Using two different elements creates new possibilities in hybrid atomic quantum computers

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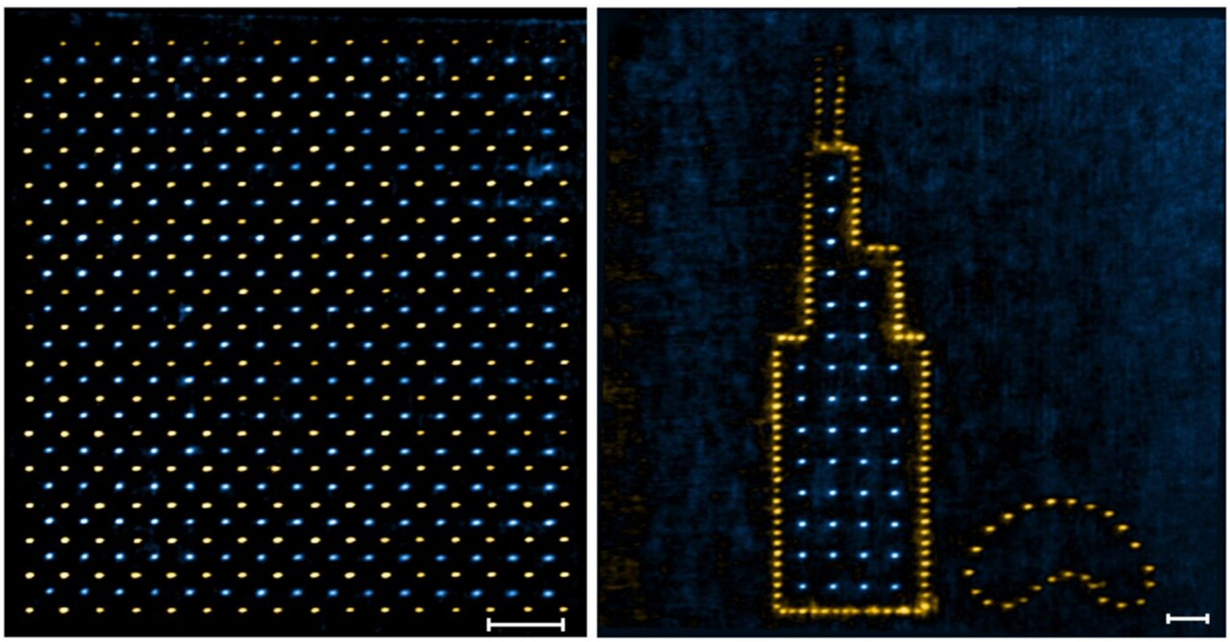

Left: A hybrid array of cesium atoms (yellow) and rubidium atoms (blue). Right: The customizability of the researchers' technique enables them to place the atoms anywhere, allowing them to create this image of Chicago landmarks Willis Tower and the Cloud Gate. The scale bar in both images is 10 micrometers. Credit: Hannes Bernien

Qubits, the building blocks of quantum computers, can be made from many different technologies. One way to make a qubit is to trap a single neutral atom in place using a focused laser, a technique that won the Nobel Prize in 2018.

But to make a quantum computer out of neutral atom qubits, many individual atoms must be trapped in place by many laser beams. So far, these arrays have only been constructed from atoms of a single element, out of concern that making an array out of two elements would be prohibitively complex.

But for the first time, University of Chicago researchers have created a hybrid array of neutral atoms from two different elements, significantly broadening the system's potential applications in quantum technology. The results were funded in part by the NSF Quantum Leap Challenge Institute Hybrid Quantum Architectures and Networks (HQAN), and published in *Physical Review X*.

"There have been many examples of quantum technology that have taken a hybrid approach," said Hannes Bernien, lead researcher of the project and assistant professor in University of Chicago's Pritzker School of Molecular Engineering. "But they have not been developed yet for these neutral atom platforms. We are very excited to see that our results have triggered a very positive response from the community, and that new protocols using our hybrid techniques are being developed."

Double the potential

While manmade qubits such as superconducting circuits require quality control to stay perfectly consistent, neutral atoms made from a single element all have exactly the same properties, making them ideal, consistent candidates for qubits.

But since every atom in the array has the same properties, it's extremely difficult to measure a single atom without disturbing its neighbors—they're all on the same frequency, so to speak.

"There have been quite a few milestone experiments over the last few years showing that atomic array platforms are extremely well suited for quantum simulation and also quantum computation," Bernien said. "But measurements on these systems tend to be destructive, since all the atoms have the same resonances. This new hybrid approach can be really useful in this case."

In a hybrid array made of atoms of two different elements, any atom's nearest neighbors can be atoms of the other element, with completely different frequencies. This makes it much easier for researchers to measure and manipulate a single atom without any interference from the atoms around it.

It also allows researchers to sidestep a standard complication of atomic arrays: it is very difficult to hold an atom in one place for very long.

"When you do these experiments with the single atoms, at some point, you lose the atoms," Bernien said. "And then you always have to re-initialize your system by first making a new, cold cloud of atoms and waiting for individual ones to get trapped by the lasers again. But because of this hybrid design, we can do experiments with these species separately. We can be doing an experiment with atoms of one element, while we refresh the other atoms, and then switch so we always have qubits available."

Making a bigger quantum computer

The hybrid array created by Bernien's group contains 512 lasers: 256 loaded with cesium atoms and 256 with rubidium atoms. As quantum computers go, this is a lot of qubits: Google and IBM, whose quantum computers are made of superconducting circuits rather than trapped atoms, have only gotten up to about 130 qubits. Though Bernien's device is not yet a quantum computer, quantum computers made from atomic arrays are much easier to scale up, which could lead to some important new insights.

"We actually don't know what happens when you scale up a very coherent system that you can isolate very well from the environment," Bernien said. "This trapped atom approach can be a wonderful tool to explore large-system quantum effects in unknown regimes."

The hybrid nature of this array also opens the door to many applications that wouldn't be possible with a single species of atom. Since the two species are independently controllable, the atoms of one element can be used as quantum memory while the other can be used to make quantum computations, taking on the respective roles of RAM and a CPU on a typical computer.

"Our work has already inspired theoreticians to think about new protocols for it, which is exactly what I hoped," Bernien said. "I hope it will inspire people to think about how these tools can be used for measurements and state control. We have already seen really cool protocols that that we are very interested in implementing on these arrays."

More information: Kevin Singh et al, Dual-Element, Two-Dimensional Atom Array with Continuous-Mode Operation, *Physical Review X* (2022). DOI: 10.1103/PhysRevX.12.011040

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