# Large-scale quantum hardware based on nanofiber cavity QED

## 1. Position in the program

Research and development on quantum computer hardware methods based on various physical systems is currently developing. However, for all methods, it is believed that implementing the large number of qubits required for a fault-tolerant universal quantum computer in a single unit is extremely difficult. Therefore, there is a demand for the development of distributed quantum computer technology, which connects several units that are equipped with small to moderate number of qubits to form a network.

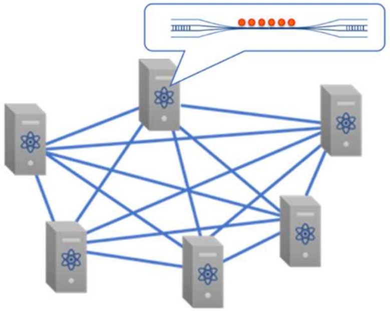

Fig. 1: Distributed fault-tolerant universal quantum computer.

The cavity quantum electrodynamics (QED) system is a hybrid quantum system of atoms and photons, and it has been significantly researched since the dawn of quantum information science owing to its status as a promising operating platform of quantum computers. In particular, it was expected that arranging several atoms in the cavity while maintaining strong coupling between individual atoms and the cavity and individually addressing the atoms would function as a multi-qubit quantum computer. It was also expected that a distributed quantum computer could be achieved if multiple cavity QED systems were connected with low loss. These tasks have been difficult to achieve with conventional cavity QED systems based on free-space optical cavities. However, they are expected to become feasible with nanofiber cavity QED technology.

Herein, we use our unique nanofiber cavity QED technology as a basis to develop new quantum computer hardware that can be scaled up and distributed. We also use it to promote social implementation. Based on this, we aim to realize a distributed fault-tolerant universal quantum computer that has an enormous number of qubits, as well as a quantum internet by 2050 (Fig. 1).

## 2. Overview of the R&D and the Challenges

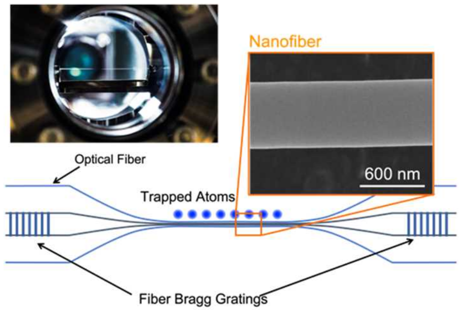


Fig. 2: Nanofiber cavity QED system.

The nanofiber cavity QED system (Fig. 2) involves quantum mechanical interaction of photons that are confined in an optical fiber cavity (nanofiber cavity) with “nanofibers” whose diameter is thinner than the wavelength of light in the center and atoms that are arranged in a line near the surface of the nanofiber. This system was developed with a unique technology that is one of a kind worldwide.

Herein, we use nanofiber cavity QED technology as a basis to develop new quantum computer hardware that can be scaled up and distributed. Specifically, we developed proof-of-principle of nanofiber cavity QED quantum computers, scaling-up technology that increases the number of qubits implemented in one unit, distribution technology that connects multiple units, quantum error correction theory that is suited for nanofiber cavity QED methods, and a light source system that enables the control of atoms with high stability and accuracy. Furthermore, we promoted the social implementation of these developments.

Particularly, the proof-of-principle of a completely new nanofiber cavity QED method that differed from existing methods and the development of distribution technology that leads to the realization of a large-scale distributed quantum computer are challenging issues.

## 3. Future plans

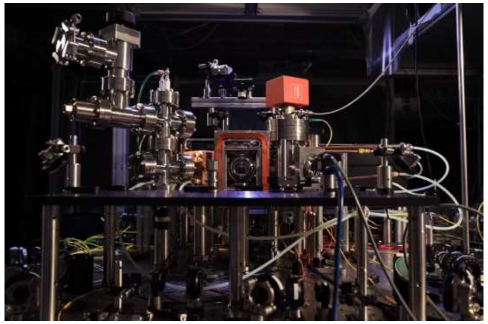

Fig. 3: Proof-of-principle unit.

We plan to develop a proof-of-principle unit (Fig. 3) with a small number of qubits and establish a PoC for a nanofiber cavity QED quantum computer hardware. We also plan to develop distributed units and achieve elemental technologies for distribution. Furthermore, we plan to develop scaling-up technologies, quantum error correction theory, and light source systems. In addition, we will promote the social implementation of our technologies.



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