Fiber-coupled Point Paul Trap

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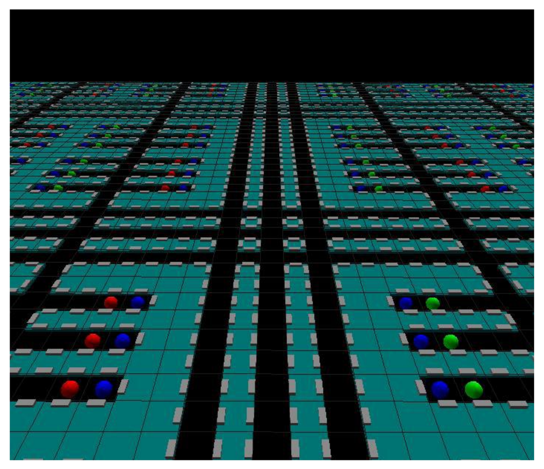
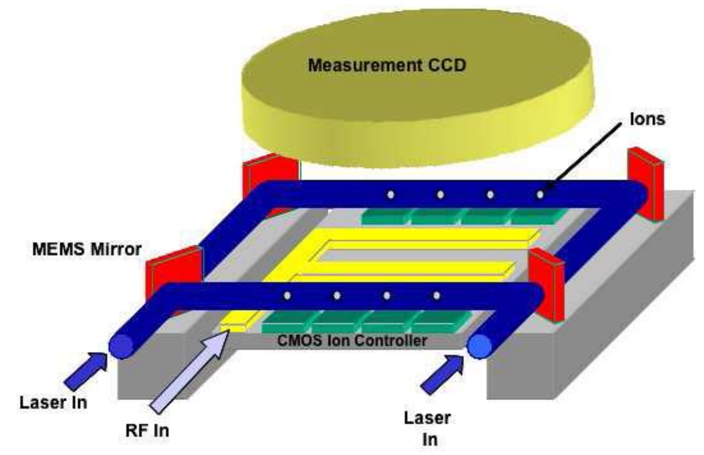
Introduction





Surface-electrode ion traps represent a distinct advance in quantum information processing, in that the trap manufacturing process inherits the inherent scalability associated with conventional microfabrication. However, the construction of large-scale ion processors (see above) 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.

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

We present the design and progress towards an ion trap primitive with an integrated optical fiber for the purpose of light delivery and ion control.

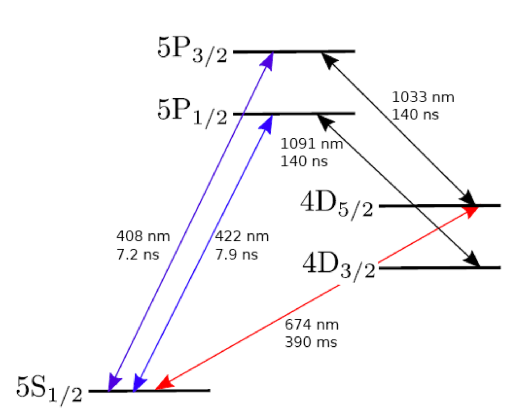
Fiber Integration: Motivations

Trap engineering:

•Laser delivery. (For instance, all $^{88}Sr^+$ transitions [see right] are supported by a photonic crystal fiber.)

•Site-specific ion readout [3]

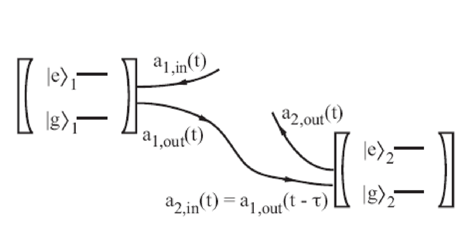
•Clean loading through fiber



Further applications:

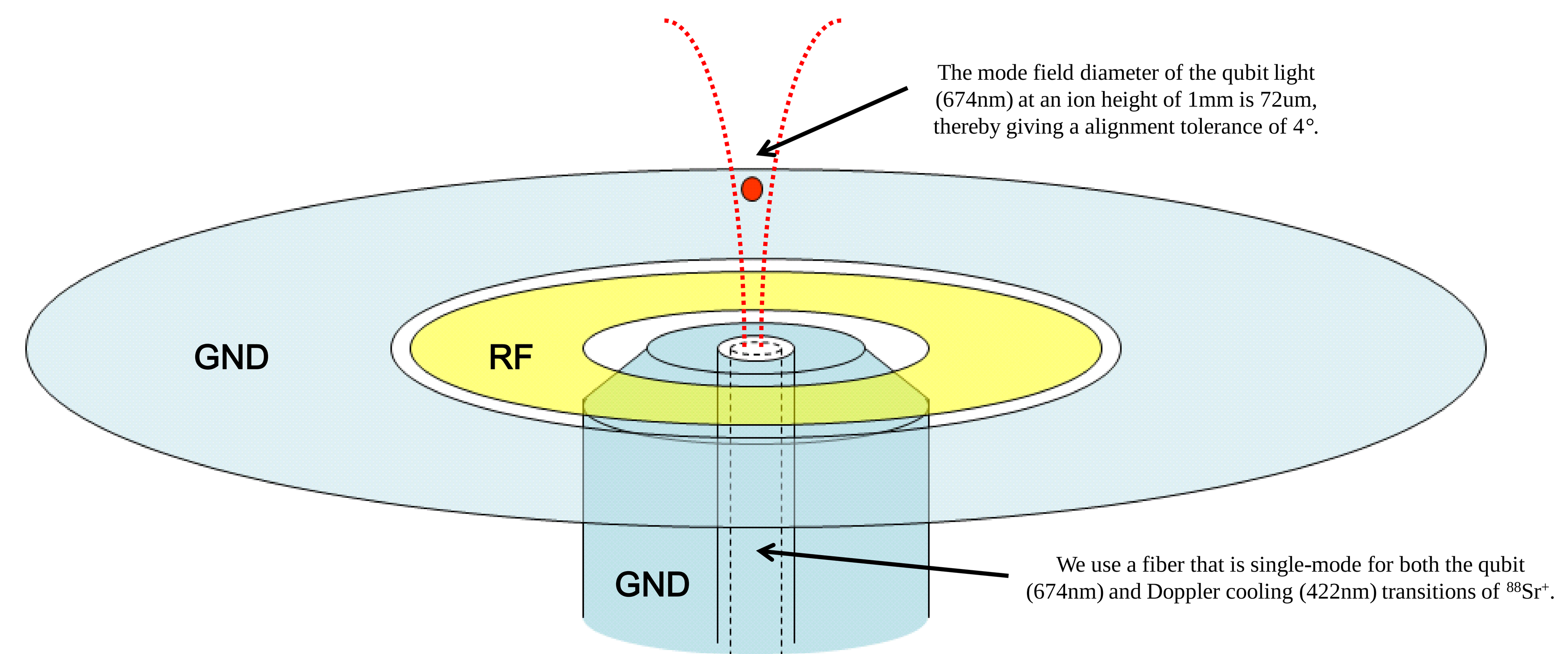
•Interconnect for quantum networks, provided state transfer between ion and field mode.

•A hollow-core fiber as an interface between ion and neutral systems.



[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, et al. *Phys. Rev. Lett.*, **105,** 023001 (2010)

Trap Design and Assembly



We have addressed the following challenges in fiber-ion trap integration:

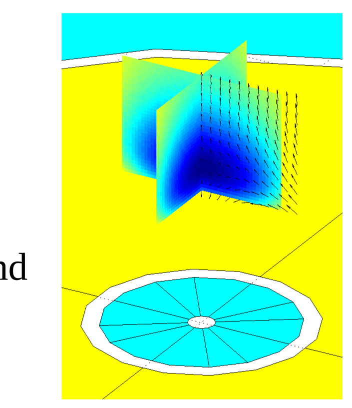
1. How to introduce fiber without perturbing the trapping fields?
   → **NEW TRAP GEOMETRY:** Design of a new "Point Paul" electrode geometry whose axial symmetry is compatible with that of the fiber.
2. How to reliably incorporate a fragile fiber to the trap?
   → **COMMERCIAL COMPONENTS:** Rely on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

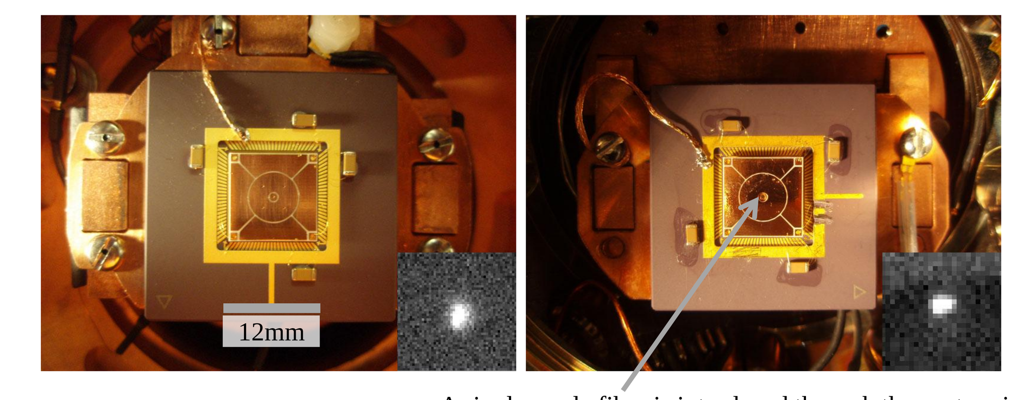
TRAP GEOMETRY

•The Point Paul design achieves ion confinement with a single RF ring.

•Necessary electrode gaps due to fiber can be modeled numerically and analytically.

•Both fully PCB traps (no fiber; see below left) and ferrule-based traps (with fiber; below right) have trapped $^{88}Sr^+$ ions stably for several hours.



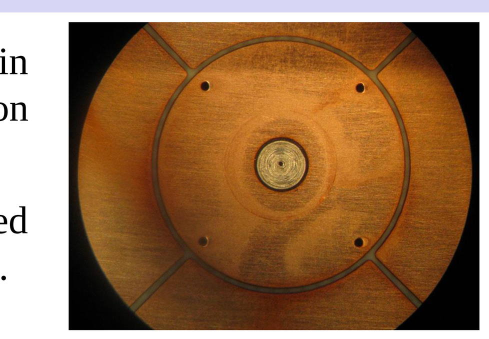


A single-mode fiber is introduced through the center via of the innermost electrode (actually a fiber ferrule).

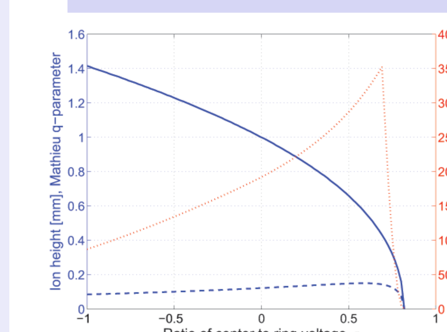
OPTICAL FERRULE

•Fiber and ferrule are polished as in conventional fiber connectorization procedure, providing robustness.

•Fiber-trap alignment can be performed with a typical precision of 25 microns.



ION MICROPOSITIONING



•Ion height can be adjusted *in situ* by adding a second RF onto the ferrule electrode. Several 100um variation is achieved.

•Up to 100um variation possible in radial plane using RF on compensation electrodes.

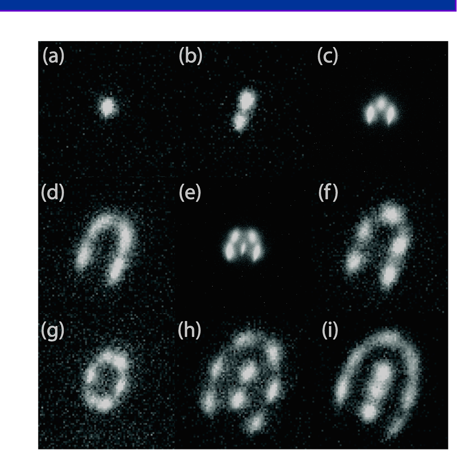
Results

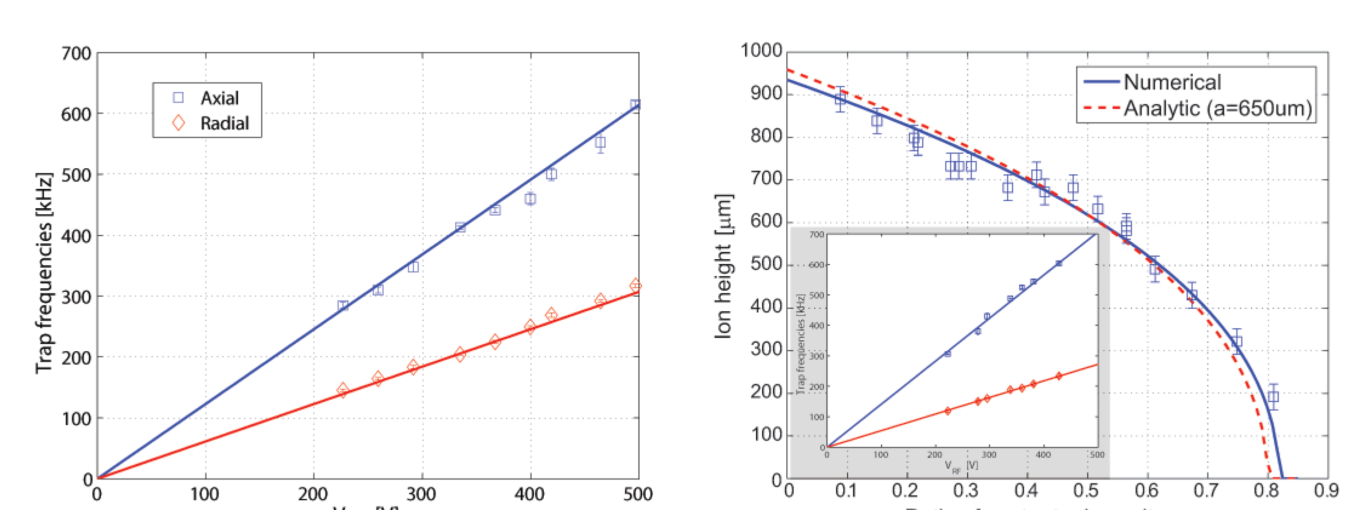
Point Paul trap design:

•Ions trapped with and without the fiber.

•Planar ion crystals of up to nine ions observed with individual ion resolution.

•Measured secular frequencies in excellent agreement with theory. (See below left.)





Ion micropositioning:

•*In situ* ion height range of 200-1100 microns achieved. Height variation (see above right) in good agreement with theory.

Future work and Outlook

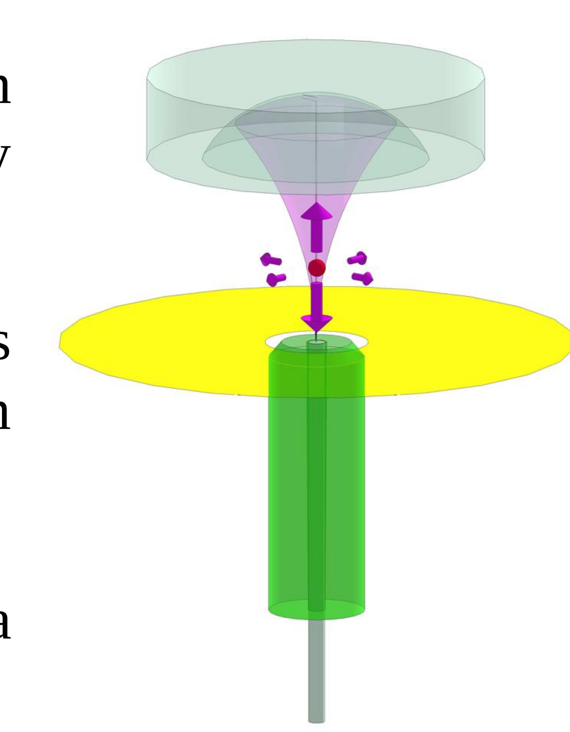
•Improve ion-fiber alignment. (Prototype fiber/ferrule trap used a different fab procedure than one outlined above.)

•Re-optimize the point Paul geometry for greater ion positioning ability in the radial plane.

•Perform stringent test of anomalous ion heating near metal surfaces, currently believed to scale as $1/z^4$.[4]

•Point Paul trap yields 2D ion crystals with the requisite structure for quantum spin simulation.

•Integration of optical cavity to realize a node in a quantum network. (See right.)



[4] L. Deslauriers, et al. *Phys. Rev. Lett.*, **97**, 103007 (2006).