冷離子研究平台開發計畫

Developing an Ion Trap Platform for Atomic and Molecular Physics Research

Jen-Huang Huang[1], Yi-Wei Liu[2], Shih-Kuang Tung[2], Li-Bang Wang[2], and Ite Yu[2]

[1]*Department of Chemical Engineering, National Tsing Hua University, Hsinchu , Taiwan*
[2]*Department of Physics, National Tsing Hua University, Hsinchu , Taiwan*
E-mail: zekest@phys.nthu.edu.tw

We thank the project review committee and the R&D department of National Tsing Hua University (NTHU) for subsidizing the project, so that our team can initiate the first research program focusing on ion traps and cold ions in Taiwan. Cold ions are one of the most promising quantum technology platforms, and have many high-impact applications, such as quantum computing, quantum sensing (optical clock), and quantum chemistry. In the period of the project, we have built an ion trap system, trapping and cooling calcium ions into ion crystals.

Our team started with an empty laboratory, and by the end of the first project year, we have constructed a complete system, including an ion trap, an ultrahigh vacuum system, and several lasers. Our ion trap, manufactured by a local company, adopts a blade-type design, see Figure 1(a). The trap is installed inside an ultrahigh vacuum chamber, as shown in Figure1(b), to prevent collisions with background atoms and molecules. A home-made helical resonator (Figure 1(c)) feeds RF power into the ion trap to trap ions. We used 4 lasers, three of them are home-built. The lasers include the 397-nm cooling laser, the 854-nm and the 866-nm repumping lasers, and the 423-nm ionization laser.

We observed the fluorescence of ions shortly after the system was completed. Figure 2 shows several fluorescence images of the trapped ions in our system. The ions in the photos are laser cooled to ~1 mK. At such a low temperatures, the thermal motions of the ions are greatly suppressed. The balance between the trapping potential and the Coulomb interaction results in the crystallization of ions. In the future, with further manipulation, these ions can be used as qubits for quantum computation.

Currently, we are investigating spectroscopic methods, such as electromagnetically induced transparency (EIT), to characterize the properties of the ions such as temperature. Figure 3 shows a typical EIT spectrum of the ions. Afterwards, we plan to investigate four-wave mixing in the system. Four-wave mixing is a nonlinear optical effect in which a particle interacts with two or three electromagnetic waves by phase matching and energy conservation. The process results an electromagnetic wave that depends on the energy level of the particle. This technique is often used to create single photons and biphotons, both useful in transmitting quantum information.

Now, close to the end of the project, we have achieved several key performance indicators (KPIs), such as (1) developing an ion trap system for future applications and investigations, (2) observing EIT spectra and studying their applications, and (3) creating new opportunities to the students who are interested in working on quantum technology associated with cold ions and ion traps. As for attracting more funding (another KPI) to our research, we have submitted a new proposal to the latest quantum technology project of the MOST. At the same time, we are also looking for collaboration with global franchises such as HonHai and others.

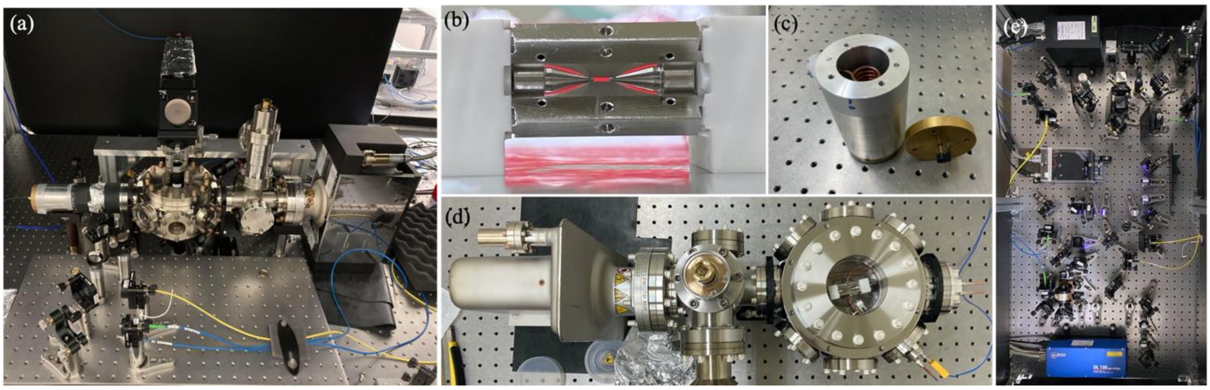

Figure 1 (a) The ion trap system of $^{40}Ca^{+}$(a) consists of: (b) a blade-type ion trap, (c) a helical resonator for driving the trap, (d) an ultrahigh vacuum system at $\sim 10^{-10}$ torr, and (e) a laser system of 4 lasers (. The picture only shows 3 lasers; (from top to bottom) they are repumping laser with a wavelength of 866nm, ionization laser of 423nm, and cooling laser of 397nm.

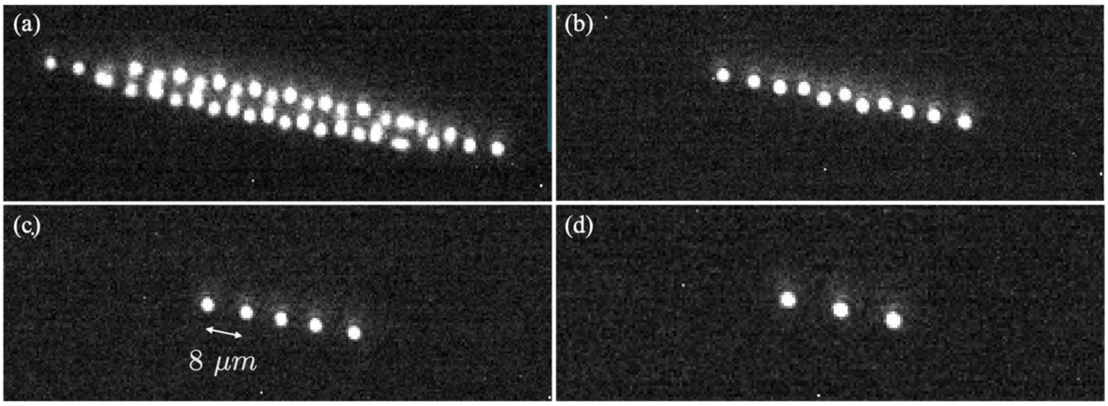

Figure 3 (a－d) Fluorescence images of trapped $^{40}Ca^{+}$ ions. Each atom shows up as a bright dot in the photos. These atoms can be used as qubits to perform quantum computation. With larger ion crystals, as in (a) and (b), the phonon modes have lower energies and easier to excite, while the ion crystal with few ions are more difficult to excite; thus a regular crystal is easier to realize with few ions.

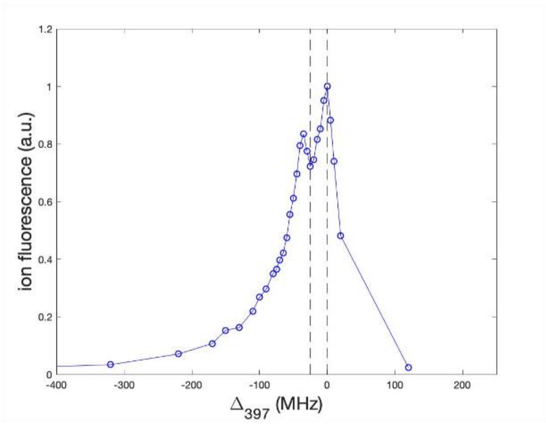

Figure 2 A EIT-like spectrum of the ions. The $4S_{1/2}$, $4P_{1/2}$, and $3D_{3/2}$ state of calcium ion form a three level system. We use 2 lasers to couple the S→P and P→D transitions. The data show the measured fluorescence as a function of laser detuning Δ