Quantum computers are a quantum leap closer

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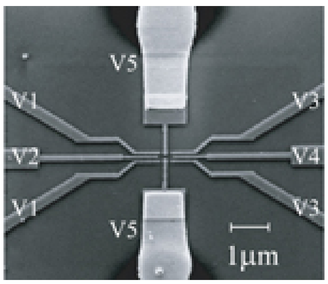

WEST LAFAYETTE, Ind. – A new breed of faster, more powerful computers based on quantum mechanics may be a step closer to reality, report scientists from Purdue and Duke universities.
By linking a pair of tiny "puddles" of a few dozen electrons sandwiched inside a semiconductor, researchers have enabled these two so-called "quantum dots" to become parts of a transistor – the vital switching component in computer chips.

Future computers that use quantum dots to store and process digital information might outperform conventional computer circuits because of both the new transistors' smaller size and their potential to solve problems that would take centuries on today's machines.

"This is a very promising candidate for quantum computation," said

Albert M. Chang, who is an adjunct professor of physics in Purdue's School of Science. "We believe this research will allow large numbers of quantum-dot switches to work together as a group, which will be necessary if they are ever to function as a computer's brain, or memory.

"For the market, quantum computers mean better encryption methods and heightened data security. For science, our research may help address the longstanding mystery of the relationship between the classical physics of the world we see every day, and the peculiar world of quantum physics that governs the tiny particles inside atoms."

The research will appear in the current (April 30) issue of Physical Review Letters. The lead author is Jeng-Chung Chen, who received his doctorate at Purdue and is now at the University of Tokyo. Co-authors are Chang, who in 2003 relocated from Purdue to Duke University, where he is a professor of physics, and Michael. R. Melloch, a professor in Purdue's School of Electrical and Computer Engineering.

As computer circuits grow ever smaller, manufacturers draw nearer to the time when their chips' tiny on-off switches – representing the 1's and 0's of binary information, or bits – can be made comparable in size to a single molecule. At smaller scales, the laws of classical physics will no longer apply to the switches, but will be replaced by the laws of the subatomic world. These laws, described by quantum physics, can appear strange to the uninitiated.

"An electron, for example, can behave like a particle or a wave at times, and it has the odd ability to seemingly be in two different states at once," Chang said. "Physicists need a different set of words and concepts to describe the behavior of objects that can do such counterintuitive things. One concept we use is the 'spin' of an electron, which we loosely imagine as being similar to the way the Earth spins each day on its axis. But it also describes a sort of ordering electrons must obey in one another's presence: When two electrons occupy the same space, they must pair with opposite spins, one electron with 'up' spin, the other 'down.'"

Spin is one property that physicists seek to harness for memory storage. After collecting 40 to 60 paired electrons in a puddle within a semiconductor wafer of gallium arsenide and aluminum gallium arsenide, the team then added a single additional unpaired electron to the puddle. This extra electron imparted a net spin of up or down to the entire puddle, which they call a quantum dot. The team also built a second quantum dot nearby with the same net spin.

"When isolated from one another, the two net spins would not seek to pair with each other," Chang said. "But we have a special method of 'tuning' the two-dot system so that, despite the similar spins, the two unpaired electrons became 'entangled' – they begin to interact with one another."

The team used eight tiny converging wires, or "gates," to deposit the electrons in the dots one by one and then electronically fine-tune the dots' properties so they would become entangled. With these gates, the team was able to slowly tune the interacting dots so they are able to exist in a mixed, down-up and up-down configuration simultaneously. In each dot, an up or down configuration would represent a 1 or 0 in a quantum bit, or "qubit," for possible use in memory chips.

"Entanglement is a key property that would help give a quantum computer its power," Chang said. "Because each system exists in this mixed, down-up configuration, it may allow us to create switches that are both on and off at the same time. That's something current computer switches can't do."

Large groups of qubits could be used to solve problems that have myriad potential solutions that must be winnowed down quickly, such as factoring the very large numbers used in data encryption.

"A desktop computer performs single operations one after another in series," Chang said. "It's fast, but if you could do all those operations together, in parallel rather than in series, it can be exponentially faster. In the encryption world, solving some problems could take centuries with a conventional computer."

But for a quantum computer, whose bits can be in two quantum states at once – both on and off at the same time – many solutions could, in theory, be explored simultaneously, allowing for a solution in hours rather than lifetimes.

"These computers would have massive parallelism built right in, allowing for the solution of many tough problems," Chang said. "But for us physicists, the possibilities of quantum computers extend beyond any single application. There also exists the potential to explore why there seem to be two kinds of reality in the universe – one of which, in everyday language, is said to stop when you cross the border 'into the interior of the atom.'"

Because a quantum computer would require all its qubits to behave according to quantum rules, its processor could itself serve as a laboratory for exploring the quantum world.

"Such a computer would have to exhibit 'quantum coherence,' meaning its innards would be a large-scale system with quantum properties rather than classical ones," Chang said. "When quantum systems interact with the classical world, they tend to lose their coherence and decay into classical behavior, but the quantum-dot system we have built exhibits naturally long-lasting coherence. As an entire large-scale system that can behave like a wave or a particle, it may provide windows into the nature of the universe we cannot otherwise easily explore."

The system would not have to be large; each dot has a width of only about 200 nanometers, or billionths of a meter. About 5,000 of them placed end to end would stretch across the diameter of a grain of sand. But Chang said that his group's system had another, greater advantage even than its minuscule size.

"Qubits have been created before using other methods," he said. "But ours have a potential advantage. It seems possible to scale them up into large systems that can work together because we can control their behavior more effectively. Many systems are limited to a handful of qubits at most, far too few to be useful in real-world computers."

For now, though, the team's qubit works too slowly to be used as the basis of a marketable device. Chang said the team would next concentrate on improving the speed at which they can manipulate the spin of the electrons.

"Essentially, what we've done is just a physics experiment, no more," he said. "In the future, we'll need to manipulate the spin at very fast rates. But for the moment, we have, for the first time, demonstrated the entanglement of two quantum dots and shown that we can control its properties with great precision. It offers hope that we can reach that future within a decade or so."

The original news [here](#).

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