

R&D Item

1. Large-scale and high-coherence fault-tolerant quantum computer with dynamical atom arrays

Progress until FY2024

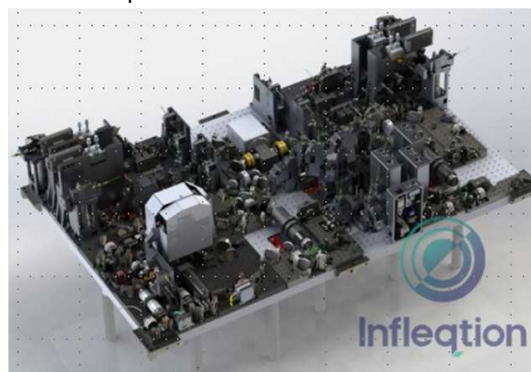
1. Outline of the project

In this R&D Item, we aim to construct a practical cold-atom, fault-tolerant quantum computer with a large array of cold-atom qubits using the “optical tweezers” technique, in which atoms are individually captured by a laser beam. A key innovation of our approach is the implementation of a dynamic qubit array that allows each atomic qubit to be moved freely and rapidly during the computation, and performs gate manipulation, fault detection and correction. Furthermore, through close collaboration with leading academia and industry, we will integrate and package all components such as vacuum vessels, laser sources, optics, electronics, and imaging devices to achieve unprecedented stability and usability. These advancements will enable precise and reliable control of large atomic qubit arrays and realize fault-tolerant quantum computers that will revolutionize the economy, industry, and national security by 2050.

To realize this goal, we are conducting research and development on the following items.
We are developing a scalable cold-atom quantum computer platform through the development of a vacuum chamber to accommodate atomic qubits and a larger array of qubits. We will also develop fault-tolerant, high-coherence, and high-precision qubit manipulation. A key focus of our research is the development of a novel quantum fault detection and correction architecture that takes advantage of the characteristics of cold atoms, both theoretically and experimentally. In parallel, we will develop a laser system dedicated to cold-atom quantum computers, which will serve as the basis for the above research and development. In addition, from the viewpoint of diversity, we are conducting research and development on rubidium (Rb), ytterbium (Yb), and strontium (St) atoms for the quantum bit.

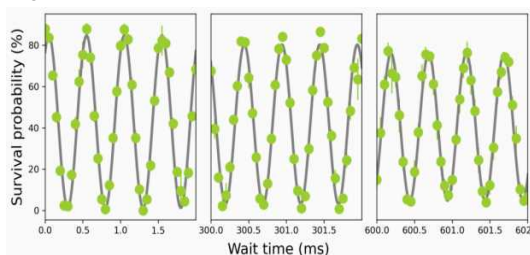
2. Outcome so far

As part of our quantum computing platform development, we have successfully completed the fabrication of the QPU (Quantum Processing Unit) module and have commenced fundamental experiments.



QPU Module developed with Inflektion, Inc.

In the development of quantum gates, we successfully constructed a high-power 325nm light source for Yb atomic excitation and achieved a qubit detection fidelity exceeding 99% and a nuclear spin coherence time more than a million times longer than the duration required to operate a single qubit gate.



Coherence of the nuclear spin qubit : ¹⁷¹Yb

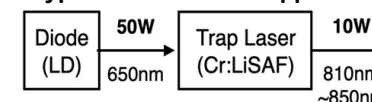
We have successfully achieved atomic wave function squeezing, 800-tweezer shaping, homogenization, and full

automation for Rb atoms.

In the development of quantum fault detection and correction architecture, we have successfully verified the principle of state-selective, nondestructive measurement of atomic qubits, and are making steady progress toward achieving higher fidelity. As part of our efforts to develop high-stability and high-intensity laser systems, we have built prototype light sources for new laser technologies (including a pulsed laser for gate manipulation and atomic trap laser) and constructed the database of the physical properties of laser materials.



Prototype Cr:LiSAF and sapphire bonded chip



Example of trap laser configuration

3. Future plans

In our efforts to develop a scalable quantum computing platform, we will collaborate with ColdQuanta, Inc. d.b.a. Inflektion to build a full-stack quantum computer that integrates each module. We will be also developing a quantum operating system prototype that incorporates resource management and other functions. In the development of high-coherence and high-fidelity quantum gates, we will collaborate with Keisuke Fujii (Osaka University) on the theoretical aspects of fault tolerance, drawing upon previous research, to achieve even longer coherence times. In the development of high-stability and high-intensity laser systems, we will work on increasing the output power of atomic trap laser sources for large-scale qubit arrays and developing highly stable pulsed laser sources for ultra-fast quantum gates.