# Researchers developed a quantum 'light switch'

December 10 2007

Infinitely secure cryptography that renders any computer unhackable. Computers that can solve the structure of a complicated protein at the drop of a hat. Programs to decrypt complicated enemy secrets. Optical data connections up to 100 times faster than current technology allows.

Photons and atoms hold the power to make these innovations reality; scientists just have to figure out how to unlock their potential. Now, researchers at Stanford and the University of California-Santa Barbara have developed a quantum "light switch" that could have implications for the future of certain kinds of computing.

A team of scientists led by Jelena Vuckovic, assistant professor of electrical engineering, has succeeded in directly probing a solid quantum system with light. This finding could be a milestone on the road to building a functional "quantum computer," a machine where information is coded in individual particles that flip between different states instead of in transistors switching on and off. The finding could lead to better quantum cryptography and faster optical data connections. Their study was published in the Dec. 6 issue of *Nature*.

"This effect has been previously demonstrated only in complicated atomic physics systems," Vuckovic wrote in an e-mail, "but ours is the first demonstration in solid state."

Previous demonstrations of the technique on atoms suspended in a gaseous state used machines that would dwarf an office desk. Vuckovic's team used solid material on a chip smaller than a thumbnail.

Scientists have been dreaming of a quantum computer for over 25 years. In such a machine, bits of information would be encoded in systems that walk to the beat of quantum mechanics—the field of physics that describes the quirky behavior of tiny atomic and subatomic particles.

Certain problems that scientists want to answer, such as predicting the way a complicated protein will fold, which might aid drug discovery, or factoring large integers into prime numbers to decrypt encoded messages, are extremely difficult to do with classical computers. In 2005, a 200-digit number was decomposed into prime numbers using multiple computers running for 18 months—scientists estimated that it would have taken one relatively speedy computer over 50 years to do the same task. A single powerful quantum computer, if it existed, could have done it in minutes.

One of the difficulties in actually creating a quantum computer comes from the fact that no one particle can do it all, said Dirk Englund, doctoral student in applied physics and one of the lead authors of the study. Photons are great for carrying information, and they are easy to move around, but they can't interact with each other. Conversely, atoms can interact, but can't easily communicate information. Scientists hope to get around this problem by using both, through something called a quantum network that would connect a series of atoms with a photonic channel. "In this approach, you're trying to exploit the best parts of both the atom and the photon," Englund said. "Communicate with the photon, interact with the atom."

But the problem of how to transfer the information between a single atom and a single photon still remains. If you just lob a photon at an atom, chances are it will miss, Englund said. So to give the photon a fighting chance at finding the atom, the scientists built a cavity of mirrors. The photon shoots into the cavity from a finely tuned laser beam and, like a pinball in a pinball machine, it ricochets around and around until it finally hits its target.

In this case, the target is an artificial atom termed a "quantum dot"—a microscopic blob of semiconductor material—nestled in a cavity inside another semiconductor. The blob confines charged particles to a tiny volume, much like an atom confines electrons in the tiny boundaries of its shell. Because of this confinement, the quantum dot behaves much as an artificial atom, including the ability to occupy different energy states that could represent the binary "ones" and "zeros" of digital information. If you think of the quantum dot like a spinning top, Englund said, "you'd call a spinning top that's upright a 'one' and a spinning top that pointed down a 'zero.'"

When the quantum dot is inside the semiconductor cavity, the cavity can be switched from transparent to opaque when the laser beam shines on it—meaning the team of researchers has succeeded in making a light switch out of just one photon and one quantum dot. The team includes study co-authors Andrei Faraon and Ilya Fushman, doctoral students in applied physics.

Previous groups had probed the quantum dot/cavity pair using indirect methods, but nobody had ever directly accessed the quantum system with photons before, Englund said. A research team from the California Institute of Technology published a study in the Dec. 6 issue of *Nature* that also demonstrates direct probing of a quantum system with photons, using a different system and technique.

The tiny chips used by Vuckovic's group have the advantage that they could easily be manufactured using technologies similar to those for computer chip manufacturing, Englund said.

While it will probably be a while before Vuckovic's system challenges the transistor as a new computational unit of information, it has that potential, Englund said. The next important step is to make some changes to the quantum dot to demonstrate that information can actually be transferred from the photonic channel to the dot—that is, to show that a piece of information from the photon could be relayed by changing the dot's energy state or spin direction.

Quantum dots might pave the road to the computer of the future, but that doesn't mean quantum computers will stock the shelves of your local electronics store, Englund said. Quantum information devices are most sought after because of their special applications to certain problems, such as unbreakable encryption systems and simulations of intricate molecular structures.

"In the next 20 years you might well see a quantum computer in a scientific research setting or defense," Englund said, "but you won't see Dell making one."

The paper's other authors are Nick Stoltz and Pierre Petroff of the University of California-Santa Barbara.

Funding for the study was provided by the Office of Naval Research, the Okawa Foundation, the U.S. Department of Defense, the U.S. Army, the U.S. Disruptive Technology Office, the Center for Integrated Systems at Stanford and the National Science Foundation.

Source: by Rachel Tompa, Stanford University