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Hue-ing to quantum computing

By Eric Smalley, Technology Research News

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The starting gun has sounded in the marathon of developing solid-state quantum computers, and one lead team jockeying for position is betting that shining different color lasers on impure diamonds will get them across the finish line.

The researchers are building their quantum computer using spectral hole burning, which tunes atoms or molecules trapped in a transparent solid to specific light wavelengths, or colors.

The researchers have tuned nitrogen atoms embedded in diamond to a range of slightly different wavelengths, said Selim M. Shahriar, a research scientist in the Research Laboratory of Electronics at the Massachusetts Institute of Technology. The differences in color are imperceptible to humans, he added.

Each atom is tuned to two wavelengths. If a laser beam of one of the wavelengths hits it, the atom will emit light of the other wavelength, Shahriar said. In addition, a pair of atoms each tuned to two wavelengths can be linked to each other. For example, if atom A is tuned to wavelengths 1 and 2 and atom B is tuned to wavelengths 2 and 3 and the atoms are hit with lasers tuned to wavelengths 1 and 3, both atoms emit light of wavelength 2, he said.

This allows the atoms to be coupled by quantum entanglement. When two atoms are entangled, a change in the state of one is immediately reflected by a corresponding change in the other regardless of the physical distances between the atoms.

An atom can serve as a quantum bit, or qubit, because it spins in one of two directions, and its spins can represent the ones and zeros of binary computing. Because isolated bits are of little use, linking atoms is a prerequisite for quantum computing.

The researchers expect their spectral hole burning technique to yield

300 or more qubits, Shahriar said. That number is significant because a 300-qubit quantum computer would be able to factor numbers larger than any conventional computer will likely ever be able to handle.

"The experiment is already in progress. We have already demonstrated that each atom has the two-color response that we need. We have already demonstrated how we can line [the atoms] all up to be spinning in the same direction. That's the starting point of the quantum computer," Shahriar said.

How long the qubits last is as important as the number of qubits. Qubits are fragile because the slightest influence from the outside environment can knock the atoms out of their quantum state. The nitrogen-infused diamond spectral hole burning technique would probably last long enough to yield 40,000 quantum operations, Shahriar said.

"You need to be able to do more operations, but there are ways to increase that number," he said.

The other early favorites in the race for solid-state quantum computing are techniques based on superconductors, electron spins in quantum dots and nuclear spins in semiconductors.

"It's very important to pursue a lot of different things at this stage because it's very unclear exactly what type of hardware is going to be useful in the long run," said John Preskill, professor of theoretical physics and director of the Institute for Quantum Information at the California Institute of Technology. "So it's a healthy thing that there are a lot of different ideas floating around, spectral hole burning being one of them."

The first step toward solid-state quantum computers is demonstrating good control over a qubit in a system "which has at least the potential to be scaled up," Preskill said.

Other researchers have demonstrated seven-qubit systems using nuclear magnetic resonance (NMR). However, NMR techniques are not expected to scale up significantly, hence the race to develop solid-state quantum computing. Solid-state devices are based on semiconductors or other crystalline solids.

Schemes that are good candidates for quantum computing should support reliably readable results, reliable preparation of the initial states of their qubits, and logic gates with good fidelity, Preskill said. NEC researchers in Japan have gone the furthest in solid-state quantum computing with a superconducting implementation in which they have established a qubit, he said.

The nitrogen-diamond spectral hole team is in the last year of a three-year project to establish the viability of the technique, Shahriar said.

"We expect to demonstrate quantum entanglement within nine months," he said. "At the end of the next three-year [period] we expect to have at least 10 of these atoms coupled to one another. And that'll be a pretty significant step."

Though useful quantum computers are at least 20 years away, quantum information processing could be used for secure communications in five to ten years, Shahriar said.

Shahriar's colleagues are Philip R. Hemmer of the U.S. Air Force, Seth Lloyd and Jeffery A. Bowers of MIT, and Alan E. Craig of Montana State University. The research is funded by the Air Force Office of Scientific Research, the Army Research Office and the National Security Agency.

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