Just One Electron Spin Control Makes a Huge Step to Quantum Computing

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Quantum computing, which holds the promise of nearly unlimited processing power, secure communications and the ability to decode encrypted conversations by terrorists and others, is a significant step closer to becoming a reality today with new research published by a team of UCLA scientists in the journal Nature.

The UCLA team **succeeded in flipping a single electron spin upside down in an ordinary commercial transistor chip**, and detected that the current changes when the electron flips. Their report of controlling and detecting a single electron's spin is published in the July 22 issue of Nature.

Scientists had manipulated millions of electron spins in a transistor before. "We have gone from millions to just one," said Hong Wen Jiang, a UCLA professor of physics and member of the California NanoSystems Institute, in whose laboratory the experiments were conducted.

"Our research demonstrates that an ordinary transistor, the kind used in a desktop PC or cell phone, can be adapted for practical quantum computing," Jiang said. The research makes quantum computing closer and more practical, he added.

A single electron spin represents a quantum bit, the fundamental building block of a quantum computer.

Many scientists believe that an exotic new technology would be required for quantum computing. However, Jiang said, "I would not be surprised one day to see a quantum computer built, based almost entirely on silicon technology."

"We have measured a single electron spin in an ordinary transistor; this means that conventional silicon technology is adaptable enough, and powerful enough, to accommodate the future electronic requirements of new technologies like quantum computing, which will depend on spin," said Eli Yablonovitch, UCLA professor of electrical engineering, director of UCLA's Center for Nanoscience Innovation for Defense, member of the California NanoSystems Institute and co-author of the Nature paper.

"We've done this with a commercial silicon integrated circuit chip, literally off a shelf," Yablonovitch said. "Silicon is the dominant technology of our time, and will remain so for some time. For those who think silicon has too many limitations, silicon technology is surprisingly adaptable, enough so to meet the futuristic requirements of the 21st century. In the electronics of the 21st century, we will manipulate single electron spins — not just the charge of the electron, but the spin of the electron."

When quantum computing becomes a reality, the government may be able to use it to eavesdrop on terrorists and quickly break sophisticated secret codes, Yablonovitch said. Quantum computing will use quantum physics to communicate much more securely; if someone tries to intercept a quantum message, the information would be destroyed, Jiang said. Perhaps future elections will be held using secure quantum voting.

"We've manipulated one spin," Yablonovitch said. "A year from now, manipulating a single spin might be all in a day's work, and in 10 years, perhaps it will have a commercial role."

If manipulating a single electron's spin will soon seem routine, until now it has been anything but. Jiang and his UCLA graduate student Ming Xiao worked day and night to achieve this goal, and thought about quitting more than once.

"There were so many unknowns," Jiang said, "but our initial theoretical calculations were very favorable, and gave us confidence to persevere."

While flipping a single electron was difficult, detecting that they had actually done so proved even harder.

"We couldn't tell whether it was flipping," Jiang said. "It was like looking for a needle in a haystack."

Making the detection was like searching an enormous basket filled with thousands of balls, all the same color, and trying to find the one that is just slightly different in size. (The detected electron spin has a slightly different frequency from the others.)

Jiang and Xiao succeeded in working with the transistor at low temperatures: minus more than 400 degrees Fahrenheit. Jiang and Yablonovitch have ideas for operating in the future at room temperature, which would be much more practical commercially.

Jiang and Xiao's method for controlling the electron was to shine a microwave radio frequency to flip the spin of the electron. The experiments last but a fraction of a second, but required years of work to reach this point.

Electrons rotate like spinning tops. The UCLA team can target a single electron and control when it is right side up and when it is upside down by changing the microwave frequency.

Two other research groups, one from IBM and one from the Netherlands, also are reporting the detection of a single electron spin. The groups used different methods to measure a single electron spin.

How powerful can quantum computing be?

"With 100 transistors, each containing one of these electrons, you could have the implicit information storage that corresponds to all of the hard disks made in the world this year, multiplied by the number of years the universe has been around," Yablonovitch said. "And why stop with 100 transistors?"

A next step is to demonstrate the "entanglement" of two spins, where the orientation of one electron determines the orientation of the other — a puzzle identified by Albert Einstein.

The research, a combination of physics and engineering, was funded by the United States Defense Advanced Research Projects Agency, the United States Defense MicroElectronics Activity and the Center for Nanoscience Innovation for Defense.

Ivar Martin, a theoretical physicist at Los Alamos National Laboratory, is a co-author on the Nature paper.

In the late 1990s, Yablonovitch formed a team of physicists, engineers, materials scientists and mathematicians to create an electronic device that could some day be used for quantum information processing.

"The collaboration with Eli has been my best experience at UCLA," Jiang said. "This is an exciting time for nanoscience and technology."

Jiang often monitors experiments from home in the middle of the night.

"It's so exciting," he said, "I don't want to wait until morning to know the outcome of the experiments."

Source: University of California - Los Angeles