# Reduction and Understanding of Surface Noise, Quantum information processing with electrons

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Quantum science and quantum information with trapped ions

Trapped ions for quantum algorithms, teleportation, quantum simulations, non-linear systems, tests of fundamental physics.
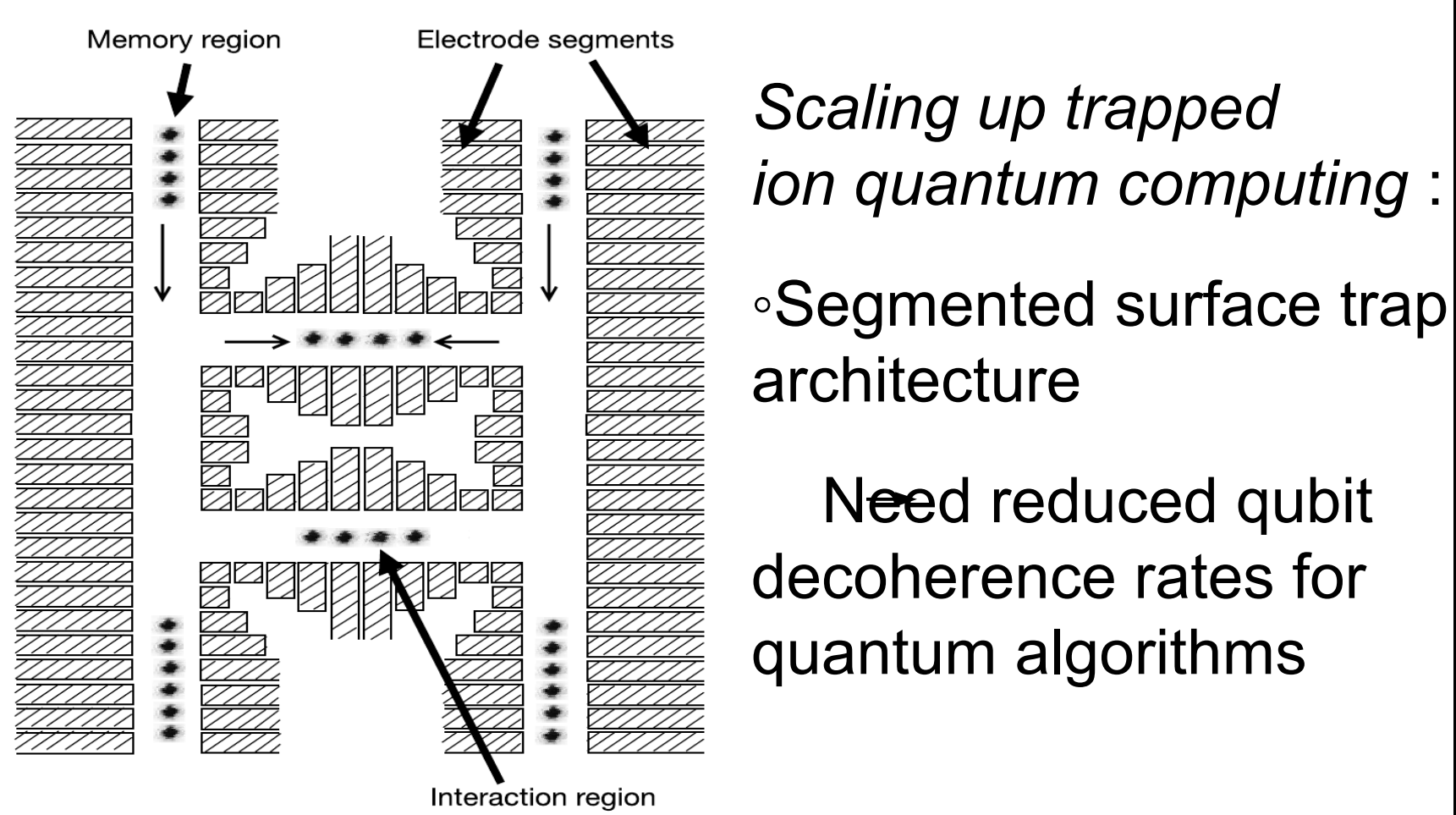

Scaling up trapped ion quantum computing :

∘ Segmented surface trap architecture

Need reduced qubit decoherence rates for quantum algorithms

D. Kielpinski, C. Monroe, and D. J. Wineland, Nature 417 709 2002

Challenges: Surface electric field noise

- Ion trap noise 100-1000 times higher than expected!

- Apparent $1/f^\alpha$ scaling with frequency; α ranges from 0.5 to 1.5

- $1/d^4$ scaling with size ?
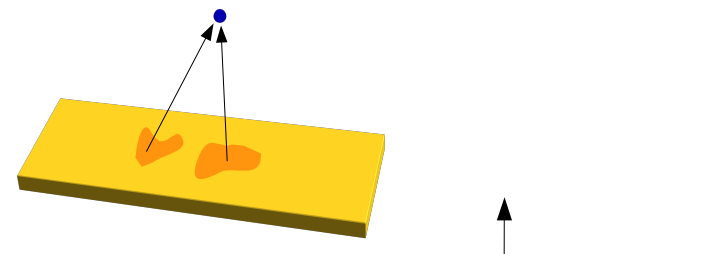
- Material independent, ion species independent ?
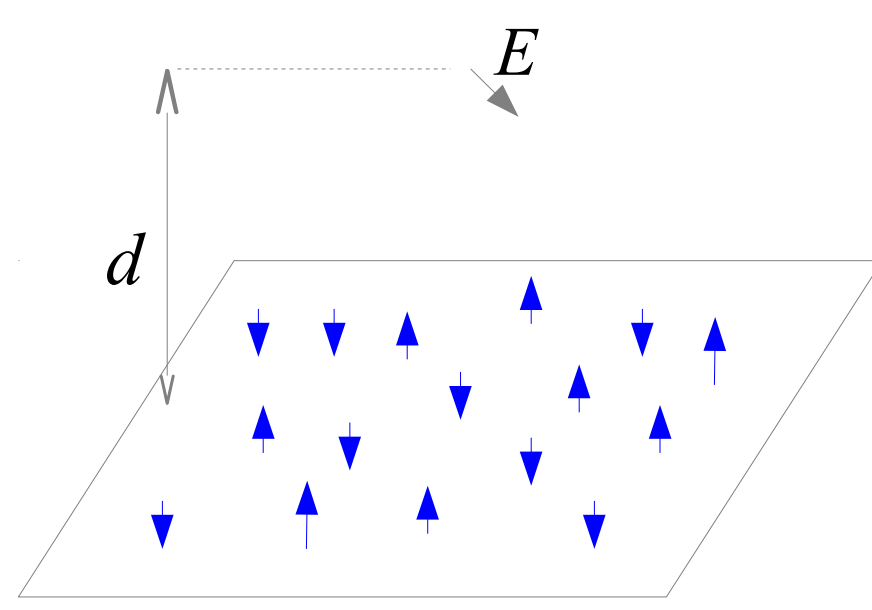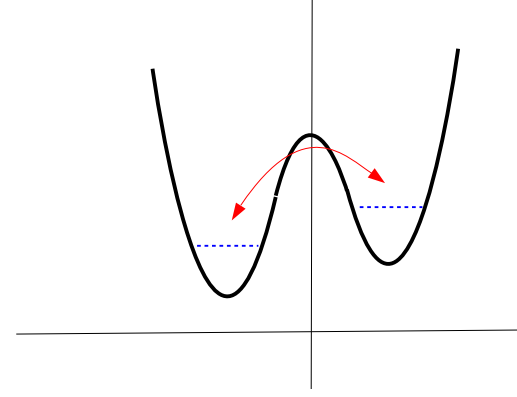

Fluctuating electrical dipoles on surfaces?

N. Daniilidis, S. Narayanan, S. Moller, R. Clark, T.E.Lee, P.J.Leek,A.Wallraff, St.Schulz, F.Schmidt-Kaler, and H.Haeffner, NJP, 13, 013032, 2011.
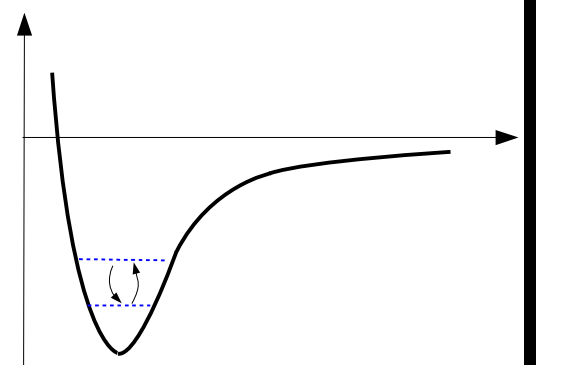
Surface noise models

Patch potentials[1]

Two-level fluctuators[2]

Phonon-induced fluctuations[3]

Surface diffusion[4]

1. G. H. Low, P. F. Herskind, and I. L. Chuang, PRA, **84**, 053425, 2011.
2. W. A. Phillips, Reports on Progress in Physics, **50**, 1657, 1987.
3. A. Safavi-Naini, E. Kim, P. F. Weck, P. Rabl, and H. R. Sadeghpour, PRA, **87**(2), 023421.
4. .J. Wineland, C. Monroe, W.M Itano, D. Leibfried, B.E. King, and D.M. Meekhof, J. Res. Natl. Inst. Stand. Technol.**103**, 259 (1998).

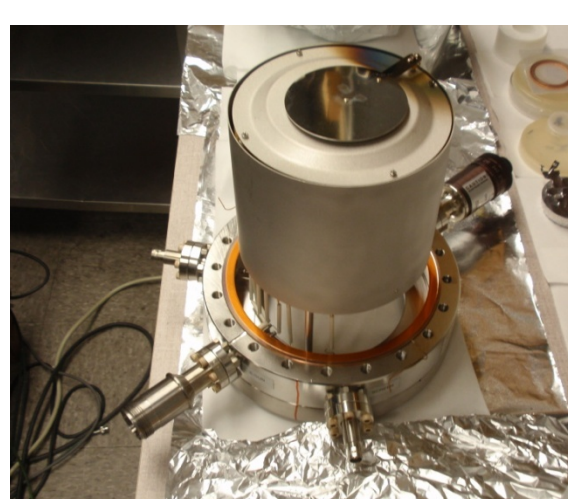## Capabilities : Research Areas
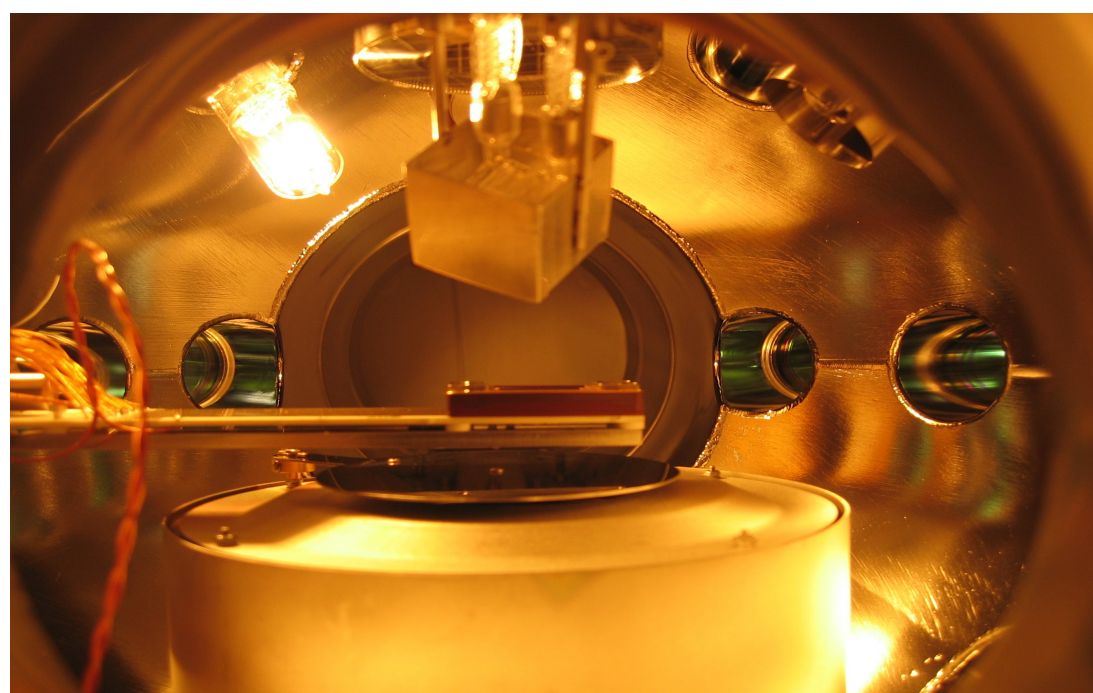
Multi-function vacuum system
- Many-way optical, electrical access
- Integrated surface science tools
- Precise trap/sample positioning
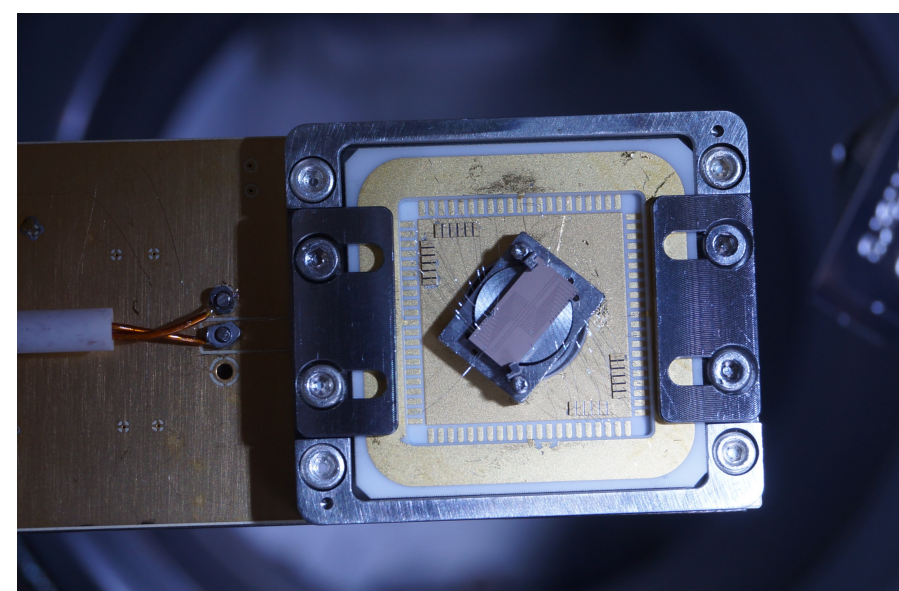
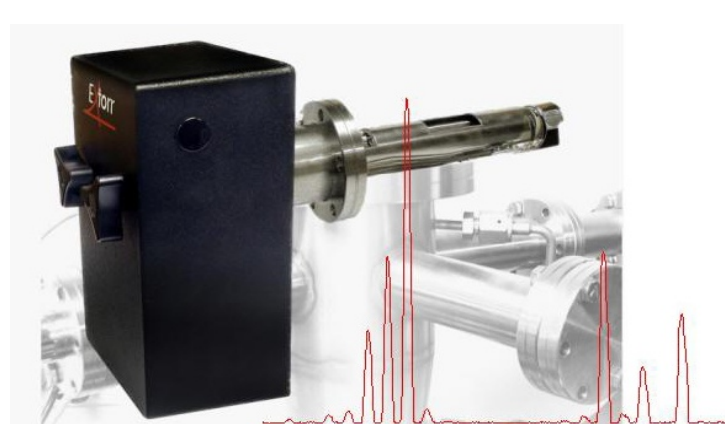Single ion noise sensing $^{40}Ca^+ \, S_{1/2}$-$D_{5/2}$ qubit
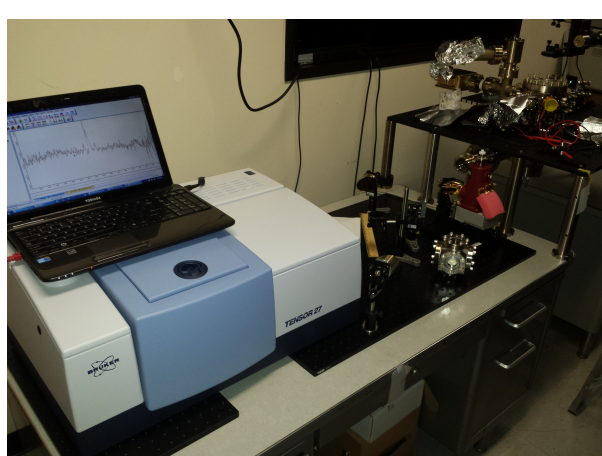

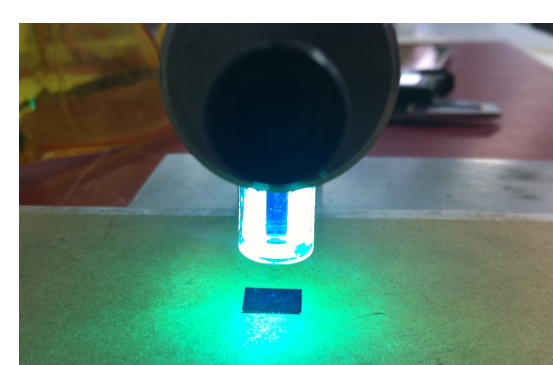Auger-LEED analysis

Ion milling

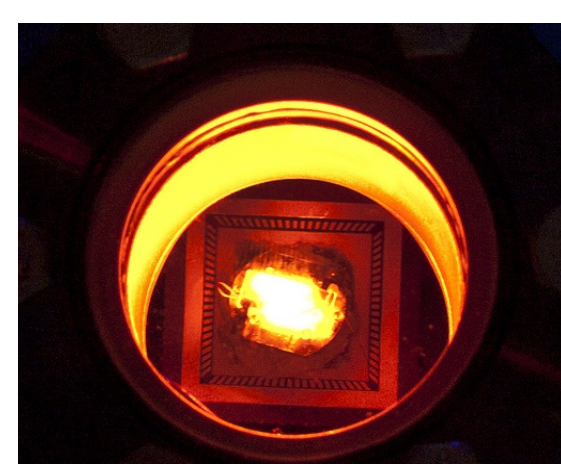*Surface science* : Characterization, surface treatment

Residual gas analysis

IR spectroscopy
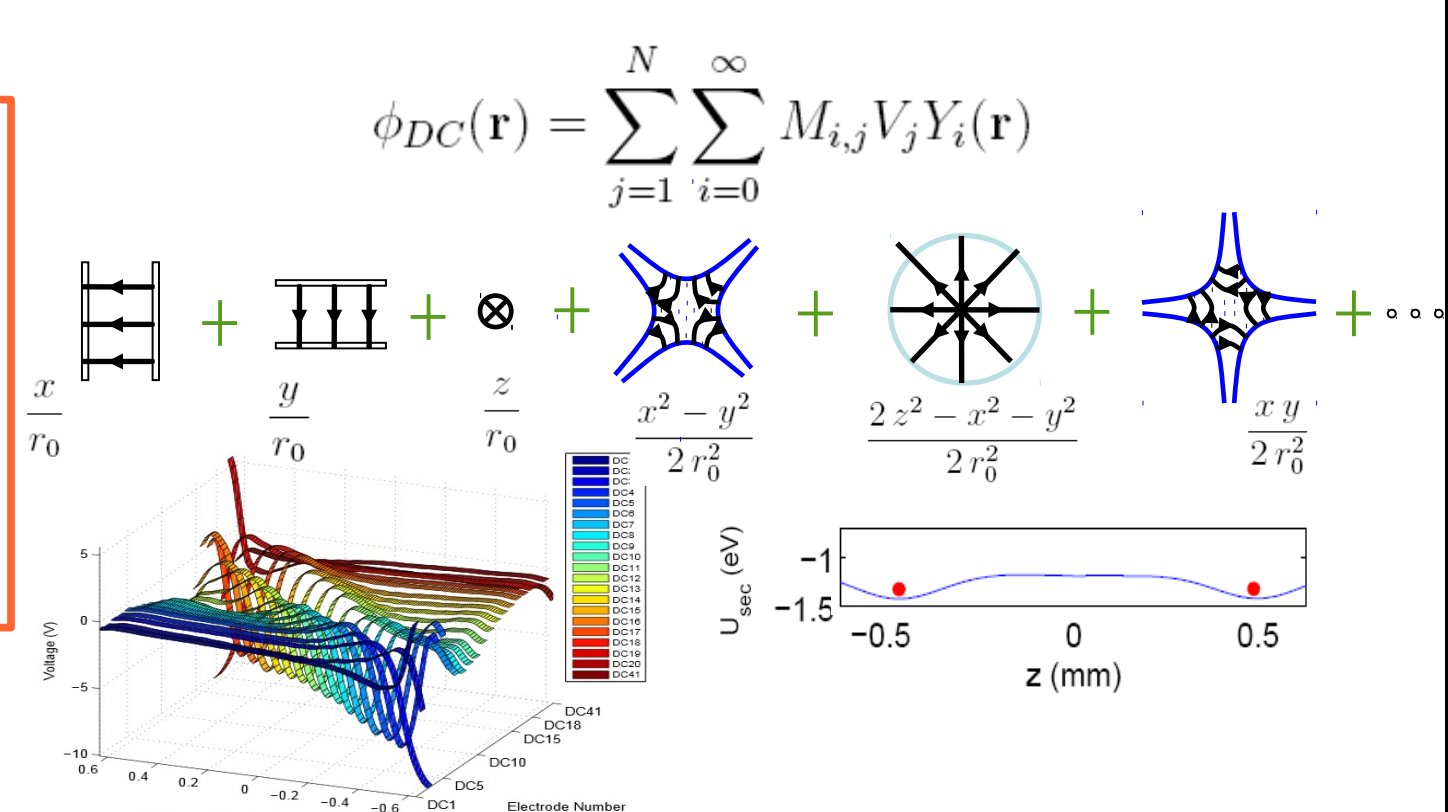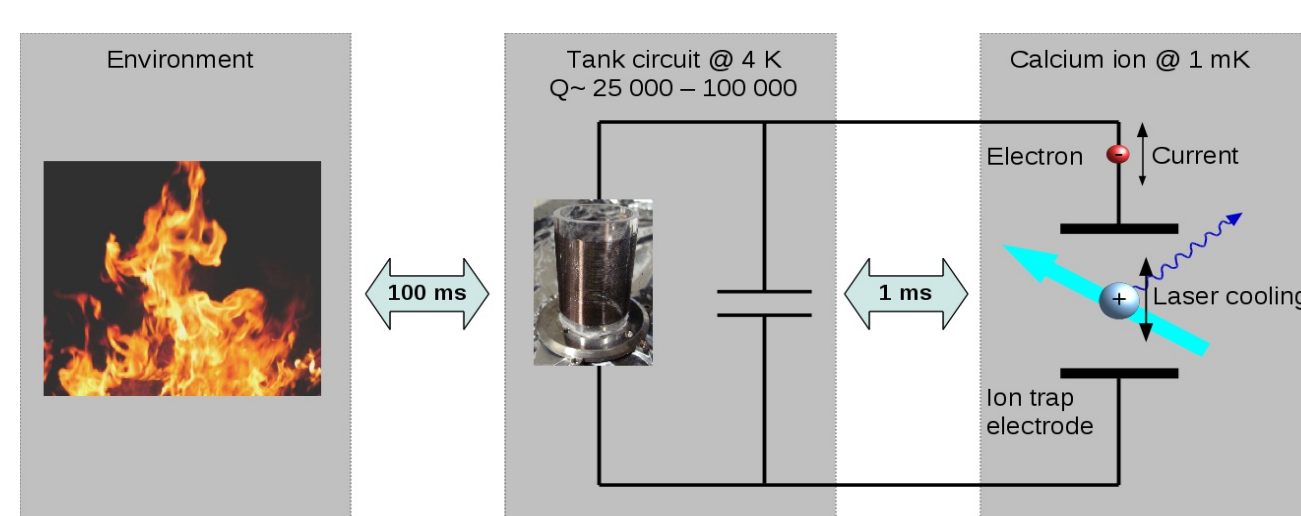
VUV treatment

Annealing

Trap control : Numerical tools to calculate trapping potentials for ion transport and multi-site loading
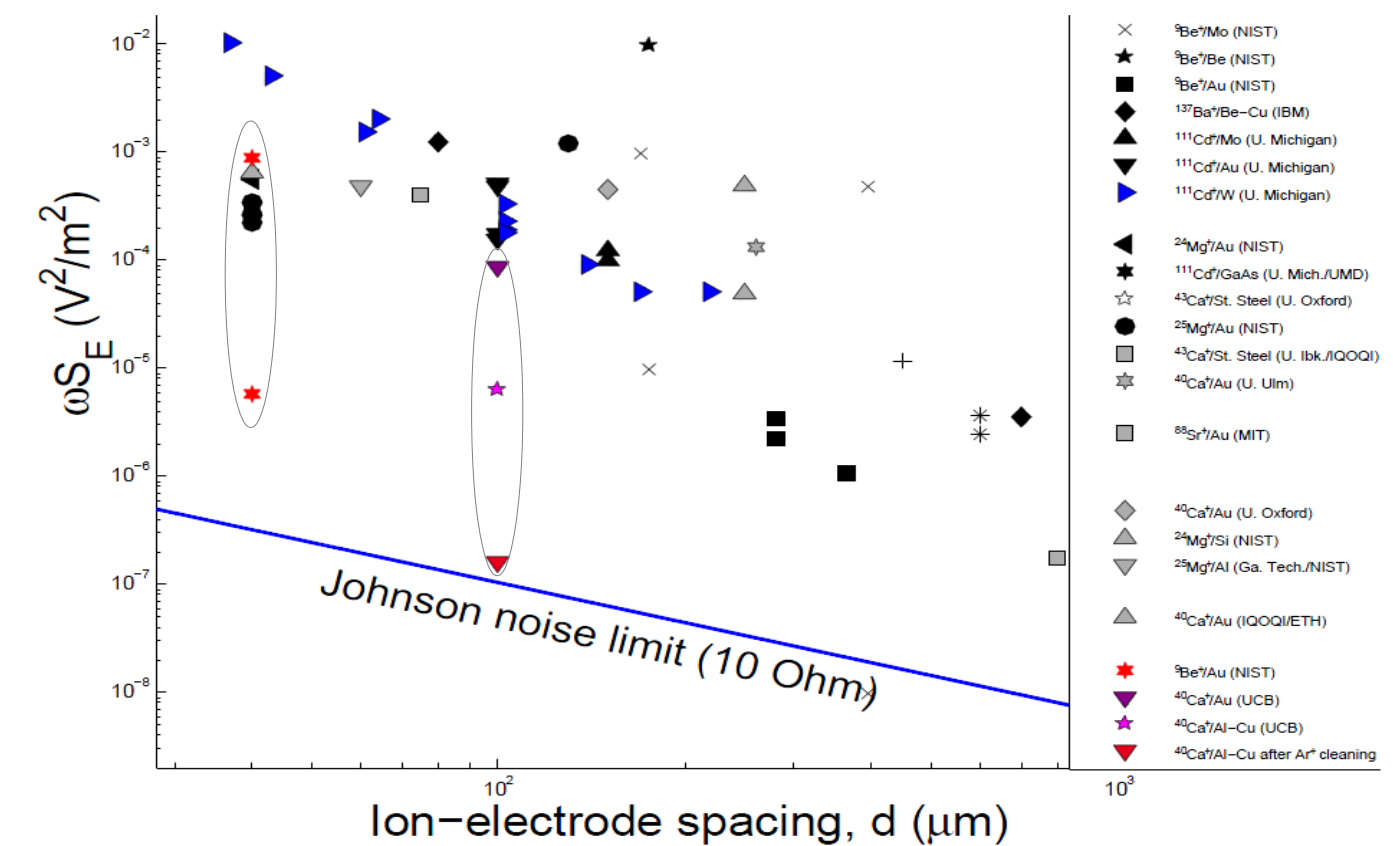
$$\phi_{DC}(\mathbf{r}) = \sum_{j=1}^{N} \sum_{i=0}^{\infty} M_{i,j} V_j Y_i(\mathbf{r})$$

Quantum Electronics : Coupling ions to electrical circuits → Scalable QIP with electrons

Present Approach

Ar+ ion milling for low electric field noise

- Trap-quality post milling (?)

- Best delivery technique (?)

- Determining factors:chemistry and/or morphology(?)

Research Interests

- Identify surface preparation and cleaning procedures applicable to ion trap setups.

- Develop controlled, user-friendly ion milling methods.

- Identify alternate processes for surface treatment.

- Investigate roles of surface morphology, chemistry on excessive noise, which microscopic models?

- Development of compact, low-noise, integrated ion-trapping apparatus.

- Engineering normal mode spectrum for QIP.

- Scalable QIP with trapped electrons no lasers, no optics, 100 times faster gates and read-out, flexible interface to Josephson junction devices.