Fiber-integrated Point Paul Trap

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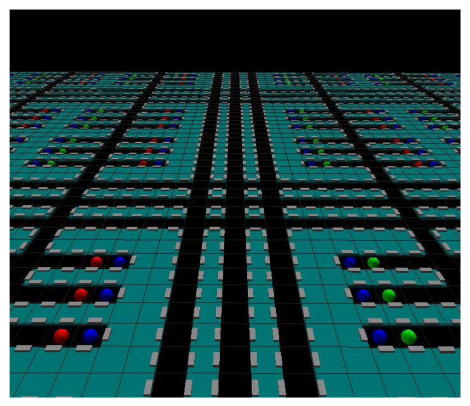
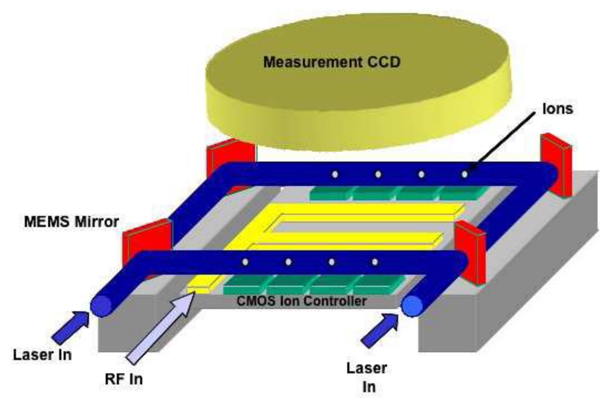
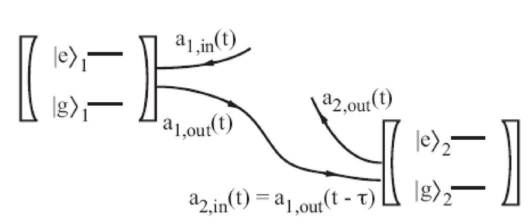
Introduction





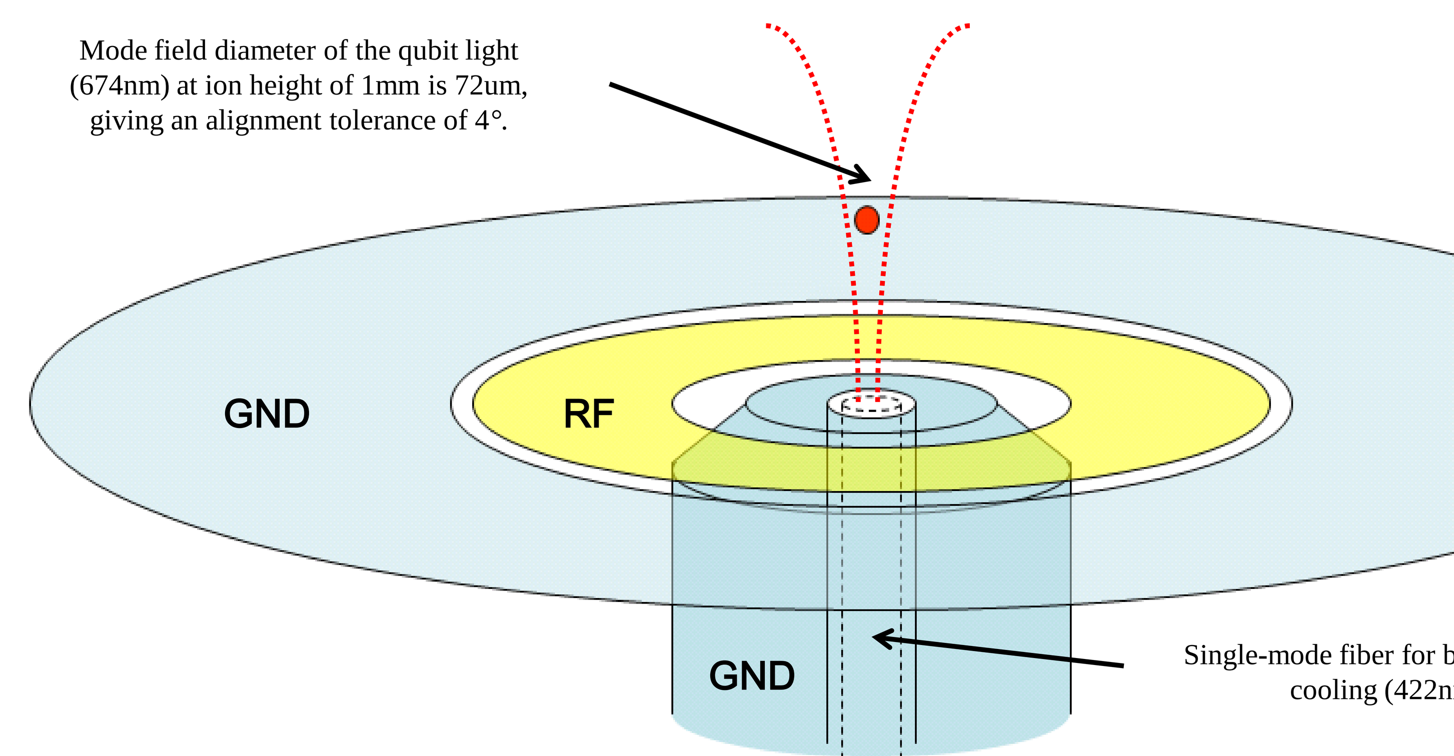
Surface-electrode ion traps represent a distinct advance in quantum information processing, in that the trap manufacturing process assumes the inherent scalability associated with conventional microfabrication. However, the construction of large-scale ion processors will require not only a sensibly scalable 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.

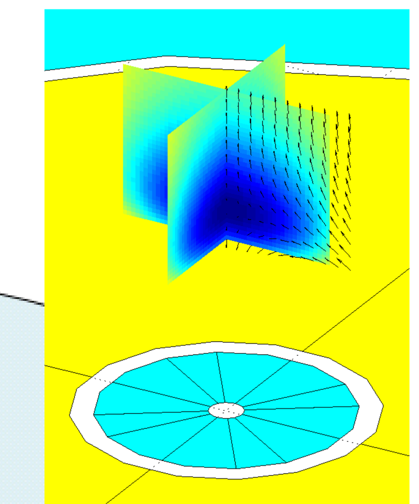
At the same time, a fiber-coupled ion trap enables novel structures such as ion trap quantum nodes on an optical fiber network[1], and a interface platform between ions and cold neutral atoms[2].



We present design of an ion trap with an integrated optical fiber for the purpose of light delivery and ion control. This scheme complements recent work[3] on ion detection through fibers.

Trap Design and Assembly



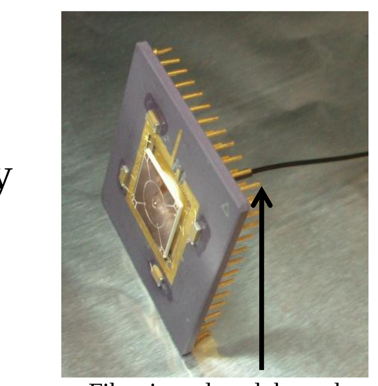


We address the following challenges in fiber-ion trap integration:

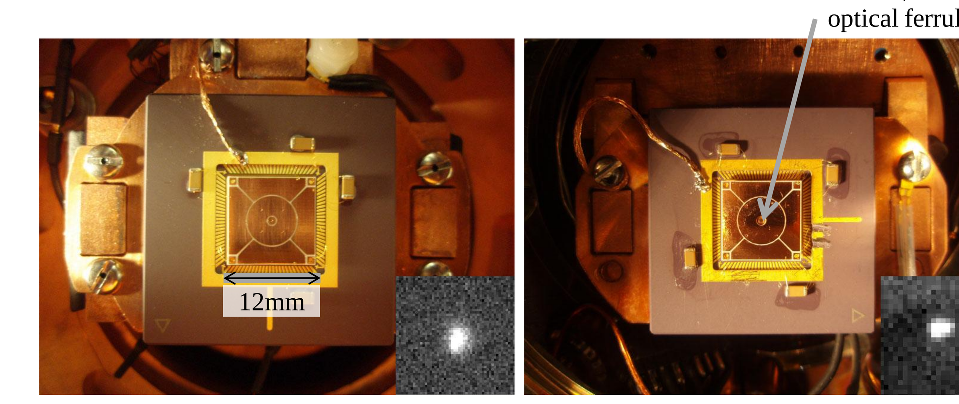
1. How to introduce fiber without perturbing the trapping fields?
   → Design of a new "Point Paul" electrode geometry whose axial symmetry is compatible with that of the fiber.
2. How to reliably incorporate a fragile fiber to the trap?
   → Rely on off-the-shelf optical components as much as possible, such as standardized optical ferrules.
3. How to fine-tune the ion-fiber mode overlap?
   → The Point Paul trap is ideally suited for an ion micropositioning scheme through additional RFs that translate the quadrupole node.

POINT PAUL TRAP

- Ion confinement with a single RF ring electrode.[5]
- Gaps due to fiber modeled numerically and analytically.
- Typical RF drive 300V, 8MHz
  → 200meV trap depth
  → ~0.5MHz trap frequency



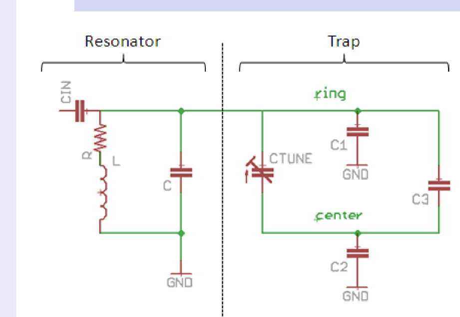
Fiber introduced through the center of innermost electrode (actually an optical ferrule).



OPTICAL FERRULE

- Fiber and ferrule polished as in conventional fiber connectorization.
- Axis alignment with precision of 25 microns.

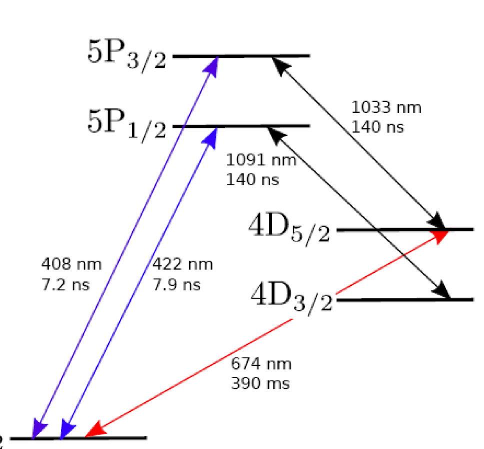
ION MICROPOSITIONING

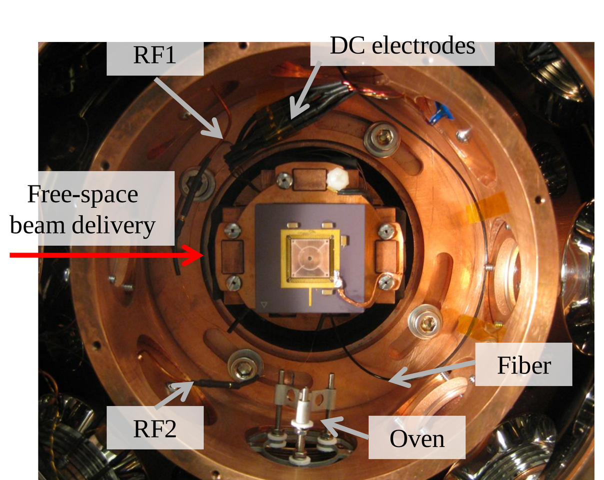


- Ion height adjusted *in situ* by second RF on ferrule electrode. Order of magnitude variation feasible.
- ~100um variation in radial plane using RF on compensation electrodes.

Ion control through fiber

- $^{88}Sr^+$ optical qubit: $5S_{1/2} \leftrightarrow 4D_{5/2}$ transition
- Fiber simultaneously single-mode for:
  - 422nm: 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.





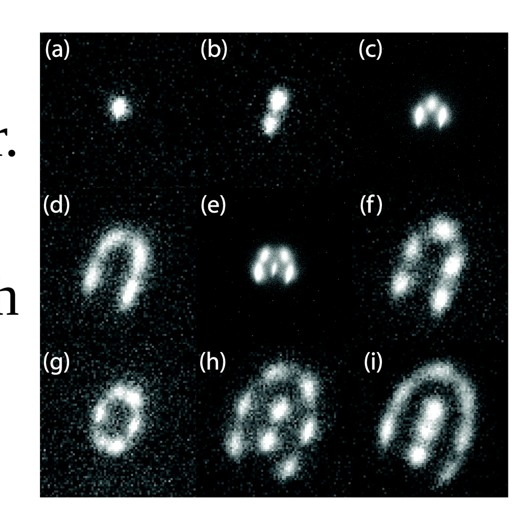
40K chamber (5" diameter) of cryostat. [4]
Trap mount is at 4K

[1] J. I. Cirac, P. Zoller, H. J. Kimble, and H. Mabuchi. *Phys. Rev. Lett.*, **78**, 3221 (1997)
[2] C.A. Christensen, S. Will, M. Saba, G.-B. Jo, et al. *Phys. Rev. A* **78** , 033429 (2008)
[3] A. P. VanDevender, Y. Colombe, J. Amini, D. Leibfried and D.J. Wineland. *Phys. Rev. Lett.*, **105,** 023001 (2010)
[4] P.B. Antohi, D. Schuster, G.M. Akselrod, et al. *Rev. Sci. Instrum.*, **80**, 013103 (2009).

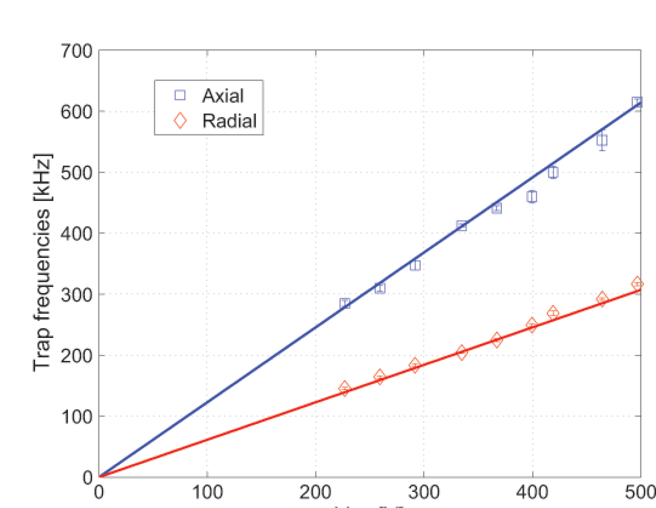
Results

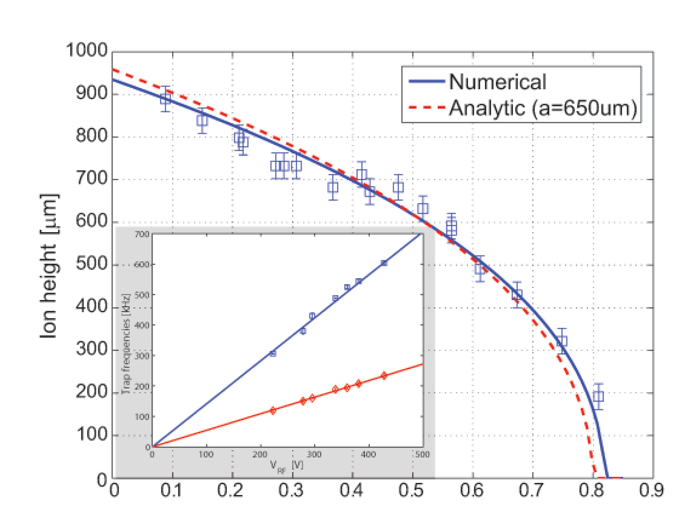
Point Paul trap design:

- Ions trapped with and without the fiber. >Hours lifetime with Doppler cooling.
- Planar crystals of up to nine ions with individual ion resolution.
- Secular frequencies agree with theory.



(Each panel: 70um×70um)





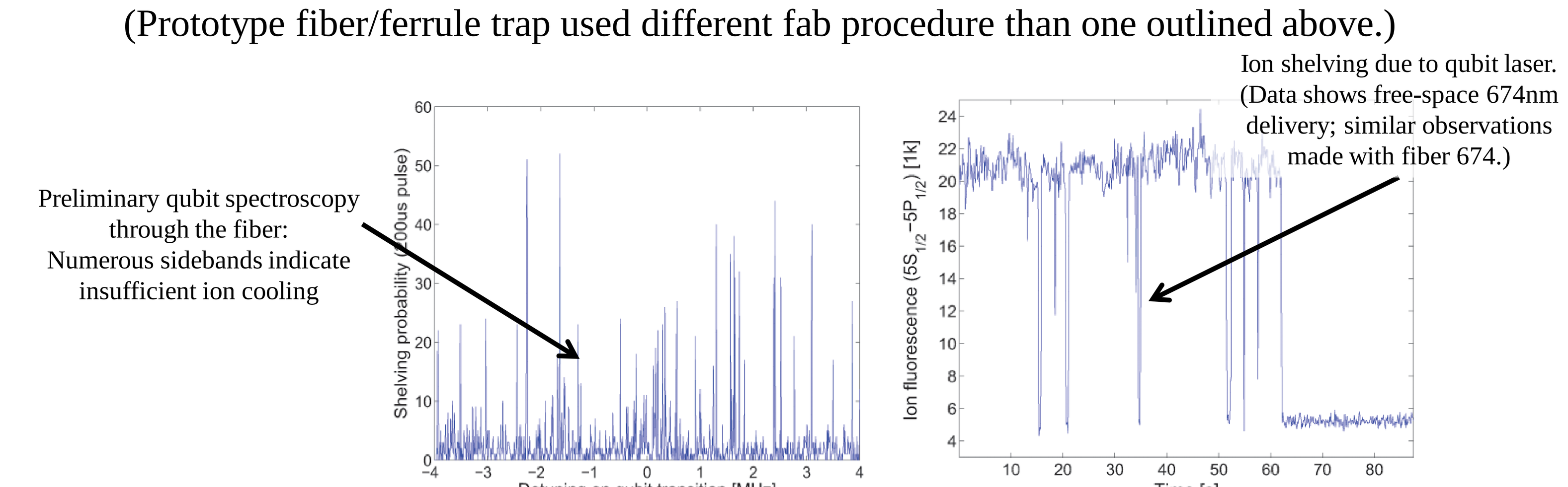
Ion micropositioning:

- *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.

(Prototype fiber/ferrule trap used different fab procedure than one outlined 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)^4.[6]
- Quantum simulation using planar crystals.

[5] C. Pearson. *Theory and Application of Planar Ion Traps*. S.M. thesis, MIT (2006)
[6] L. Deslauriers, S. Olmschenk, D. Stick, et al. *Phys. Rev. Lett.*, **97**, 103007 (2006).