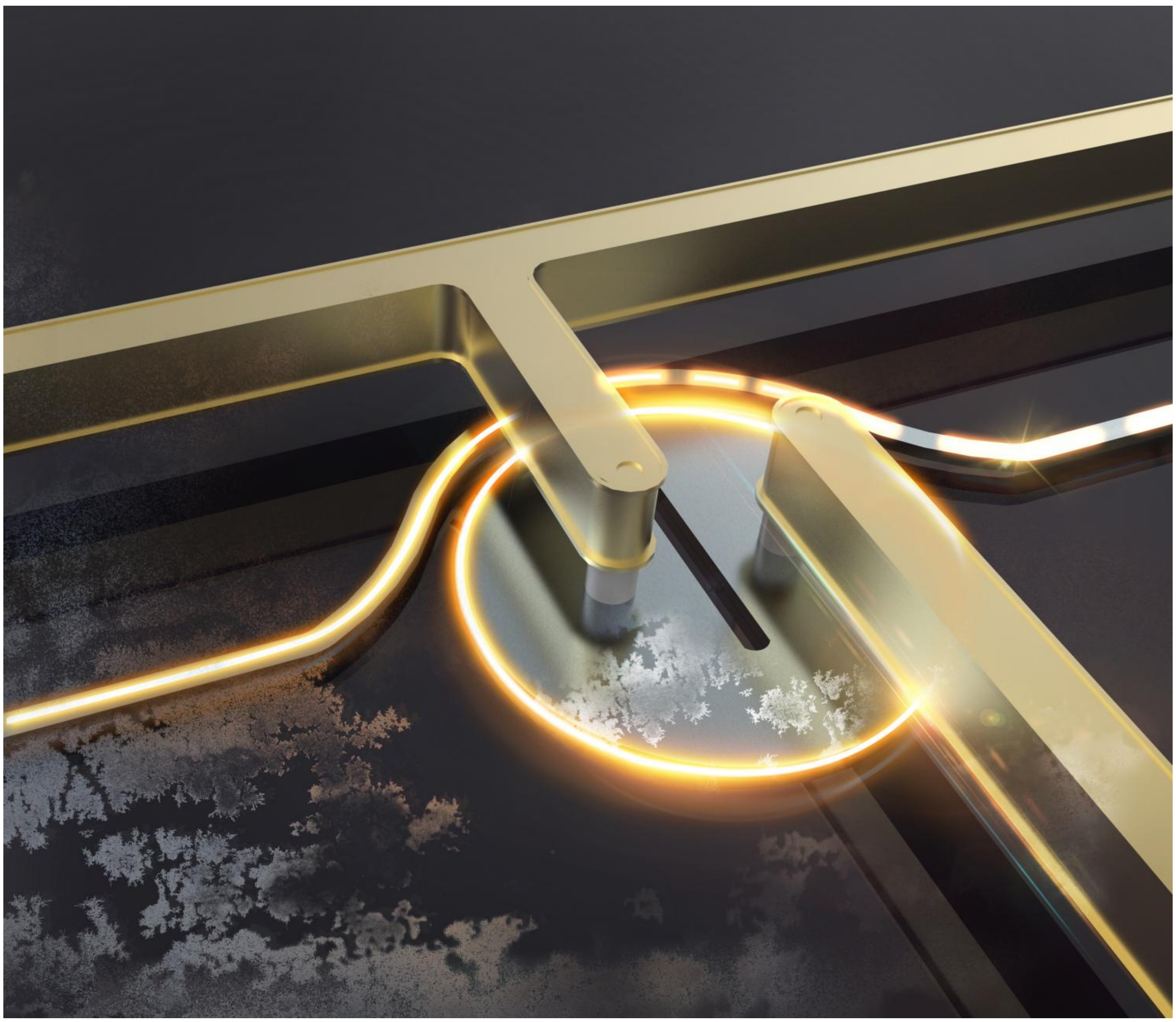

An illustration of a silicon photonic micro-disk modulator operating at cryogenic temperatures. Light traveling down the silicon waveguide couples to the resonance of the micro-disk cavity. An electrical signal applied to the disk shifts the resonance and as a result modulates the light passing through the waveguide. (Rendered by Hanqing Kuang) Credit: Michael Gehl, Sandia National Laboratories

A silicon optical switch newly developed at Sandia National Laboratories is the first to transmit up to 10 gigabits per second of data at temperatures just a few degrees above absolute zero. The device could enable data transmission for next-generation superconducting computers that store and process data at cryogenic temperatures. Although these supercomputers are still experimental, they could potentially offer computing speeds ten times faster than today's computers while significantly decreasing power usage.

The fact that the switch operates at a range of temperatures, offers fast data transmission and requires little power could also make it useful for transmitting data from instruments used in space, where power is limited and temperatures vary widely.

"Making electrical connections to systems operating at very cold temperatures is very challenging, but optics can offer a solution," said lead researcher Michael Gehl, Sandia National Laboratories, New Mexico. "Our tiny switch allows data to be transmitted out of the cold environment using light traveling through an optical fiber, rather than electricity."

In The Optical Society's journal for high impact research, *Optica*, Gehl and his colleagues describe their new silicon micro-disk modulator and show that it can transmit data in environments as cold as 4.8 Kelvin. The device was fabricated with standard techniques used to make CMOS computer chips, which means it can be easily integrated onto chips containing electronic components.

"This is one of the first examples of an active silicon optical device operating at such a low temperature," said Gehl. "Our device could potentially revolutionize technologies that are limited by how fast you can send information in and out of a cold environment electrically."

Optics excels at low temperatures

For low-temperature applications, optical methods provide several benefits over electrical data transmission. Because electrical wires conduct heat, they often introduce heat into a system that needs to stay cold. Optical fibers, on the other hand, transmit almost no heat. Also, a single optical fiber can transmit more data at faster rates than an electrical wire, meaning that one fiber can do the job of many electrical connections.

The micro-disk modulator requires very little power to operate—around 1000 times less power than today's commercially available electro-optical switches—which also helps reduce the heat the device contributes to the cold environment.

To make the new device, the researchers fabricated a small silicon waveguide (used to transmit light waves) next to a silicon micro-disk only 3.5 microns in diameter. Light coming through the waveguide moves into the micro-disk and travels around the disk rather than passing straight through the waveguide. Adding impurities to the silicon micro-disk creates an electrical junction to which a voltage can be applied. The voltage changes the material's properties in a way that stops the light from moving into the disk and allows it to instead pass through the waveguide. This means that the light signal turns off and on as the voltage switches on and off, providing a way to turn the ones and zeroes that make up electrical data into an optical signal.

Although other research groups have designed similar devices, Gehl and his colleagues are the first to optimize the amount of impurities used and the exact placement of those impurities to allow the micro-disk modulator to operate at low temperatures. Their approach could be used to make other electro-optical devices that work at low temperatures.

Low error rate

To test the micro-disk modulator, the researchers placed it inside a cryostat—a small vacuum chamber that can cool what's inside to very low temperatures. The micro-disk modulator converted an electrical signal sent into the cryostat to an optical signal. The researchers then examined the optical signal coming out of the cryostat to measure how well it matched the incoming electrical data.

The researchers operated their device at room temperature, 100 Kelvin and 4.8 Kelvin with various data rates up to 10 gigabits per second. Although they observed a slight increase in errors at the highest data rate and lowest temperature, the error rate was still low enough for the device to be useful for transmitting data.

This work builds on years of effort to develop silicon photonic devices for optical communication and high performance computing applications, led by the Applied Photonics Microsystems group at Sandia. As a next step, the researchers want to demonstrate that their device works with data generated inside the low temperature environment, rather than only electrical signals coming from outside the cryostat. They are also continuing to optimize the performance of the device.

More information: Michael Gehl et al, Operation of high-speed silicon photonic micro-disk modulators at cryogenic temperatures, *Optica* (2017). DOI: 10.1364/optica.4.000374

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