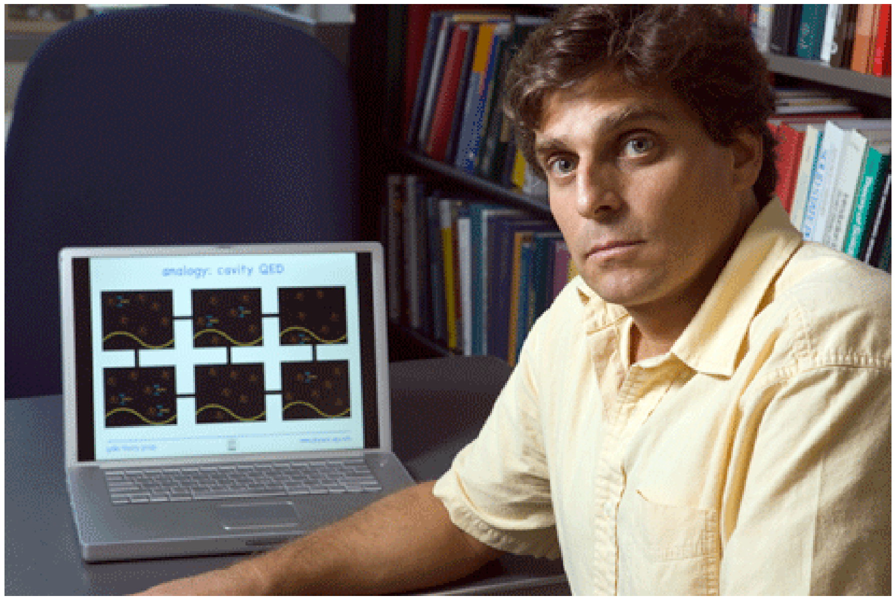

Physicist Michael Geller and a colleague at UC Santa Barbara have proposed using Josephson junctions and nanomechanical resonators to create a quantum computer. (Photo by Paul Efland)

Atomic power at your fingertips

Quantum computers envisioned in new research

By Alan Flurry
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An article in the August 2004 issue of *Physical Review Letters* makes an intriguing proposal for performing quantum computation with a solid state circuit by using nanomechanical resonators to couple quantum devices made from superconductors.

The article, written by UGA physicist Michael Geller and Andrew Cleland of the University of California at Santa Barbara, describes their proposal to combine desirable features of both atomic systems and solid-state electronics to make a large-scale quantum computer.

A quantum computer, if one could be built, would transform information technology by providing vastly increased computational power for certain specialized tasks, such as searching databases or breaking codes. Unlike the transistors in today's computers, a quantum computer would be constructed from building blocks that obey the counterintuitive laws of quantum mechanics, such as that governing an atom or a laser.

Whereas a conventional digital computer processes and stores information in the form of bits, each bit being a "0" or a "1," a quantum computer uses quantum bits, which can be in a "0" or "1" state, or anywhere in between.

"The encryption method used in the financial sector and by defense departments around the world could be compromised by eavesdroppers using quantum computers to factor large numbers," says Geller. "That's why governments are racing to build the first machine."

Factoring, which is the process of decomposing an integer into a product of prime numbers, is notoriously difficult with conventional computers.

"The world record right now is a number 129 digits long, and factoring a 1,000-digit number is estimated to take longer than the age of the universe," says Geller. "But a quantum computer could do this in a reasonable amount of time."

Despite the tremendous effort by scientists and engineers, and support by governments worldwide, no one has so far been able to build a functioning quantum computer.

"The problem is that it is hard to control a quantum system, such as an atom, enough to make it compute for you, but without disturbing the delicate pattern of its motion," says Geller. "One is always fighting against Heisenberg's uncertainty principle."

In Cleland and Geller's design, there are no delicate atoms, but instead superconducting devices called Josephson junctions, which behave like atoms but are much larger. Their design, in fact, looks much like an ordinary microprocessor chip.

"There is great potential here," says Geller, "to make a truly large-scale quantum computer, using the very fabrication technology developed by the semiconductor industry."

A key ingredient in Cleland and Geller's design is the use of nanometer-scale solid-state resonators, much like the quartz crystals in a watch, to couple the Josephson junctions together and to allow quantum information to be stored in memory.

According to Cleland and Geller, a nanomechanical resonator has resonances in the right frequency range, about 1 GHz, to couple Josephson junctions effectively, and also has a high "quality factor," in that information is channeled efficiently and is not lost or scrambled. Cleland has tested resonators made from disks of aluminum nitride slightly more than one micrometer wide and several hundred nanometers thick. At low temperatures, approaching 4.2 Kelvin, these devices display a sharp resonance and maintain an extremely high quality factor.

To perform a quantum logic operation, the quantum state of a Josephson junction is transferred to the resonator, from where it would then be processed by another junction. Calculations by Cleland and Geller suggest that their nanomechanical resonator can perform basic quantum computing operations in a few tens of nanoseconds. Two junctions can also be prepared in an entangled state by a resonator, by allowing a quantum bit to be "teleported" between the Josephson junctions, a form of quantum communication.

"Using this design, we believe that we will be able to build the core of a small quantum computer, using mostly existing technology," Geller says.

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