Superconducting Qubits: Quantum Computing with Josephson Junctions

From 2000-02-01 to 2004-01-03 | SQUBIT Website

Objective

We propose to establish a European collaboration - SQUBIT - to demonstrate the feasibility of quantum information processors using scalable solid-state low-Tc Josephson junction (JJ) nanotechnology. The project aims at fabrication of systems of quantum logic gates by developing Josephson junction, single-electron and SQUID technologies to achieve initiation, processing and read-out of superconducting qubit (SQUBIT) information. A major objective is to fabricate SQUBITs and to control the dynamics and de-coherence long enough for the relevant operations to be achieved. The next step aims at the control of several coupled SQUBITs. The final goal is to demonstrate the functioning of a SQUBIT XOR gate and a circuit for SQUBIT entanglement using superconducting tunnel junction technology. After successful assessment of the feasibility of SQUBIT information processors, a "Roadmap for Quantum Computing" should be formulated.

OBJECTIVES

The proposal addresses two QIPC objectives: the development (a) of novel applications and (b) of an elementary scalable quantum processor. The project concerns fabrication of systems of quantum logic gates by developing Josephson junction (charge and flux state) qubits, single-electron and SQUID technologies to achieve initiation, processing and read-out of information. A major objective is to maintain coherence of single qubits long enough for the relevant operations to be performed. The ultimate aim of the project is to demonstrate the functioning of a quantum XOR gate using Josephson junction circuits. In parallel a theoretical analysis of the dynamics of qubit systems and quantum gates should be continued. Major objectives involve design optimisation, non-destructive control of qubit systems, effects of quantum leakage on single and two-qubit operations, and study of the fidelity of various operations and simple quantum algorithms.

DESCRIPTION OF WORK

Low-capacitance superconducting tunnel junctions have a unique potential for building sufficiently large scale, still controllable coherent systems of qubits of information with long de-coherence time. They represent one of the most promising and realistic approaches for creating a technology of quantum computers. At low temperatures the circuit variables (flux and charge) at the circuit nodes behave quantum mechanically. One can use external potentials on gate electrodes or external magnetic fields to vary the quantum mechanical coupling in the systems, and tune the coherent superposition of the circuit variables. The ability to control this superposition with an external control knob is an important step towards implementation of quantum computing schemes. Furthermore, the fact that one can design the circuit using standard electron lithography techniques makes them most appropriate for physical implementation. The role of dissipation and its influence on de-coherence requires careful investigation and optimisation. A very important step was recently demonstrated by Nakamura et al. at the NEC Fundamental Research Laboratories in Japan (Nature 398, 786 (1999)), who succeeded to manipulate Josephson junction qubits in a quantum coherent way over several nanoseconds. The SQUBIT team is at the same technical level and is therefore in an excellent position to accomplish real progress towards an elementary quantum processor using scalable solid-state nanotechnology.
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Last updated on 2005-06-13
Retrieved on 2019-09-12