


Development of Superconducting Spintronic Hybrid Quantum Technology for Realizing Sub-megabit Quantum Computers

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Purpose and Background of the Research

● Outline of the Research

A quantum computer is a next-generation computing device to solve problems that are difficult for even high-performance classical computers. The scaling up of superconducting quantum computers has been progressing rapidly. IBM has reported a quantum computer exceeding 1,000 qubits (qubit: fundamental unit of quantum computer). However, around one million (1 megabit) qubits are needed for practical applications and further large-scale development is an urgent challenge.

Currently, major challenges in scaling up quantum computers are the qubits and their control methods. Regarding qubits, while improvements in the lifetime (time for which a quantum state can be maintained) of the mainstream transmon are progressing, there are concerns about errors during high-speed control and crosstalk between qubits. Various attempts are being made to mitigate these issues, but they remain challenges in achieving large-scale quantum computer.

As for control methods, individual qubits are controlled using microwave signals generated from room-temperature electronics. However, this approach requires high-frequency wiring between the qubits at ultralow temperature (around -273°C) and the room-temperature electronics. As the number of qubits increases, the number of wires also increases, leading to a severe problem of heat load and noise through the wiring. A scalable approach that can control one million qubits has yet to be established.

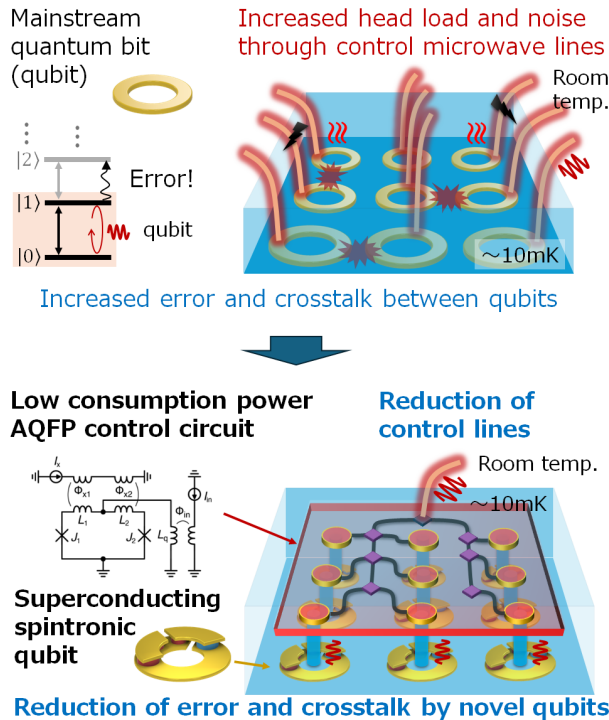


Figure 1. Schematics of challenges in scaling up quantum computers (top) and the approach in this study (bottom).

This research aims to develop new fundamental quantum technologies for scaling up to one million qubits by creating multi-qubit circuits with superconducting spintronic qubits, adiabatic quantum control circuits, and their multi-chip module. The superconducting spintronic qubit is a qubit incorporating a ferromagnet/superconductor hybrid structure, known as a n-junction. Owing to its high anharmonicity, it can theoretically reduce the errors during high-speed control and mitigate crosstalk. Regarding the adiabatic control circuit, the adiabatic quantum flux parametron (AQFP) with ultralow power consumption (heat generation) close to physical limits are developed. This feature allows it to be implemented inside a refrigerator with limited cooling capacity, making it a feasible candidate for scalable control circuits capable of controlling one million qubits. To integrate superconducting spintronic qubits with adiabatic control circuits, we develop the multi-chip implementation technique of multi-qubit circuits and AQFP circuits. We aim to explore technologies for the expansion of superconducting quantum computers to the sub-megabit level, paving the way for practical large-scale quantum computer.

Expected Research Achievements

To achieve the above objectives, we will challenge the following research items:

● Research items

1. Superconducting spintronic quantum unit circuits

We will expand the superconducting spintronic qubits, which have been demonstrated in principle, into multi-qubit unit circuits and realize scalable circuits from the perspectives of anharmonicity and circuit structure.

2. Adiabatic quantum bit control circuits

We will develop multi-qubit control circuits using ultralow-power AQFP circuits. We will verify the scalability to the sub-megabit level by reducing power consumption and the number of control wires.

3. Circuit fabrication and multi-chip module integration technology

We will further develop our circuit fabrication and multi-chip module integration techniques to realize hybrid circuits with quantum unit circuits and AQFP circuits, thereby demonstrating qubit control and scalability.

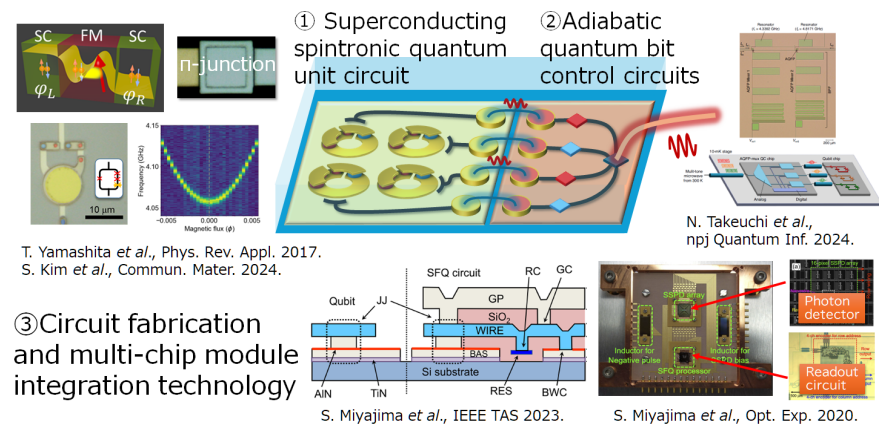


Figure 2. Schematics of the research items.