【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project : Large-scale superconducting spintronics quantum computing circuits toward the realization of quantum supremacy

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【Purpose and Background of the Research】

Recently, the development of superconducting quantum computers becomes extremely active worldwide. A key to realize the superconducting quantum computers is whether the large-scale quantum circuits with many quantum bits (qubits) can be realized or not without degrading their performances. One of the important performance indices of the qubit is the coherence time which indicates the lifetime of the quantum state. However, the coherence time becomes smaller due to the increases of noises and/or difficulty in the qubit control when the number of the qubits increases, and the quantum supremacy has not been demonstrated yet. In this research, we develop the large-scale quantum computing circuits by introducing the superconducting spintronics techniques and aim for the demonstration of the quantum supremacy.

【Research Methods】

In conventional superconducting flux qubits, the external magnetic field is required for the operation, and the precise control of the field is essential to realize the optimum point leading to the longest coherence time. In this research, the magnetic Josephson junction (π junction), which is one of the superconducting spintronics devices, is implemented to the qubit (π qubit). Due to the π junction, the π qubit requires no external magnetic field to operate at the optimum point. This feature of the π qubit relaxes the difficulty of the qubit control and is expected to suppress the enlargement of the external noise when the number of the qubit increases. In addition, the material option is also important to achieve the good coherence time. Here we adopt the nitride-based junctions without any oxides which degrades the coherence (Fig. 1(a)) to realize the quantum circuit with the good coherence time. Fig. 1(b) shows the image of the developed π quantum circuit.

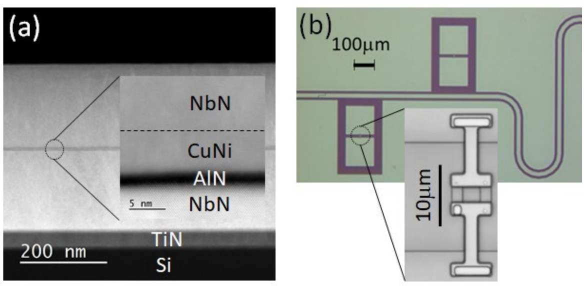

Figure 1 (a) Transmission electron microscope (TEM) image of a nitride-based magnetic Josephson junction. (b) Photograph of the π quantum circuit with the π qubits.

Furthermore, the external noise via the control lines from the room temperature environment will increase when the number of the qubits increases. In this research, we adopt the superconducting logic circuits operated at low temperatures to control the quantum states, and aim for the ultimate reduction of the external noises. To realize the milli-Kelvin operation, we develop a novel half-flux-quantum circuit with π junction which is expected to show the ultralow power consumption.

【Expected Research Achievements and Scientific Significance】

The realization of the large-scale quantum computing circuit with the quantum circuits and the control circuits (Fig. 2) and the demonstration of the quantum supremacy are expected as well as the clarification of the physical origin to limit the coherence time.

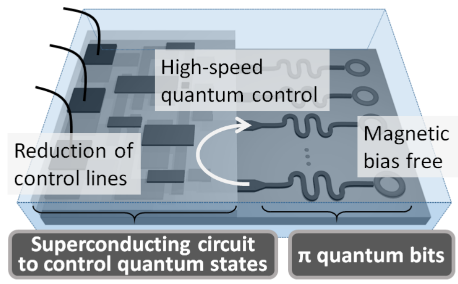

Figure 2 Schematics of large-scale quantum computing circuit in the research.

【Publications Relevant to the Project】

・T. Yamashita, K. Tanikawa, S. Takahashi, and S. Maekawa, “Superconducting π Qubit with a Ferromagnetic Josephson Junction,” Physical Review Letters, vol. 95, pp. 097001-1-4 (2005).
・T. Yamashita, A. Kawakami, and H. Terai, “NbN-Based Ferromagnetic 0 and π Josephson Junctions,” Physical Review Applied, vol. 8, no. 5, pp. 054028-1-5 (2017).

【Term of Project】 FY2019-2023

【Budget Allocation】 156,600 Thousand Yen

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