Development of Quantum Interfaces for Building Quantum Computer Networks

Here begins our new MIRAI
MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

R&D Theme

Optomechanical Cavity

Progress until FY2022

1. Outline of the project

Although there are many candidates for quantum computers, the potential of diamond is second to none in other physical systems (Fig. 1). In this project, we aim to develop a superconducting optical quantum interface, in which superconducting microwave photons and optical photons are quantum-connected by diamond (Fig. 2), to realize a large-scale distributed superconducting quantum computer system. In this R&D theme, we will develop optomechanical cavities that will be the building blocks of the interface. We have achieved the following outcome.

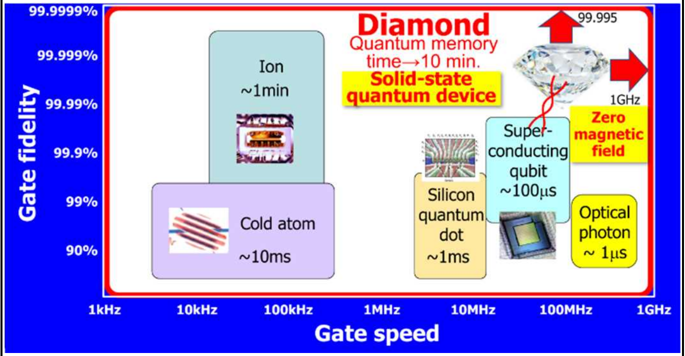

Fig. 1. Candidate physical systems that constitute a quantum computer and comparison of their performance.

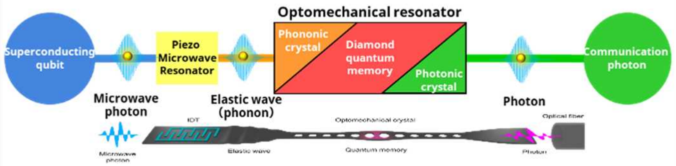

Fig. 2. Role of optomechanical cavity in quantum IF.

2. Outcome so far

Subject 1: Photonic Crystal Optical Cavity

・In a photonic crystal cavity consisting of diamond and aluminum nitride (AlN) stacked structures, we have found a structure in which the Purcell factor, which is an indication of the intensity of the emission increase from the diamond color center, greatly exceeds the initially set target value (over 100).

・ We developed fabrication technology for diamond optomechanical cavities and succeeded in realizing an air-bridged diamond photonic crystal nanobeam cavity structure (Fig. 3). We also conducted basic studies for integration.

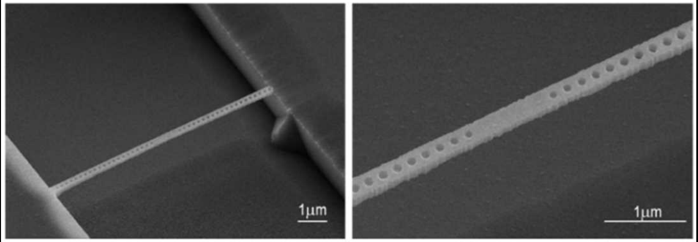

Fig. 3. SEM photograph of the structure of a diamond air-bridge photonic crystal nanobeam cavity.

Subject 2: Photonic Crystal Optical Cavity Mounting

・The goal was to design a coupling structure from the optical fiber to the optomechanical cavity (Fig. 4) with a loss of 10 dB or less. Specifically, a silicon nitride (SiN) waveguide was assumed for the fiber coupler and optical wiring, and tapered coupling was employed for the piezoelectric AlN and diamond laminated waveguide. In addition, we aimed for critical coupling from the waveguide to the optomechanical cavity by apodizing the end of the cavity. As a result, the total loss from the fiber to the cavity was estimated to be 1.49 dB.

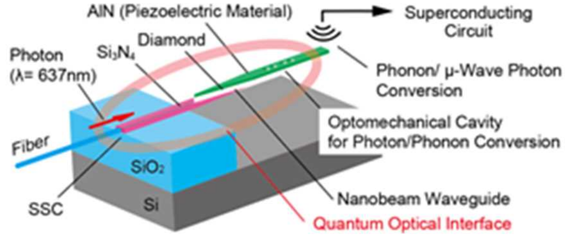

Fig. 4. Optical interface configuration.

Subject 3: Phononic Crystal Sound Cavity

・We have designed a diamond optomechanical cavity that strongly and simultaneously confines phonons and photons in a narrow region and couples quantum memory dramatically and strongly. The cavity performance far exceeded the target value. We also evaluated the conversion efficiency of microwave-to-communication wavelength photons via quantum memory (Fig. 5).

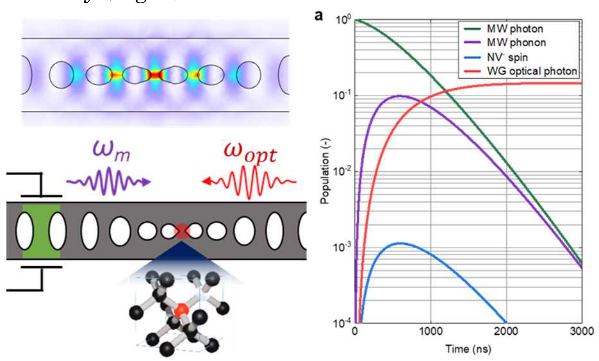

Fig. 5. Simulation of microwave-to-communication wavelength photon conversion.

3. Future plans

We will realize the diamond optomechanical cavity and integrate them with the quantum memory and the piezoelectric microwave cavity.

国立研究開発法人 科学技術振興機構 Japan Science and Technology Agency