Pairing up single atoms in silicon for quantum computing

June 16 2014, by Ry Crozier

(Phys.org) —Australian engineers detect in real-time the quantum spin properties of a pair of atoms inside a silicon chip, and disclose new method to perform quantum logic operations between two atoms.

A team of electrical engineers at UNSW Australia has observed the unique quantum behaviour of a pair of spins in silicon and designed a new method to use them for "2-bit" quantum logic operations.

These milestones bring researchers a step closer to building a quantum computer, which promises dramatic data processing improvements.

Quantum bits, or qubits, are the building blocks of quantum computers. While many ways to create a qubit exist, the Australian team has focused on the use of single atoms of phosphorus, embedded inside a silicon chip similar to those used in normal computers.

The UNSW team had already shown the world-first operation of a quantum bit based upon the magnetic dipole (or "spin") of a single phosphorus atom, placed near a silicon transistor.

The next natural step was to take two atoms and connect them to perform logic operations.

"When two atoms are placed close together, the electrons that belong to them acquire a striking quantum behaviour, where the spin direction of each electron no longer exists individually, but only in relation to the direction of the other," Associate Professor Andrea Morello of the School of Electrical Engineering & Telecommunications says.

"These unique quantum states are at the heart of quantum computation, and for the first time we have been able to observe them directly."

The first author on the experimental work, PhD student Juan Pablo Dehollain, recalls the first time he realised what he was looking at.

"We clearly saw these two distinct quantum states, but they behaved very differently from what we were used to with a single atom. We had a real 'Eureka!' moment when we realised what was happening – we were seeing in real time the `entangled' quantum states of a pair of atoms."

The experiments were performed at the ARC Centre of Excellence for Quantum Computation & Communication Technology, as a collaborative effort between the team led by Morello, and a group consisting of Professor Andrew Dzurak (UNSW), Professor David Jamieson (University of Melbourne), and Dr Andre Saraiva at the University of Wisconsin-Madison (US).

New design for quantum logic operations

Placing two phosphorus atoms close to each other is not enough to perform a logic operation of the kind necessary to run a quantum computing calculation.

"For a long time it was thought that, for the quantum computer to work, the distance between the atoms had to be set with exquisite precision – essentially, you had to place the phosphorus with atomic precision within the silicon crystal," Morello says.

Now his team has developed and patented a new strategy that allows much more tolerance in the atom's placement.

The first author of this paper, PhD student Rachpon Kalra, explains, "This new idea will allow performing 2-bit quantum logic gates between pairs of atoms placed in a wide range of distances from one another.

"Technologically, this is a real breakthrough, because it will permit building quantum computers using the same fabrication method used for normal silicon transistors."

All modern silicon microchips, as found in any computer or mobile phone, contain millions or billions of transistors, whose electrical properties are fine-tuned by introducing different atoms such as phosphorus.

The industry-standard method to introduce the atoms does not allow atomic-level precision in their final position.

However, the new design for a quantum logic gate by the UNSW team is tailor-made to ensure that the existing technology remains usable to build quantum computers.

The key breakthrough to arrive at this new idea was to exploit the ability to control the nuclear spin of each atom. This ability was demonstrated for the first time by the UNSW team in 2013, and published in a landmark paper in *Nature*.

With that insight, the team has now conceived a unique way to use the nuclei as facilitators for the quantum logic operation between the electrons.

"It is this key idea, grounded in the experimental reality, that will give us a way to make robust [quantum logic](#) gates without the need for atomic precision in the placement of the atoms", Kalra says.

A clear road ahead

The two papers published this week, in the prestigious journals *Physical Review Letters* and *Physical Review X*, dissipate many of the clouds that still potentially obscured the path towards a silicon-based quantum computer.

The UNSW team is currently working on the experimental demonstration of their ideas, and expects to have implemented a 2-qubit logic gate very soon.

More information: "Single-Shot Readout and Relaxation of Singlet and Triplet States in Exchange-Coupled P31 Electron Spins in Silicon." *Phys. Rev. Lett.* 112, 236801 – Published 9 June 2014. Juan P. Dehollain, Juha T. Muhonen, Kuan Y. Tan, Andre Saraiva, David N. Jamieson, Andrew S. Dzurak, and Andrea Morello. journals.aps.org/prl/abstract/ … ysRevLett.112.236801

"Robust Two-Qubit Gates for Donors in Silicon Controlled by Hyperfine Interactions." *Phys. Rev. X* 4, 021044 – Published 6 June 2014. Rachpon Kalra, Arne Laucht, Charles D. Hill, and Andrea Morello. journals.aps.org/prx/abstract/ … 03/PhysRevX.4.021044

Provided by University of New South Wales