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Quantum computers get in tune

Ultra-powerful quantum computers could use nanoscale resonators for passing information between the quantum data devices or qubits.

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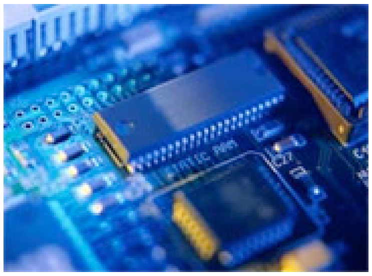

Can quantum computers be made with solid-state electronics?

The quantum computer will transform information technology, providing vastly increased computational power while side-stepping the technical hurdles of miniaturization by embodying computer logic in a completely new architecture. The only problem is that no one knows how to make one. Now two researchers have a new proposal for performing quantum computation in the solid state, which involves using nanoscale meachnical resonators to couple the quantum bits (qubits) of such a device[1].

Andrew Cleland of the University of California at Santa Barbara and Michael Geller of the University of Georgia say that their nanoresonators combine some attractive features of both optical and solid-state electronic approaches to a quantum-computer architecture. Their devices can be made in chip-based arrays using conventional microfabrication technology.

So far, the researchers have only made the nanoscale resonators. They show theoretically that these structures can be used to pass information between qubits constructed from Josephson junctions, in which a thin slice of insulating material is sandwiched between two superconductors. But they have yet to demonstrate this experimentally.

In quantum computing, data is stored and manipulated in the form of specific energy states of the qubits, just as it corresponds to digital electronic or magnetic states in the bits of conventional computers. In other words, a typical qubit might have two quantum energy states, corresponding to the '0' and '1' of electronic logic circuits.

But where quantum computers differ from conventional computers is that the possible settings of a qubit are not just twofold: 1 and 0, or 'on' and 'off'. In addition, a qubit can exist in a quantum superposition of states, a kind of mixture of the 1 and 0 states. For a large collection of qubits, this furnishes many more data states than a conventional computer can support, and it allows a single quantum computer effectively to act like many normal computers working in parallel, greatly boosting the computer's power.

Several realizations of quantum logic have so far been achieved by optical means: encoding the qubits in the quantum states of photons (for example, their polarization states). But it can be hard to store the quantum information carried by a photon. So quantum computers are likely to need some way of storing qubits in the solid state, and indeed there have been several proposals for realizing qubits in solid-state microelectronic devices[2].

None of these ideas have, however, advanced much beyond the proposal stage. The big problem for quantum computing is that quantum superpositions are typically very delicate — they collapse easily into 1's and 0's, a phenomenon called decoherence. This scrambles the information. Decoherence is caused by interactions between the qubits and their environment — it is hard to keep qubits isolated enough, while still making them accessible for writing and reading of data. Because of such difficulties, quantum computations have been so far limited to just three or four qubits. You can't get much computation done that way.

The quantum computer proposed by Cleland and Geller has no magic solutions to the problem of decoherence; but they do think that it should be at least as convenient and effective as other solid-state structures suggested previously. The Josephson junctions are quantum devices with a ladder of energy levels, and can be regarded as 'atoms' with just one or two accessible excited states. The ground state and first excited state might thus correspond to the 0 and 1 settings of the qubit.

These qubits are coupled through a nanomechanical resonator. The basic idea of coupling Josephson-junction qubits via resonators with quantized energy states has been proposed before[3], but no one else has thought of doing it mechanically. The basic idea is that two qubits can become linked by tuning their energy states to the resonant frequency of the resonator — at that point, the resonator becomes a conduit that allows information to flow between the qubits. A nanomechanical resonator has resonances in the right frequency range (around 1 GHz) to couple Josephson junctions, and it can also have a high 'quality factor', meaning that the information is channelled efficiently and doesn't leak out.

In the present case this information flow happens electrically, and the nanoresonators made by Cleland and Geller enable that by being made of piezoelectric material, so that their oscillation sets up an electrical signal. The researchers have made resonators from disks of aluminium nitride a little more than 1 μm wide and several hundred nm thick. At low temperatures (4.2 K) these devices display a sharp resonance with a high quality factor.

To carry out a quantum logic operation, the quantum state of a qubit would be transferred to the resonator, from where it could be passed on to another qubit. Thus the resonator must be able to store the quantum information (in its resonant vibrational state) without letting it get washed away by environmental noise. This is analogous to the way a photon emitted from an atomic qubit might be stored in an optical cavity, where it can be regarded as 'bouncing' around the walls. Cleland and Geller perform calculations that imply that their nanomechanical resonator can indeed receive and hold onto information from a Josephson-junction qubit when the two are brought into resonance for a few tens of nanoseconds.

This state can then be loaded from the resonator into another qubit in the same way. And two qubits can be held in an entangled state by a resonator. In such a state, the quantum settings of the two qubits are correlated with one another. Entanglement could be a crucial element of quantum computing, for example allowing information to be 'teleported' between qubits.

The researchers say that simple quantum-computing operations between qubits coupled this way can be achieved provided that significant decoherence does not happen faster than within a few hundred nanoseconds.

References

1. Cleland A. N. & Geller M. R. Superconducting qubit storage and entanglement with nanomechanical resonators. *Phys. Rev. Lett.* **93,** 070501 (2004)
   Article
2. Kane B. E. A silicon-based nuclear spin quantum computer. *Nature* **393,** 133–137 (1998)
   Article
3. Shnirman A., Schön G. & Hermon Z. Quantum manipulations of small Josephson junctions. *Phys. Rev. Lett.* **79,** 2371–2374 (1997)
   Article