論 文 の 内 容 の 要 旨
Abstract

論文題目　Scalable Generation of Cluster State with Superconducting Circuit
(超伝導回路を用いたスケーラブルなクラスタ状態生成手法)

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Recently, fault tolerant quantum computation such as surface coding and topological quantum computation has been paid attention to due to high threshold against computational errors compared with that of conventional gate-model quantum computation. These schemes use a two or three-dimensional cluster state as universal resources for quantum computation. We can generate a cluster state by performing controlled-phase gates on an initial state prepared in $|+\rangle$ state, where the control-phase gates are realized by nearest neighbor Ising type interactions. There are many proposal to realize Ising type interaction such as ultracold atoms in an optical lattice, superconducting charge qubits, superconducting spin qubits, resonator wave guides, nitrogen-vacancy centers, and quantum dots. Among many candidates, we especially discuss superconducting fluxqubits. Superconducting flux qubits have a strong anharmonicity, so that we can perform high-speed single-qubit rotation with excellent fidelity.

Usually, implementation of high-fidelity two-qubit gates is the hardest part for the realization of quantum computation. Two qubit gates require in-situ turn on/off the interaction between qubits by the external control apparatus. Since imperfection of the interaction control tends to induce spatially correlated

errors between qubits, sophisticated technology is required to suppress such error rate below the threshold of fault tolerant quantum computation. Up to now, the generation of a large cluster state using solid-state qubit has not been demonstrated in a scalable manner yet. One of the main obstacles is the requirement for independent control of two-qubit gates that are necessary for the scalable quantum information processing. For a superconducting flux qubit, existing method uses applied magnetic field to control the interaction. It is known that the application of magnetic field to local area is difficult. Thus, it is hard to implement local control of the interaction without cross-talk problem where unwanted errors occurs between qubits.

Firstly, we propose a novel way to control a number of two-qubit gates independently without using the on/off switching of locally applied magnetic field. Specifically, we assume the superconducting flux qubits that are inductively coupled with each other via always-on Ising interaction. Unlike the previous method to change the interaction strength with unitary operations, we fully make use of non-unitary properties of projective measurements so that we can effectively turn on/off the interaction via quantum feedforward. Also, we show how to generate a two or three-dimensional cluster state that are universal resource for fault tolerant quantum computation with constant step-size operations. The on/off switching of locally applied magnetic field is not always necessary to perform projective measurements and quantum feedforward. Thus, it is expected that our scheme may contribute to achieve a scalability of flux qubits system.

Secondly, we propose the interaction generating method using capacitively-coupled flux qubits to overcome the cross-talk problem. In this scheme, we generate Ising type interaction by applying bias voltage to qubits which are connected via capacitor. Our scheme has a property that we can control the interaction strength by applying vias voltage, which does not require on/off switching of applied magnetic field. Furthermore, for an arbitrary size of the system, we propose the constant step-size procedure for generating a scalable two-dimensional cluster state. In this scheme, we can sufficiently suppress non-nearest neighbor interactions. Also, we estimate the parameter range to implement fault torelant quantum computation in this architecture.

Our proposals pave the way for scalable quantum information processing with superconduct flux qubits.