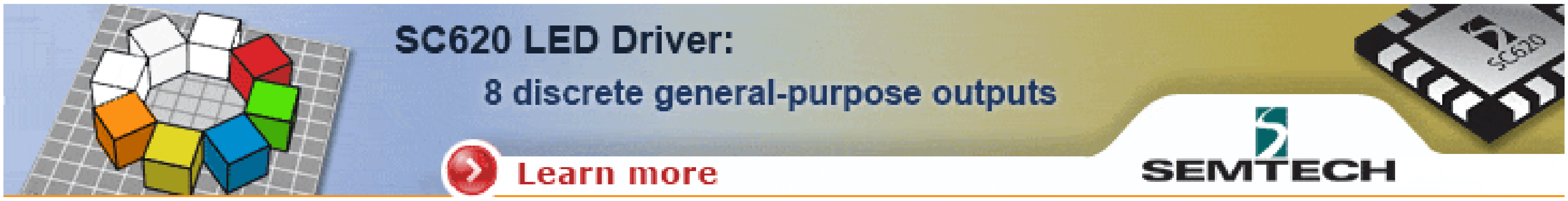

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Superconducting junctions eyed for quantum computing

R. Colin Johnson R. Colin Johnson
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ANN ARBOR, Mich. — Josephson junctions, a superconducting type of transistor, are being investigated as a possible route to scalable quantum computers by a physicist at the University of Michigan. Franco Nori, who has been investigating the concept with scientists at the NEC Fundamental Research Lab (Tsukuba, Japan) and Riken (Wako-shi, Japan), believes Josephson junctions will be the key element in integrated circuits that can process quantum bits, or qubits.

"There are many steps involved in designing and building a quantum computer," said Nori, who has been working with NEC researcher Jaw-Shen Tsai and Riken researcher J.Q. You. In a project that will likely need years of additional research, the group has pinpointed "two key next steps," Nori said: "First, we have a scalable architecture that can be extended to large arrays using microfabrication; and, second, any group of qubits in these arrays can be coupled, rather than just nearest neighbors." Even more important, he said, "we have provided a sequence of operations that would allow efficient quantum information processing."

Quantum states allow a given logic device to have many different possible values simultaneously — a big advantage over conventional methods for representing information, which are confined to a single logical value at any given time. There are many types of quantum variables, from electron spin direction to photon polarization angles, all sharing the ability to exist in a nebulous state that is not resolved until their value is measured.

In information-processing terms, detecting a quantum state is the final readout operation in a computation, so that the entire algorithm can progress while in multiple possible quantum states, creating a built-in version of parallel processing. By encoding 1s and 0s in these unresolved nebulous states, quantum computers could achieve a very dense form of parallel processing .

The research team chose the quantum state of two electrons bound in a "Cooper pair" for their quantum computer architecture. Cooper pairing is the basic mechanism behind low-temperature superconductivity. First the scientists defined an aluminum "box" on a substrate using aluminum oxide sandwiched between aluminum ($Al/Al_2O_3/Al$) — 700 x 50 x 15 nanometers in an earlier NEC prototype. Cooper pairs of electrons are able to tunnel through and once inside, they exist in a combined "superposition" of states with other Cooper pairs.

Even though a Cooper pair box can contain millions of electrons at any one time, the box exhibits only two quantum states — neutral or charged — depending upon whether or not a Cooper pair of electrons has recently tunneled into the box. By gating the Cooper pairs into the box with an appropriate pulse width, previous research has shown that a coherent superposition of the two states can enable quantum computations.

Interbit coupling

Two breakthroughs in quantum-computing architectures in recent years form the basis for Nori's current work. One used Josephson junctions to perform a superposition of states using electrons confined to a Cooper pair box. In the other, nearest-neighbor qubits were shown to be capable of interbit coupling that potentially performs calculations without resolving the qubits' quantum state.

This research ups the ante by providing a means of controlling the coupling between qubits that have been fabricated in arrays on chips. Others have shown coupling between nearest-neighbor qubits via physical proximity; the new twist is to allow controllable interbit coupling among any group of qubits on a chip.

Interbit coupling among qubits is accomplished with two dc Squids — superconducting quantum interference devices — per Cooper pair box, which gate onto a common superconducting inductance. By activating the Squids of selected Cooper pair boxes, any combination of qubits can interact within the common inductor regardless of where they are located on the chip.

By applying a magnetic field, the Squids for two Cooper pair boxes permit the charge inside to form a loop in a common superconducting inductance. Both ac and dc superposed currents can flow through the loop, yielding interbit coupling that does not involve an observation. During this period of coherent superposition, quantum calculations can be accomplished in a single step. The time during which these quantum computations can take place is called the decoherence period.

"Other architectures have not been able to perform quantum calculations in a single step," said Nori. Not only is the new architecture "scalable in the sense that any two qubits on a chip can be effectively coupled by a superconducting inductance," but more important, "we require only a single step to perform a two-qubit operations," he said.