Quantum computing in silicon hits 99% accuracy

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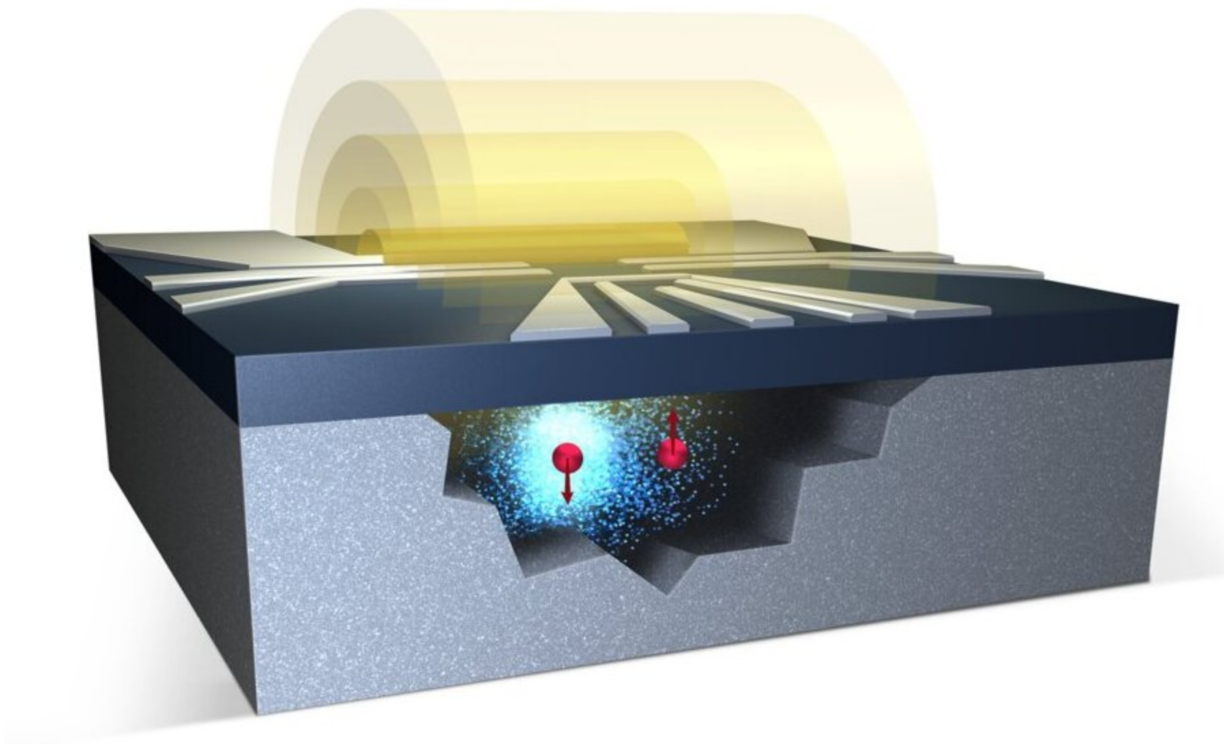


The silicon nanoelectronic device used to hold the quantum processor was built using methods compatible with industry standards for existing computer chips. (The authors demonstrated universal quantum logic operations using a pair of ion-implanted 31P nuclei in a silicon nanoelectronic device. The device is manufactured using methods compatible with the industry-standard processes used for all existing computer chips.). Credit: Tony Melov / UNSW

UNSW Sydney-led research paves the way for large silicon-based quantum processors for real-world manufacturing and application.

Australian researchers have proven that near error-free quantum computing is possible, paving the way to build silicon-based quantum devices compatible with current semiconductor manufacturing technology.

"Today's publication in *Nature* shows our operations were 99 percent error-free," says Professor Andrea Morello of UNSW, who led the work.

"When the errors are so rare, it becomes possible to detect them and correct them when they occur. This shows that it is possible to build quantum computers that have enough scale, and enough power, to handle meaningful computation."

This piece of research is an important milestone on the journey that will get us there," Prof. Morello says.

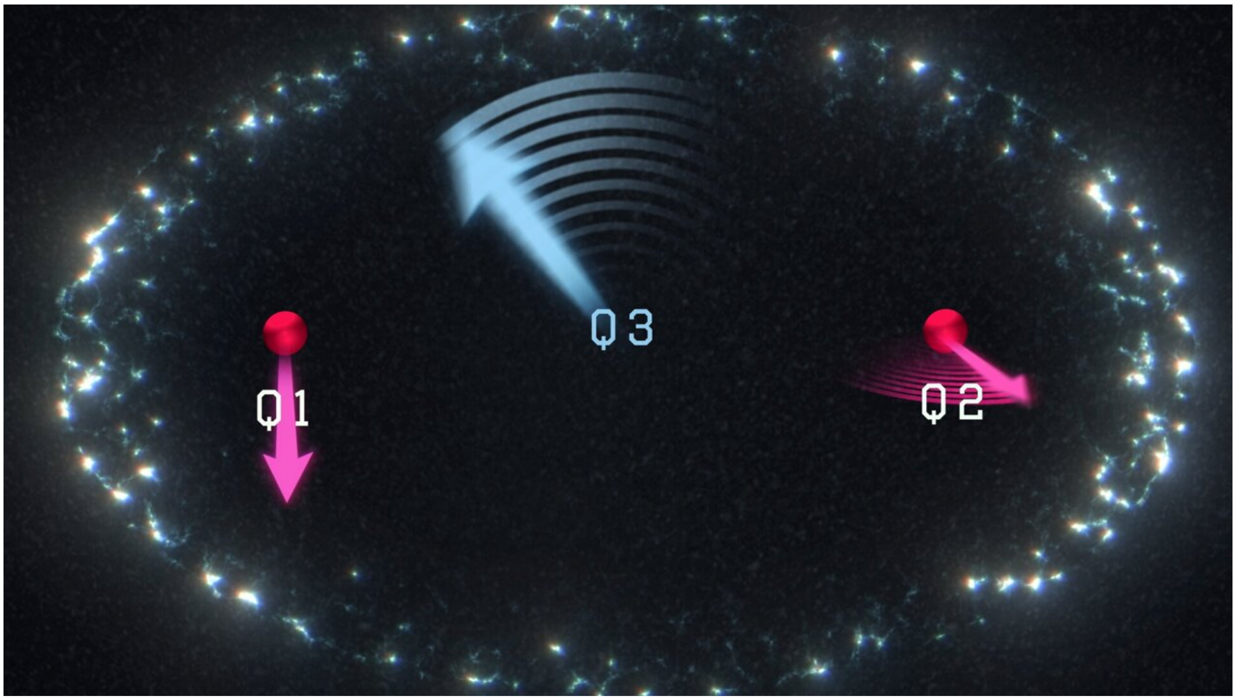
Quantum computing in silicon hits the 99% threshold

Morello's paper is one of three published today in *Nature* that independently confirm that robust, reliable quantum computing in silicon is now a reality. This breakthrough features on the front cover of the journal.

- Morello et al achieved 1-qubit operation fidelities up to 99.95 percent, and 2-qubit fidelity of 99.37 percent with a three-qubit system comprising an electron and two phosphorous atoms, introduced in silicon via ion implantation.
- A Delft team in the Netherlands led by Lieven Vandersypen achieved 99.87 percent 1-qubit and 99.65 percent 2-qubit fidelities using electron spins in quantum dots formed in a stack

of silicon and silicon-germanium alloy (Si/SiGe).

- A RIKEN team in Japan led by Seigo Tarucha similarly achieved 99.84 percent 1-qubit and 99.51 percent 2-qubit fidelities in a two-electron system using Si/SiGe quantum dots.



A visualisation of UNSW's three-qubit system, which can perform quantum logic operations with over 99% accuracy. (Quantum operation fidelities above 99% were obtained in a three-qubit silicon quantum processor. The first two qubits (Q1, Q2) are the nuclear spins of individually-implanted phosphorus atoms (red spheres). The third qubit (Q3) is the spin of an electron that wraps around both nuclei (shiny ellipse).). Credit: Tony Melov / UNSW

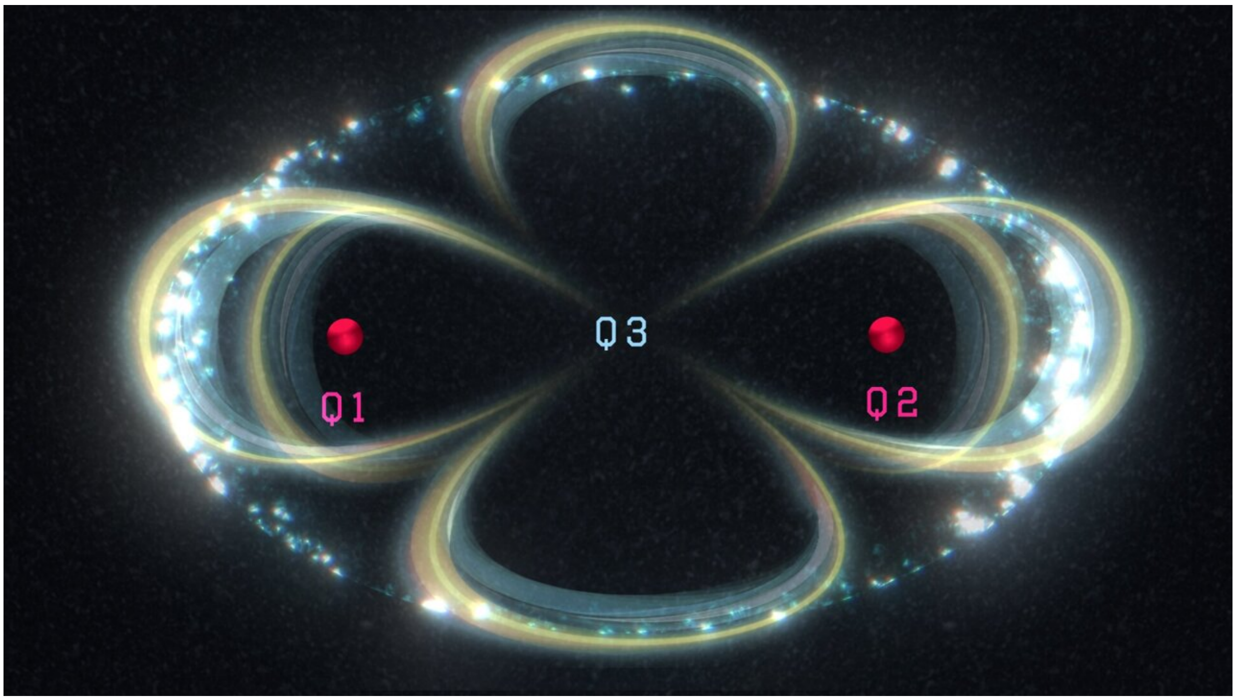
The UNSW and Delft teams certified the performance of their quantum processors using a sophisticated method called gate set tomography, developed at Sandia National Laboratories in the U.S. and made openly available to the research community.

Morello had previously demonstrated that he could preserve quantum information in silicon for 35 seconds, due to the extreme isolation of nuclear spins from their environment.

L-R Asaad, Morello, Madzik (composite image): Serwan Asaad, Andrea Morello and Mateusz Mądzik are lead authors of the UNSW paper which demonstrated 99 per cent error-free quantum operations. Credit: Kearon de Clouet / UNSW

"In the quantum world, 35 seconds is an eternity," says Prof. Morello. "To give a comparison, in the famous Google and IBM superconducting quantum computers the lifetime is about a hundred microseconds—nearly a million times shorter."

But the trade-off was that isolating the qubits made it seemingly impossible for them to interact with each other, as necessary to perform actual computations.



The three qubits can be prepared in a quantum entangled state, which unlocks the exponential power of quantum computers. (Nuclear spins are exceptionally good qubits, because of their exceptional isolation from the environment. This same feature, however, makes it difficult for them to interact and perform quantum logic operations. The team's breakthrough consists in using a common electron to mediate the interaction, leading to high-fidelity universal quantum logic operations. Furthermore, the electron itself is a high-quality qubit, and can be placed in a fully quantum-entangled state with the two nuclei.). Credit: Tony Melov / UNSW

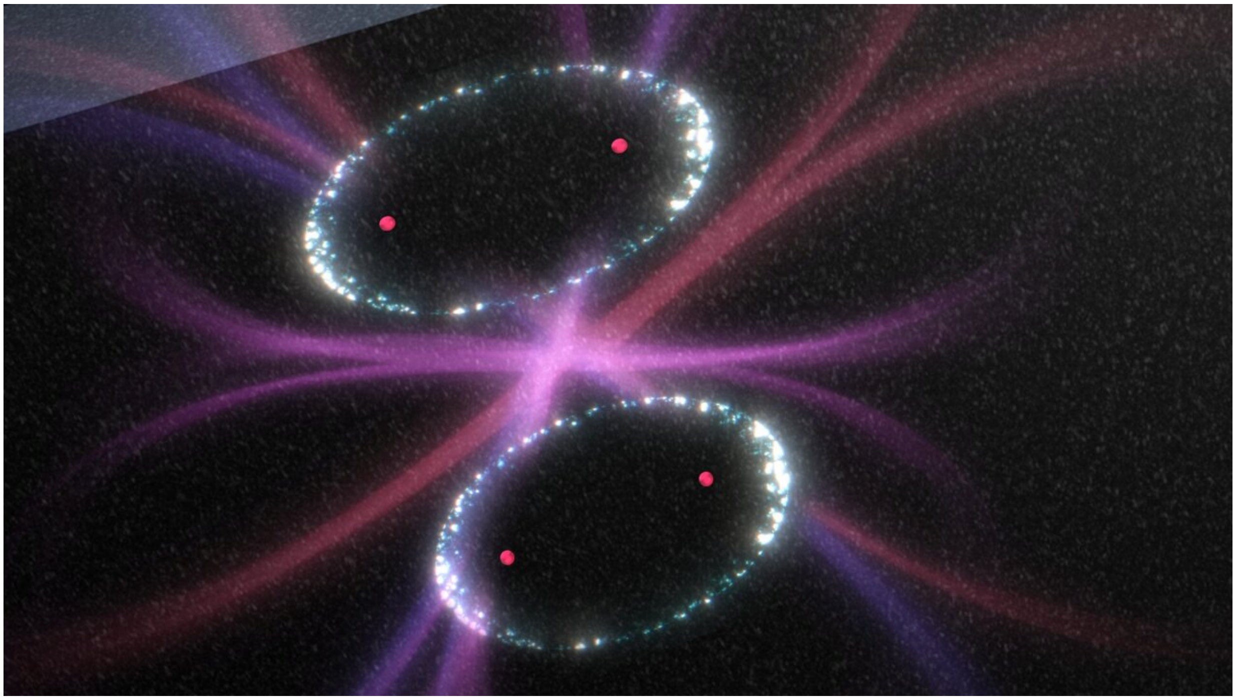
Nuclear spins learn to interact accurately

Today's paper describes how his team overcame this problem by using an electron encompassing two nuclei of phosphorus atoms.

"If you have two nuclei that are connected to the same electron, you can make them do a quantum operation," says Dr. Mateusz Mądzik, one of the lead experimental authors.

"While you don't operate the electron, those nuclei safely store their quantum information. But now you have the option of making them talk to each other via the electron, to realize universal quantum operations that can be adapted to any computational problem."

"This really is an unlocking technology," says Dr. Serwan Asaad, another lead experimental author. "The nuclear spins are the core quantum processor. If you entangle them with the electron, then the electron can then be moved to another place and entangled with other qubit nuclei further afield, opening the way to making large arrays of qubits capable of robust and useful computations."



The three-qubit system paves the way to scaling up the quantum processor in the future, because the electron can be easily entangled with other electrons or moved across the chip. (The three-qubit entangled state of nuclei and electron paves the way to scaling up the quantum processor in the future. The electron can be easily entangled with other electrons, or physically moved across the chip. In this way, the UNSW team will be able to manufacture and operate large arrays of qubits capable of robust and useful computations.). Credit: Tony Melov / UNSW

Mateusz Mądzik, one of the lead authors. Credit: UNSW

David Jamieson, research leader at the University of Melbourne, adds: "The phosphorous atoms were introduced in the silicon chip using ion implantation, the same method used in all existing silicon computer chips. This ensures that our quantum breakthrough is compatible with the broader semiconductor industry."

All existing computers deploy some form of error correction and data redundancy, but the laws of quantum physics pose severe restrictions on how the correction takes place in quantum computer. Prof. Morello explains: "You typically need error rates below 1 percent, to apply quantum error correction protocols. Having now achieved this goal, we can start designing silicon quantum processors that scale up and operate reliably for useful calculations."

More information: Andrea Morello, Precision tomography of a three-qubit donor quantum processor in silicon, *Nature* (2022). DOI: 10.1038/s41586-021-04292-7. www.nature.com/articles/s41586-021-04292-7

Lieven Vandersypen, Quantum logic with spin qubits crossing the surface code threshold, *Nature* (2022). DOI: 10.1038/s41586-021-04273-w. www.nature.com/articles/s41586-021-04273-w

Akito Noiri, Fast universal quantum gate above the fault-tolerance threshold in silicon, *Nature* (2022). DOI: 10.1038/s41586-021-04182-y. www.nature.com/articles/s41586-021-04182-y

Provided by University of New South Wales