Hot qubits break one of the biggest constraints to practical quantum computers

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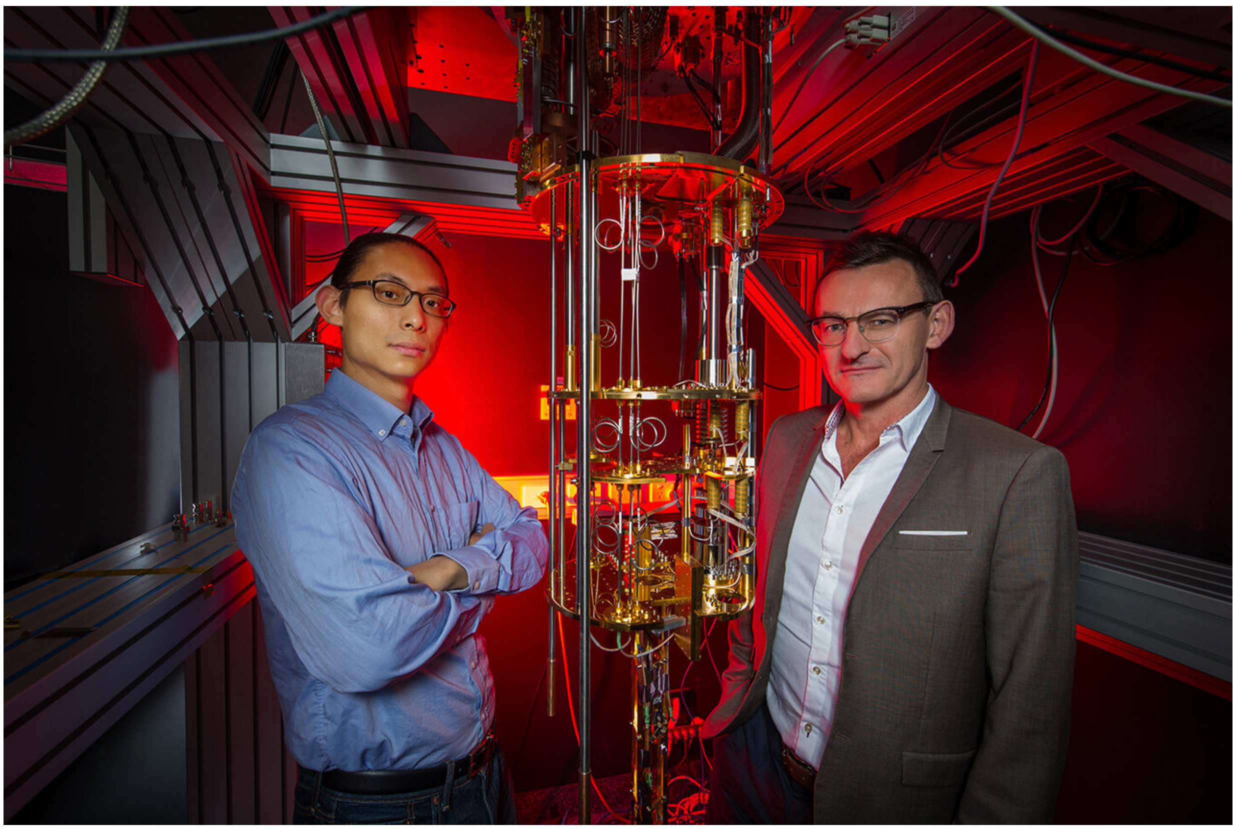

Dr Henry Yang and Professor Andrew Dzurak, UNSW School of Electrical Engineering & Telecommunications. Credit: UNSW Sydney

Most quantum computers being developed around the world will only work at fractions of a degree above absolute zero. That requires multi-million-dollar refrigeration and as soon as you plug them into conventional electronic circuits they'll instantly overheat.

But now researchers led by Professor Andrew Dzurak at UNSW Sydney have addressed this problem.

"Our new results open a path from experimental devices to affordable quantum computers for real world business and government applications," says Professor Dzurak.

The researchers' proof-of-concept quantum processor unit cell, on a silicon chip, works at 1.5 Kelvin—15 times warmer than the main competing chip-based technology being developed by Google, IBM, and others, which uses superconducting qubits.

"This is still very cold, but is a temperature that can be achieved using just a few thousand dollars' worth of refrigeration, rather than the millions of dollars needed to cool chips to 0.1 Kelvin," explains Dzurak.

"While difficult to appreciate using our everyday concepts of temperature, this increase is extreme in the quantum world."

Quantum computers are expected to outperform conventional ones for a range of important problems, from precision drug-making to search algorithms. Designing one that can be manufactured and operated in a real-world setting, however, represents a major technical challenge.

The UNSW researchers believe that they have overcome one of the hardest obstacles standing in the way of quantum computers becoming a reality.

In a paper published in the journal *Nature* today, Dzurak's team, together with collaborators in Canada, Finland and Japan, report a proof-of-concept quantum processor unit cell that, unlike most designs being explored worldwide, doesn't need to operate at temperatures below one-tenth of one Kelvin.

Dzurak's team first announced their experimental results via the academic pre-print archive in February last year. Then, in October 2019, a group in the Netherlands led by a former post-doctoral researcher in Dzurak's group, Menno Veldhorst, announced a similar result using the same silicon technology developed at UNSW in 2014. The confirmation of this 'hot qubit' behaviour by two groups on opposite sides of the world has led to the two papers being published 'back-to-back' in the same issue of *Nature* today.

Qubit pairs are the fundamental units of quantum computing. Like its classical computing analogue—the bit—each qubit characterises two states, a 0 or a 1, to create a binary code. Unlike a bit, however, it can manifest both states simultaneously, in what is known as a "superposition".

The unit cell developed by Dzurak's team comprises two qubits confined in a pair of quantum dots embedded in silicon. The result, scaled up, can be manufactured using existing silicon chip factories, and would operate without the need for multi-million-dollar cooling. It would also be easier to integrate with conventional silicon chips, which will be needed to control the quantum processor.

A quantum computer that is able to perform the complex calculations needed to design new medicines, for example, will require millions of qubit pairs, and is generally accepted to be at least a decade away. This need for millions of qubits presents a big challenge for designers.

"Every qubit pair added to the system increases the total heat generated," explains Dzurak, "and added heat leads to errors. That's primarily why current designs need to be kept so close to absolute zero."

The prospect of maintaining quantum computers with enough qubits to be useful at temperatures much colder than deep space is daunting, expensive and pushes refrigeration technology to the limit.

The UNSW team, however, have created an elegant solution to the problem, by initialising and "reading" the qubit pairs using electrons tunnelling between the two quantum dots.

The proof-of-principle experiments were performed by Dr. Henry Yang from the UNSW team, who Dzurak describes as a "brilliant experimentalist".

More information: Operation of a silicon quantum processor unit cell above one kelvin, *Nature* (2020). DOI: 10.1038/s41586-020-2171-6 , nature.com/articles/s41586-020-2171-6

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