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Researchers find strong constraint on delivery of optical signals to computers

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Optics, a form of data transmission that utilizes beams of light, has the promise to outperform the beams of electrons that drive your computer or smartphone. Engineers have long sought a way to miniaturize optical technology, which is present in today's fast-paced fiber-optic cables, so they can bring the speed and efficiency of light-based data transmission to a computer chip.

But engineers at Stanford University have announced a strong theoretical limitation to what was long hoped to be a simple, promising device that would permit one-way optical data transmission on a computer chip.

Stanford electrical engineering Professor Shanhui Fan and graduate student Yu "Jerry" Shi announced their findings in a paper published in the journal *Nature Photonics*. In the short term, their news may be disappointing to some engineers. But both believe that their findings will guide researchers searching for ways to build a one-way street for light on a computer chip.

Fan and Shi studied a device called a nonlinear isolator, which researchers had hoped would allow information from beams of light to travel in only the "forward" direction, while prohibiting transmission in the "backward" direction. Such a device would simplify data transmission on computer chips.

"But it turns out that there is backward leakage that no one previously recognized in this class of device," said Fan.

Fan and Shi studied the mathematics of optical data transmission to come to their conclusions, backed up with computer simulations.

Engineers need computer chips that transmit information in one direction, be it today's beams of electrons or tomorrow's beams of light. Today's chips contain special devices called diodes that keep these electron beams – and therefore the flow of information – flowing in the right direction while blocking electron beams that try to flow backward, thus preventing signals from getting garbled.

An optical computer chip, which uses beams of light, would also need an "optical diode," also known as an "optical isolator." Without such a device, signals would get garbled amid the ferocity of background noise.

For decades, a device called a nonlinear isolator had shown promise as an optical isolator that could help keep optical information flowing forward and block signals from beams of light flowing backward.

"It was a natural approach and it's an idea that's been around for many decades," said Fan.

But Fan and Shi's findings point to a strong limitation of nonlinear isolators. Though the researchers used mathematics and simulations to prove their point, their reasons to oppose nonlinear isolators are straightforward.

In previous works, researchers used a specific method to test whether nonlinear isolators on a chip could keep information flowing in the right direction. They would direct a beam of light in the "forward" direction and verify that the isolator would let the light through. Then they would direct a beam of light in the "backward" direction toward the isolator, and verify that the isolator would block that beam. It was not standard practice to test forward and backward beams at the same time.

"There are perhaps more than 100 papers using this method, and I have written some of them," said Fan.

Based on these tests, nonlinear isolators appeared to work. It looked like they could keep light beams flowing in one direction on optical computer chips. But, as Fan and Shi studied the mathematics underlying nonlinear isolators, they found a problem: When the forward beam is on, the backward beam leaks through the device.

"Once you understood the underlying theory, the problem was pretty evident," said Fan. "It would jump out at you."

Shi drew up mathematical proofs and used computer simulations to show that nonlinear isolators are actually two-way streets.

"If the light is on in the 'forward' direction, then light from the opposite direction can go through," said Fan.

This finding is important for designing isolators for optical chips. Engineers will need to look elsewhere for devices that can keep optical information flowing in one direction, but not the other.

Fan and Shi realize they're delivering what is probably unwelcome news to their colleagues.

"It's an idea that's been around for many decades. But now it won't be that simple," said Fan. "We're closing off a dead end, saying, 'Don't go down that road.'"

But they remain hopeful that this news will renew interest in other methods to create one-way streets for optical communication on a computer chip. In fact, Shi hopes to work on this sort of question for the rest of his doctoral research.

More information: "Limitations of nonlinear optical isolators due to dynamic reciprocity." *Nature Photonics* 9, 388–392 (2015) DOI: 10.1038/nphoton.2015.79

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