

what's next

High Noon for

qubits

By Neal Singer

In the twilight of Moore's Law, researchers around the world are searching for efficient, reliable quantum bits, or qubits, to replace ordinary bits, the little yes-no circuits that are the bread and butter of today's computers. Exceptional qubits would be vital to a far faster, more energy-efficient quantum computer.

"There are a half dozen methods that might achieve working qubits," says Sandia Advanced Device Technologies manager John Aidun. "It's still the Wild West out there, and fun, as long as you can convince someone to pursue the work."

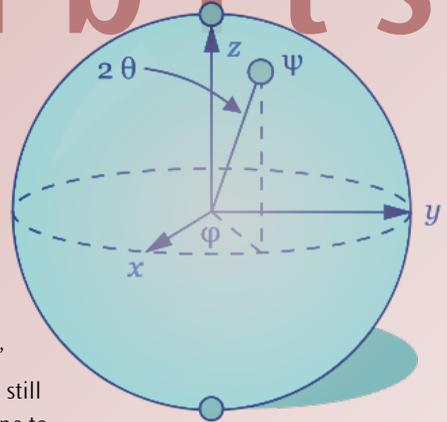
Computational modeler Rick Muller threw his hat in the ring, using quantum double dots and embedded donor atoms to create qubits with help from Sandia's Microsystems and Engineering Sciences Applications complex and Ion Beam Laboratory and the Center for Integrated Nanotechnologies, a Department of Energy facility jointly operated by Sandia and Los Alamos national laboratories.

Quantum dots are nanoparticles of semiconductor material. Donor atoms add electrons. Together they create small "puddles" of electrons in a semiconductor system. And they require only standard microelectronic fabrication techniques.

Muller colleagues Erik Nielsen, Ralph Young and Xujiao (Suzey) Gao write software to accelerate development of the donor and dot devices. Their Quantum Computer Aided Design (QCAD) software can predict properties of qubit structures before they are created in the laboratory and help identify promising candidates among various designs. The modelers work closely with experimental scientists to ensure the software becomes a valuable tool for the research team.

The semiconductor qubits use the electron's spin to deliver information. Because the spin's direction is either up or down relative to an external magnetic field, the natural two-level systems can define a quantum bit. And because of the exotic properties of quantum mechanics, electron spins can be in a "superposition" that lets them spin up and down at the same time. Classical bits are either on or off but not both. A computer made from qubits can use that difference to solve some thorny computational problems more efficiently.

The joint efforts of the modelers and the experimental groups are paying off. Experiments have identified donor systems with long decoherence times — up spins change slowly to down spins — suggesting there will be enough time to run computations before the qubit fully decoheres. ■



A quantum bit is the fundamental unit of quantum information. But unlike classical bits, which store information in either a "0" or a "1" state, quantum bits can take on values between "0" and "1," inclusive.

Because of special properties not found in the realm of classical physics, quantum-bit-based computing could greatly speed up processing. It also could help solve problems that are extremely challenging for today's computers.

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Through a quantum tunnel

By Neal Singer and Toby Jacobson

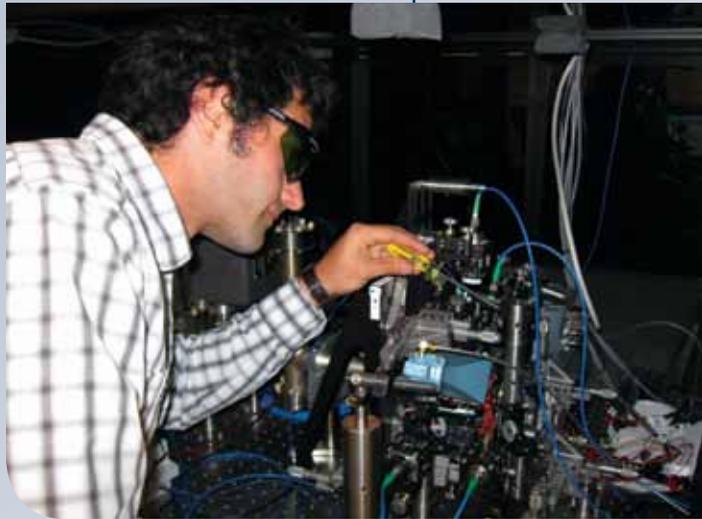
Quantum computing has captured the imagination of researchers because it promises to solve problems that overwhelm a classical computer.

But quantum computation relies on the delicate handling of quantum bits, or qubits. Among the technologies researchers are experimenting with are trapped ions, electrons in semiconductors and magnetic flux in superconductors. These require isolating qubits from the environment while allowing the operator to control and manipulate them.

Achieving a balance between isolation and control is a daunting challenge. Sandia's AQUARIUS project explores an alternative design for a quantum computer that could provide greater immunity to environmental noise. Called adiabatic quantum computing (AQC), it expresses the solution to a problem as the lowest energy configuration, or ground state, of the collection of qubits in the computer. The ground state is obtained by exploiting the phenomenon of quantum tunneling to transform an initial, easily produced configuration of qubits into the complex configuration that gives the solution.

Cooling the qubits eventually leads to the ground state, but can take a long time. Quantum tunneling can bring about the ground state dramatically faster for some problems. But how to verify that the ground state was a result of quantum tunneling rather than thermal cooling? AQUARIUS started with a single qubit and developed a test that answers the question.

The test identifies whether quantum tunneling has taken place. As scientists build more advanced devices for adiabatic quantum computation, it is critical to test and establish their quantum nature at each stage of development. Preserving the delicate properties of a quantum computer makes the quantum speed-up over classical computers possible. ■



Researcher L. Paul Parazzoli adjusts Sandia's first operational (one-qubit) quantum processor. Because these superposed states of one qubit can be combined with other superposed qubits, a string of quantum bits has an enormous capacity for encoding information.