Vertical cavity quantum switch could lead us away from electronics-based computing

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(PhysOrg.com) -- Right now, many researchers around the world are working on ways to move away from electronics-dominated computing systems. There are a number of ideas about how this can be accomplished. "We are trying to demonstrate an all-optical switch that, at the first stage, could be used in ultrafast optical communication systems," Chaoyuan Jin tells *PhysOrg.com*. "It might also be useful for optical interconnection to replace present day electronic links which transfer tremendous data between computer chips, or perhaps useful for optical computing on-chip."

Jin is a scientist at Kobe University, in Japan. Working with Kojima, Kita and Wada at Kobe University, and with Hopkinson at the University of Sheffield in the United Kingdom, Jin is part of a group that is proposing to use a vertical geometry for an optical phase shifter using semiconductor quantum dots. Their work is published in *Applied Physics Letters*: "Observation of phase shifts in a vertical cavity quantum dot switch."

"When we think of optics, we think of long-range communications," Jin says. "Now, we're trying to use photonic devices for short-range functions within optical networks, from Internet routers towards inter-chip, or on-chip levels ."

Jin sees a great deal of potential for using an all-optical switch for Internet routers. He points out that energy consumption around the world is massive from Internet routers: "One of the major problems of the conventional Internet router is that it employs a optics-electronics-optics (O/E/O) interface, which requires additional energy to exchange the information carried by photons to electrons then go back to photons. To Use an all-optical switch, which means a light beam directly controlled by another light beam, could possibly cut off the additional energy consumption due to the O/E/O interface."

There is also potential to use all-optical switches to help more effectively reduce the size of computers. "Scaling down computer systems which can cause extra delay in short electronic wires, which further blocks the data transfer rate," Jin explains. "To do the interconnection using optics would possibly avoid the delay and distortion in the conventional electrical interconnection." Without the some of the drawbacks of electronics-based computing, an all-optical switch could ultimately overcome the current bottleneck of electronic chips.

Unfortunately, there are problems with building the faster interconnection devices Jin mentions. "Novel logical devices based on optics need to access a high nonlinear region of photonic materials, and hence requires high operation energy. Energy consumption would be a huge problem for photonic devices," Jin admits. "You need many transistors, and you need power to operate them. That is one of the issues we have right now, since we want the power use to be relatively low."

In order for logical devices to be realized, the power problem will have to be solved. "For the development of optical networks between chips and at chip level, the required energy per pulse is expected to be less than 1 pico-joule (10^{-12} joule) per bit, Jin says. "Most of the existing candidates for all-optical switching would fail this target."

In order to solve this problem, Jin thinks that quantum dots might help. "Semiconductor nanostructures such as quantum dots may be able to meet such a system goal as a consequence of their small volume and atom-like properties which leads to very high optical nonlinearity," Jin explains. "We have already demonstrated an optical switch using quantum dots in a vertical cavity. Each bit only requires operation energy at femto-joule (10^{-15} joule) levels, which is lower than the pico-joule requirement."

The improvement to the power setup, though, leads to a trade-off in speed, according to Jin: "The remaining issue is how to access a high switching speed. Now our quantum dot switch only works at around 40 gigabits per second. We are aiming for a practical device that can be used for a Tbits per second transfer rate. To explore phase shifts inside quantum dot may provide a solution for the ultrafast operation, and in the meanwhile, keep the low energy consumption and small size."

Jin thinks that there could be a number of applications for optical switches that make use of semiconducting quantum dots and phase shifts. "This novel device might be used for future computer with photonic enabled processors," he says. Current computer chips take a more horizontal approach for integration. "A vertical architecture could be also possible if we integrate several layers, containing vertical cavity surface emitting lasers, vertical cavity switches and detectors." Jin continues. This may ultimately shape the future computational machines to meet the scalable and energy efficiency goals many scientists are trying so hard to achieve.

More information: C.Y. Jin, O. Kojima, T. Kita, O. Wada, and M. Hopkinson, "Observation of phase shifts in a vertical cavity quantum dot switch," *Applied Physics Letters* (2011). Available online: link.aip.org/link/doi/10.1063/1.3596704