

My name is Tony Hyun Kim, and I am currently a graduate student working with Prof. Isaac Chuang at MIT. With your support, over the last two weeks I was able to attend ICAP 2010 (International Conference on Atomic Physics) held in Cairns, Australia.

Our work is in the field of ion trap quantum computation – the premise being that one can isolate and trap one or a few ions, and then manipulate their “internal” states (configuration of the valence electron) and also the “external” states (motion of the atomic ion) for the purposes of information processing. As such, our work falls within the broader category of atomic physics. At ICAP, I had the opportunity to learn about recent work from other quantum information groups around the world, as well as updates from further-removed subfields. Of these, the physics of molecule production – in which researchers navigate the complicated sea of molecular quantum states in order to drive a chemical reaction deterministically – and integrated photonic devices were of special interest to me.

An integral part of the conference was the poster session, in which students from worldwide presented on their current work. I too gave a poster on my project, which could be aptly described as “trap engineering.” Namely, I am building an ion trap with an integrated optical fiber. Below is a copy of the poster that I presented.

Fiber-integrated Point Paul Trap
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Introduction
 Surface-electrode ion traps represent a distinct advance in quantum information processing, in that the trap manufacturing process assumes the inherent scalability associated with conventional microfabrication. However, the construction of large-scale ion processors will require not only a sensibly scalable electrode architecture for trapping many ions simultaneously, but also additional infrastructure for optical readout and control of the many ion qubits, such as that offered by device-level integration of optical fibers.

Trap Design and Assembly
 We address the following challenges in fiber-ion trap integration:
 1. How to introduce fiber without perturbing the trapping fields?
 2. How to reliably incorporate a fragile fiber to the trap?
 3. How to fine-tune the ion-fiber mode overlap?

Ion control through fiber
 • ⁸⁸Sr⁺ optical qubit: 5S_{1/2} → 4D_{3/2} transition
 • Fiber simultaneously single-mode for:
 -42nm Doppler cooling
 -674nm Qubit transition
 • Doppler beam from fiber prepares ion in Lamb-Dicke regime along fiber axis.
 • Pulsed 674nm light through fiber performs qubit rotation.
 • State readout using conventional imaging optics.

Results
 Point Paul trap design:
 • Ions trapped with and without the fiber.
 • Ions lifetime with Doppler cooling.
 • Planar crystals of up to nine ions with individual ion resolution.
 • Secular frequencies agree with theory.

Ion micropositioning:
 • In situ ion height of 200-1100 microns achieved. Height variation in good agreement with theory.

Ion control through fiber:
 • Preliminary ion-fiber overlap observed.
 • Further improvement in alignment expected.
 (Pulsed fiber-Raman trap used different fab procedure than the one defined above.)

Future Outlook:
 • Reoptimization of Point Paul geometry for additional ion positioning in the radial plane.
 • Test of anomalous ion heating near metal surfaces, currently believed to scale as 1/(ion height)³ [5]
 • Quantum simulation using planar crystals.

Of all the ion trap quantum information posters that were presented, it was surprising for me to find that only a very few groups were actually using the devices for their actual intended use of quantum computation and simulation. (Two projects stood out in particular: [1] Simulation of the Dirac equation, and [2] Simulation of magnetism using an ion chain.) Instead, many projects – like mine – seemed to be occupied with incremental advances in trap engineering and design. At the end of the poster sessions, I concluded that I too wish to utilize ion traps for novel applications, rather than just its incremental development. After all, that is why anyone is interested in *quantum information processing* in the first place, rather than conventional computing!

With this in mind, during conference downtime, I reviewed previous efforts in our own group in quantum simulation. I also took the time to think about a particular *strategy*: what are the advantages and disadvantages based on the infrastructure available in our group already? The following was my summary of the state of things:

- Proof-of-principle demonstrations of many algorithms and simulations have already been conducted with a few ions. For such demonstrations, the simplest type of ion trap – the three-dimensional linear Paul trap – is not only sufficient but ideal for numerous reasons.
- The infrastructure in our lab is geared for rapid prototyping of new (two-dimensional) traps, and short-term deployment – not particularly suited for long-term work in demonstration of computation, etc.
- At the same time, MIT also makes available a fabrication facility for in-house two-dimensional trap production.
- There is no inherent advantage of two-dimensional ion traps over the conventional 3D versions. In fact, much of the trap parameters suffer. However, the key advantage with the former type is that it can be interfaced with other on-chip technologies.

With this background, I decided on a following course of action:

- Identify a computational task that can be assisted by on-chip elements. (I have in mind structures such as optical lattices, produced by integrated waveguides.)
- Use the chip-elements as a leverage to implement a significantly larger-scale simulation than what has been previously achieved.

To conclude, based on my tour of ICAP 2010, I now feel that trap engineering ought to be pursued with an ultimate (quantum information) task in mind. And once that task has been identified, I would like to leverage as much on-chip fabrication technology as possible in order to produce the largest-scale implementation of the particular problem to date. I am very optimistic with this new outlook, since, at the same time, it will allow me a chance to delve deeper into the techniques of fabricating micron-sized structures. I believe this skill will very well complement and augment my current ability for “macroscopic” mechanical and electrical engineering.

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After the conference, I stayed a few extra days in Australia, and went out snorkeling in the Great Barrier Reef for two of those days. This was some of the most fun I’ve had, and got me almost to not think about my work for those few days. Below, I enclose a picture of me and Wally taken during this refreshing break after ICAP. In closing, thank you again for supporting our trip to ICAP 2010 in Australia!

Sincerely,

-Tony Hyun Kim

