SAND2015-1045C

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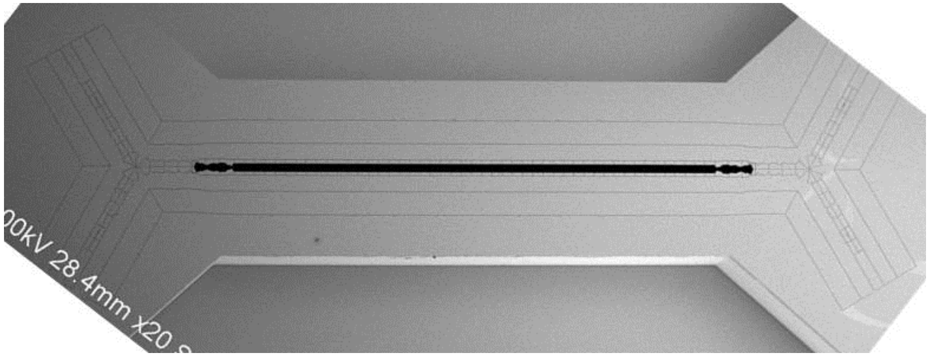

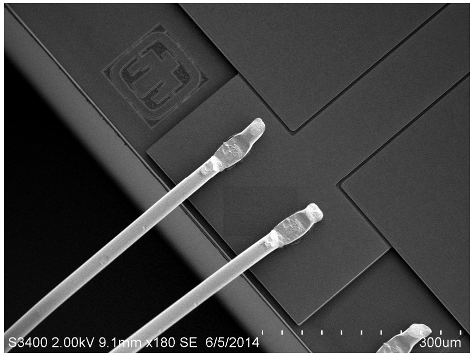

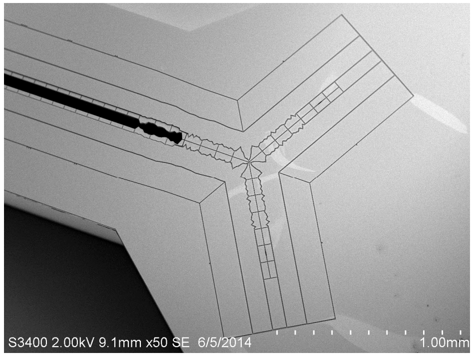

Characterization of a High-Optical-Access surface trap optimized for quantum information processing

Peter Maunz, Craig R. Clark, Raymond Haltli, Andrew Hollowell, Jonathan Mizrahi, John Rembetski, Paul Resnick, Jonathan D. Sterk, Daniel L. Stick, Boyan Tabakov, and Matthew G. Blain

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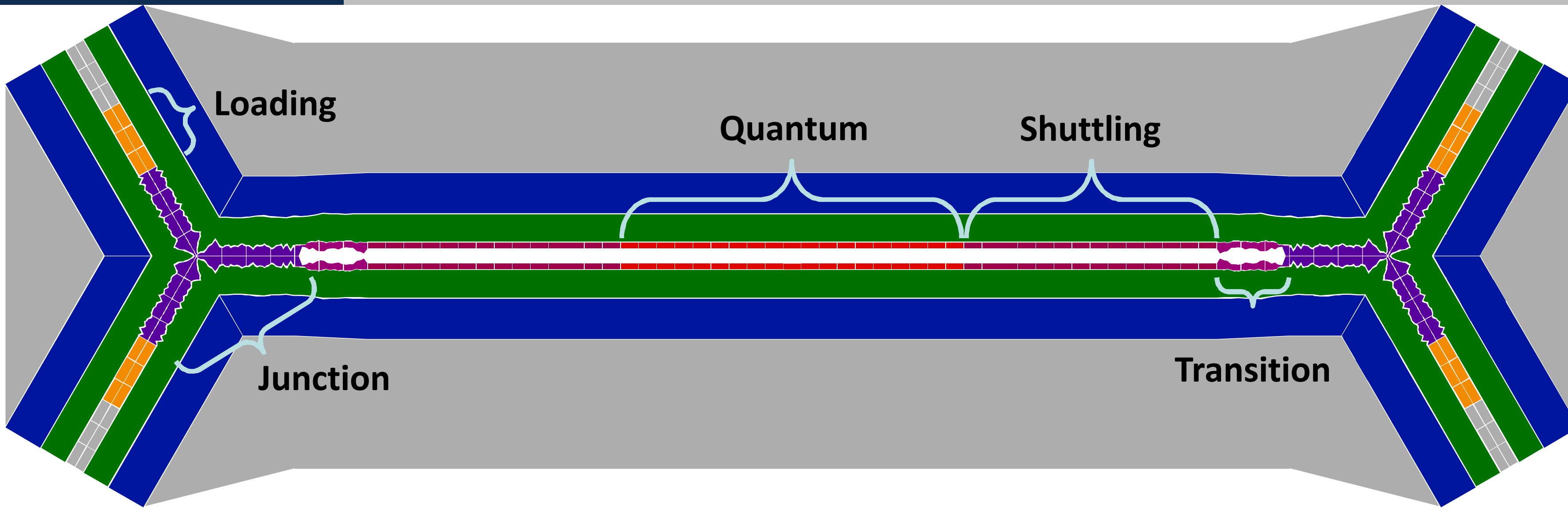
HOA 2.0 Re-Optimization

Objective	
Principal axes	Enable rotation of principal axes while maintaining translational symmetry. • Independent control voltages on all 4 DC “rails”
Trap frequencies	Improve trap frequencies • Re-optimize the linear section • Influence of oxide thickness
Axial control	Better axial control voltage efficacy • Move segmentation to inner DC rails • Splitter electrodes to efficiently split and recombine ion chains • Compensation of long chains and multi well potentials
Shuttling Yb^+ and Ba^+	Co-shuttling of Yb and Ba • Match the loading region trap frequency to slotted region • Re-optimize junction and transition
Co-Wiring	Optimized the control voltage count

Trap Features



Long linear section:

- Multiple adjacent trapping regions
  - Remote entanglement
  - Local multi-qubit gates
  - State detection region

Junctions:

- Assembling and re-arranging ion chain
- Loading holes

Region	# Electrodes	# Independent Voltages
Quantum	19 pairs	38
Shuttling	28 pairs	8
Outer DC	10 electrodes	6
Junction	24 pairs	24
Transition	6 pairs	6
Loading	12 pairs	12
Total:		94

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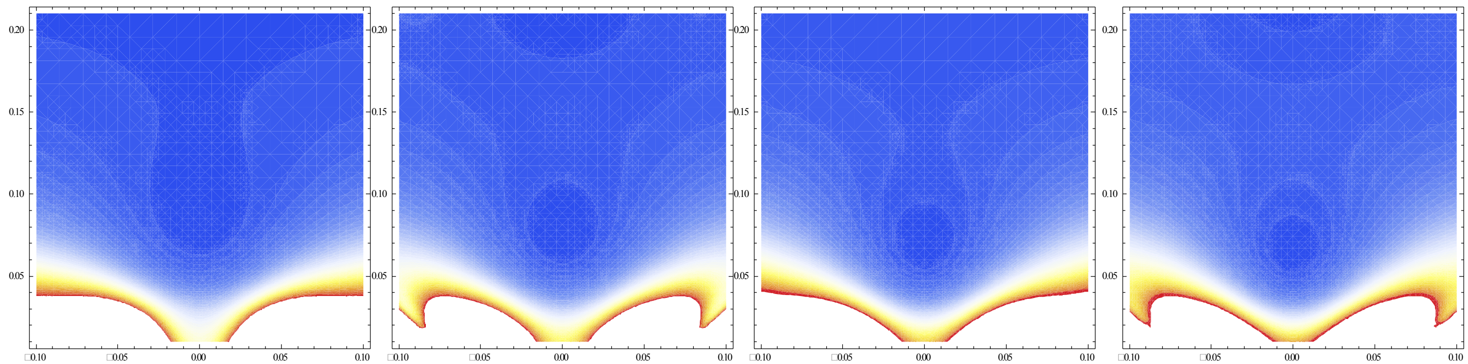
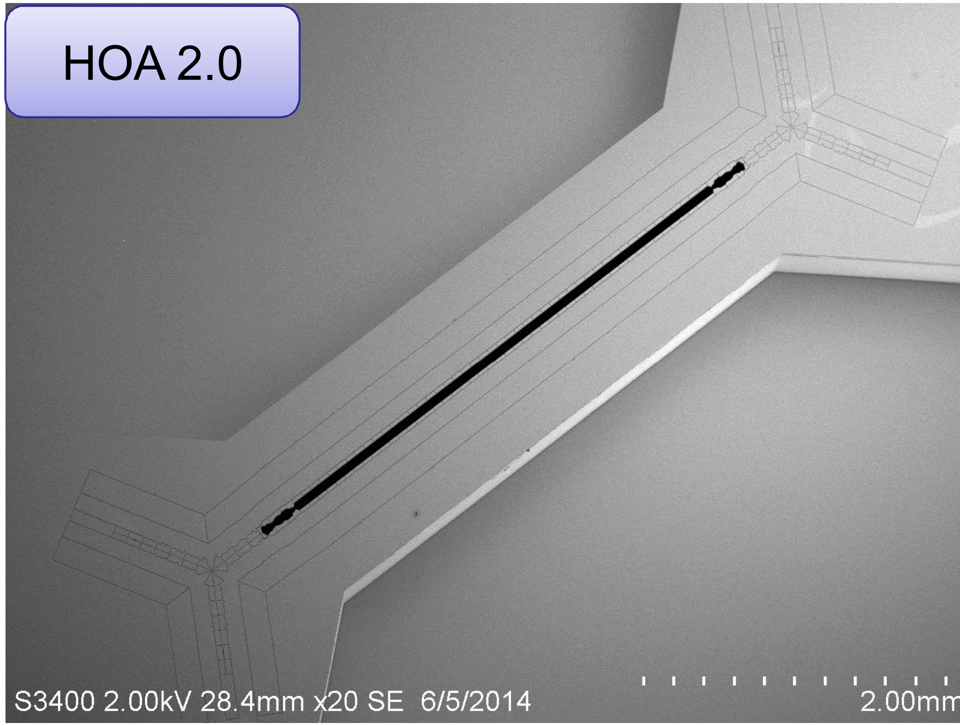
Optimization of slotted linear section
Influence of oxide thickness

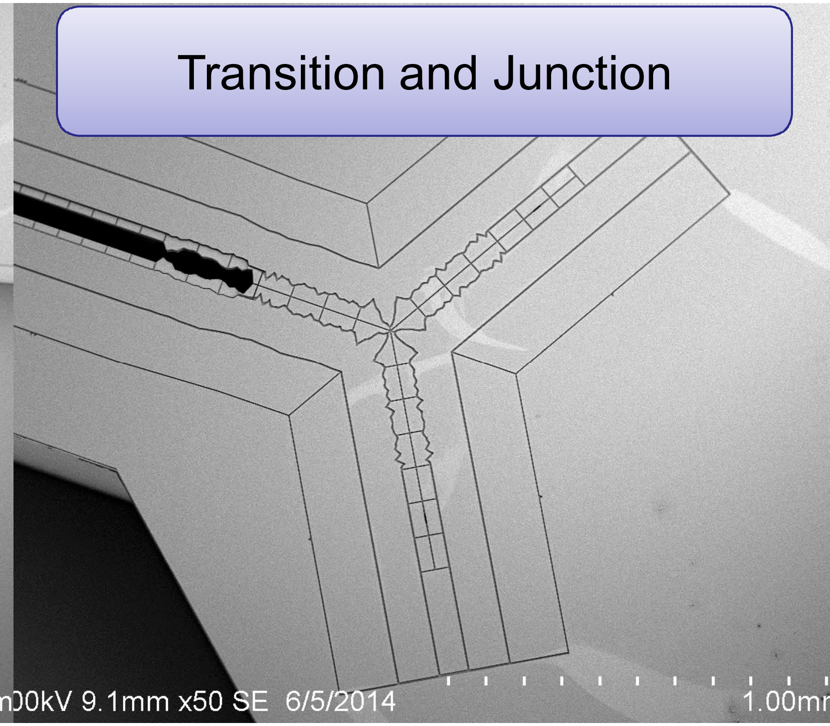


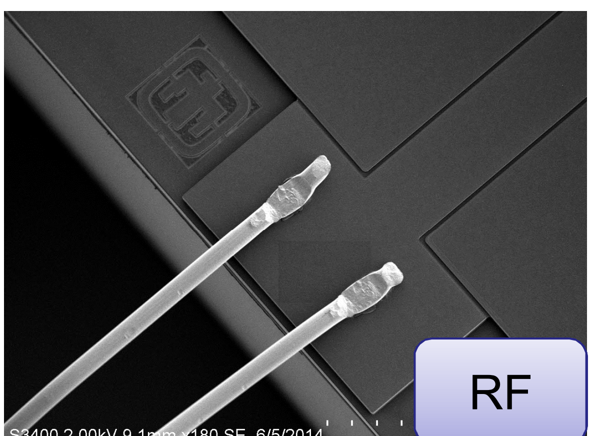
Oxide thickness	0µm (M4)	8µm (M3)	12.5µm (M3)	16µm (M3)
Ion height	82µm	74µm	69µm	65µm
Trap frequency*	2.1MHz	2.4MHz	2.7MHz	2.9MHz
Trap depth*	94meV	123meV	147meV	164meV
Trap freq* @q=0.2	2.56MHz	2.78MHz	2.92MHz	3.02MHz
Characteristic distance†	165µm	152µm	144µm	140µm

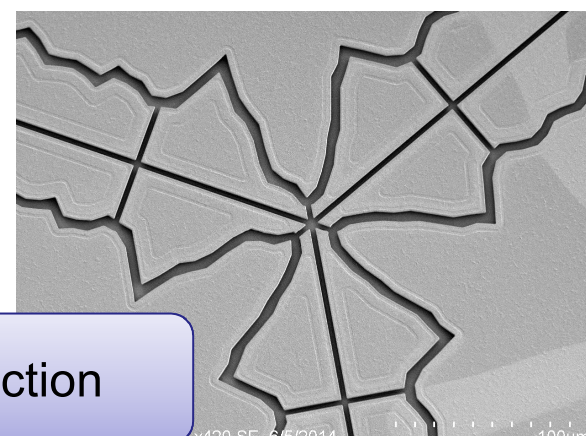
Trap frequency and depth for rf potential only and for $^{171}Yb^{+}$, 250V, 45MHz

Trap details



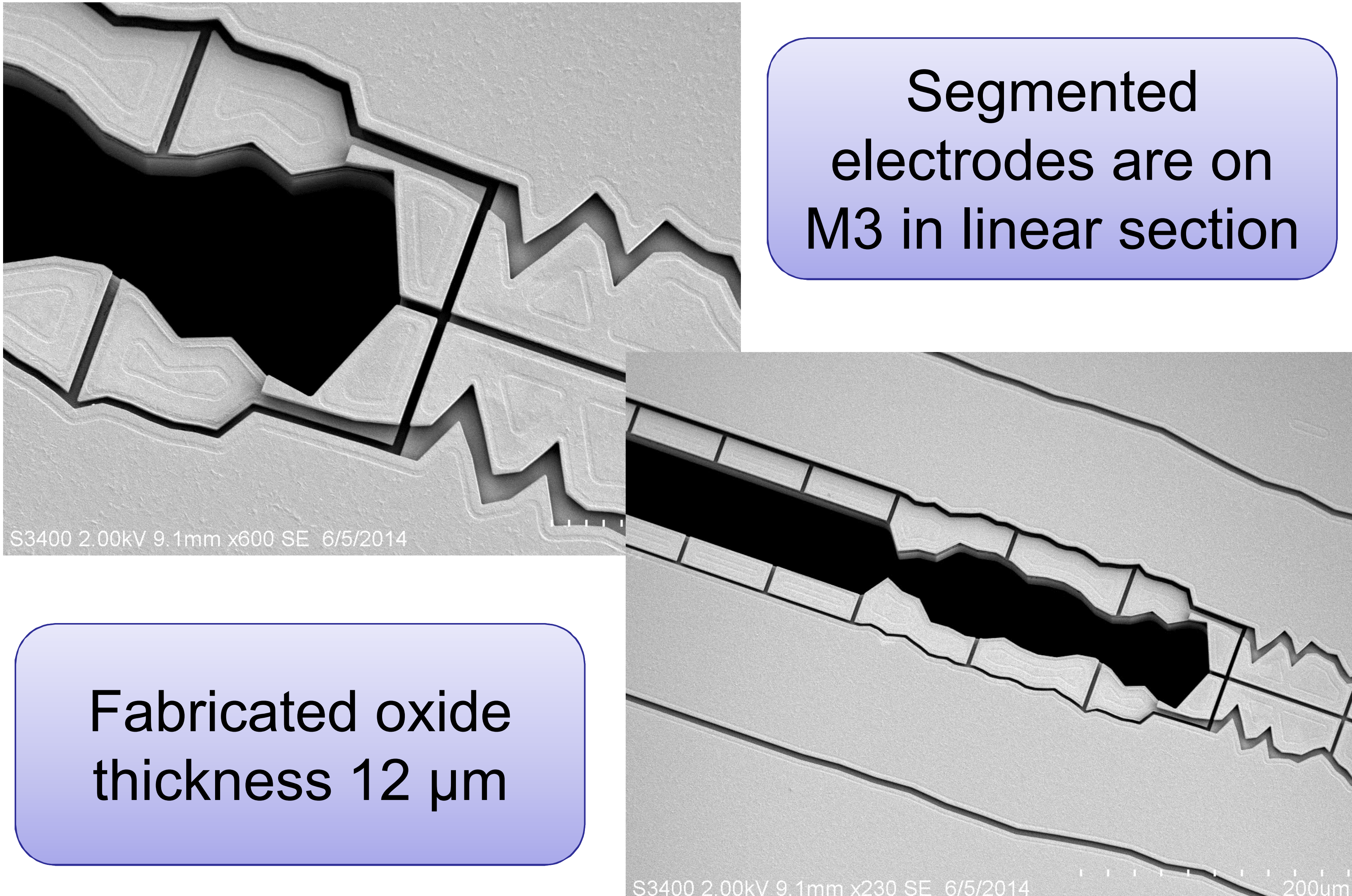






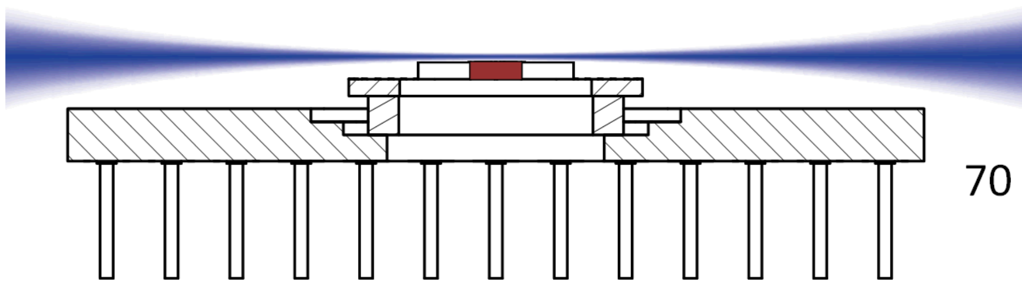
Segmented electrodes

Segmented electrodes are on M3 in linear section

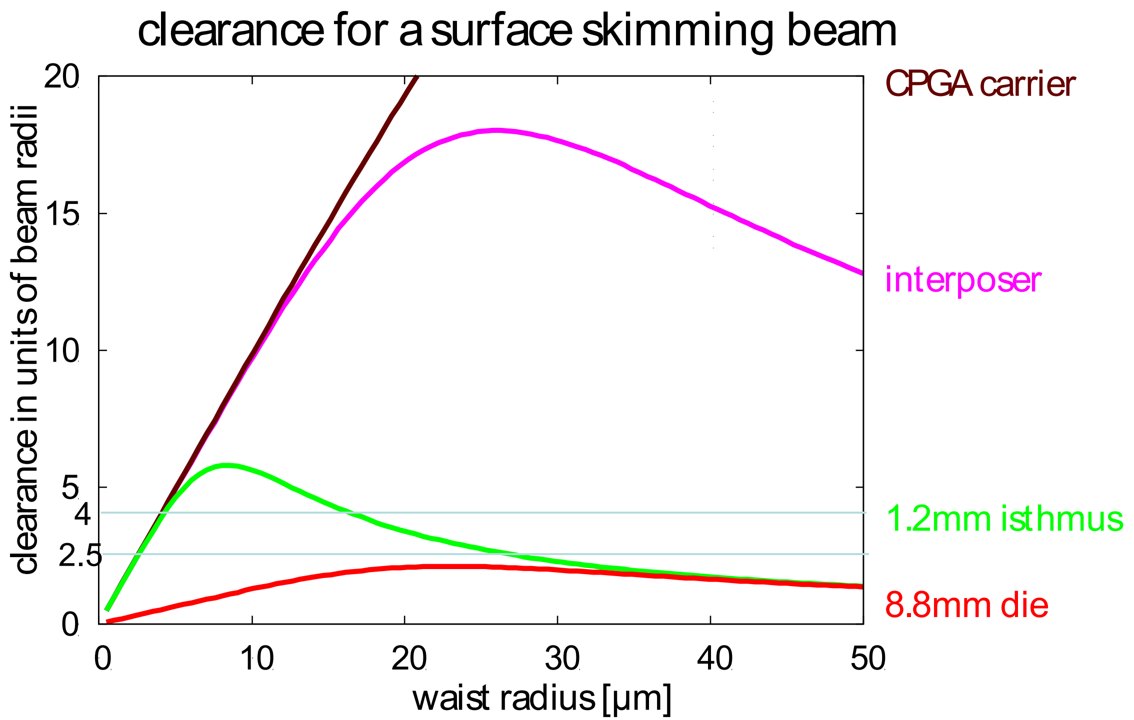


Fabricated oxide thickness 12 µm

High Optical Access trap *beam clearance*



70 µm ion height



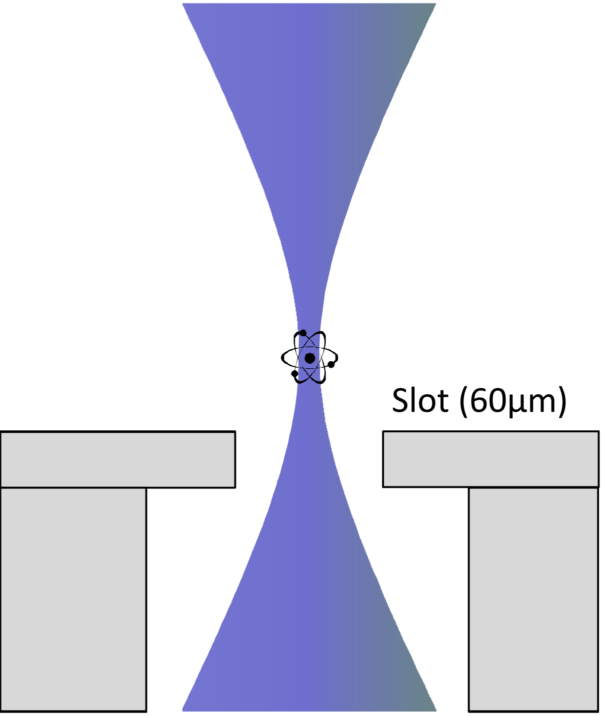
4: $<2\times10^{-14}$

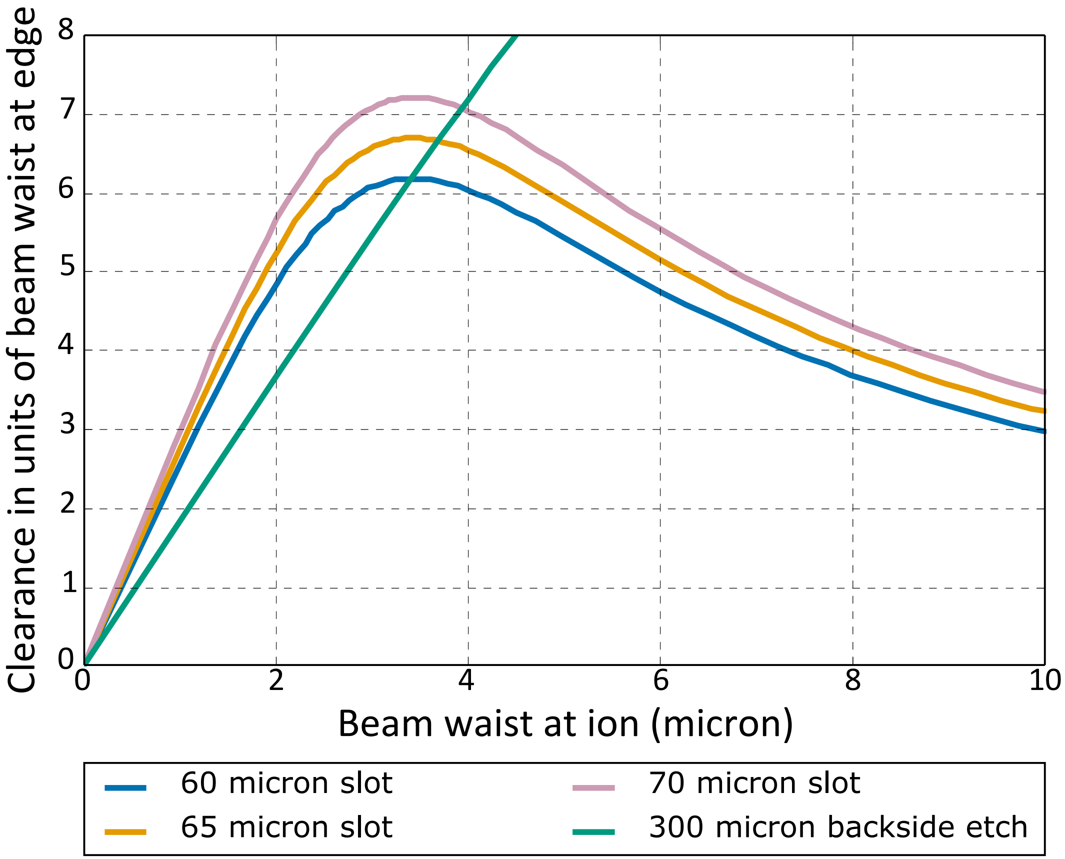
3: $<2\times10^{-8}$

2.5: $<3\times10^{-6}$

4 µm waist is possible

HOA2
Vertical beam clearance

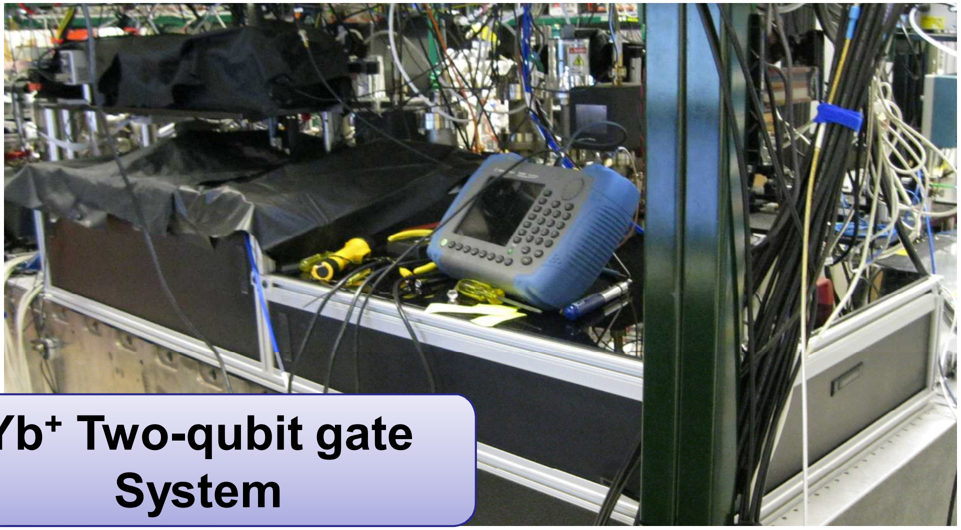




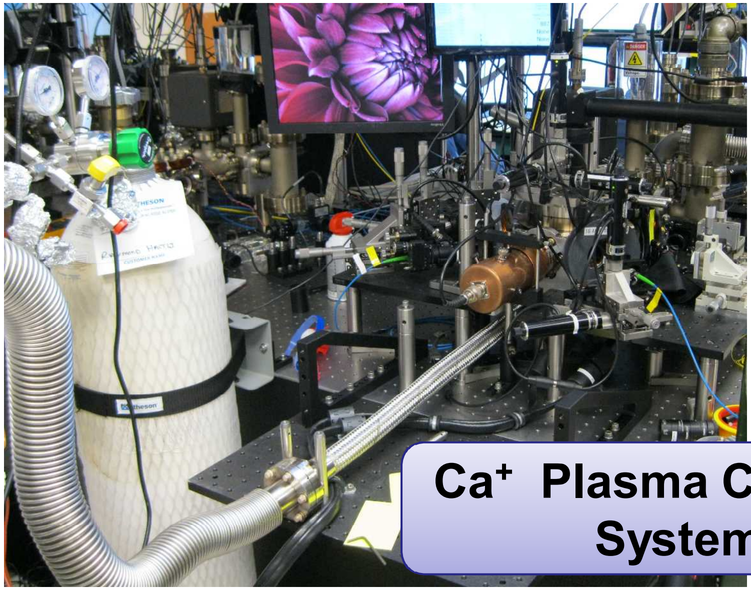
HOA2: 60µm slot

- Minimal effect on (vertical) optical access
- Greater voltage efficacy for DC control

HOA-2 test setups

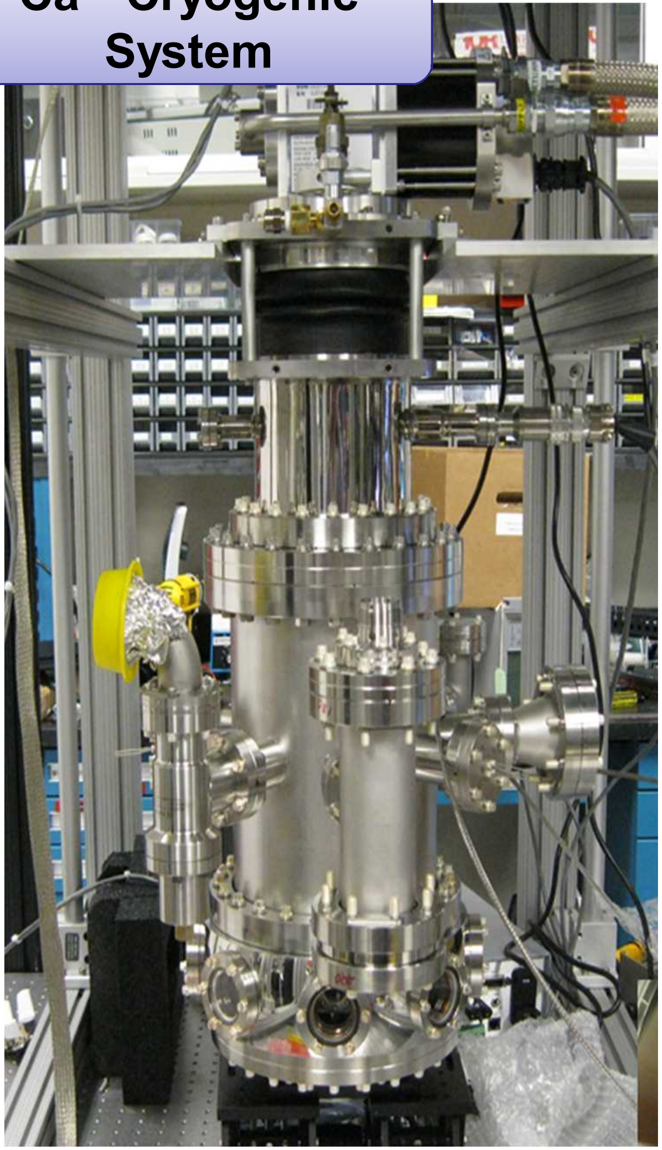


Yb$^+$ Two-qubit gate System



Ca$^+$ Plasma Cleaning System

Ca$^+$ Cryogenic System



HOA-2 testing trapping and trap lifetimes

Ytterbium

Trap frequencies:
- radial 2.7 MHz
- rf frequency 34 MHz
- stable for two ions

Simulation:
- q=0.23

Trapping time:
- >8 h observed with continuous measurements
- >5 min without cooling

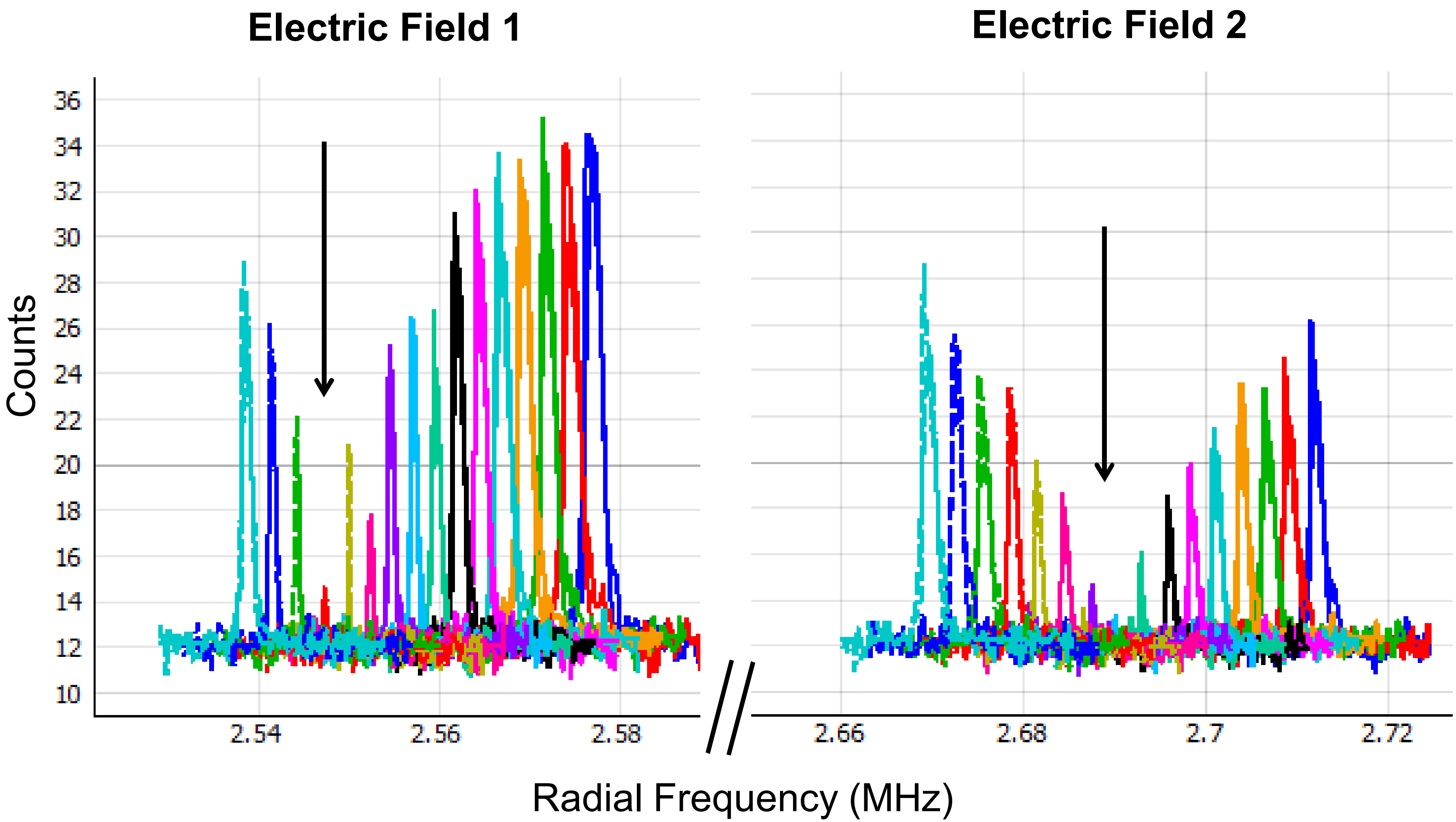
Calcium

Trap frequencies:
- axial up to 4 MHz
- radial > 8 MHz
- rf frequency 39 MHz

Simulation:
- 250 meV depth
- q=0.53

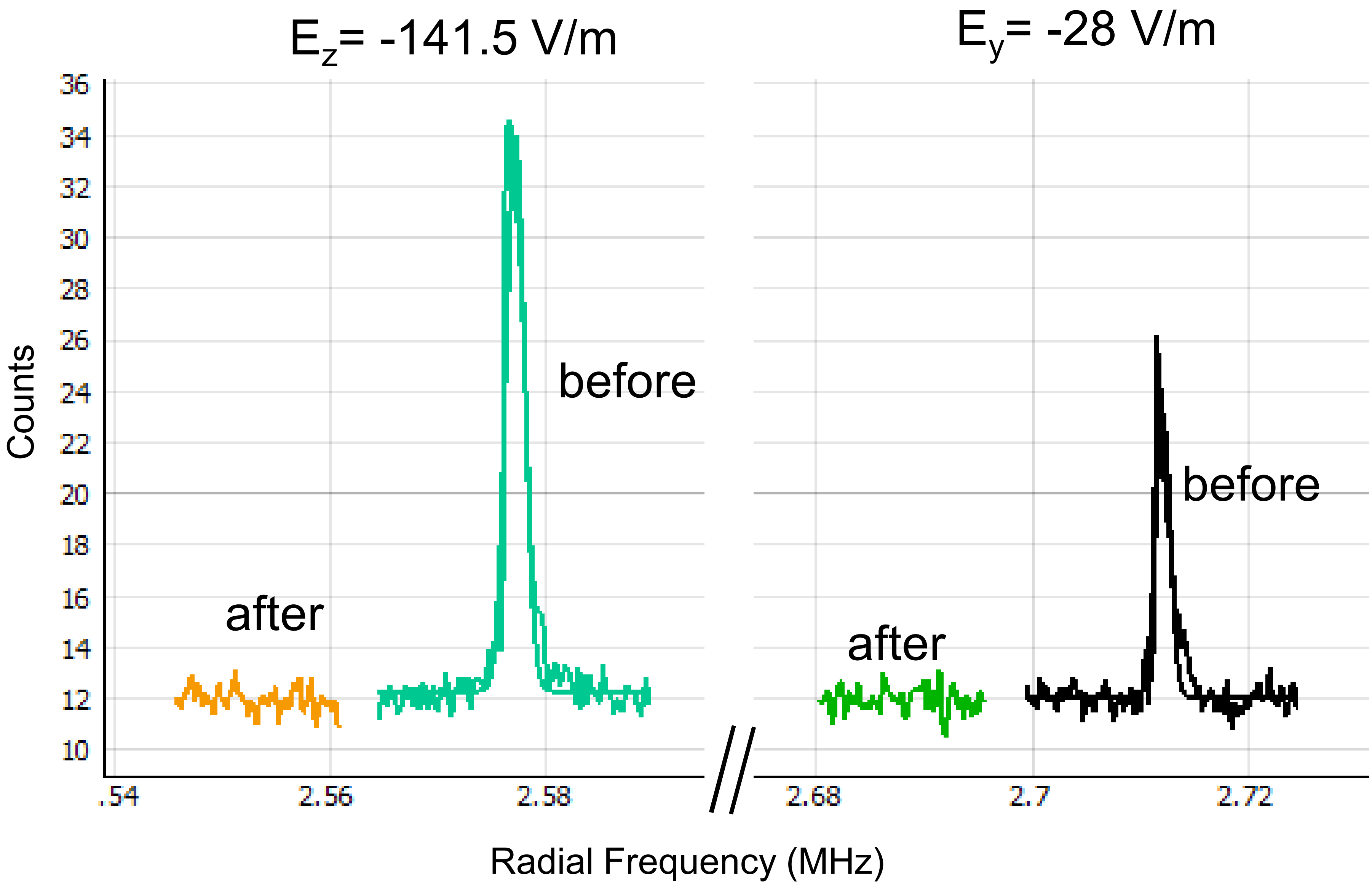
Trapping time:
- >8.5 h observed with continuous measurements
- >1 min without cooling

HOA-2 testing trap compensation



S. Narayanan, et al., J. Appl. Phys. 110, 114909 (2011)

HOA-2 testing trap compensation



Micro-motion compensation with Raman transitions

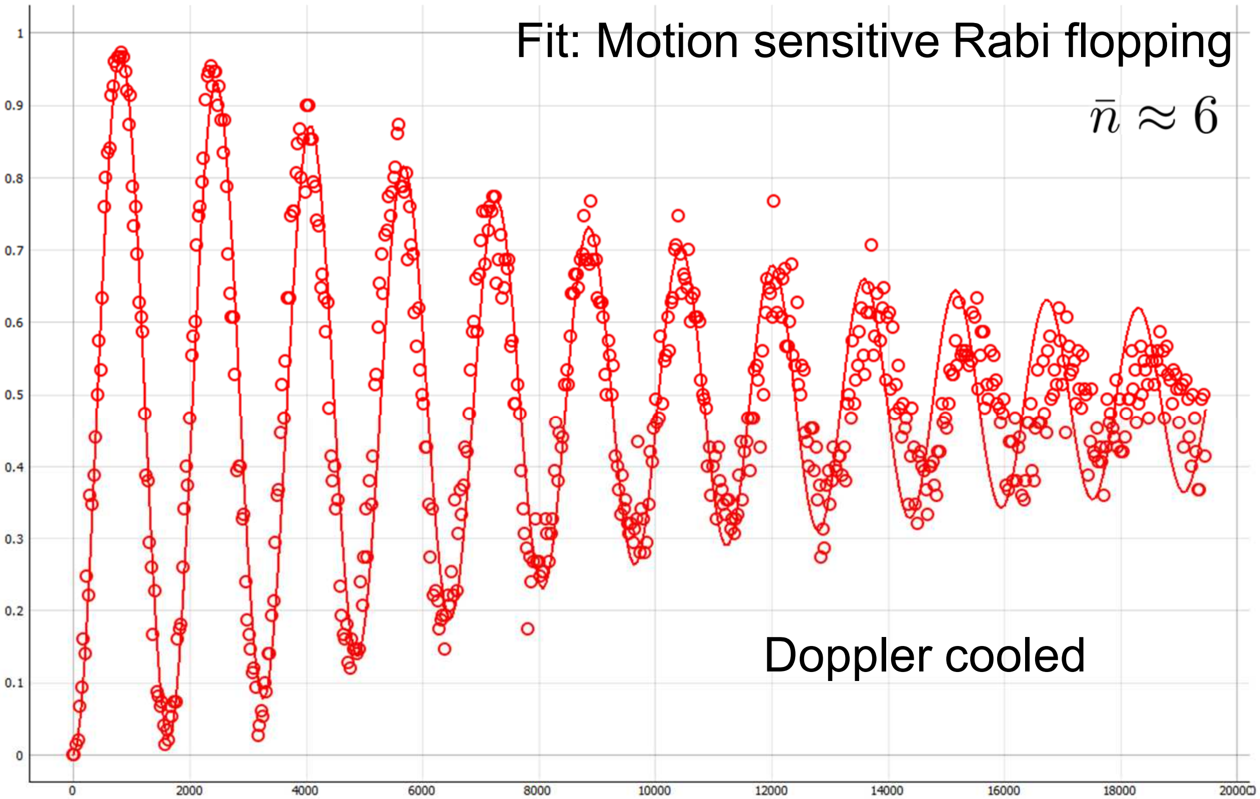
Measurement of the micro-motion sideband of the Raman carrier transition as a function of the adjustment field in transversal direction

To be inserted here is on plot with adjustment voltage on x-axis, height of micromotion sideband of Raman carrier transition on the y-axis. The data was taken today and shows a quadratic minimum

Allows straightforward compensation in the direction of the Raman beams

Heating in HOA-2 (Yb^+)

Carrier Rabi Oscillations. There are not changing the motional state. However, the decay of the contrast is governed by the ion temperature.

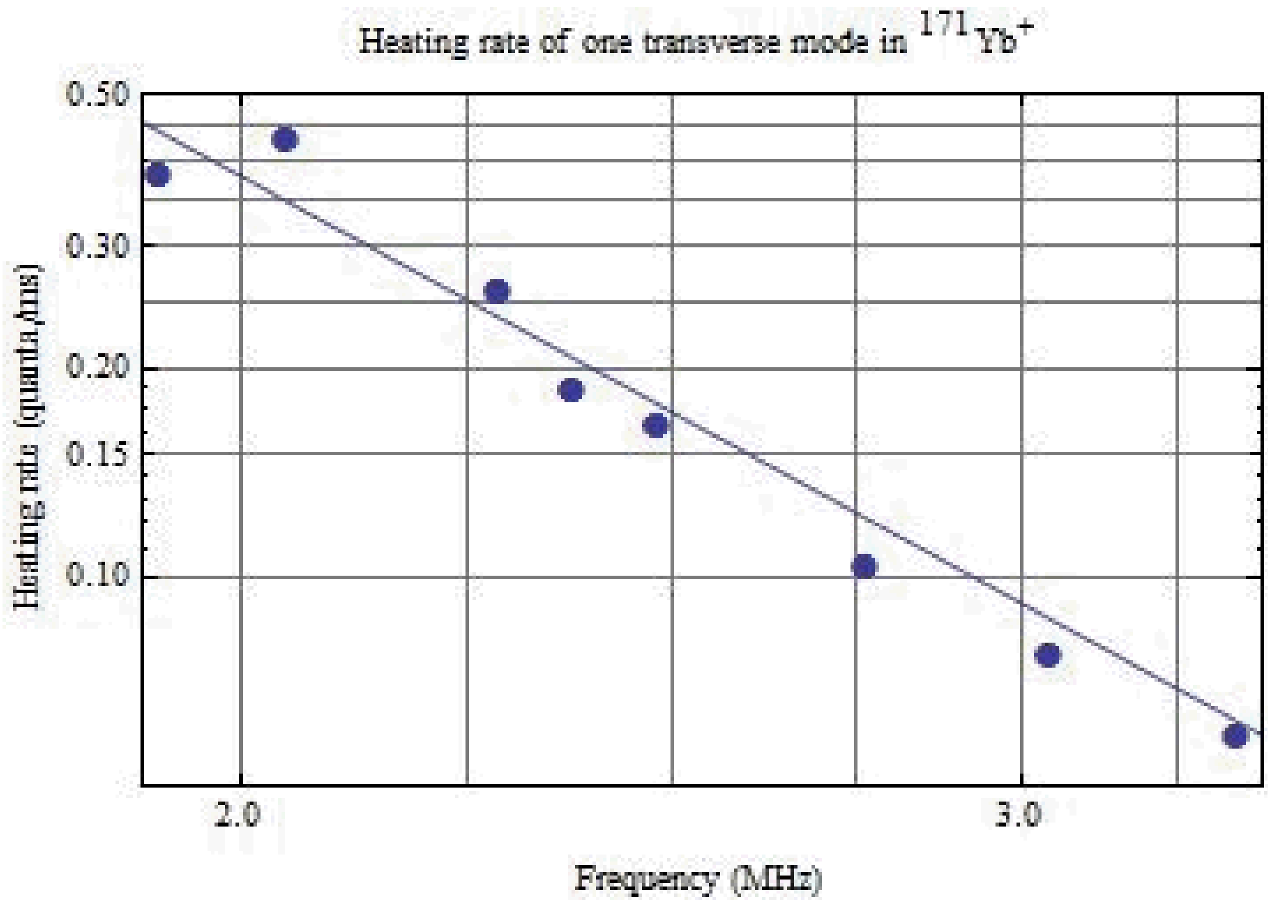


Rabi Init Time (us)

20ms

We are hopeful to find low heating rates

Heating in HOA-2 (Yb^+)



$c \times f^{\alpha}$

$c = 4.4$

$\alpha = -3.5$

Frequency dependence point to problems with technical noise

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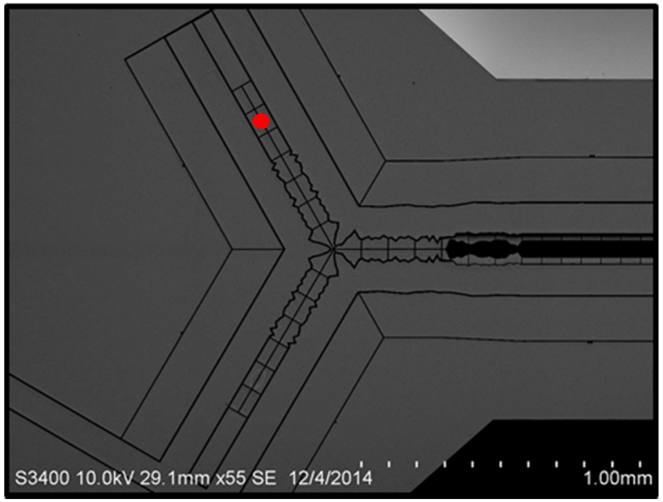
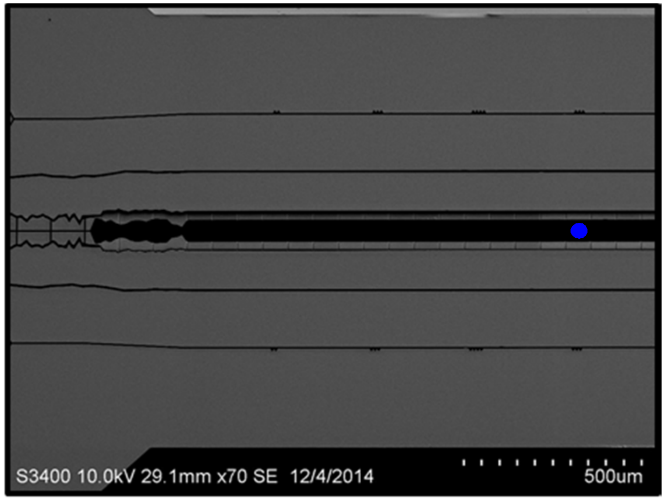
Heating in HOA-2 (Ca^+)

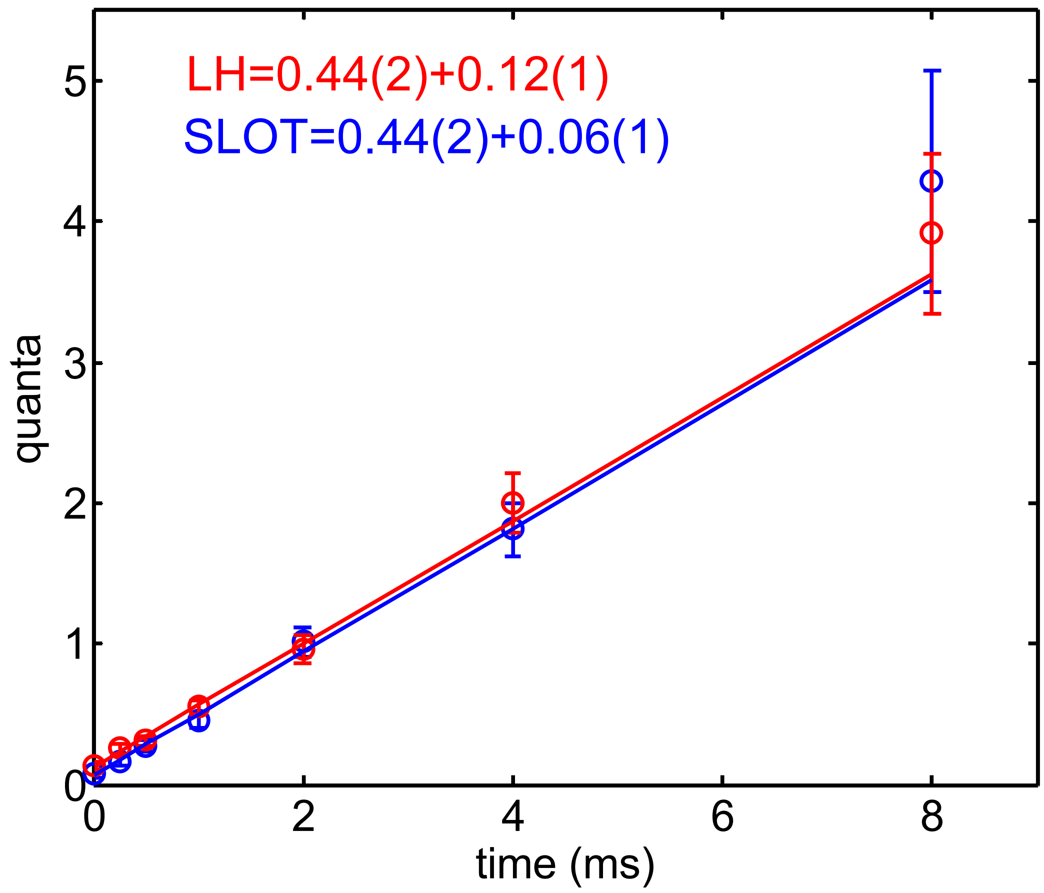
Loading hole



Slotted region

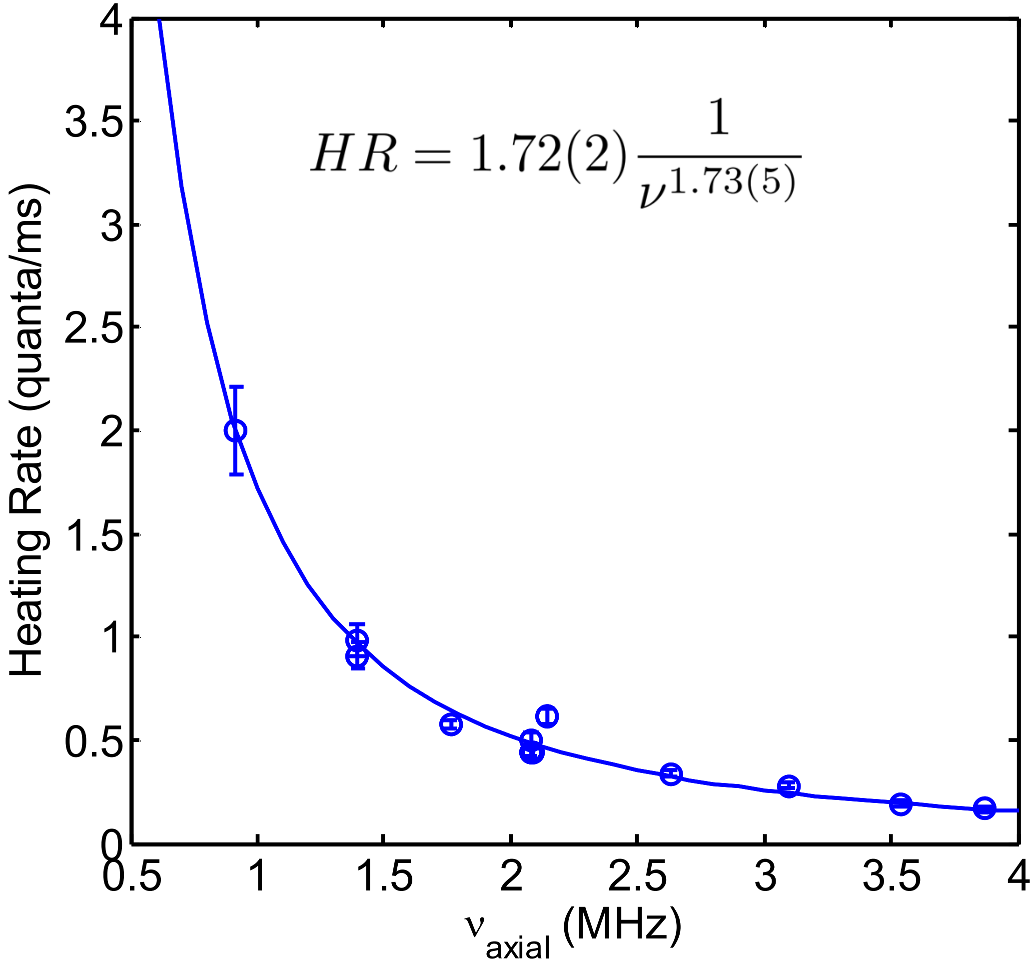


$$\nu_{axial} = 2.1\ \mathrm{MHz}$$



Heating in HOA-2 (Ca^+)

Heating rate vs Frequency



Future HOA-2 testing

Harmonic potential

+ - - - +

+ - - - +

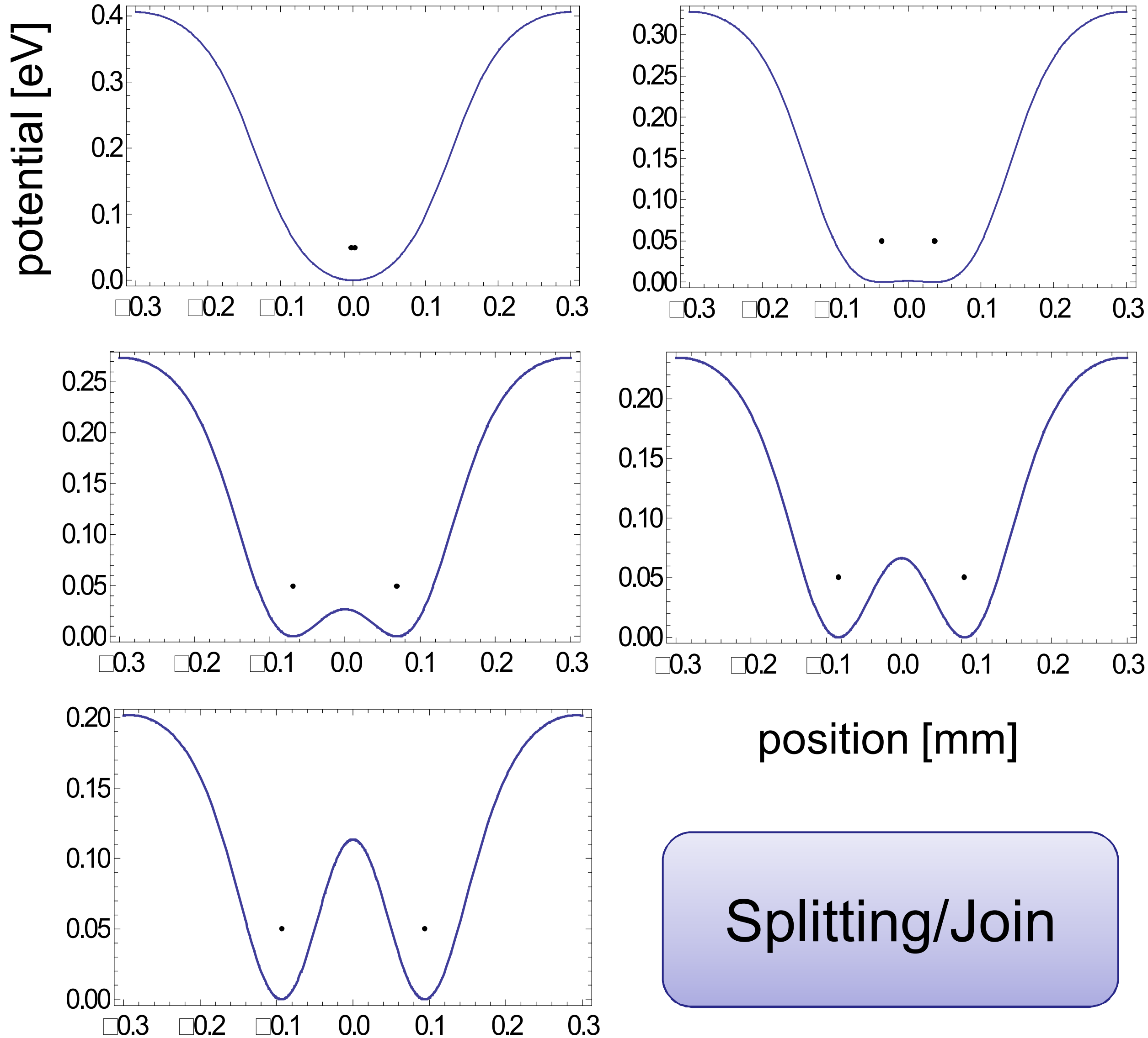
+ - 0 - +

+ - 0 - +

W potential

+   +   +

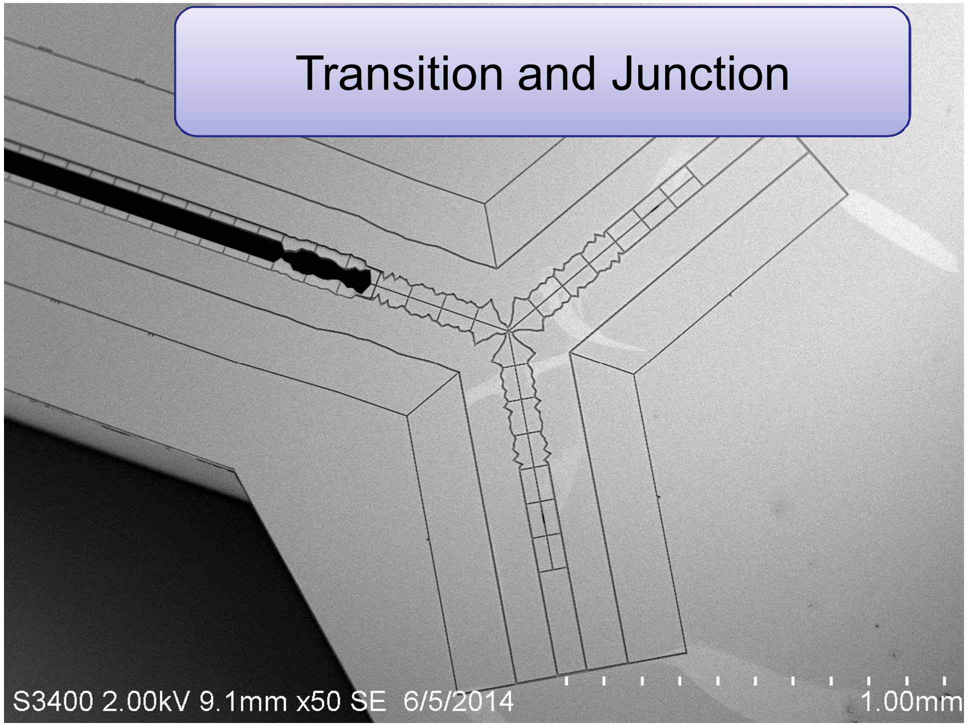
+   +   +

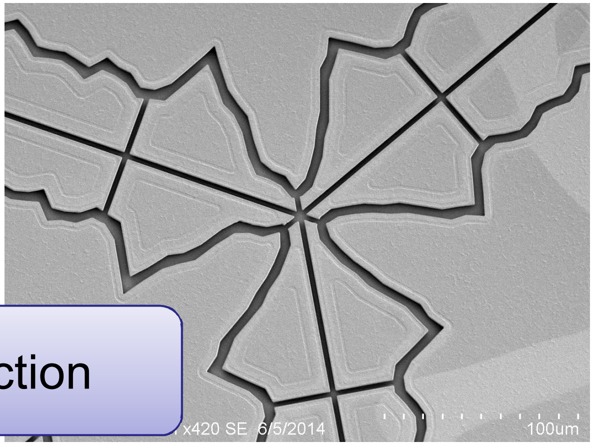


Splitting/Join

Future HOA-2 testing

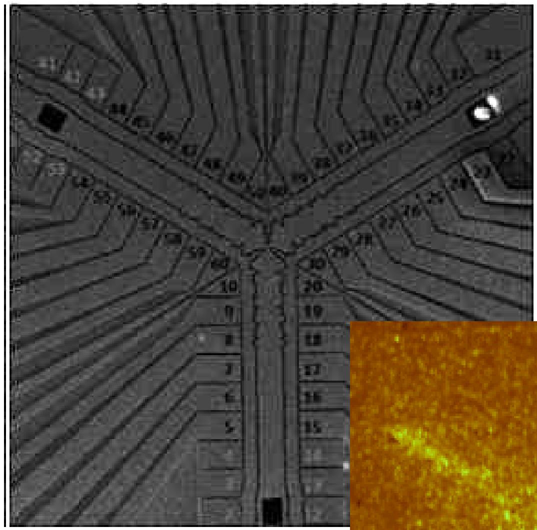
Transition and Junction

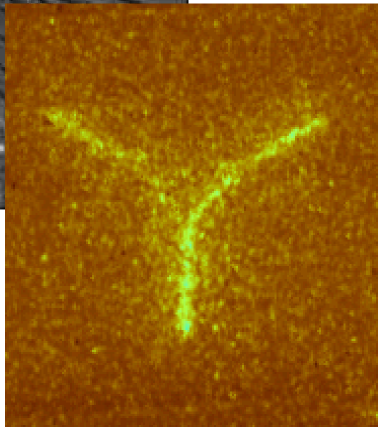




Junction

Previous successful with other junctions





Shuttling

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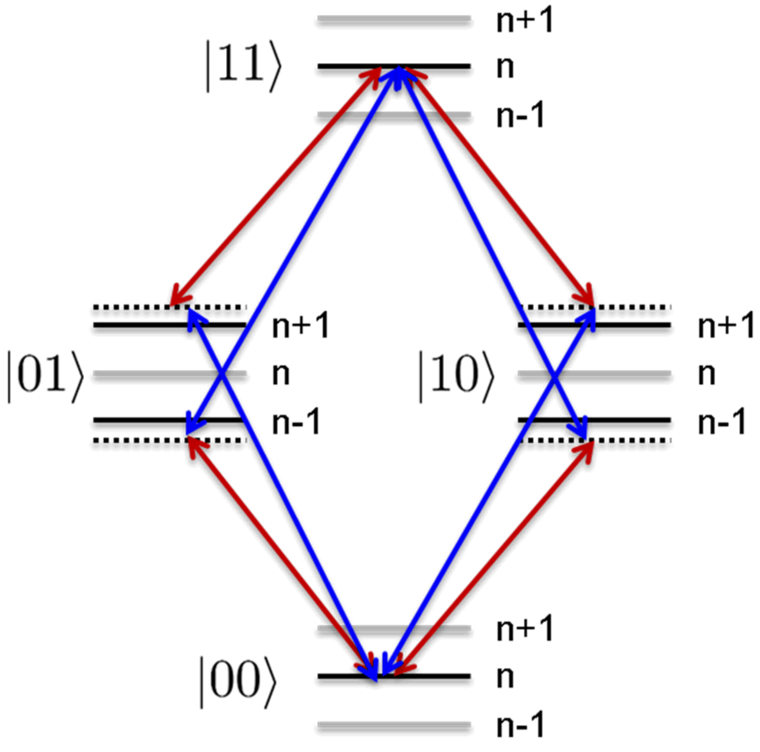
Future HOA-2 testing

MS Gate



$$|00\rangle \rightarrow |00\rangle + |11\rangle$$

- Implement MS Gate using Yb^+.
  - Improve fidelity over thunderbird trap (F=95%)

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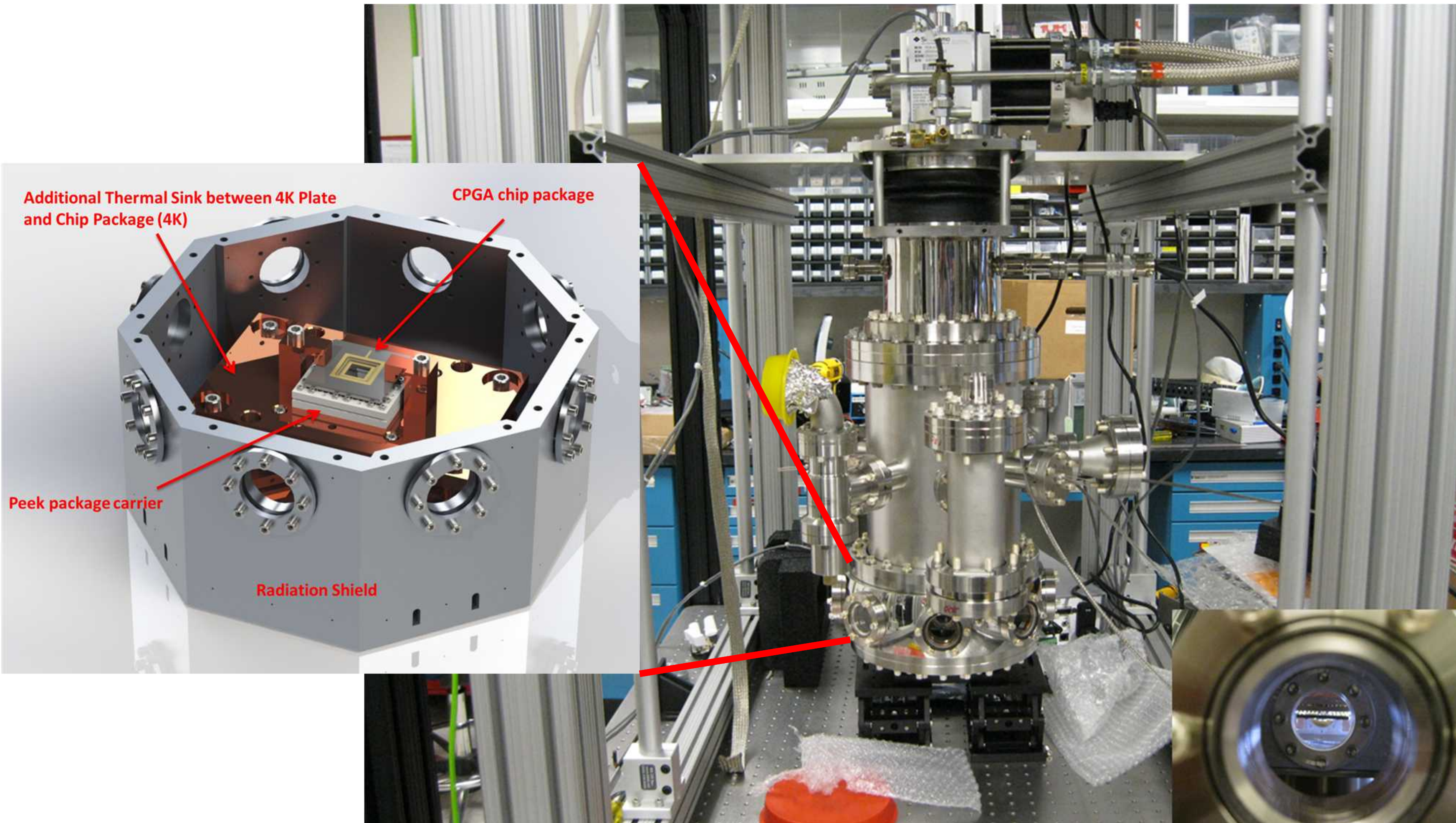
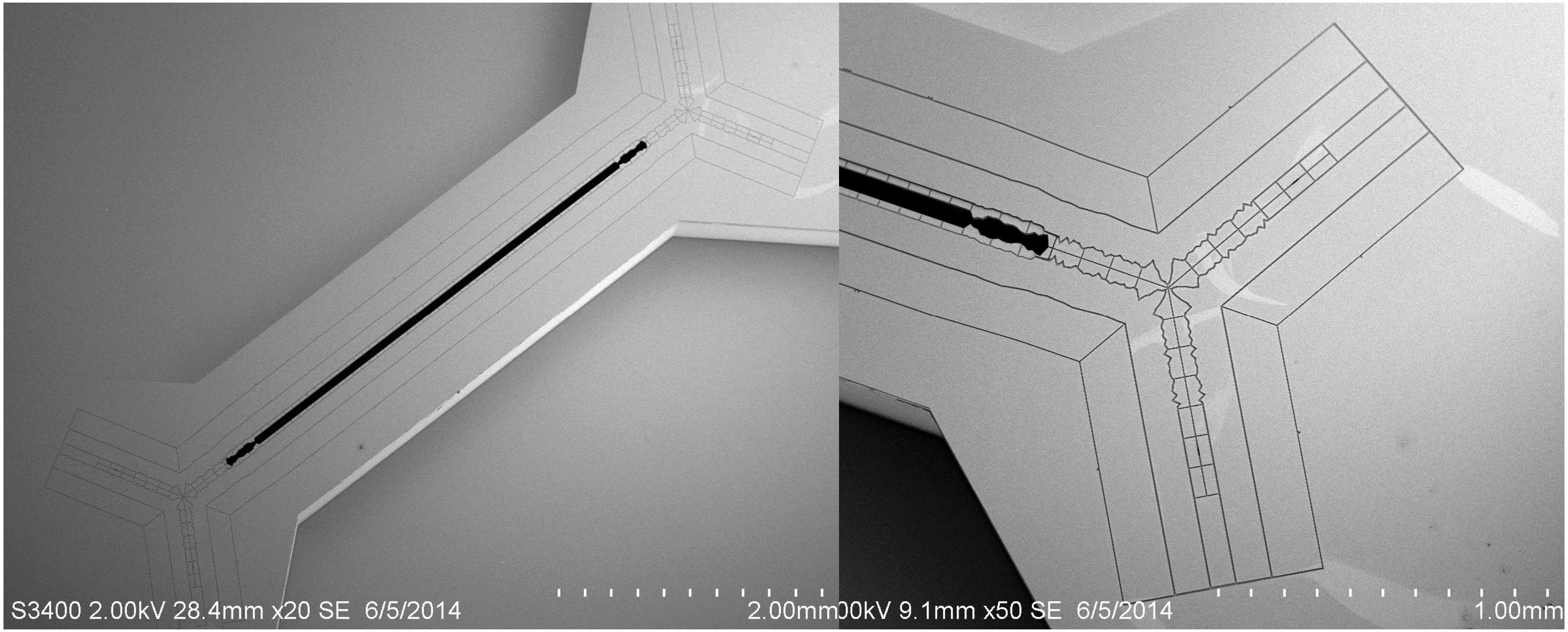
Future HOA-2 testing

Cryo Compatibility



HOA-2



This might be the right trap for your application

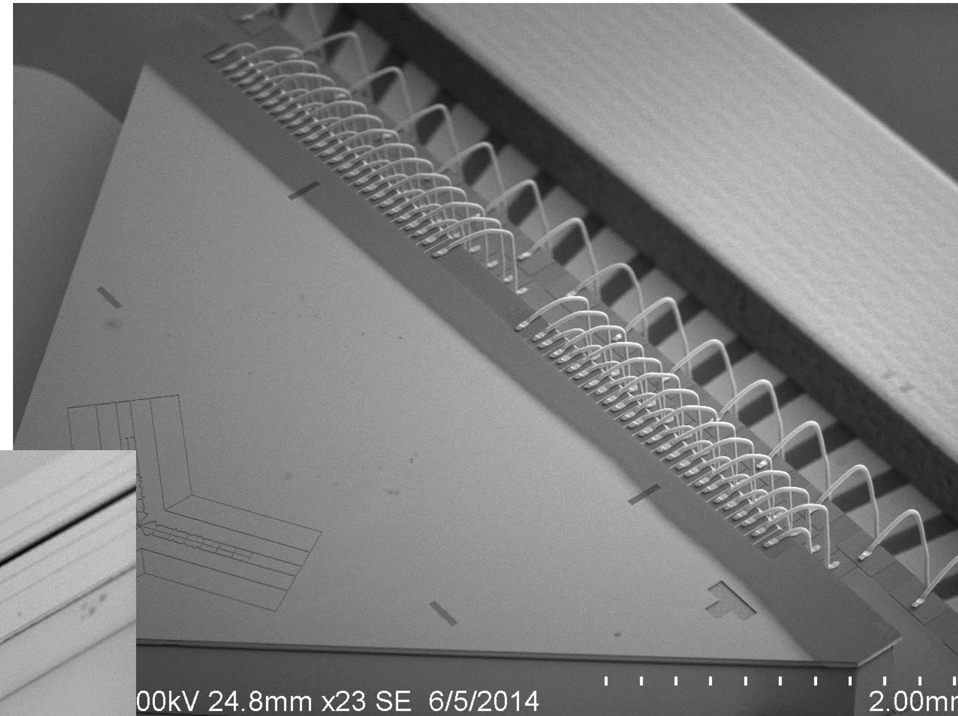
Thanks

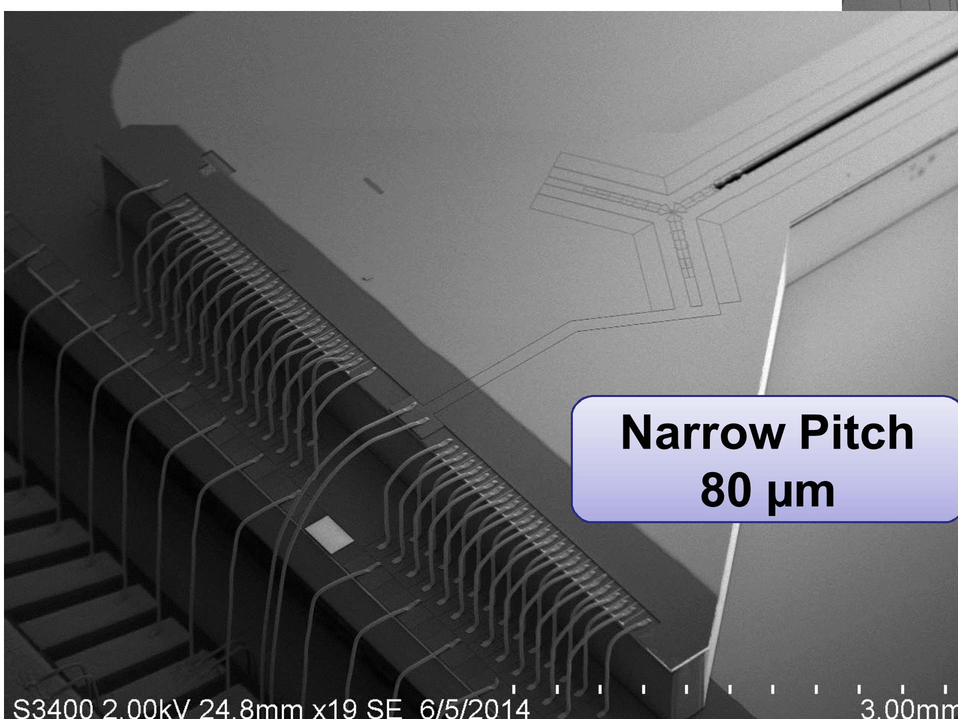
Job openings for postdocs:
http://Sandia.jobs opening 648055

plmaunz@sandia.gov
dlstick@sandia.gov

Wirebonds

All wirebonds are located at the wide ends of the bow tie





Narrow Pitch 80 µm

Wirebonds have low protrusion