R&D Theme

Superconducting circuit ion traps with low-vibrational cryostat

Progress until FY2022

1. Outline of the project

Ion trap quantum computers are based on uniform qubits prepared in vacuum and ultra-precise manipulations have been achieved. However, even higher precision must be achieved for the fault-tolerance. In this theme, we will develop superconducting-circuit ion traps. Ion trapping at cryogenic temperatures has been studied as a stage for high-performance ion traps due to improvements in electrical noise and vacuum. Furthermore, by incorporating superconducting microwave circuit technology, we will construct a high-performance ion trap system that combines low power consumption and high-precision operation.

2. Outcome so far

1. Basic technologies required for cryo-ion trap

We first developed a low-vibration refrigerator, whose vibrations were evaluated to be less than 100 nm relative to

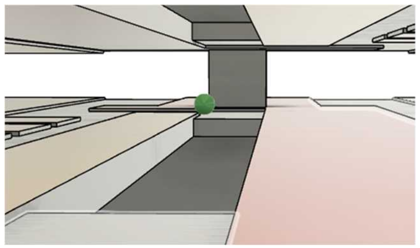
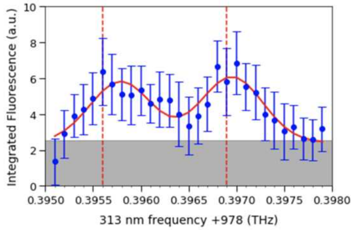


Fig. 1 Microfabricated superconducting ion trap



Fig, 2 Beryllium ion spectrum with laser ablation

an optical table. An imaging system was also developed to microscope the ions inside the refrigerator from the outside with multiple radiation shielded windows.

2. Stable atomic source with a laser ablation

low-heat atomic sources based on laser ablation have been used for cryo-ion trap. However, it is difficult to achieve stable atomic flux with laser ablation. We achieved a stable atomic source of beryllium using a nanosecond ultraviolet laser and beryllium oxide. Figure 2 shows the spectrum of beryllium ions produced by this atomic source.

3. Superconducting circuit for ion traps

We have developed a compact superconducting circuit for microwave control of trapped ion qubits with followed

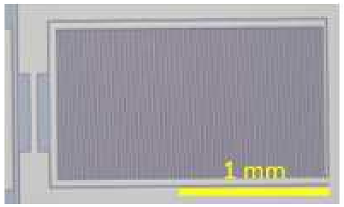


Fig. 3 Low impedance superconducting circuit

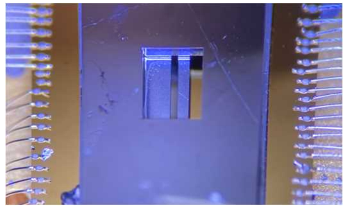


Fig. 4 Flip-chiped circuits

characteristics:

a. Low impedance resonator with large capacitance
b. Small footprint for the integration into trap electrodes
c. High Q-value at 4-6K

Figure 3 shows a interdigit superconducting Nb circuit.

4. Flip-chip integration

Superconducting circuits are integrated two-dimensionally on a silicon substrate. We use flip-chip method to achieve strong confinement of ions and a strong microwave field with a 2D circuit. We have developed substrate fabrication and assembly techniques for this purpose. Figure 4 shows a flip-chip mounted superconducting circuit.

3. Future plans

We will realize a cryo-ion trap and to integrate the various technologies to realize a superconducting-circuit ion trap. By applying a large magnetic field gradient to ions in a superconducting circuit, ultra-precise quantum state manipulation can be achieved without the use of lasers. Furthermore, we will identify and overcome the implementation issues by integrating the ion trap optical connection technology developed in other themes.