R&D Theme

Diamond Quantum Memory

Progress until FY2022

1. Outline of the project

We are developing quantum interfaces that connect superconducting quantum computers with optical fiber quantum communications to realize a distributed quantum computer system (Fig. 1). The core of this project is the quantum memory and optomechanical crystals, and integrated development from the diamond growth and nanofabrication to 3D mounting will be carried out. In this R&D theme, we have achieved the following outcome.

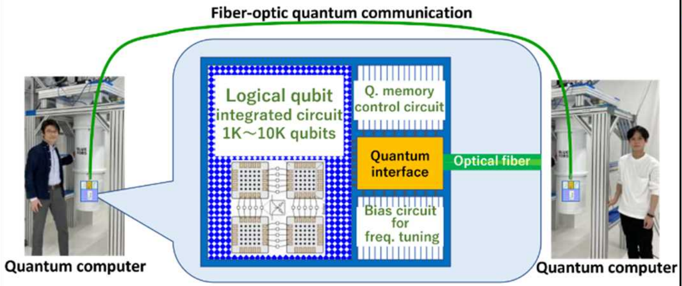

Fig. 1. Distributed quantum computer system.

2. Outcome so far

Subject 1: Diamond Quantum Memory

- Quantum entanglement light source development

Using nitrogen vacancy (NV) centers in diamond (Fig. 2), we have achieved quantum entanglement generation between photons and electrons with a fidelity of 98%.

- Fault-tolerant universal quantum gate operation for quantum memory

We have achieved fault-tolerant universal quantum gate manipulation with a fidelity of 99.97% by performing geometric quantum manipulations on the electron spins in the NV center.

- Complete Bell measurement in quantum memory

We have achieved a complete Bell measurement between two carbon nuclear spins with a fidelity of 90%.

- Laser irradiation color center generation

Toward the formation of deterministic quantum memory in nanostructures, we have succeeded in generating GR1 defects, which are the nuclei of NV centers, by irradiating intense ultrashort laser pulses.

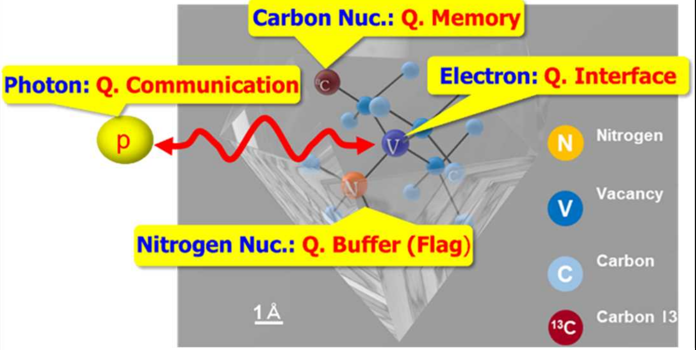

Fig. 2. Quantum system in the diamond NV center.

Subject 2: Diamond Quantum Structures

- Fabrication of diamond nanostructures

We have developed submicron patterning technology using an electron beam lithography system to fabricate nanostructures such as diamond optomechanical cavities and micro comb-shaped electrodes (IDTs).

- Fabrication of diamond piezo structures

A surface acoustic wave (SAW) device was fabricated by forming IDT electrodes on an aluminum nitride (AlN)/diamond multilayer film (Fig.3) and successfully generated sound waves (acoustic waves) at ~5 GHz.

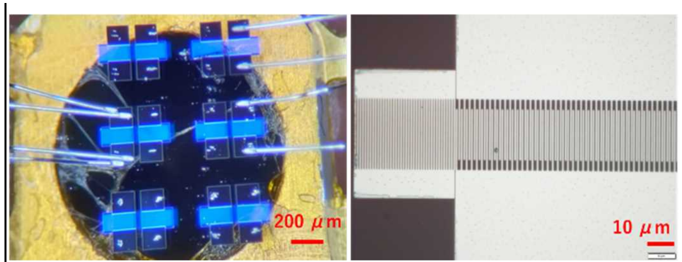

Fig. 3. (Left) 2-port diamond SAW device, (Right) enlarged view of electrode in 1-port device.

Subject 3: Diamond Quantum Crystals

- Diamond high-purity crystal growth

We have performed high-purity diamond crystal growth and impurity control to stabilize the charge state of NV centers and reduce their spectral diffusion.

Subject 4: Diamond Color Centers

- Development of ion beam for variety of color centers

In addition to the mainstream NV and SiV centers, we developed beams to create GeV, SnV, and Pb centers. We successfully developed an L-arginine beam to place carbon near the NV center (Fig. 4).

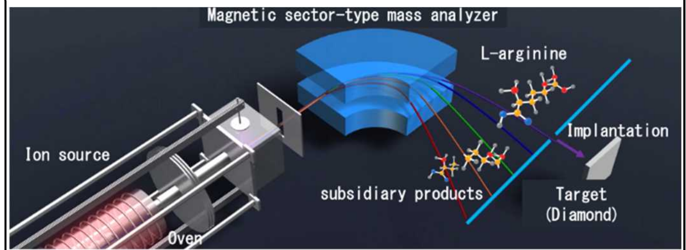

Fig. 4. L-arginine ion implantation into diamonds.

3. Future plans

We will form the quantum memory in a diamond optomechanical cavity and couple it with a piezoelectric microwave cavity.