R&D Theme

Superconducting networking technology

Progress until FY2022

1. Outline of the project

In this project, we will develop a "quantum transducer" towards networked superconducting quantum computers. We will mainly focus on a quantum transducer that converts microwave photons, the quantum information inside superconducting quantum computers, to optical photons at millikelvin temperature. As the medium for the quantum transduction, we will exploit the microwave and optical transitions of silicon-vacancy (SiV) centers in a diamond crystal.

The challenges are implementing an optical cavity including a bulk diamond crystal, stabilizing an optical cavity at millikelvin temperature, and combining microwave and optical cavities. To this end, we designed a custom dilution refrigerator that can mitigate vibrations with an equipped active-damping system.

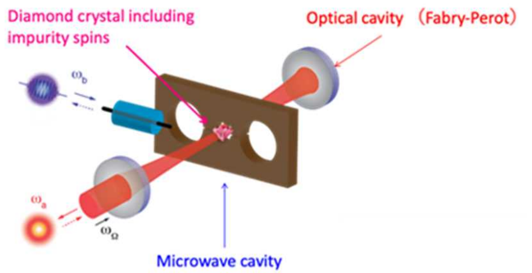

Figure 1 Schematic of the quantum transducer developed in this project.

2. Outcomes so far

1. Stabilizing an optical cavity at a millikelvin temperature in the custom dilution refrigerator was achieved.
2. An optical cavity that includes a bulk diamond crystal with an anti-reflection coat on one side and a high-reflection coat on another side was realized.
3. Microwave-optical combo cavity device was designed, fabricated, and tested at low temperatures.
4. A numerical simulation for the quantum transducer was performed.

Regarding 1, we could stabilize an optical cavity in a cryogen-free dilution refrigerator, where the pulse tube's cold-head induces vibrations, making optical cavity stabilization very challenging (Figure 2). Regarding 2, we managed to stabilize an optical cavity, even including a bulk diamond crystal. This manifests that the quantum transducer developed in this project is technically possible. Regarding 3, it is the transducer device. A diamond crystal must be placed in microwave and optical cavity modes. To this end, we designed and tested a combo-cavity (Figure 3). Regarding 4, we developed a theory of the microwave-optical photon conversion and simulated the conversion efficiency.

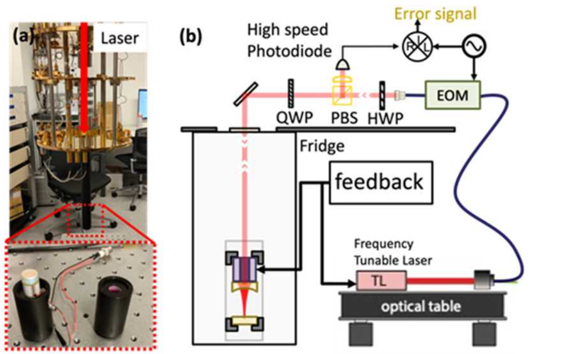

Figure 2 Stabilizing an optical cavity in a dilution refrigerator. (a) Photographs of the custom dilution refrigerator (top) and the cavity (bottom). (b) Schematic of the setup.

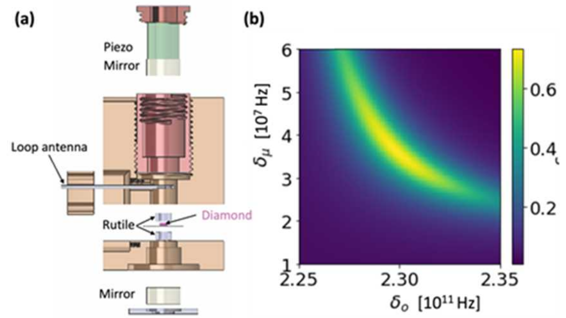

Figure 3 (a) CAD rendering of the combo-cavity device. (b) An example of numerical simulation. The conversion efficiency is plotted versus microwave and optical frequency detunings.

3. Future plans

Using the developed transducer device, we will first convert classical weak microwave or optical signals to demonstrate the proof-of-concept of the quantum transduction. We will then convert non-classical quantum microwave photons prepared by a superconducting qubit to optical photons. We will collaborate with the "Development of Integration Technologies for Superconducting Quantum Circuits" team for these objectives.