Quantum computers take step toward practicality with demonstration of new device

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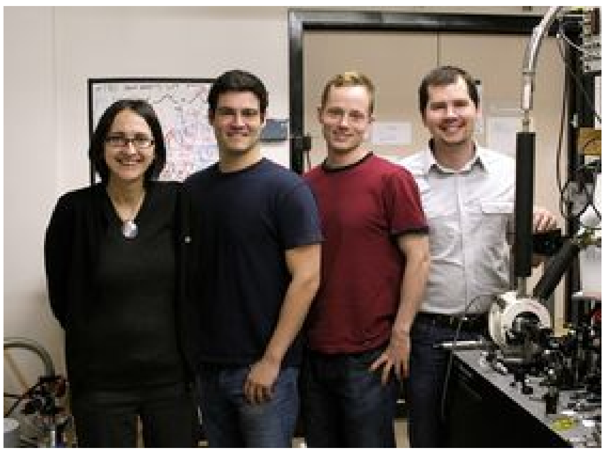

Computers based on the powerful properties of quantum mechanics have the potential to revolutionize information technology and security, but for decades they have remained more theoretical than practical, and difficult to scale up. That is changing, however, as demonstrated in a report this week in the journal *Science.*

In the paper, engineers and physicists from Stanford and the University of California at Santa Barbara demonstrate a potential progenitor of an essential component of quantum computers, "a logic gate" that enables interaction between just two particles of light.

The key advance is a solid state device that can reliably produce an interaction between the light particles, called photons. The team, led by Stanford Electrical Engineering Assistant Professor Jelena Vuckovic, did that by nestling a tiny ball of indium arsenide molecules called a "quantum dot" within a cavity on a photonic crystal, a chip of semiconducting gallium arsenide precisely drilled with holes to give it the ability to trap photons so that they interact with the quantum dot.

"We have demonstrated a system composed of a single quantum dot in a cavity that can be used to realize such a gate, and we demonstrated that two photons can be made to interact with each other via this system," says Stanford applied physics doctoral student Ilya Fushman, a lead author on the paper along with two other doctoral students from the Vuckovic group, Dirk Englund and Andrei Faraon. "So we showed that such a gate is possible and demonstrated the first necessary steps in that direction."

Prior demonstrations of strong interactions between individual photons have been only done with systems that required complicated atom trapping techniques that are not as practical as this semiconductor-chip implementation, Vuckovic says, because they would be difficult to extend to the hundreds or thousands of logic nodes required for a quantum computer. But the new device is made with materials and manufacturing processes that are familiar to computer chip makers.

Logic from light

In computing, a logic gate is built to accept a set of inputs and, depending on their properties, provide a specific output. In the binary logic found in today's electrical computers, a certain gate will yield a "1" only if all of its inputs are "1"s. Otherwise it will yield a "0." Similarly, a quantum photonic gate would work by detecting the properties of input photons from two light beams, called "control" and "signal," and then producing an output based on those, such as by flipping the polarization of one of the input photons.

In their experiment, the researchers shined two beams of photons upon the quantum dot. When a photon from the signal beam struck the dot alone, it was re-emitted without modification. If a photon from the "control" beam got there first, then the amount of time that the photon from the signal beam spent in the cavity changed. That difference in time, called a "phase shift," can be mapped to a difference in photon polarization.

The team has demonstrated that when the two photons are identical, a phase shift of 12.6 degrees is achieved. This is only a fraction of the 180-degree rotation required to make a full logic gate, Vuckovic says, but by combining several of the devices in a row, her team expects to attain the needed effect. Also, when the signal and control photons are allowed to differ, the phase shifts can be up to 45 degrees.

Other challenges include eliminating manufacturing imperfections and reliably placing the quantum dots right where they need to be within the crystals, but the team is optimistic.

"We are hopeful that these engineering challenges can be overcome to open the path to chip-based high-fidelity quantum logic with photons," Vuckovic says.

Source: Stanford University

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