Development of Quantum Interfaces for Building Quantum Computer Networks

R&D Theme

Piezoelectric Microwave Cavity

Progress until FY2022

1. Outline of the project

This project aims to develop a quantum interface that connects superconducting qubits with photons for communication to realize a large-scale distributed superconducting quantum computer. In this R&D theme, we will develop a piezoelectric microwave resonator that will be a component of the system (Fig. 1). In this R&D theme, we have achieved the following outcome.

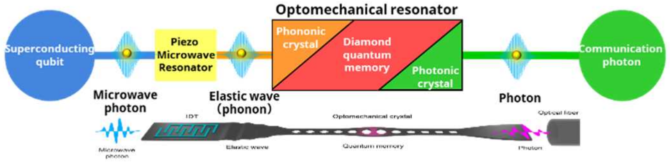

Fig. 1. Role of piezoelectric microwave cavity in quantum IF.

2. Outcome so far

Subject 1: Piezoelectric Microwave Cavity

- Material search and structural design of piezoelectric microwave cavity

In order to convert microwave photons into phonons with a wavelength of ~1 mm, which is equivalent to telecommunication photons with a wavelength 5 orders of magnitude shorter, we fabricated a diamond surface acoustic wave (SAW) device by forming a piezoelectric material, aluminum nitride (AlN), on diamond (Fig. 2).

- Conversion from microwaves to phonons

We have succeeded in quantum manipulation of NV-centered quantum memory by generating phonons from 5 GHz microwaves (Fig. 2a).

- Quantum manipulation of NV-centric quantum memory by microwaves

We have succeeded in quantum manipulation of NV-centric quantum memory by the electric field of microwaves (Fig. 2b). We have also fabricated a microwave resonator with a Q-value of 8,000.

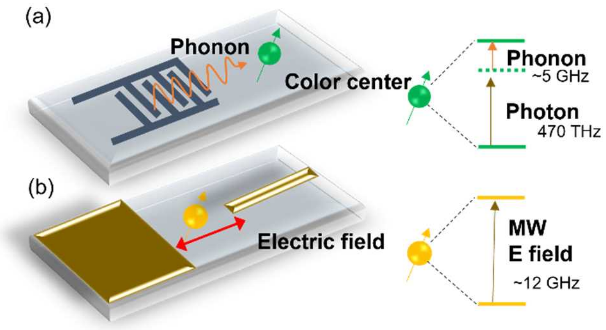

Fig. 2. Overview of quantum memory control by (a) phonon and (b) electric field.

Subject 2: Quantum-Controlled Electronic Integrated Circuits

・To achieve fast and high-fidelity quantum control of quantum circuits at cryogenic temperatures, we have developed a superconducting microwave pulse generator capable of generating microwaves of arbitrary amplitude (Fig. 3). A single flux quantum (SFQ) circuit is used to generate a 100 GHz density-modulated SFQ pulse train, and a superconducting filter is used to generate a 5 GHz microwave pulse.

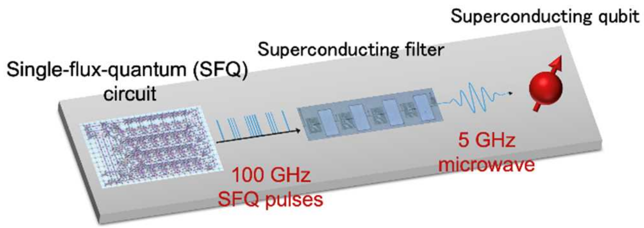

Fig. 3. 5GHz microwave pulse transmitter with 4K operation using superconducting circuits.

Subject 3: Theoretical study of quantum interface

・We theoretically investigated the quantum media conversion from a superconducting-atom qubit to a microwave-photon qubit. We proposed a method to demonstrate the SWAP gate between an atom qubit and a frequency-encoded photon qubit using a weak classical microwave pulse at the single photon level, and confirmed the bidirectional quantum state transfer. The fidelity of the atom-to-photon (photon-to-atom) state transfer reached 0.829 (0.801) (Fig. 4).

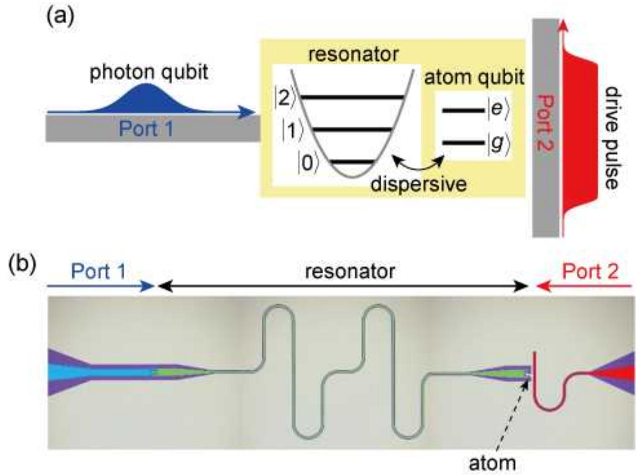

Fig. 4. The SWAP gate between a superconducting-atom qubit and a microwave-photon qubit. (a) conceptual view, (b) micrograph of the device.

3. Future plans

We will improve the performance of piezoelectric microwave cavities and integrate them with optomechanical cavities with quantum memory.

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