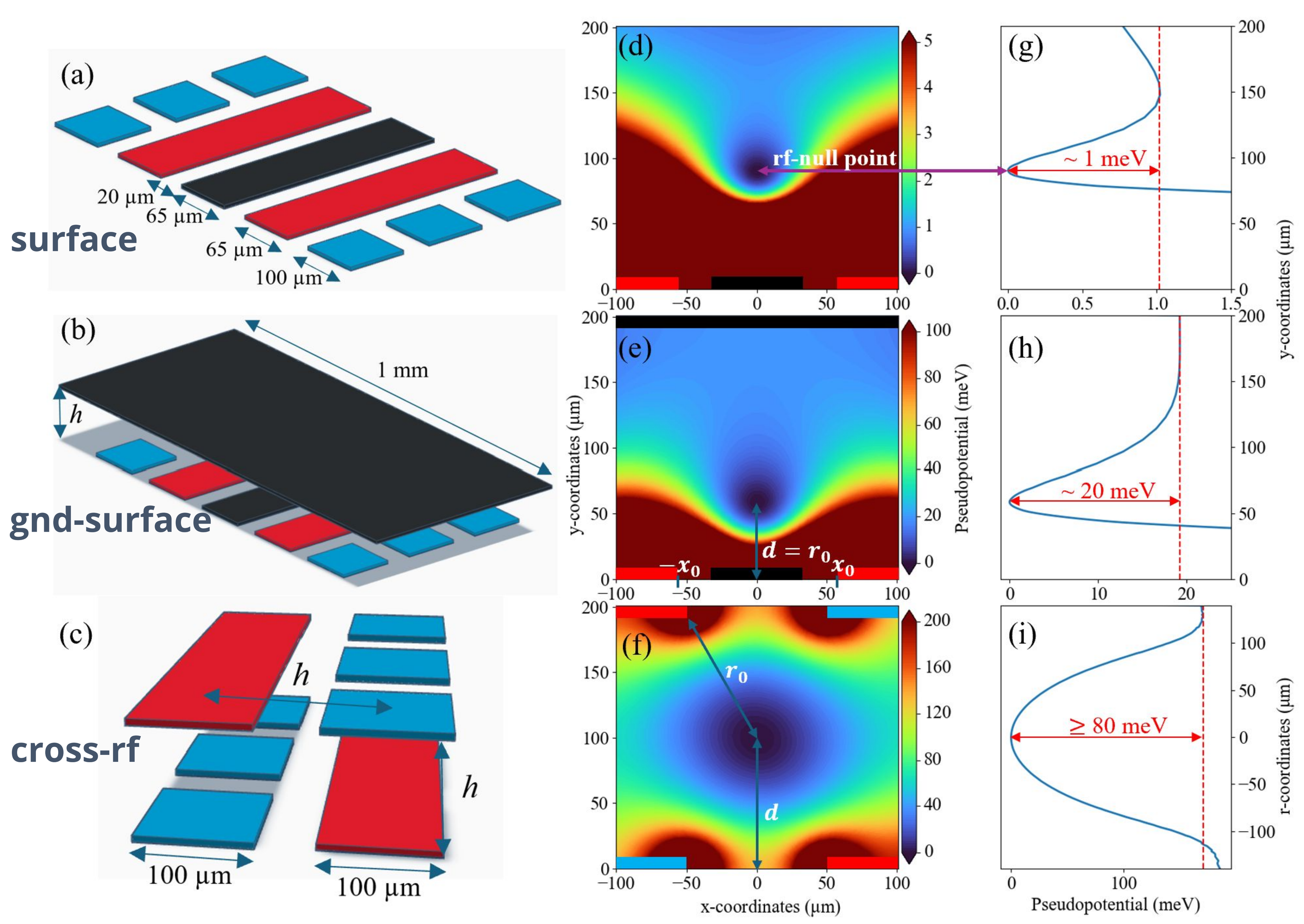
A FRAMEWORK FOR ANALYZING THE SCALABILITY OF ION TRAP GEOMETRIES[1]

LE MINH ANH NGUYEN, BRANT BOWERS, SARA MOURADIAN

Introduction

- Scalability in trap-ion quantum computing platform relates to 3 main issues:
1. Gating errors due to coupling between motional modes, electric field noise and ion loss.
2. Gate speed, which can be much faster with increasing trap frequency.
3. Power consumption when operating with millions of qubit.
- These issues can be addressed with improved trap geometries.
- A proposed framework focus on investigating figures of merit (FoM) that are dependent on trap geometries and can be used to optimize the system's performance.
- The framework is applied for 3 trap geometries:

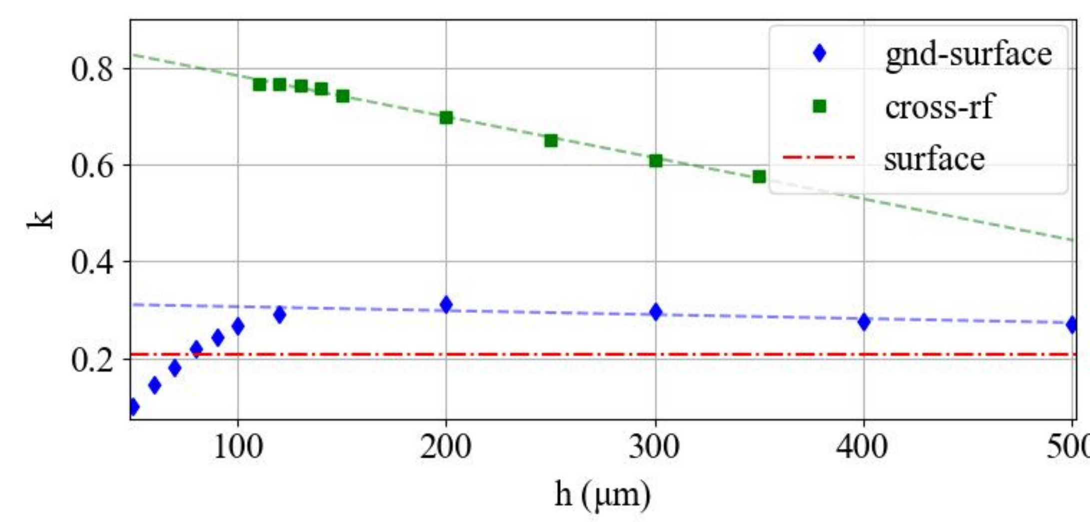


The trapping field

- Radial quadrupole field: $\Phi_{rf}(x,y,t) = \frac{V_{rf}}{2R^2}(k_x x^2 + k_y y^2)\cos(\Omega_{rf}t + \phi)$
- Pseudopotential approximation: $\psi(\mathbf{r}) = \frac{e}{4m\Omega_{rf}^2}|\nabla\Phi_{rf}(\mathbf{r})|^2 = \frac{e}{4m\Omega_{rf}^2}|E(\mathbf{r})|^2$
  - $R \simeq r_0$: the distance from the ion to the nearest electrode surface
- Simulated on COMSOL Multiphysics with $\Omega_{rf}/2\pi$ = 20 MHz and V_{rf} = 10 V for $^{40}Ca^+$.
- Field-dependent FoMs:
  - Harmonicity
  - Trap frequency
  - Trap depth
- Experimental considerations from these FoMs:
  - Heating
  - Power consumption

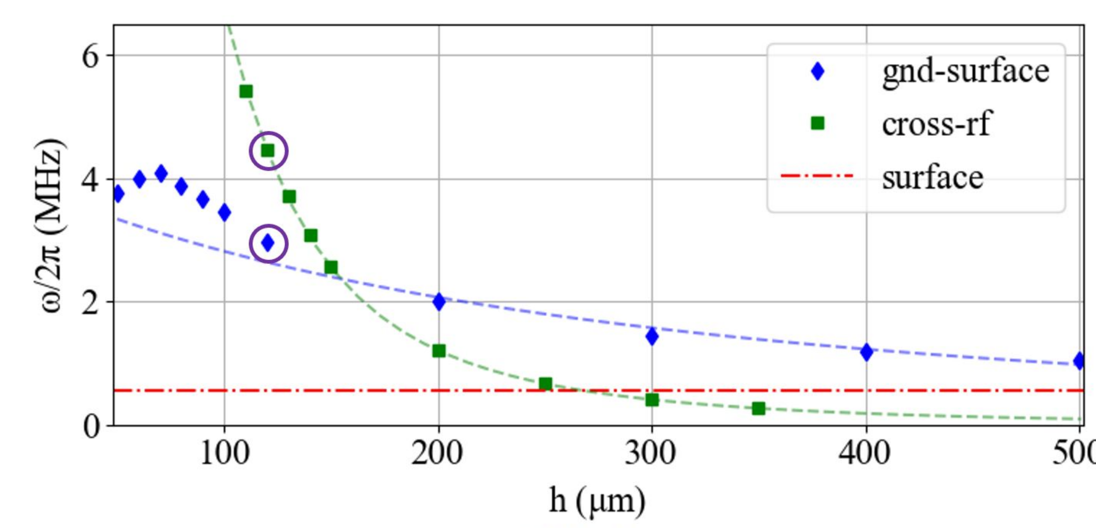
Harmonicity

- Measures how closely the trapping field resembles an ideal harmonic potential (k = 1)

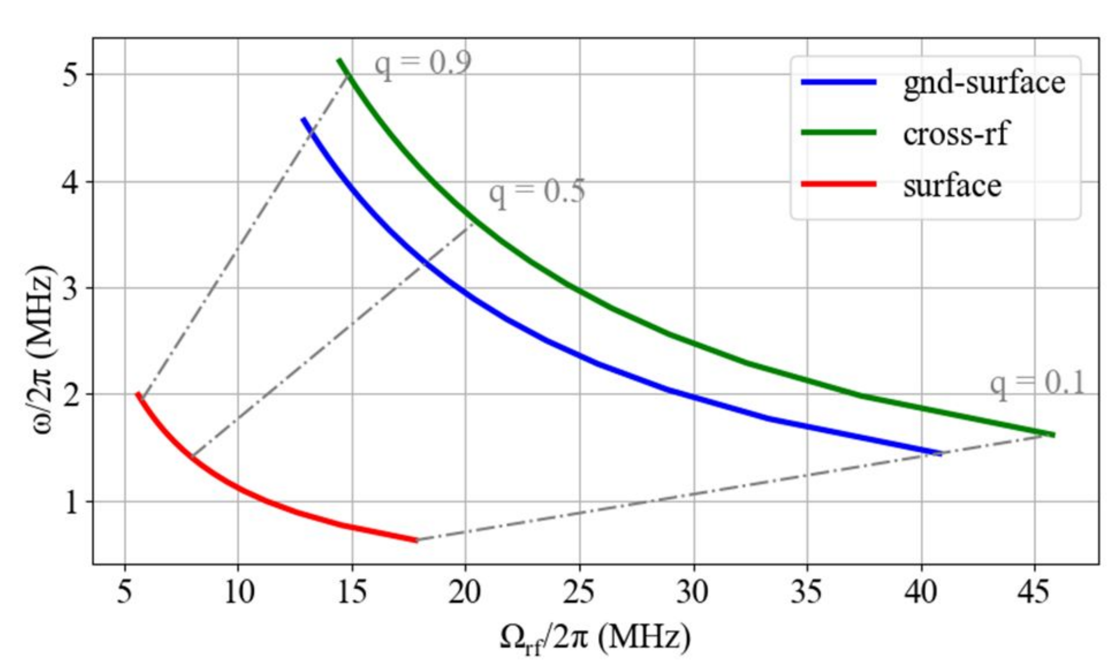


Trap frequency

- Radial trap frequency: $\omega_{rad} = \frac{V_{rf}ke}{\sqrt{2}m\Omega_{rf}r_0^2} = \frac{q\Omega_{rf}}{2\sqrt{2}}$



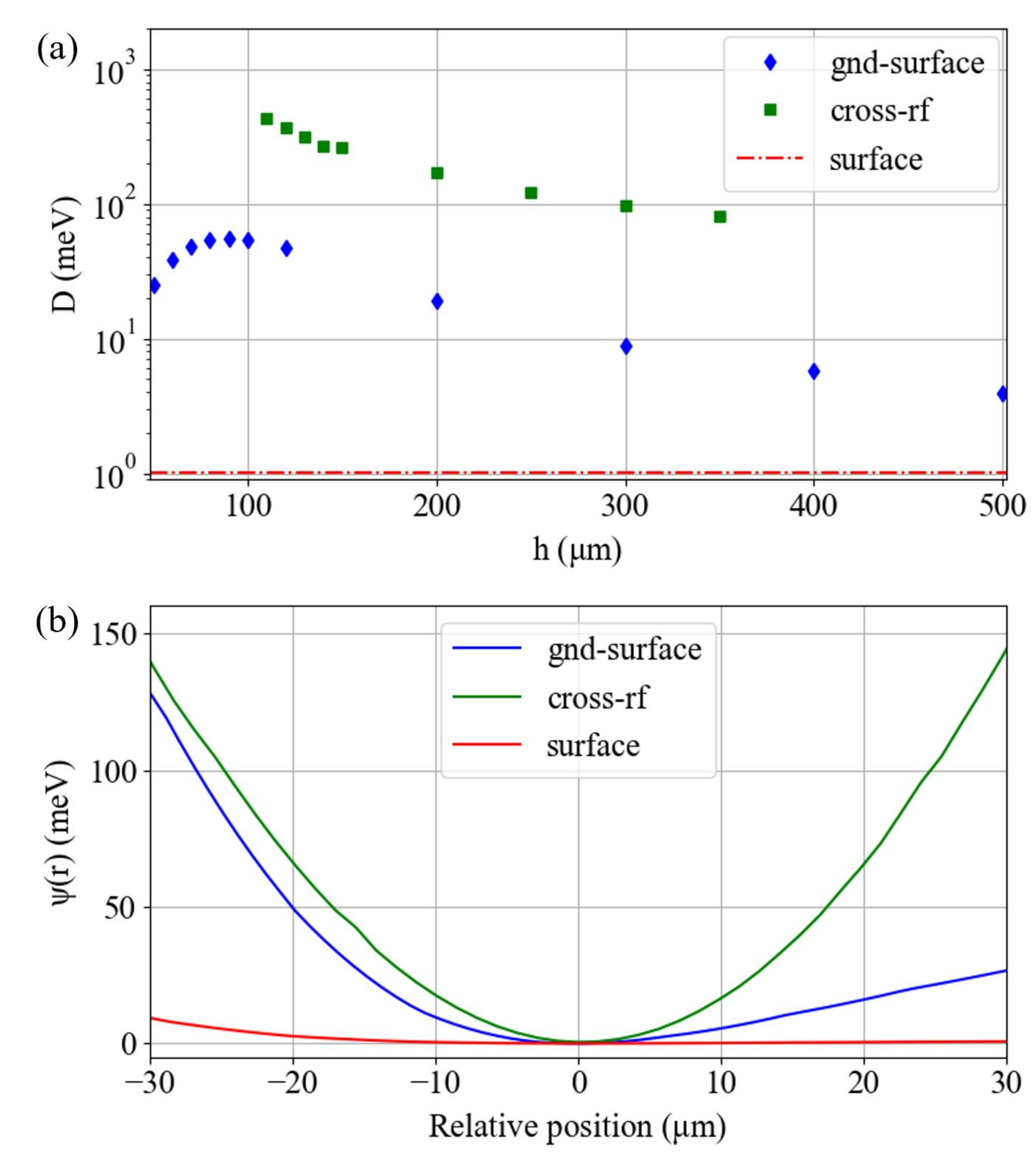
- Instability parameter: $q = \frac{2eV_{rf}k}{m\Omega_{rf}^2 r_0^2}$
- The trap frequency generally must be kept at $\omega \lesssim 0.1\Omega_{rf}$.



Geometry	d (µm)	k	$\omega_{rad}/2\pi$ (MHz)	q	V_{rf} (kV)	$\Omega_{rf}/2\pi$ (MHz)	$\bar{P}$	$\dot{n}$	D (eV)
surface	90	0.207	25	0.25	6.306	282.843	1	1	2.033
gnd-surface	46	0.291	25	0.35	0.854	201.314	~ 10^{-2}	14.65	3.417
cross-rf	60	0.765	25	0.92	0.258	76.629	~ 10^{-4}	4.79	16.555

Trap depth

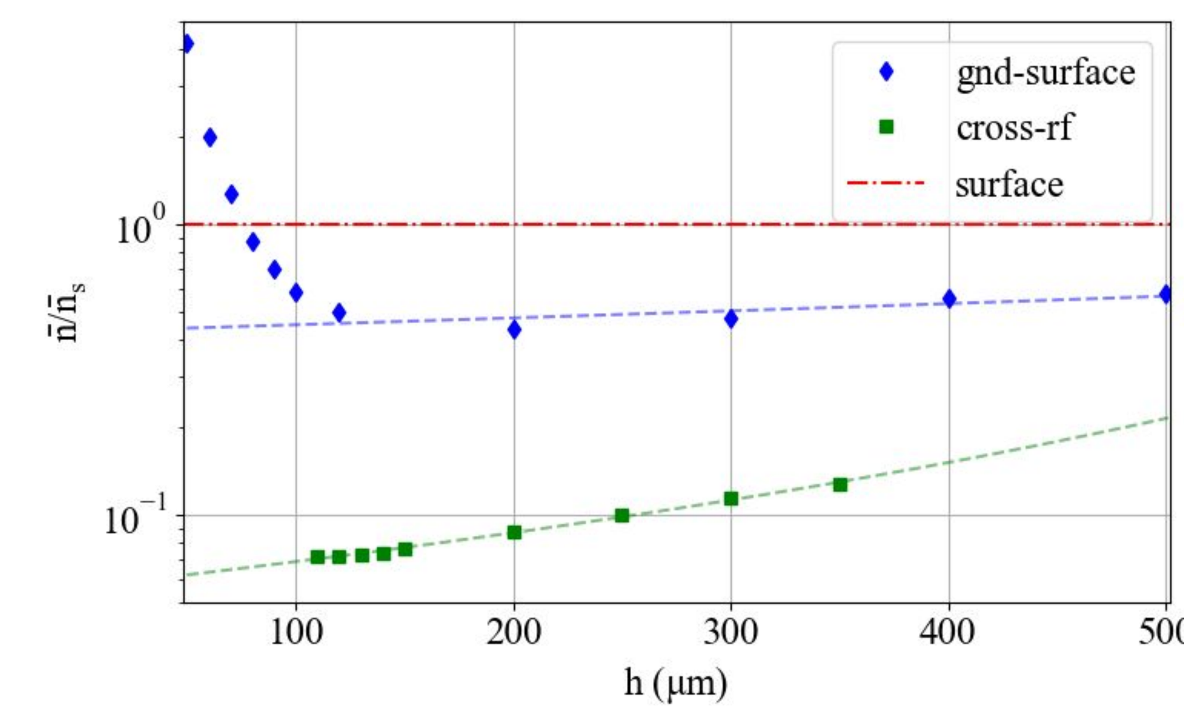
- Measures the maximum kinetic energy an ion can acquire before escaping confinement.



Heating scaling

- The increase of the phonon population from the electric field noise:

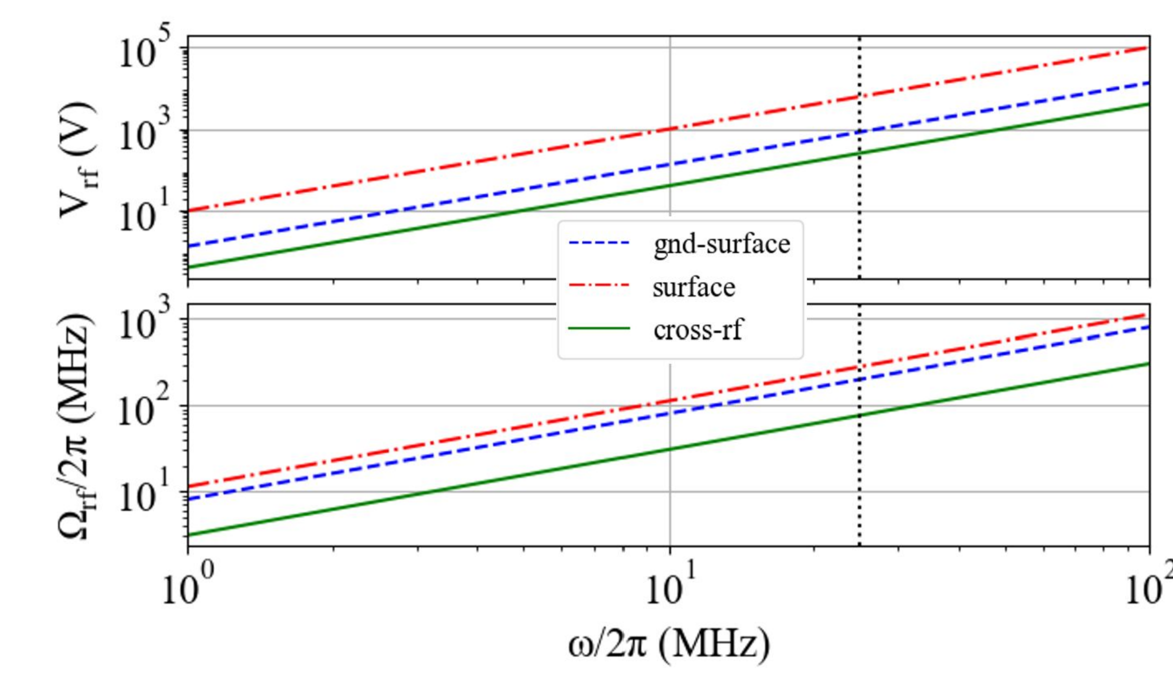
$$\dot{\bar{n}} \propto \omega^{-2} r_0^{-4}$$



Power scaling

- The electric power dissipation due to the rf traces:

$$P \propto V_{rf}^2 \Omega_{rf}^2$$



Fabrication, Conclusion, and References

- Mult-wafer traps can be fabricated using femtosecond laser-etching method [2].
- 3D trap geometries outperform 2D geometry in all field-dependent FoMs.
- gnd-surface trap hits the balance between improved performance and fabricability.

[1] the paper for this poster
[2] Simon Ragg, Chiara Decaroli, Thomas Lutz, Jonathan P. Home. Segmented ion-trap fabrication using high precision stacked wafers. Rev. Sci. Instrum. 1 October 2019; 90 (10): 103203. https://doi.org/10.1063/1.5119785

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY of WASHINGTON

ADVISOR: SARA MOURADIAN

SPONSOR: ELECTRICAL & COMPUTER ENGINEERING DEPARTMENT, UNIVERSITY OF WASHINGTON