ED5-1-INV

Deterministic generation of entanglement with up to 20 superconducting qubits

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Here I will review our recent activities on designing and fabricating superconducting circuits which integrate up to 20 qubits for scalable quantum information processing. In particular, I will introduce a superconducting quantum processor featuring 20 individually-accessible Xmon qubits that are controllably coupled to a bus resonator, based on which we deterministically produce an 18-qubit Greenberger-Horne-Zeilinger state and multi-component atomic Schrödinger cat states of up to 20 qubits. We verify genuine entanglement with simultaneous measurements of all qubits involved. With the excellent control developed in our experiment, our multiqubit superconducting circuits may provide a promising platform for simulating the intriguing physics of quantum many-body systems.

Keywords: Superconducting qubit, Entanglement, Quantum information processing

ED5-2-INV

Generation and detection of itinerant microwave photons using a superconducting qubit

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A quantum network based on itinerant microwave photons is an indispensable tool to make it easier to implement a large-scale quantum computer with superconducting qubits [1]. In this talk, we show the experimental results on the generation and detection of itinerant microwave photons by using a circuit quantum electrodynamical system, where a microwave cavity plays a crucial role in facilitating the interaction between itinerant microwave photons and a superconducting qubit [2].

First, by utilizing a microwave-assisted interaction between a superconducting qubit and a cavity mode, we generated a single-photon state in a propagating mode [3]. Moreover, we extended the generation scheme to a time-bin photonic qubit, a superposition of a single photon in two orthogonal temporal modes, which can be robust for the propagation loss. Second, we implemented a deterministic entangling gate between a superconducting qubit and an itinerant microwave photon reflected by a cavity containing the qubit. Using the entanglement and high-fidelity qubit readout, we demonstrated a quantum non-demolition detection of a single photon, a photon detection without absorbing the photon energy [4].

These results on itinerant microwave photons can be a building block for the quantum network connecting distant qubit modules. Furthermore, the generation and detection of a quantum state of itinerant microwave field have promising applications for quantum sensing and metrology in the microwave regime [5].

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ED5-3-INV

Scalable packaging and wiring for superconducting quantum computers

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Superconducting qubit devices are one of the promising candidates for realizing large-scale quantum computer. The next challenge toward building quantum computer would be implementation of quantum error correction. To implement realistic quantum error correction codes, such as surface codes, we need to prepare two-dimensional array of superconducting qubits in a scalable way. It naturally requires three-dimensional wiring to superconducting qubits, which suppose to have at least one microwave control line for every qubit. A lot of efforts have been made recently to establish three-dimensional wiring techniques which ensure scalablility of superconducting qubit devices. The techniques include flip-chip bonding [1], through-silicon vias [2], contact probes [3], and direct coaxial cable wiring [4].

In this talk, we present a way to realize scalable packaging and wiring for superconducting qubits by using direct vertical interconnect between superconducting circuits and coaxial cables. The design of our package is shown in Fig. 1. In our package, coaxial cables for qubit control and readout are directly wired from the bottom of the superconducting qubit chip. The electrical contact between superconducting circuits and coaxial cables are provided by contact probes. The electromagnetic fields from the cables are guided by through-silicon vias and transmitted to the superconducting circuits on top of the chip. This wiring scheme is fully vertical and two-dimensionally scalable. We report the results of characterization of the package and measurements of the multi-qubit chip in this package.

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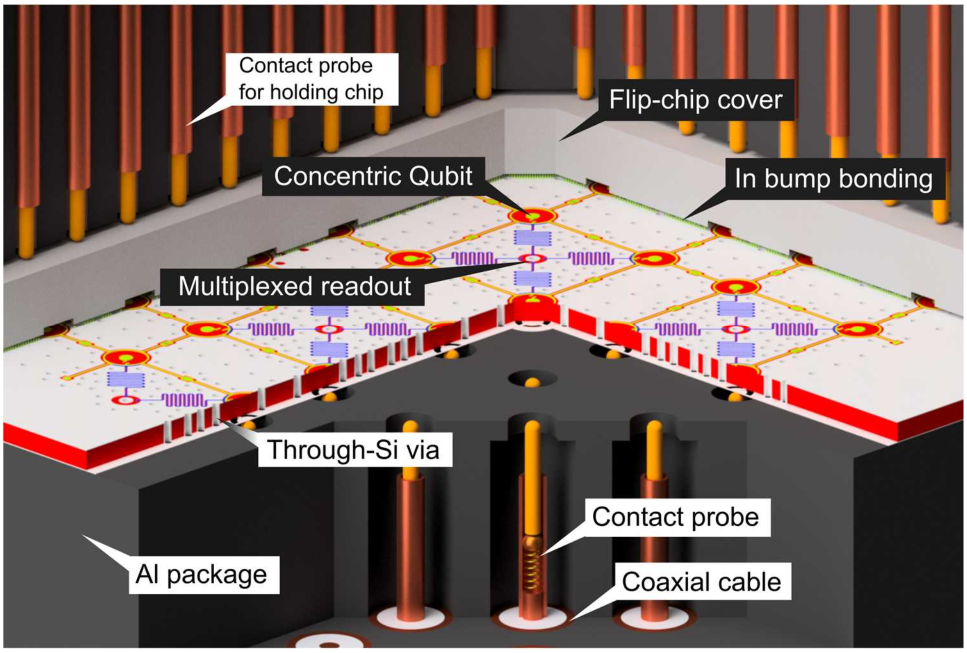

Keywords: Quantum computing, Scalable qubit packaging, Vertical interconnects

ED5-4

The Superconducting Flux Qubit for Prime Factorization Utilizing Low Jc Process

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Specific device for prime factorization utilizing a quantum annealing has been investigated[1].In this architecture, a multiplier plays an important role because its inverse operation corresponds to the prime factorization. To demonstrate this concept, we fabricated a qubit cell, which was an element of the multiplier, utilizing multi-layered Nb/AlOx/Nb Josephson junction technology with current density of 1 μA/μm^2. The cell was consisted of a superconducting flux qubit, a quantum flux parametron (QFP) and superconducting quantum interference devices (dc-SQUID) as shown in Fig. 1(a). I_c and β_L of the qubit were 6 μA and 2.8, respectively. In order to modify an energy potential, the qubit was coupled with current paths of I_{trans} and I_{Qubit}. Prior to experiments at 4.2K, bias conditions of the QFP and readout-SQUIDs were analyzed by SPICE.

At first, bias to the readout SQUID was adjusted so as to respond zero or constant value depending on a direction of a magnetic flux. Then, a current I_{QFP}, corresponding to the flux $\Phi_0/2$, was applied to the QFP. Figure 1(b) shows output signals in the readout SQUID after applying the current I_{qubit}. Here, the signals were obtained every increment of 2 μA and averaged in 20 times. Repetitions of high and zero voltage were obtained. The feature was consistent with the SPICE analysis. This indicated successful detection of the flux in the qubit where direction of a circulating current was modified by current I_{qubit}. We consider this qubit cell has possibility of constructing the multiplier for prime factorization.

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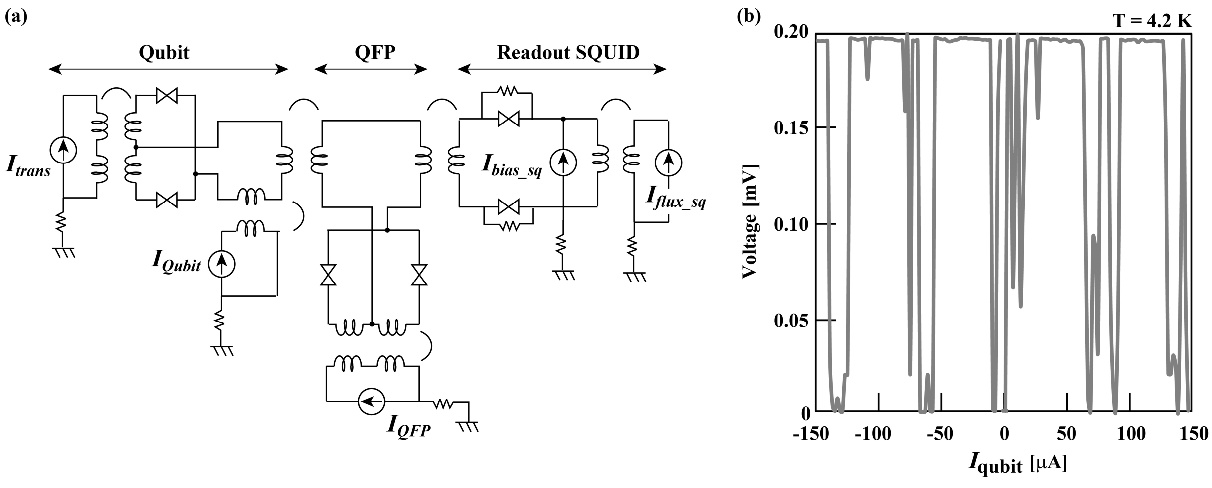

Keywords: superconducting flux qubit, Josephson junction, SQUID, quantum annealing