Microfabricated Microwave-Integrated Surface Ion Trap

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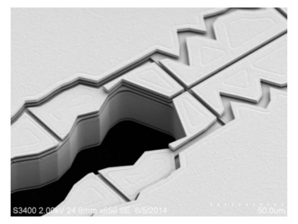
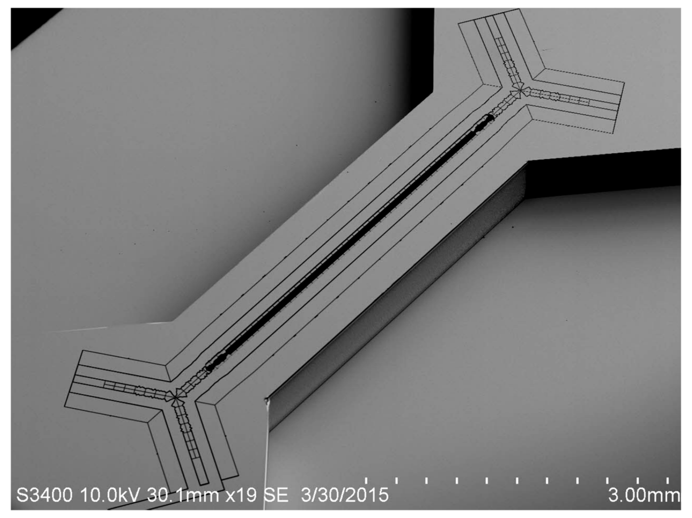
Why Microwaves?

- Trapped ions are a promising platform for the implementation of quantum information processes
- Microwave qubit transitions are long lived
- Microwave radiation is easier to control and cheaper to implement than lasers
- Antennae can be integrated into the trap which increases available optical access
- Reducing lasers decreases spontaneous emission

High Optical Access Trap (HOA-2)

Excellent optical access rivaling 3D traps
- NA 0.11 across surface
- NA 0.25 through slot





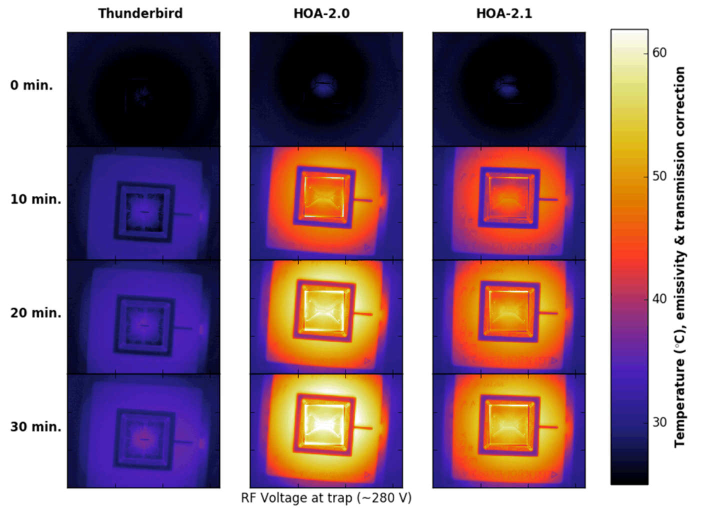
Very good trap performance
- Lifetime over 100 h in Yb while taking data
- Lifetime > 5 m without cooling

Low heating rates approx. 100 quanta/s (using Yb, 2.5 MHz trap freq)
Able to trap long chains, more than 10 ions
Trap frequencies up to 5 MHz achievable

Comparison with Previous Designs

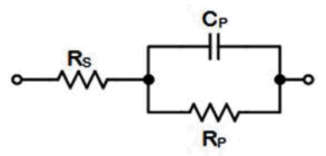
Thermal Imaging

Heating induced by on trap RF



Temperature data corrected for emissivity

Electrical Characteristics



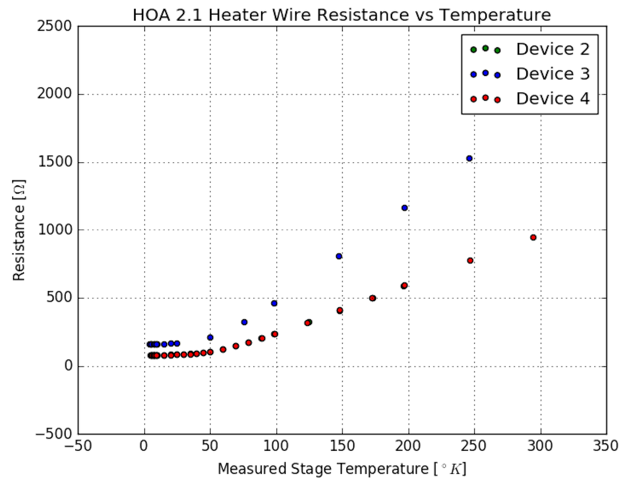
$$P_s \approx \frac{1}{2} R_s U^2 \omega^2 C_p^2$$
$$P_p = \frac{1}{2} \frac{\omega U^2}{R_p}$$

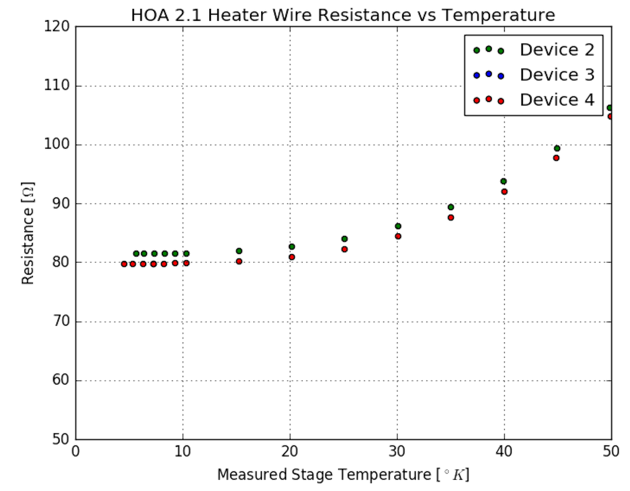
For 100 V amplitude at 100 MHz:

Trap	Temp	C_p	R_s	R_p	P_s	P_p
HOA-2	300 K	7.6 pF	1.2 Ω	1.2 MΩ	140 mW	4.2 mW
	77 K		0.7 Ω		80 mW	
	4 K		0.5 Ω		60 mW	
HOA-2.1	300 K	7.6 pF	0.9 Ω	1.6 MΩ	100 mW	3.1 mW
	77 K		0.7 Ω		80 mW	
	4 K		0.5 Ω		60 mW	
Au/FS	300 K	1.93 pF	2.0 Ω	1.4 MΩ	15 mW	3.7 mW
	77 K		1.3 Ω		10 mW	
	4 K		0.8 Ω		5.9 mW	
Thunderbird	300 K	2.4 pF	0.6 Ω	1.5 MΩ	6.7 mW	3.3 mW

RF induced Heating

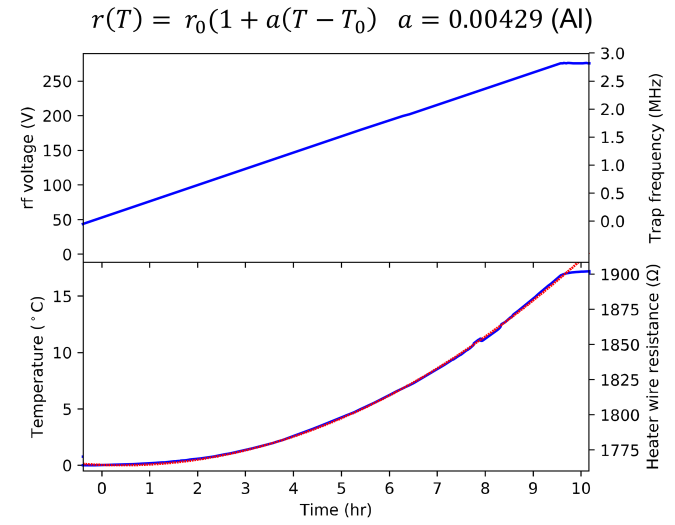
Heater Wire Characteristics





Resistive Wire Thermometry

$r(T) = r_0(1 + a(T - T_0))$ $a = 0.00429$ (Al)



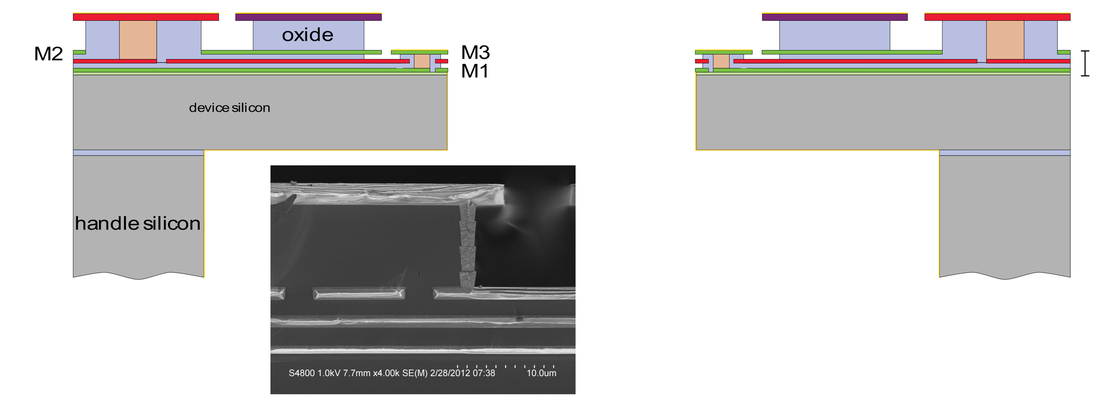
Reduction of RF Heating

- The smaller the trap, the lower the heating $P \propto L^3$
- Improve thermal conductivity
- Multiple RF input feeds

- Changes in design will be implemented in future traps

Trap Fabrication Capabilities at Sandia

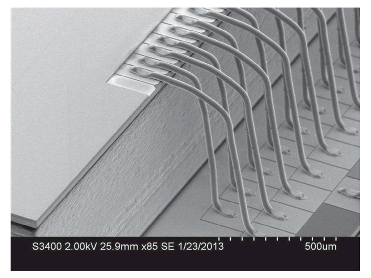
Five level metallization

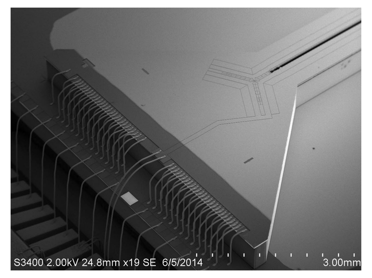


DC electrodes are routed through lower metal layers allowing for:
- simplified routing as wiring can cross in different metal layers
- islanded trap structures, such as circulators and rings
- Trap layouts that are more true to models, since electrode leads don't need to be taken into account
- Trench capacitors are integrated directly into the interposer to reduce RF pickup

Low-profile wire bonds

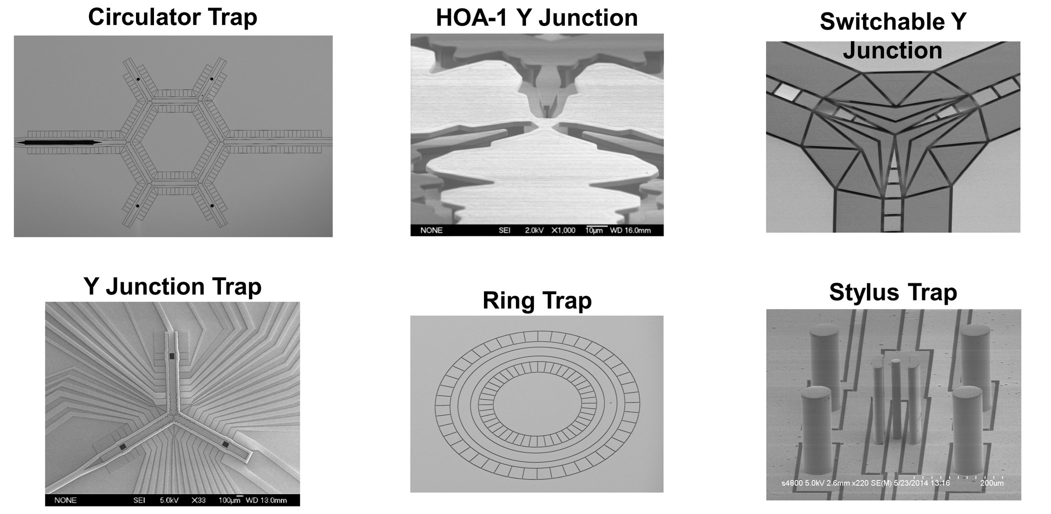
- Maximal optical access
- Minimal light scattering



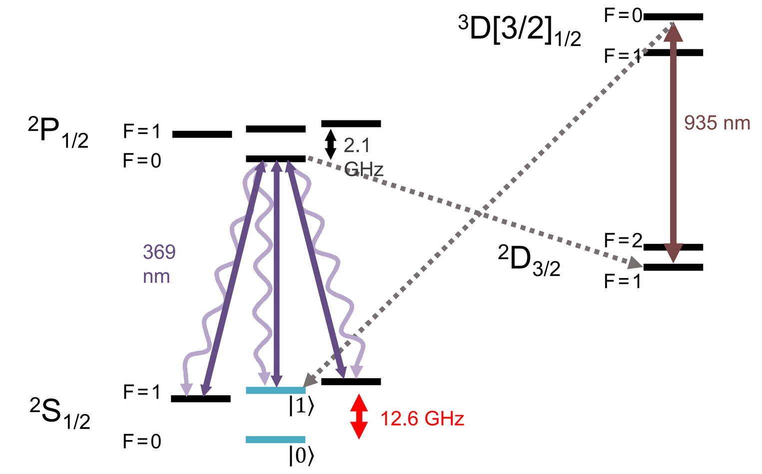


Trap configurations

- Several traps have been conceived and produced at Sandia
- Just about any electrode configuration can be realized and the traps are mechanically very stable



The $^{171}Yb^+$ Qubit



Ion is prepared in state |0⟩

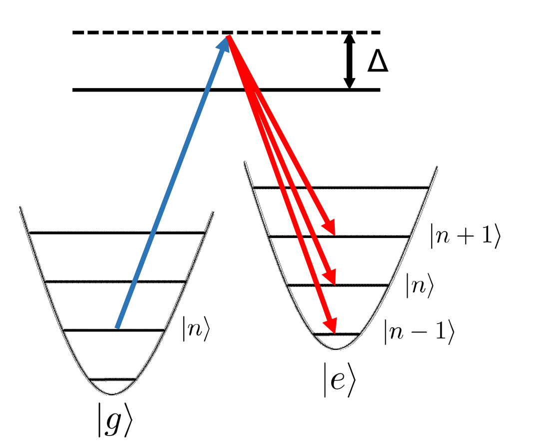
The clock state transition can be driven directly using a microwave pulse

Microwave transition insensitive to small fluctuations in $\vec{B}$

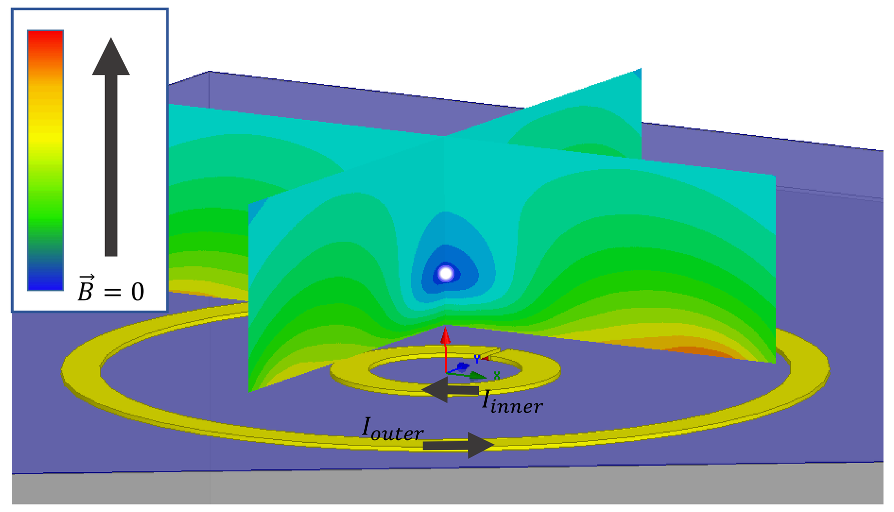
Multi-ion qubit gates require coupling the qubit state to the ion motional modes

Typically accomplished with Raman laser beams using a Mølmer-Sørenson (MS) gate

A strong spatial gradient field accomplishes this using a variation of the MS gate



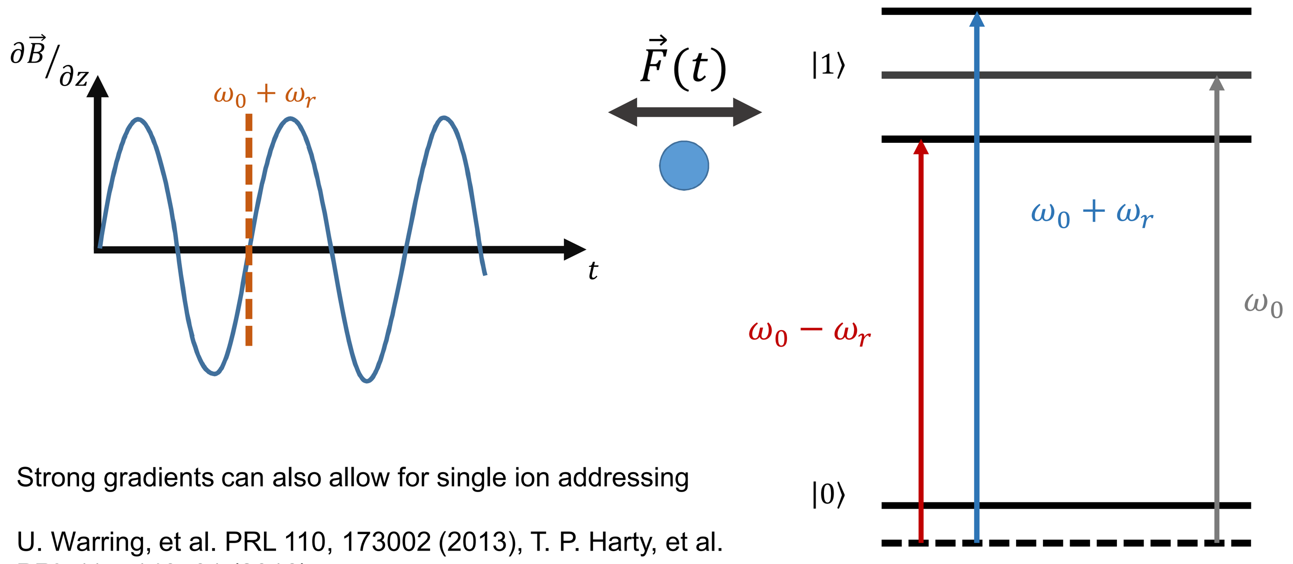
Microwave Gate



Create a strong magnetic field gradient to couple the ion qubit and motion

Concentric current loops have the ability to create a field null at the ion location

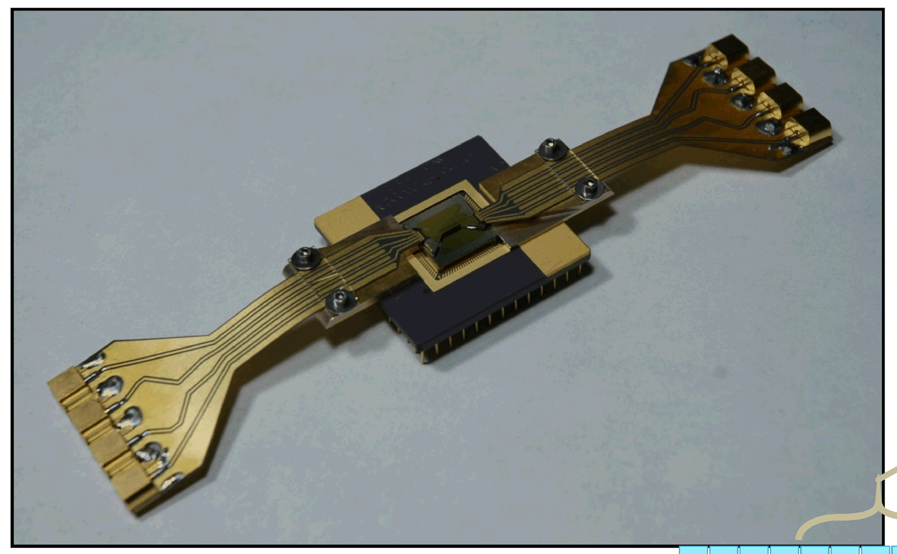
The oscillating field causes motion in the ion at the radial mode frequencies



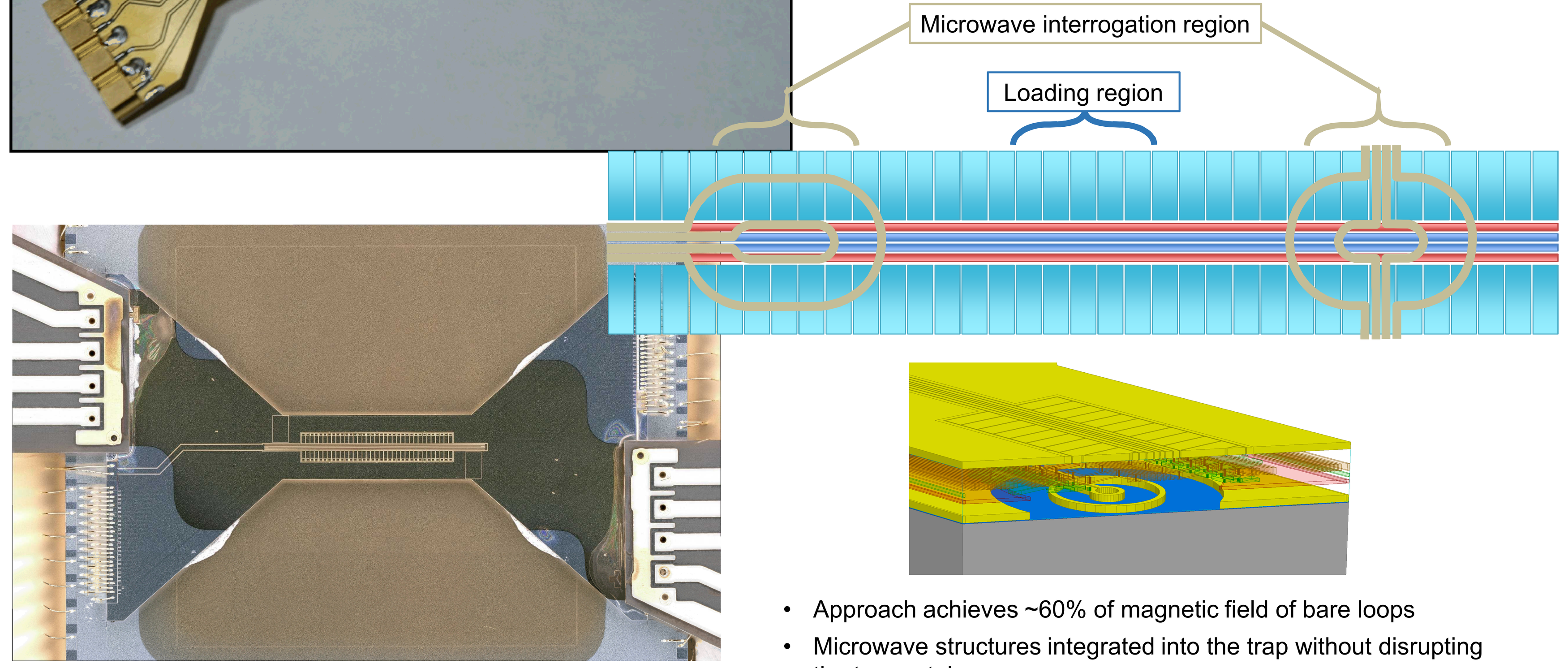
Strong gradients can also allow for single ion addressing

U. Warring, et al. PRL 110, 173002 (2013), T. P. Harty, et al. PRL 117, 140501 (2016).

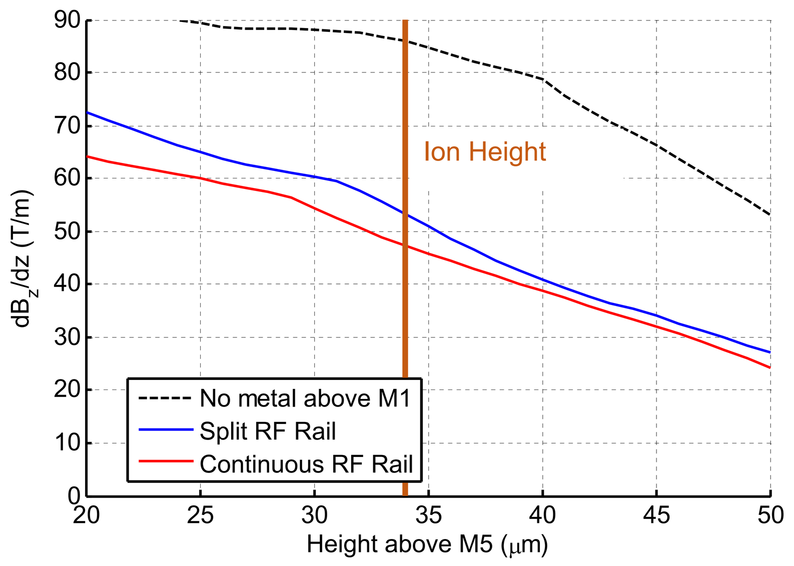
Microwave-Integrated Surface Trap

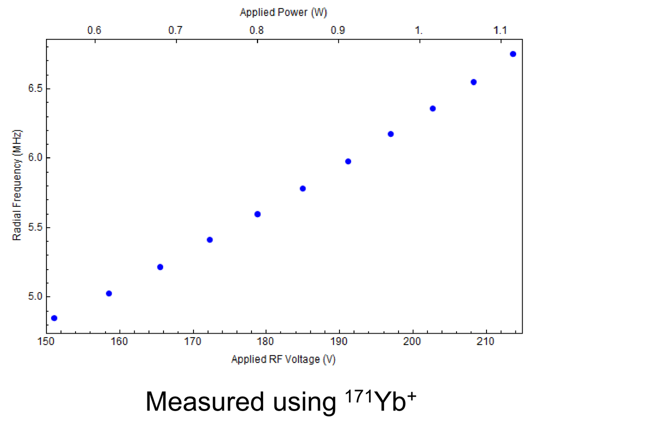


- Multi-layered device permits co-location of the microwave antennas, RF and control electrodes
- Creates localized microwave and gradient fields
- Ion height = 34 μm – leading to large radial trapping frequencies



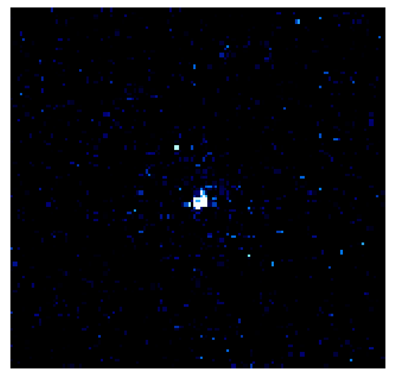
- Approach achieves ~60% of magnetic field of bare loops
- Microwave structures integrated into the trap without disrupting the top metal
- Magnetic fields couple through slots in the metal structures, without line of sight
- Microwave traces are placed next to the substrate for heat dissipation



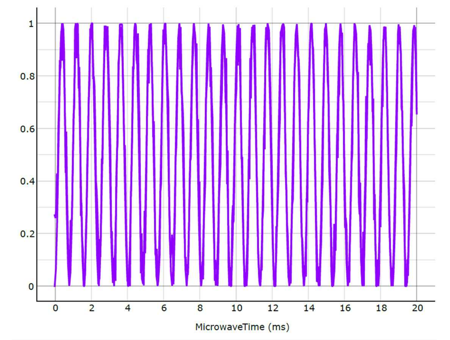


Measured using $^{171}Yb^+$

Preliminary Status



- Building a new experimental apparatus
- Successfully trapped $^{171}Yb^+$
- Typical lifetimes ≈ 2 hr
- Measured Rabi oscillations using an external microwave source



This work was supported by the Intelligence Advanced Research Projects Activity (IARPA) and Sandia's Laboratory Directed Research and Development (LDRD) Program. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.