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Sandia National Laboratories

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Fitzpatrick Institute for Photonics Annual Meeting

D. L. Moehring, T. Barrick, F. Benito, M. G. Blain, A. A. Cruz-Cabrera, A. R. Ellis, L. Fang, R. A. Haltli, C. Highstrete, S. A. Kemme, T. L. Lindgren, J. Sterk, D. Stick, B. Tabakov, C. P. Tigges, M. Descour

IARPA
BE THE FUTURE

NNSA
National Nuclear Security Administration

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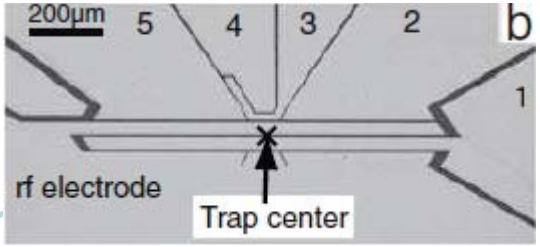
Sandia National Laboratories

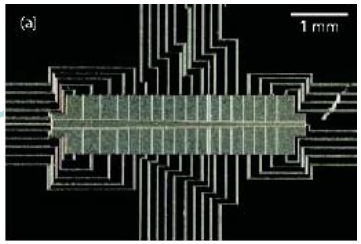
Ion Trapping 101: Trap Development

Lithographically fabricated GaAs trap, demonstrated at Michigan



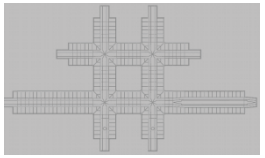
Demonstrated surface trap at NIST

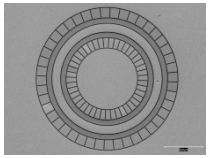
2006

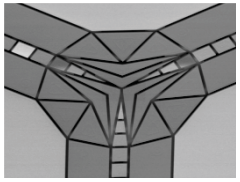


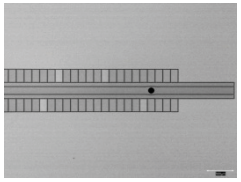
2007

Trap foundry 1 demonstrated a micro-fabricated surface trap

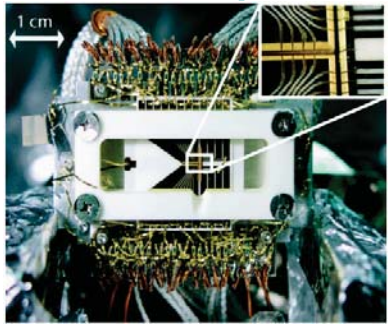








MQCO Trap Foundry

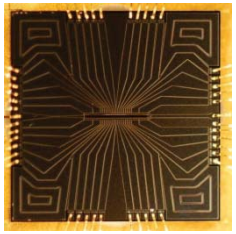


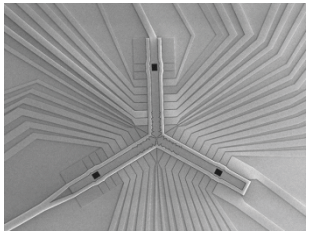
Demonstrated junction shuttling in 3 layer trap (~80% success rate)

2008

2009

Sandia Ion Trap Foundry 2



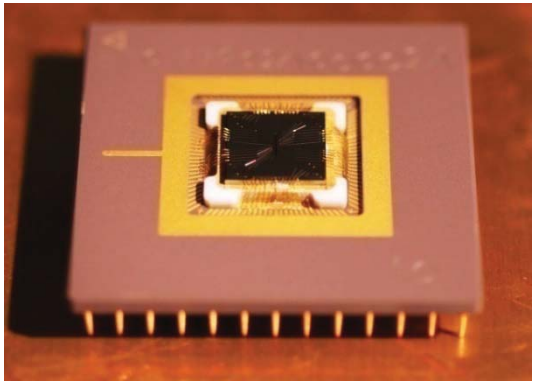


2010

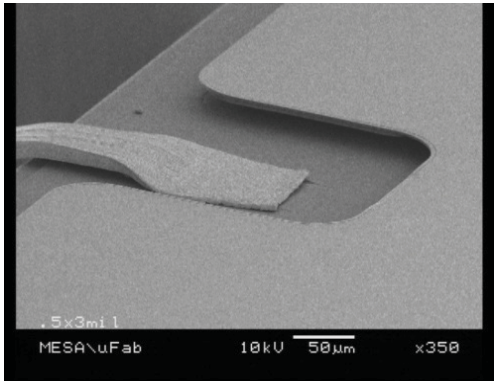
2011

Sandia Ion Trap Foundry: General Capabilities

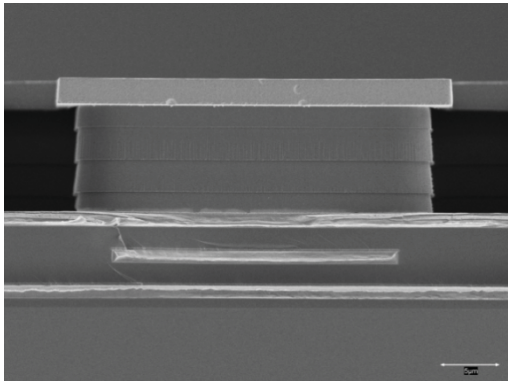
Plug-and-Play design



Low profile wire bonding

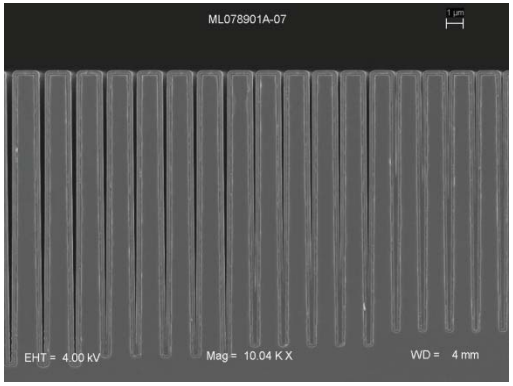


Controlled dielectric setback

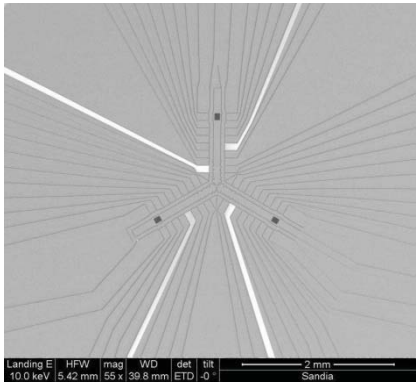


Custom coated electrodes

Integrated capacitors



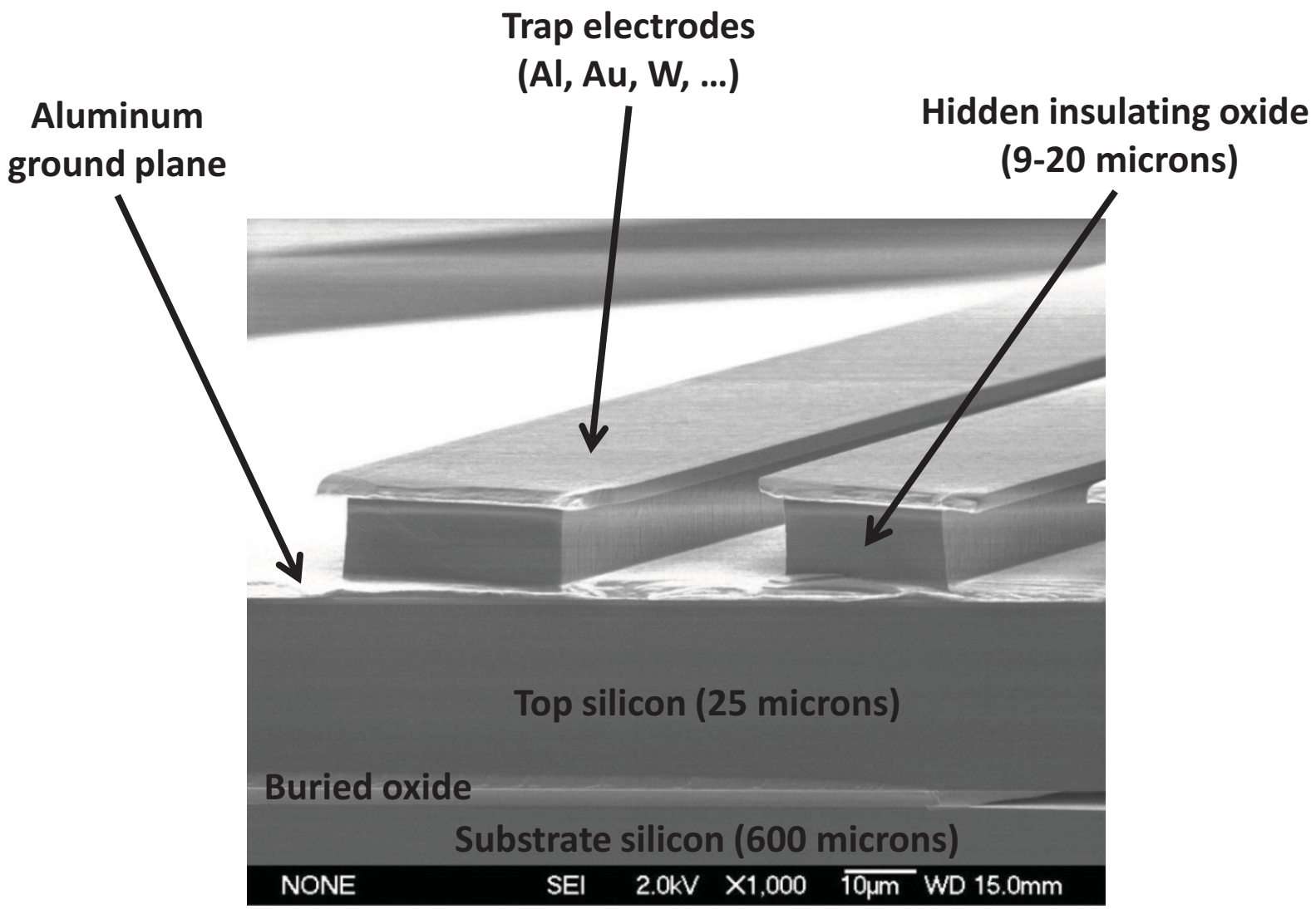
Novel testing techniques



D. Stick, *et al*. arXiv:1008.0990v1 (2010).

D. L. Moehring, *et al.* New J. Phys 13, 075018 (2011).

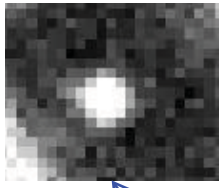
Sandia Ion Trap Foundry: General Capabilities



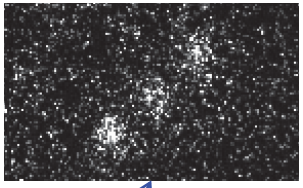
D. Stick, *et al*. arXiv:1008.0990v1 (2010). D. T. C. Allcock, *et al.* arXiv:1105.4864v1 (2011).

Sandia Ion Trap Foundry: Current Testing

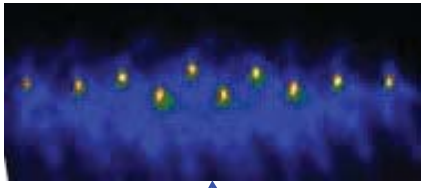
Georgia Tech: Calcium ions

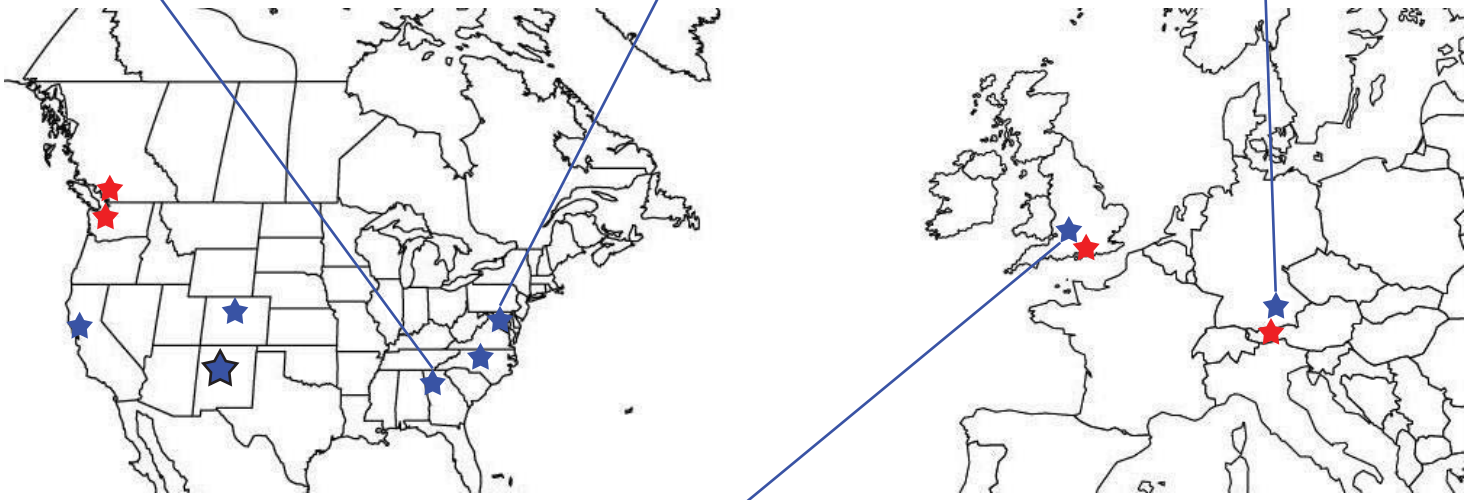


University of Maryland: Ytterbium ions

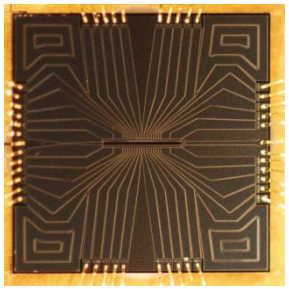


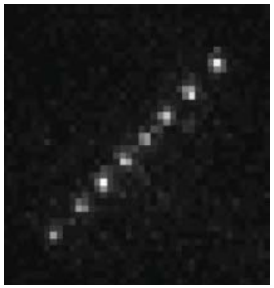
MPI for Quantum Optics: Magnesium ions

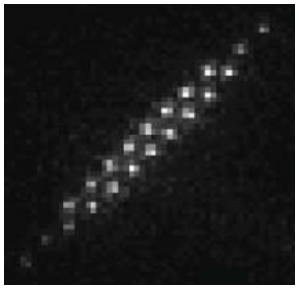


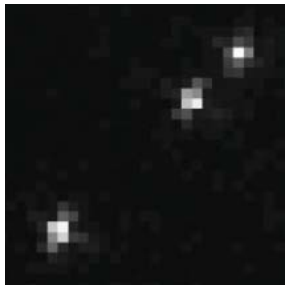


University of Oxford: Calcium ions ($^{40}Ca^{+}$ & $^{43}Ca^{+}$) – arXiv:1105.4864v1 [quant-ph] (2011).

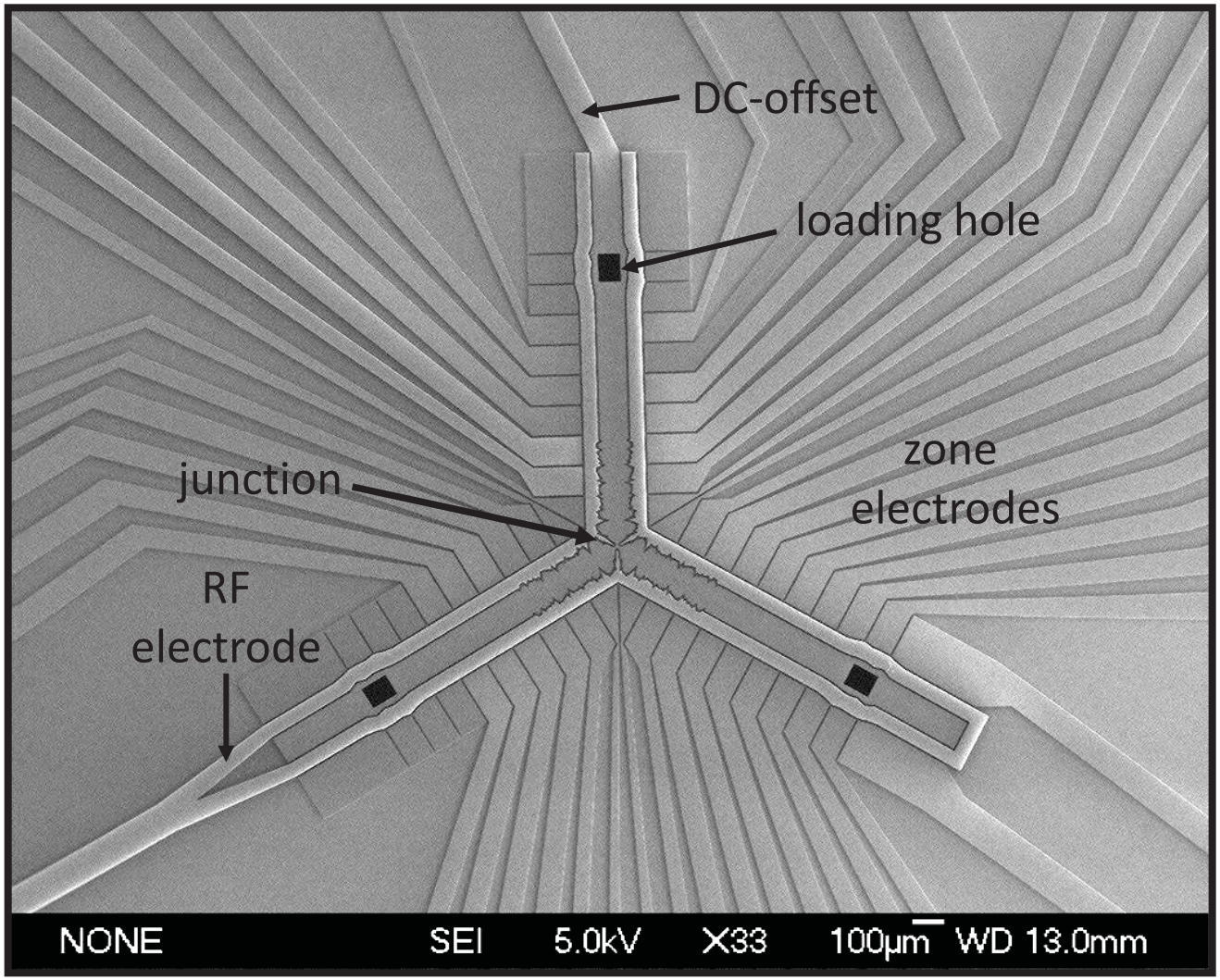


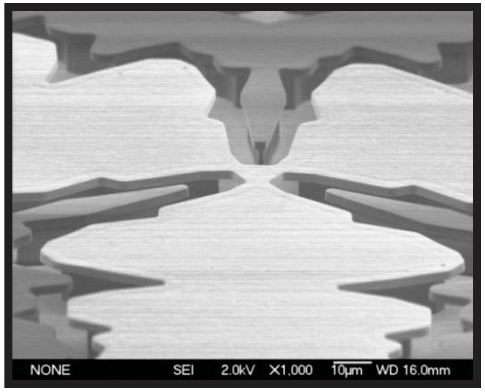


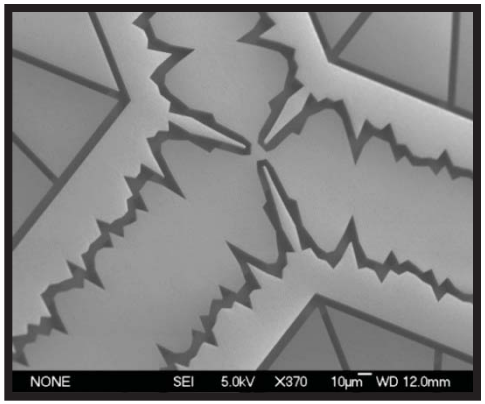


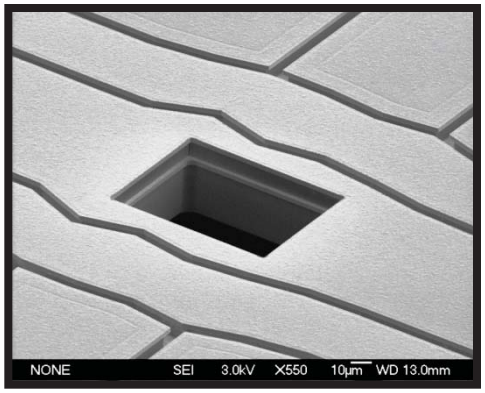


Sandia Ion Trap Foundry: Y-junction Surface Microtrap





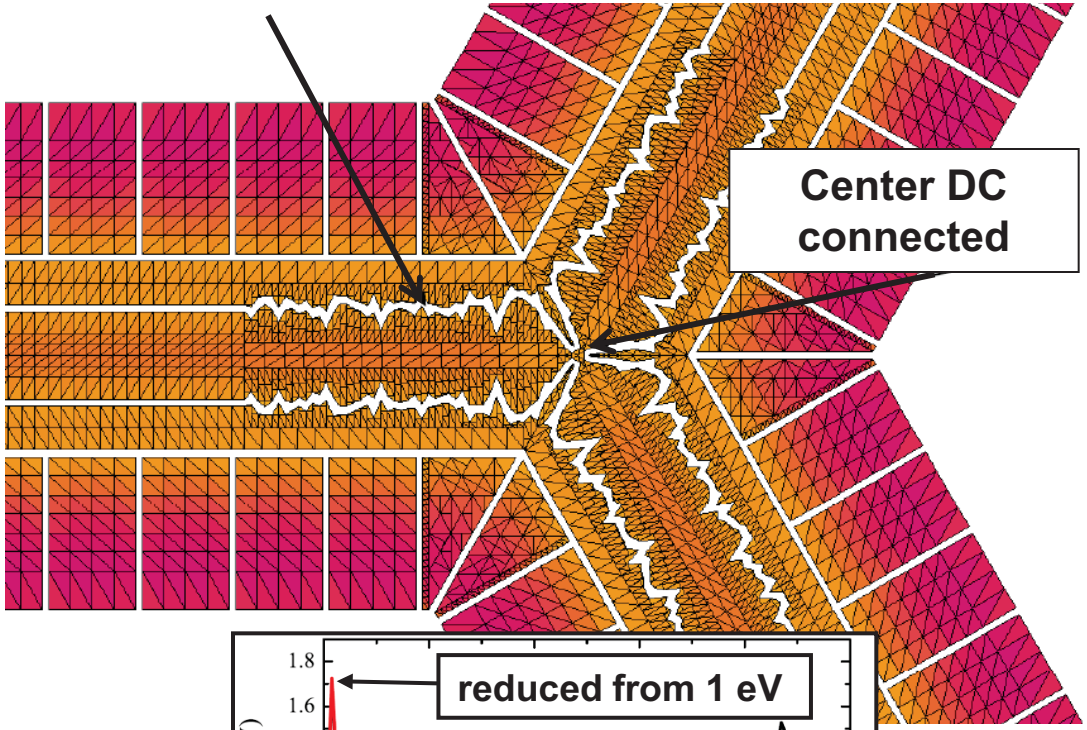


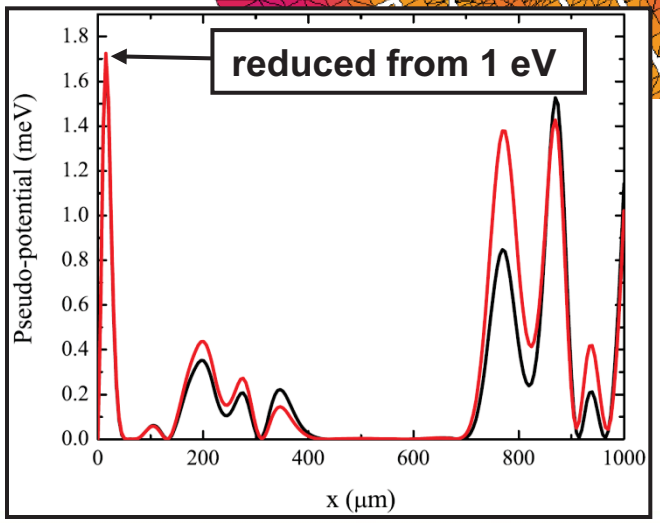


D. L. Moehring, *et al.* New J. Phys 13, 075018 (2011).

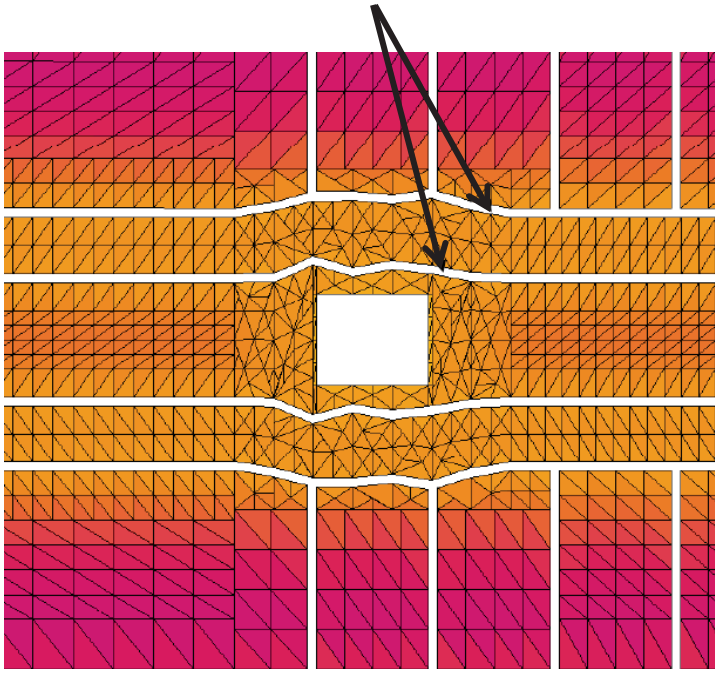
Sandia Ion Trap Foundry: Y-junction Surface Microtrap Design

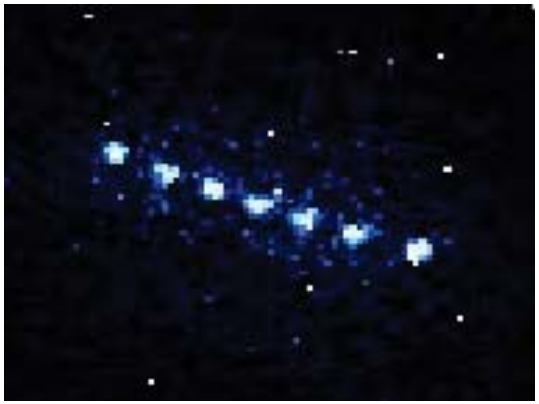
Single edge modulated
High spatial frequencies



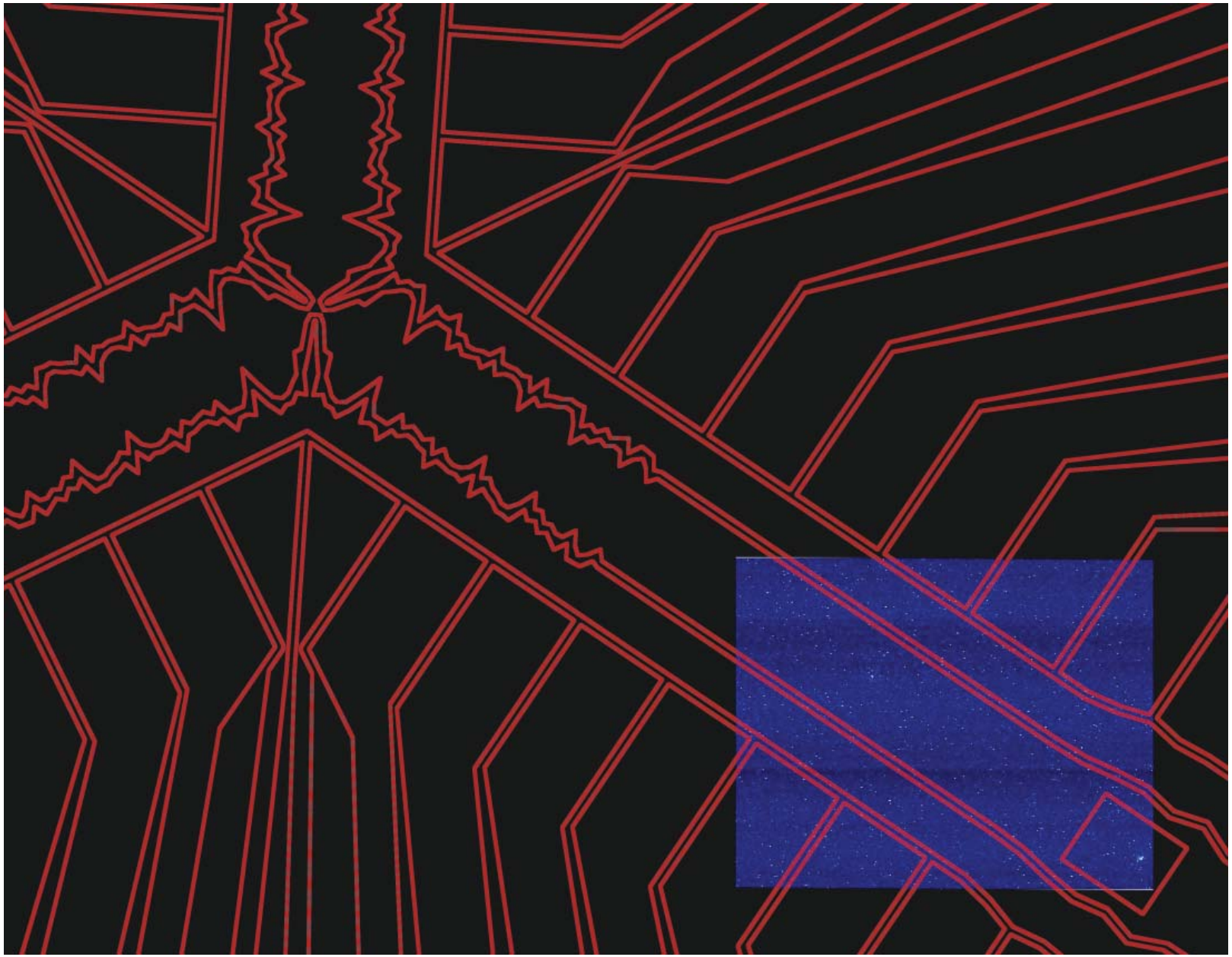


Two edges modulated
Low spatial frequencies

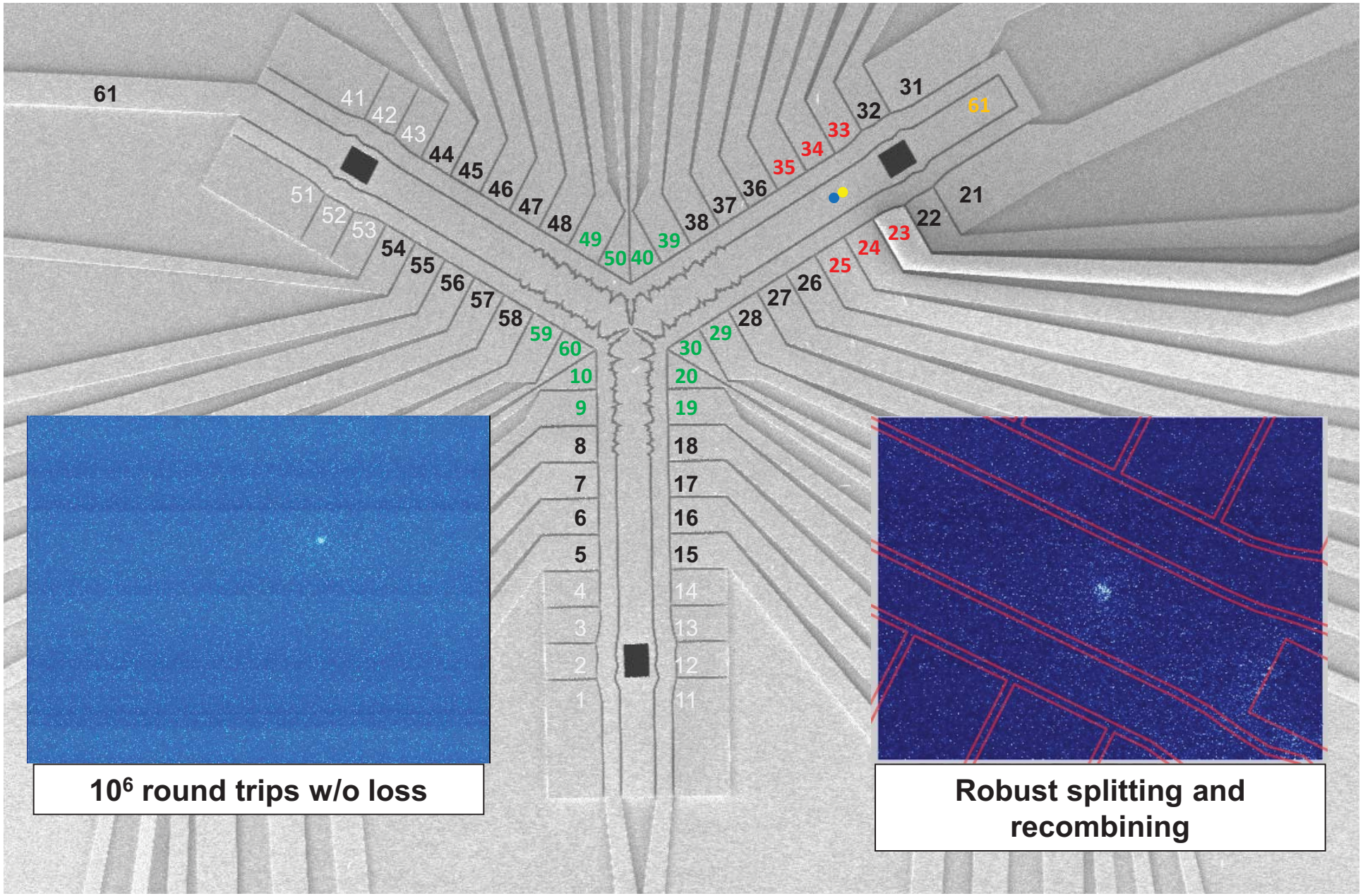




Sandia Ion Trap Foundry: Y-junction Surface Microtrap Testing



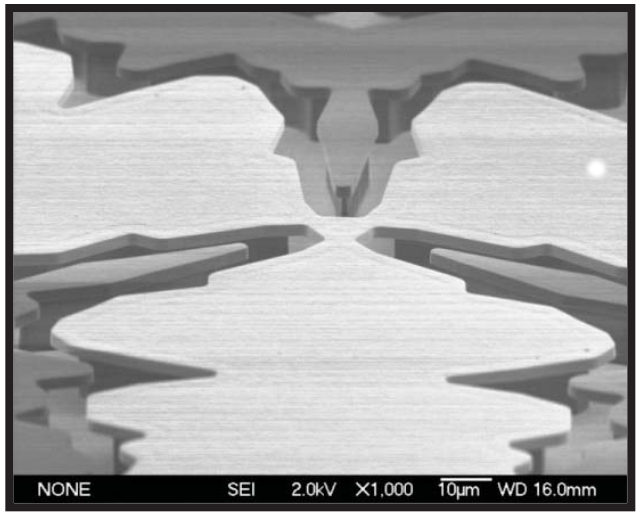
Sandia Ion Trap Foundry: Y-junction Surface Microtrap Testing



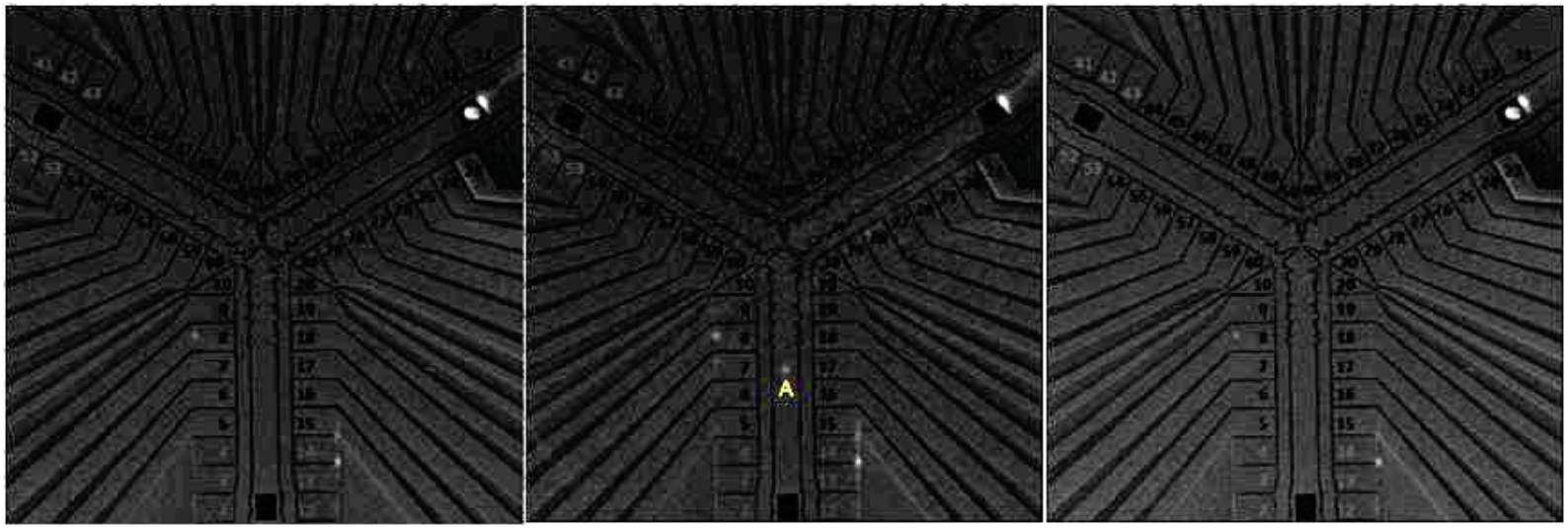
10^6 round trips w/o loss

Robust splitting and recombining

Sandia Ion Trap Foundry: Y-junction Surface Microtrap Testing & Collaboration



Successful shuttling in multiple independent systems, including Georgia Tech collaborators, with identical voltage solutions.

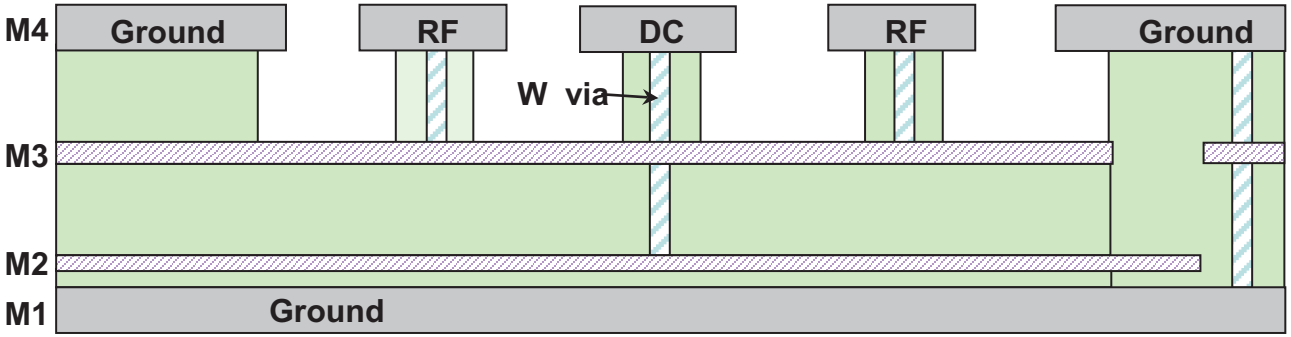


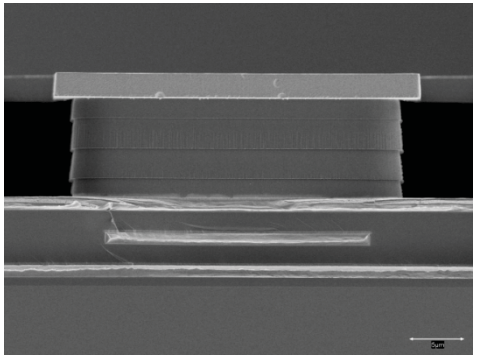
D. L. Moehring, *et al.* New J. Phys, 13, 075018 (2011).

New Technology: Multi-level process for electrode crossovers

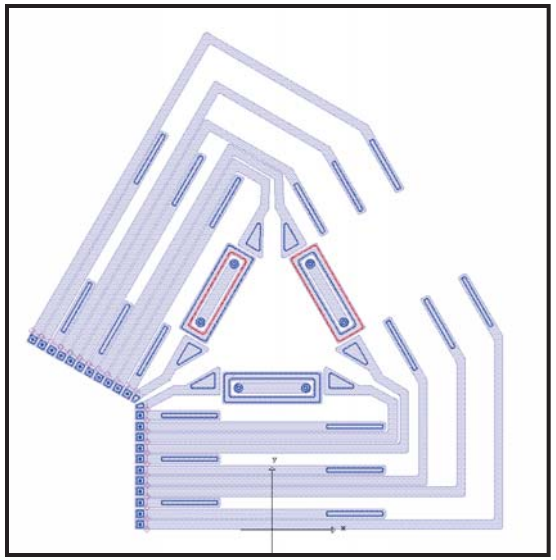
Routing of RF and Crossing of DC electrodes is required away from trapping regions

- **DC lead crossings below M4 electrode level and above M1 ground**
- **RF routing occurs in micro-stripline configuration with RF on M4; M4-M3 separation maximized**

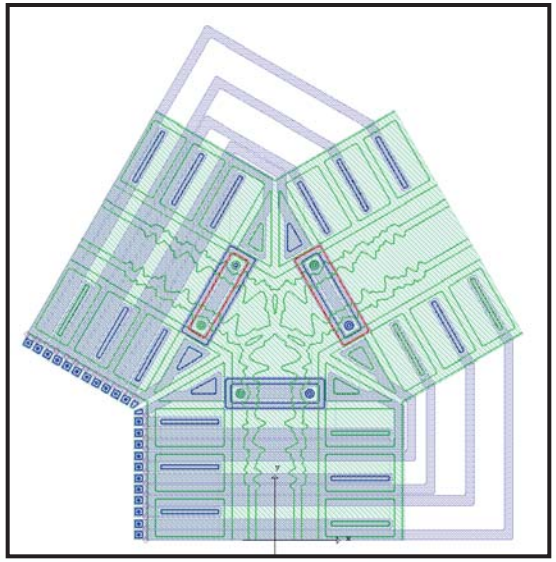




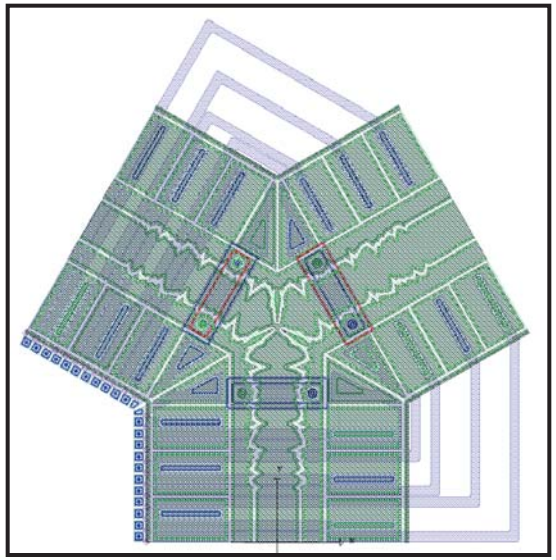
M2



M2 + M3

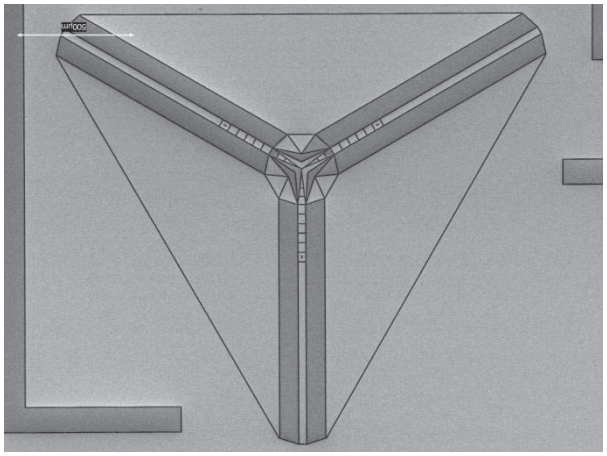


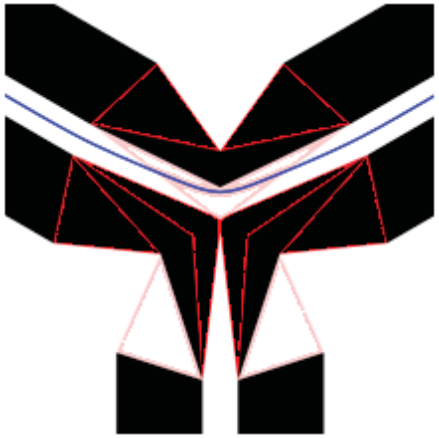
M2 + M3 + M4

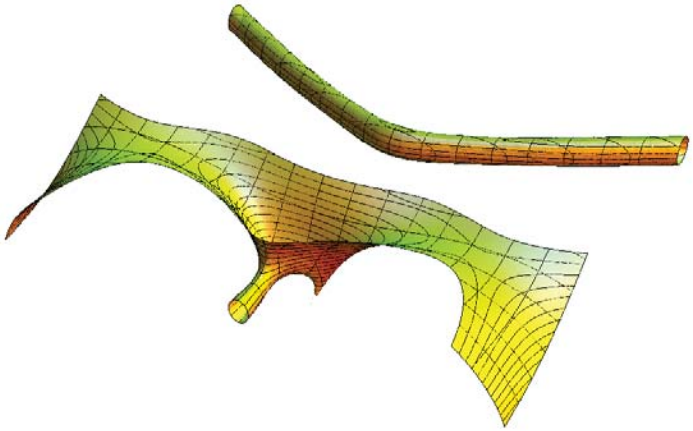


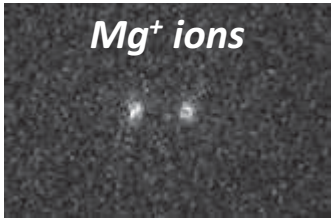
Next Generation *Switchable-Electrode* Y-Junction Trap

Collaboration with NIST (Didi Leibfried) and MPQ (Roman Schmied)



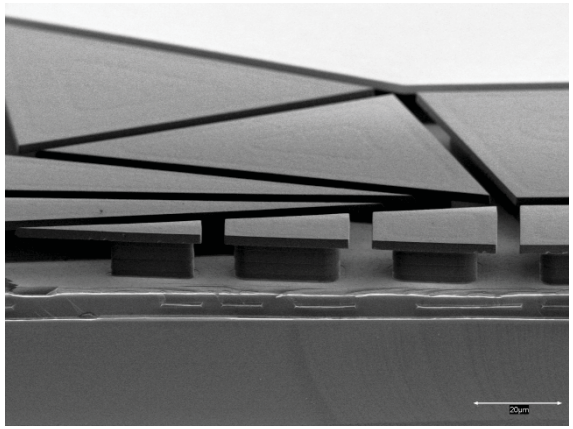


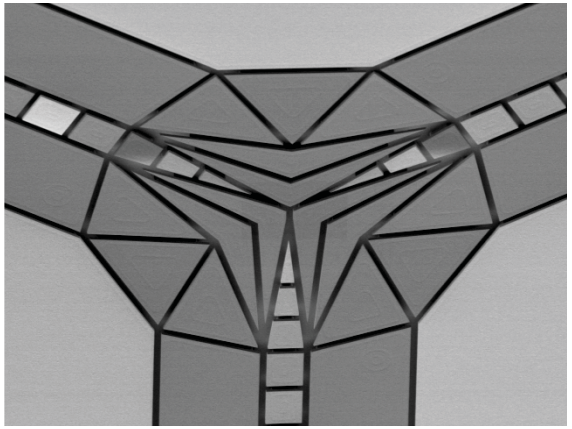


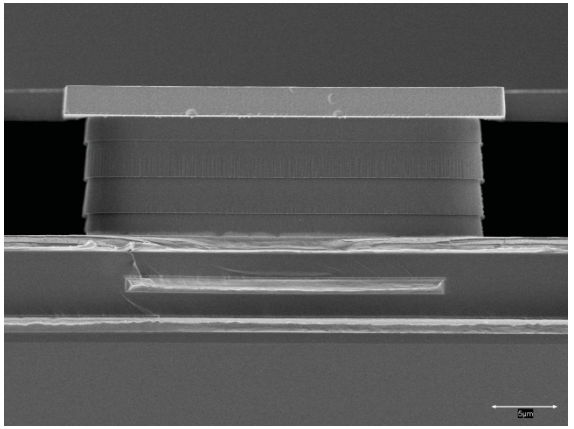


White: RF-ground
Black: always RF
Red: switched RF on
Pink: switched RF off

RF-tube for the switch state on the left (other states will rotate tube by 120°).

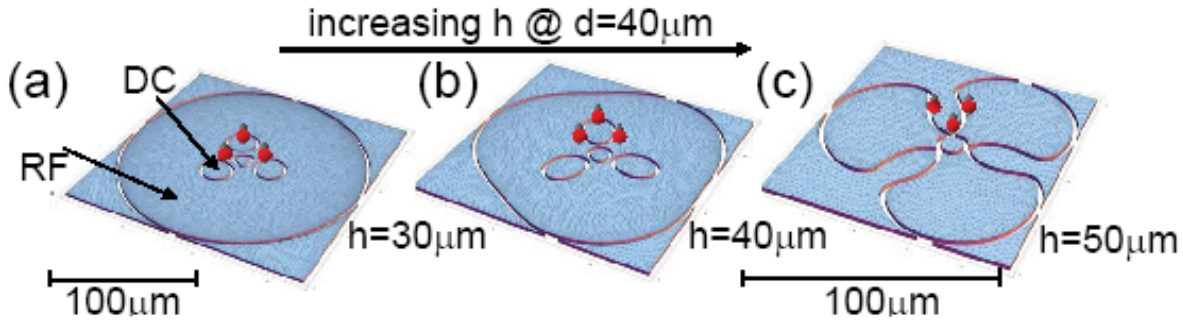


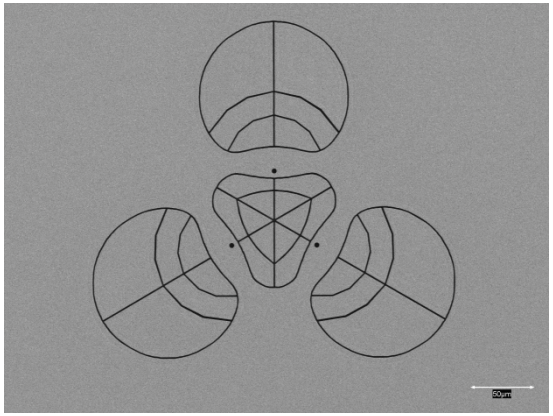


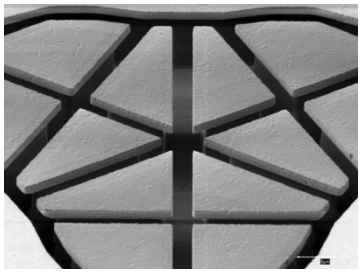


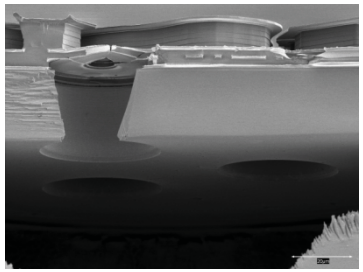
Two-Dimensional Trap Arrays for Quantum Simulation

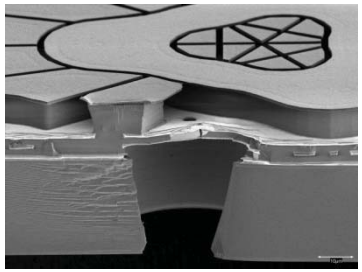
Collaboration with NIST (Didi Leibfried) and MPQ (Tobias Schätz and Roman Schmied)

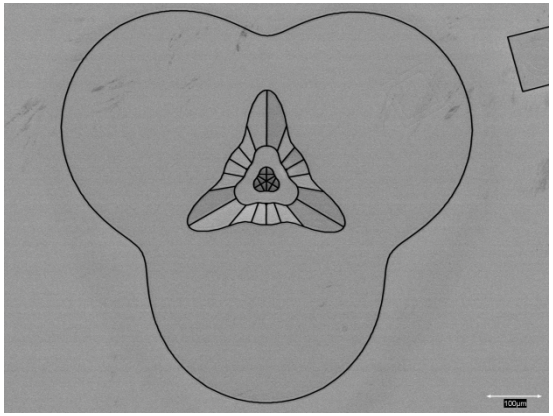




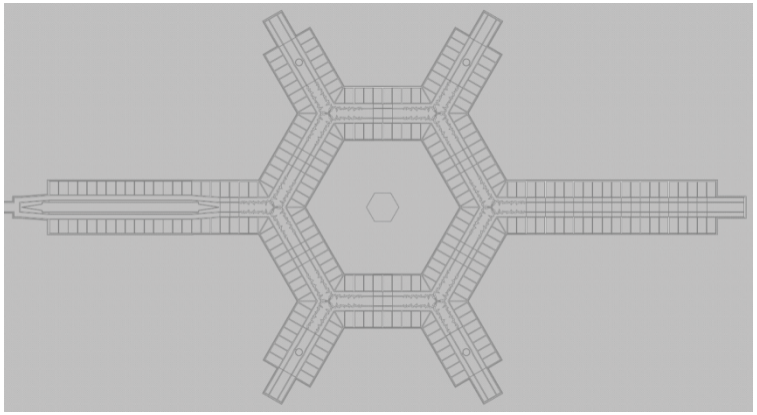


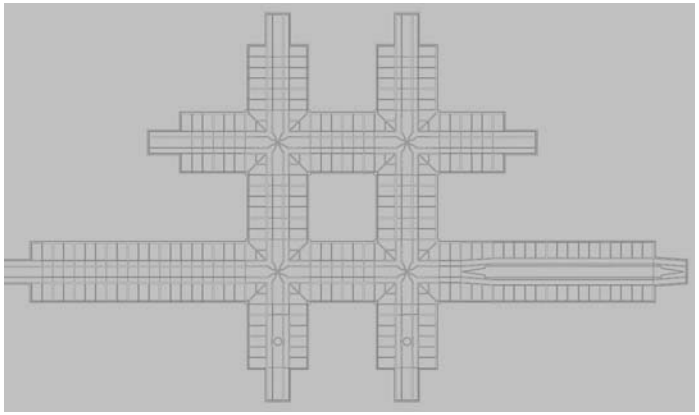


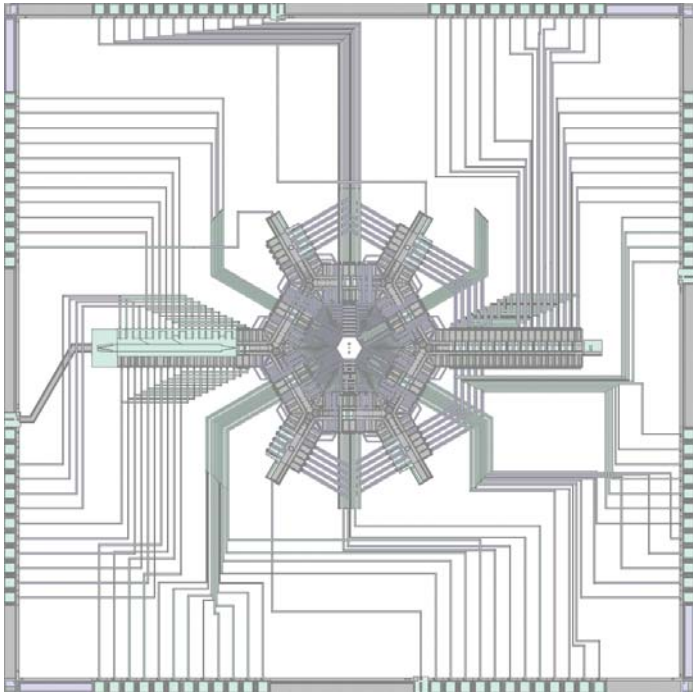


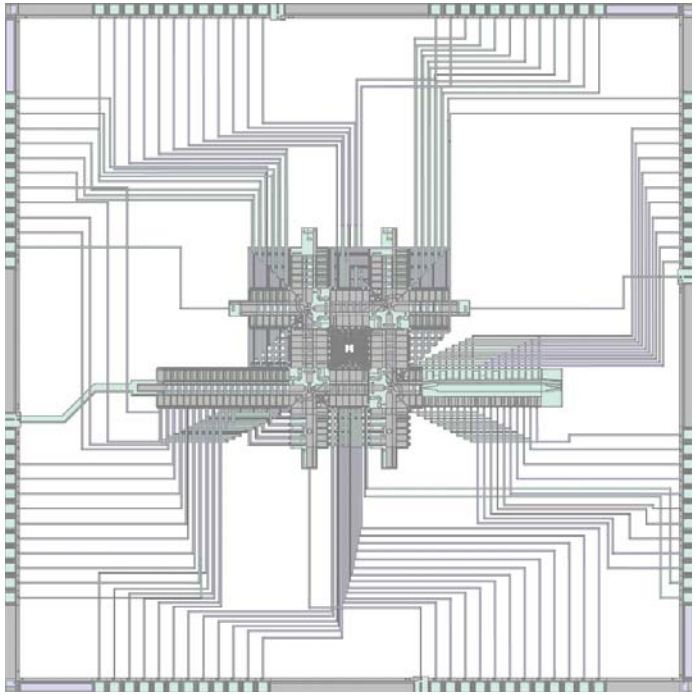


Next Generation *Circulator* Junction Trap – Collaboration with Ken Brown, et al.



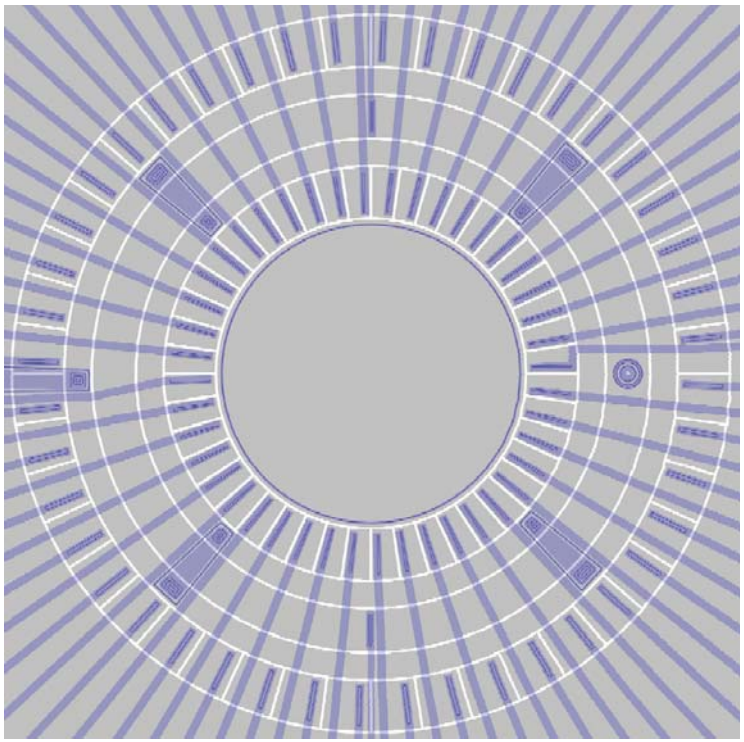


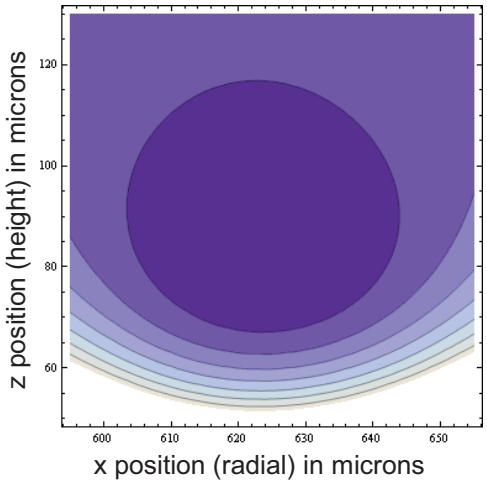




Ring-Shaped Ion Trap: Design and Fabrication – Collaboration with Washington

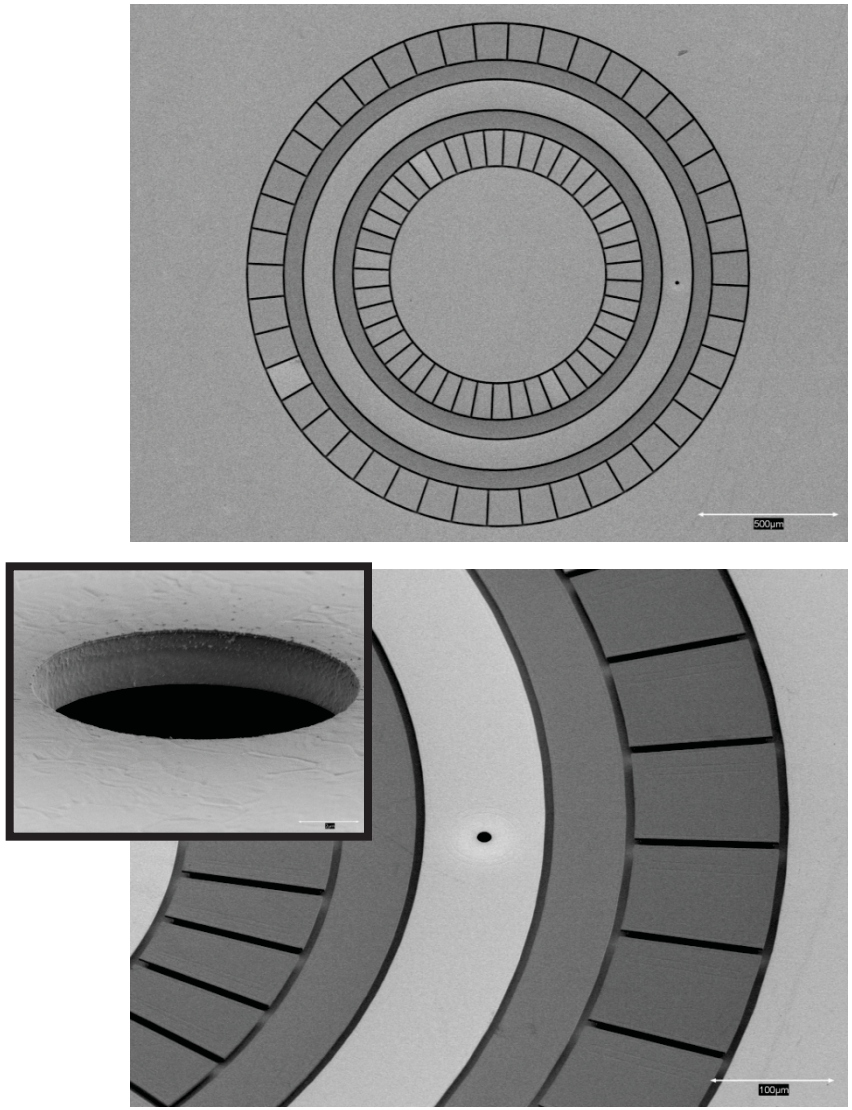
- With islanded electrodes, it is essential to use multi-level metallization.
- Designed for testing with Ca^+ at Sandia and implementation with Ba^+ at Washington.
- By loading entire ring, ions are equally spaced = ideal for transverse quantum gates.



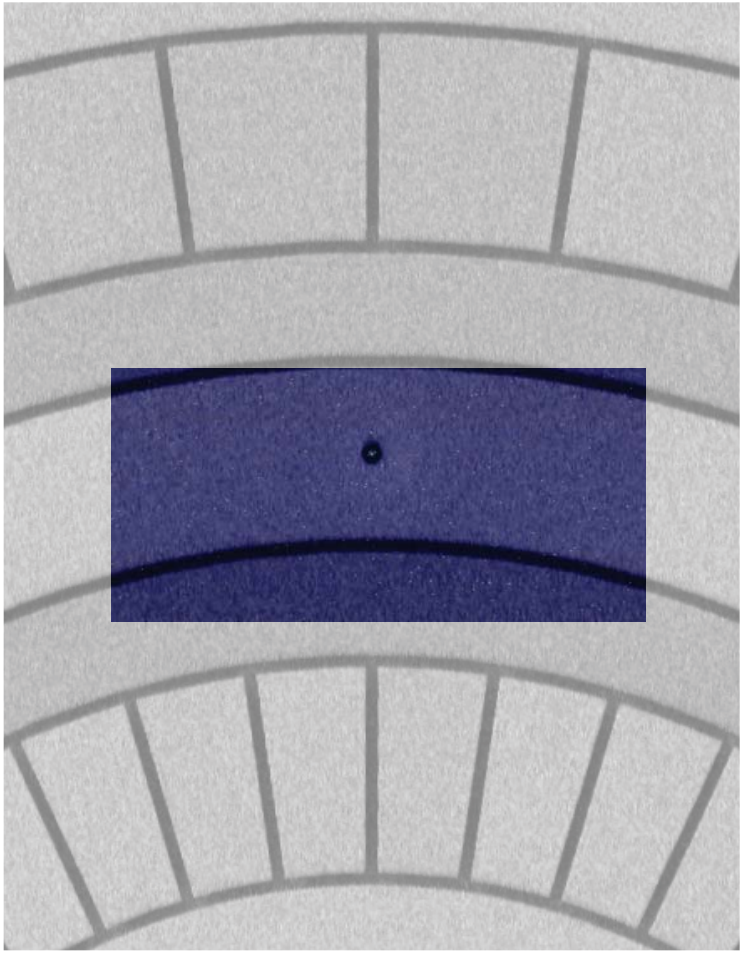


Ring-Shaped Ion Trap: Testing at Sandia

SEM eye-candy



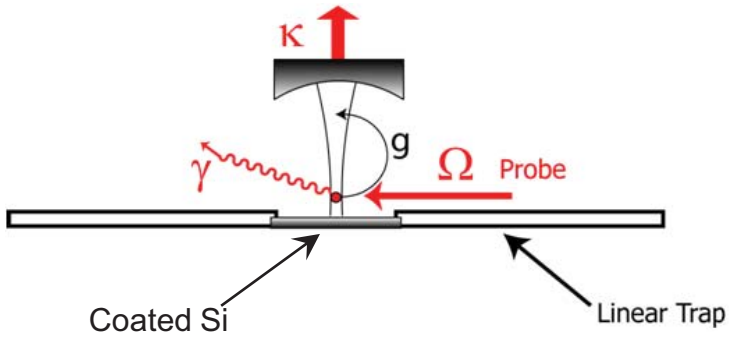
Initial testing results

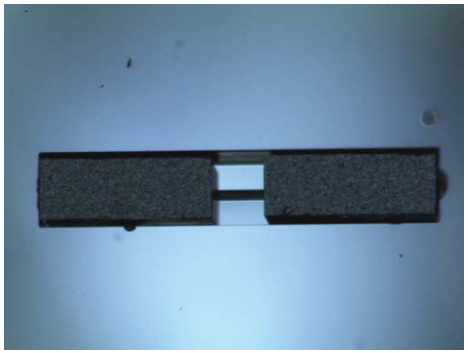


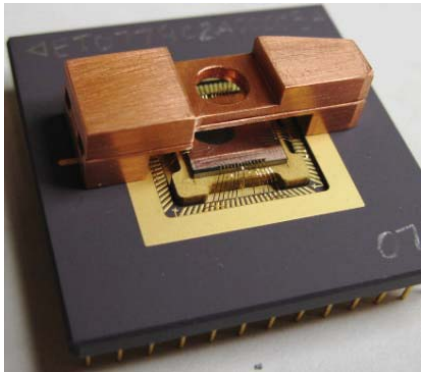
1000s of loops in both directions

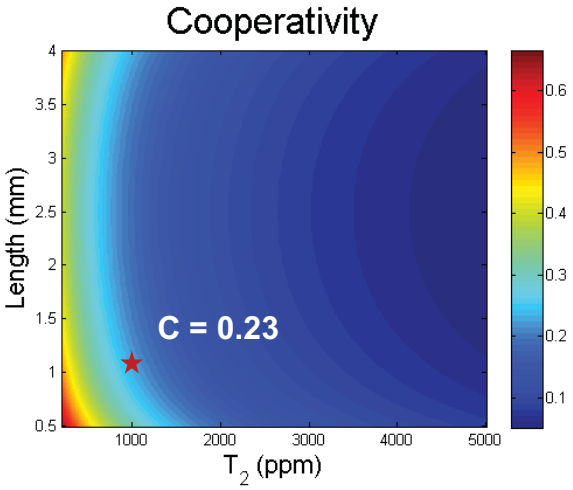
Integrated Cavity QED: High-Efficiency Single Photon Collection – Duke & UM

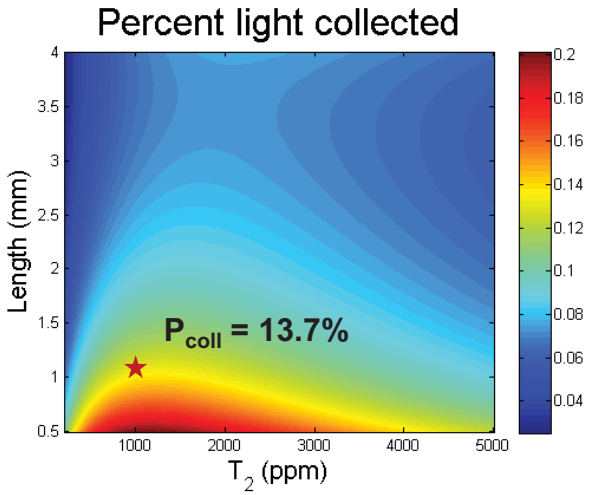
Integration of micro-fabricated ion trap and micro-optics







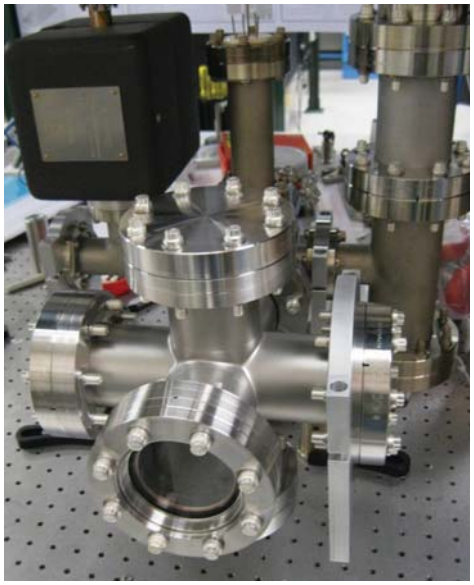


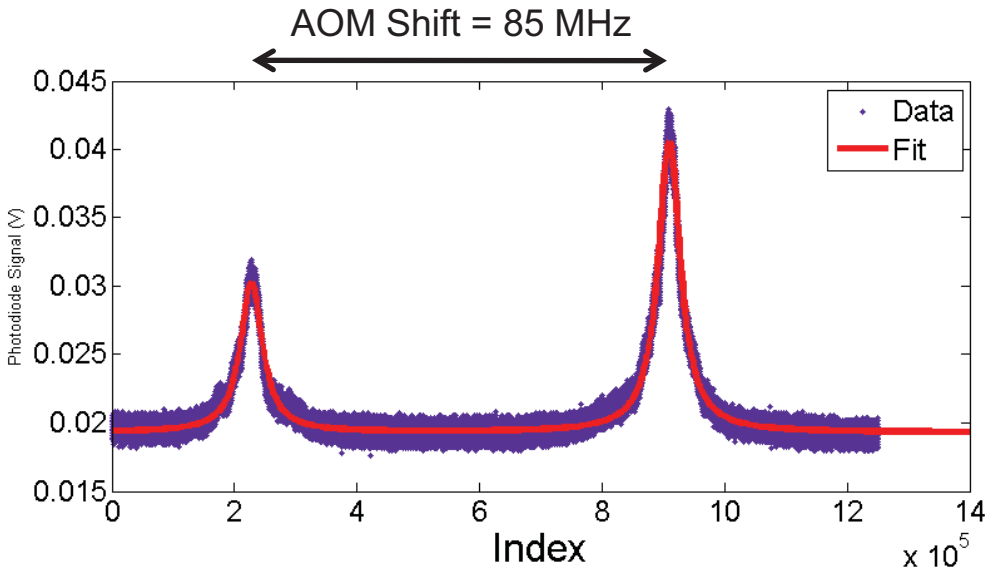


$$C = g^2 / \kappa \Gamma$$

$$P_{col} = \frac{T_2}{\mathcal{L}} \left(\frac{2\kappa}{2\kappa + \Gamma} \right) \left(\frac{2C}{1+2C} \right)$$

Integrated Cavity QED: Mirror Characterization – See also Duke results





Initial Results

L = 7 mm

RoC = 2.5 cm

FSR = 21.44 GHz

$\Delta \upsilon_T = 5.233$ GHz

$\kappa = 2.55$ MHz

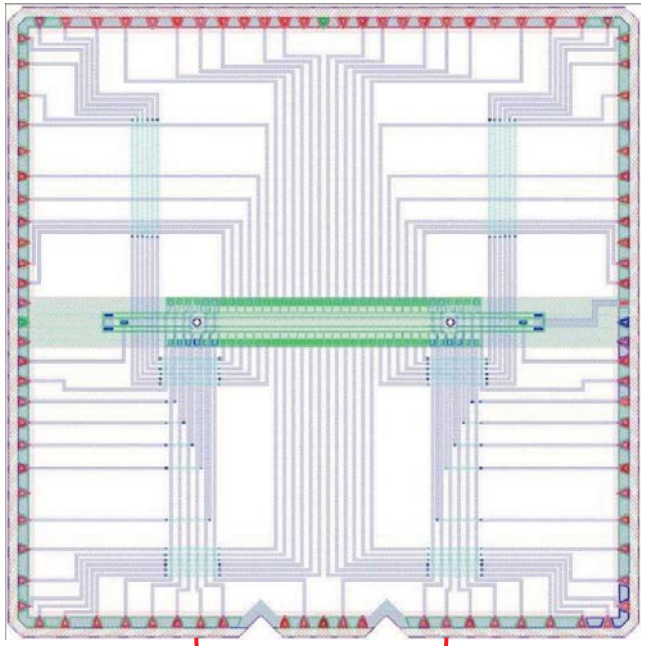
$T = 215$ ppm

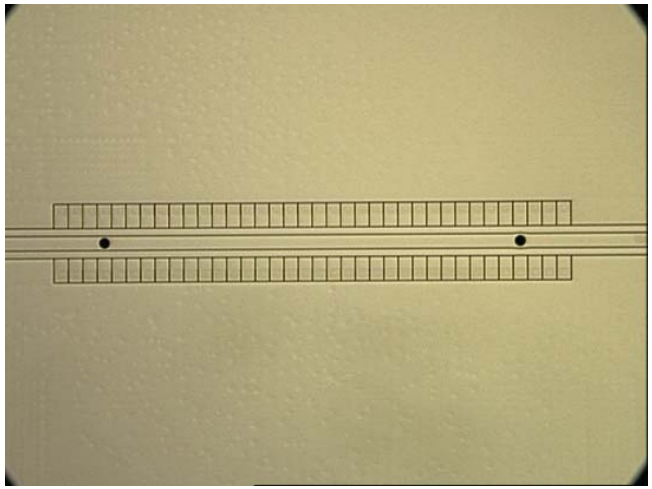
Scatter Loss = 532 ppm

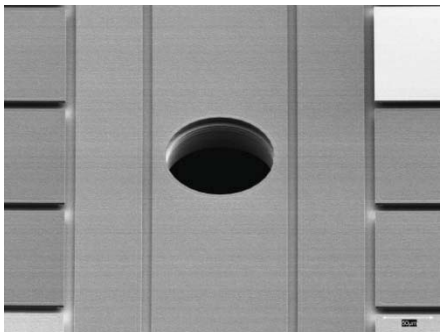
Total Loss = 1495.3 ppm

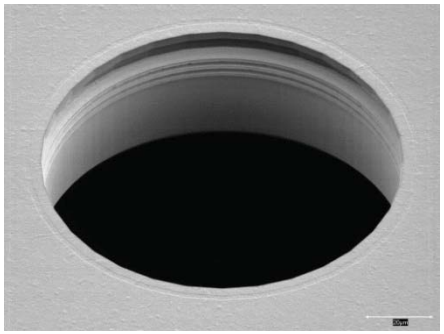
Finesse = 4403

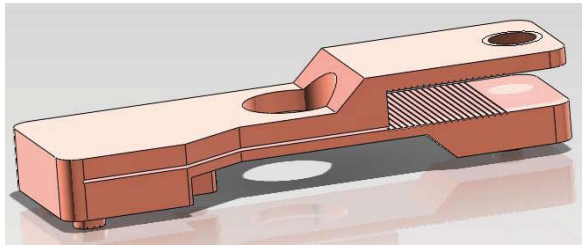
Integrated Cavity QED: Trap Design and Fabrication

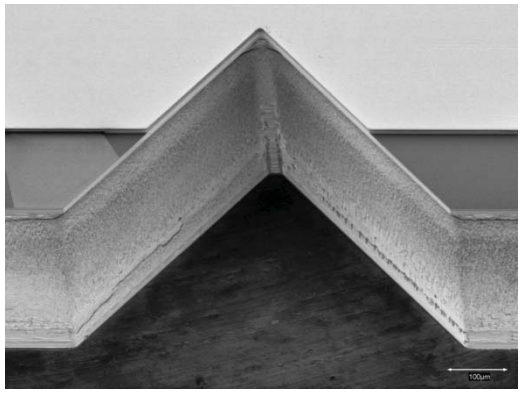




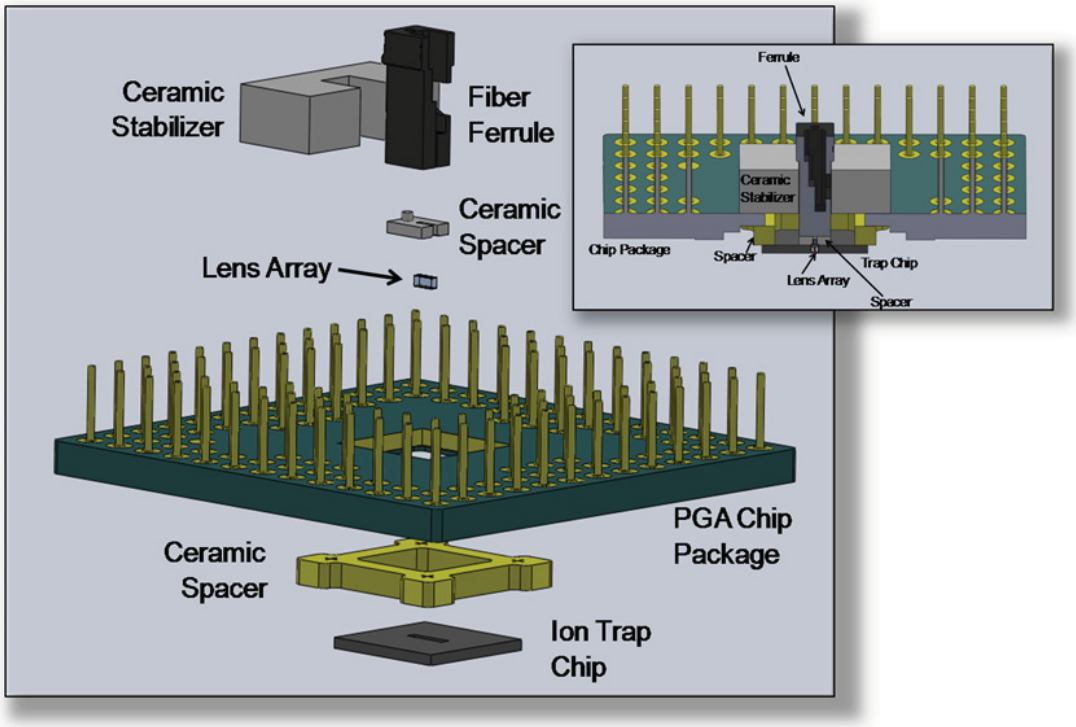


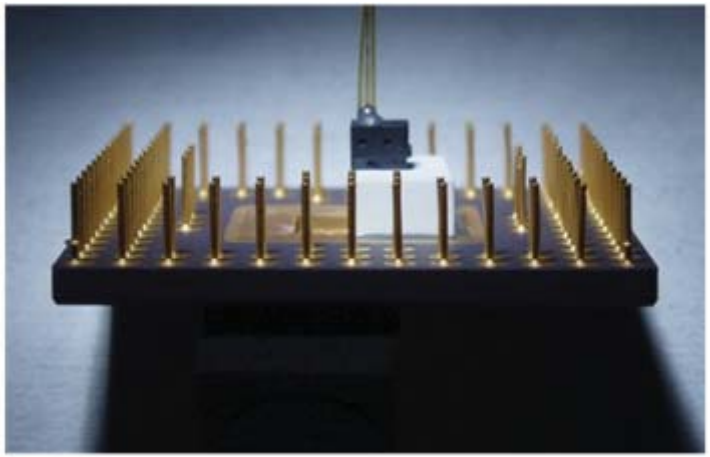


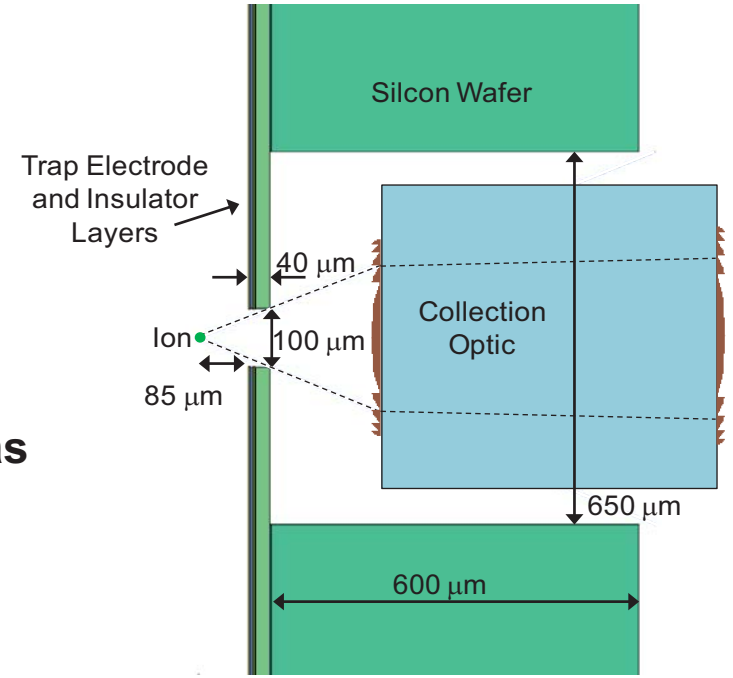




Other Technologies: Integrated Optics





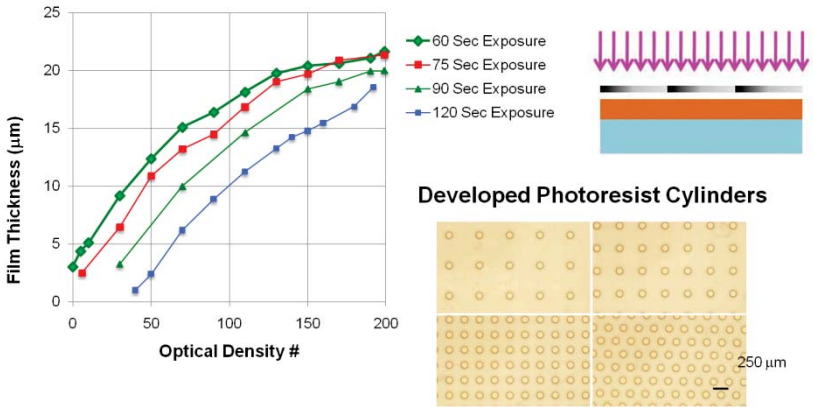


- **Optics have been integrated into linear ion trap.**
- **No detrimental effects to ultra-high vacuum.**
- **Successful shuttling with same voltage solutions as linear trap without integrated optics.**
  - **Dielectric lenses ~200 microns away from ion.**

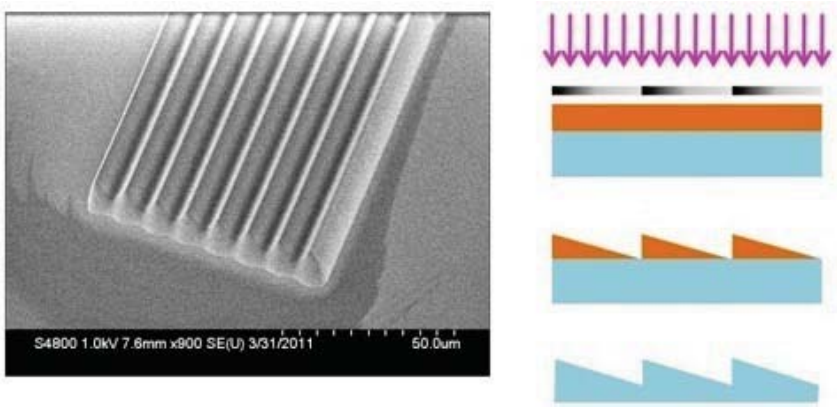
G. R. Brady, *et al.* Appl. Phys. B: Lasers and Optics 103, 801-808 (2011).

Other Technologies: Integrated Optics – Grayscale

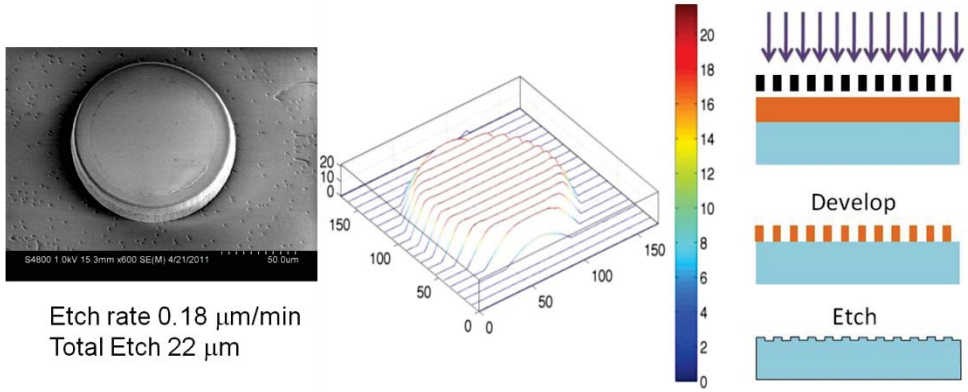
Grayscale Micro-Optics: Photoresist Thickness vs Mask Optical Density



Grayscale Micro-Optics: Grating Replicated in Photoresist

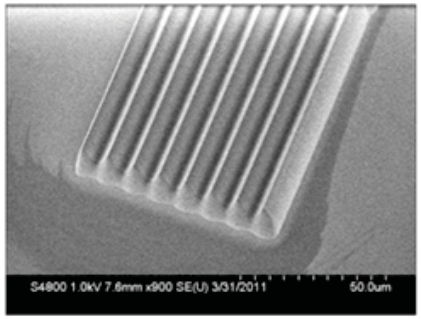


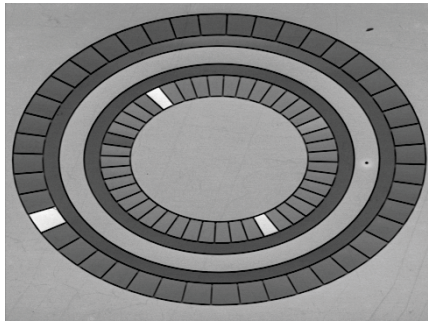
Grayscale Micro-Optics: Deep Binary Structures in Fused Silica

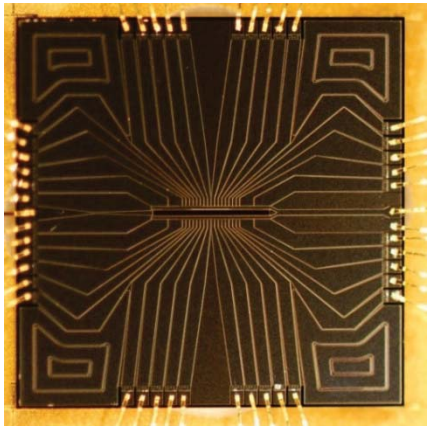


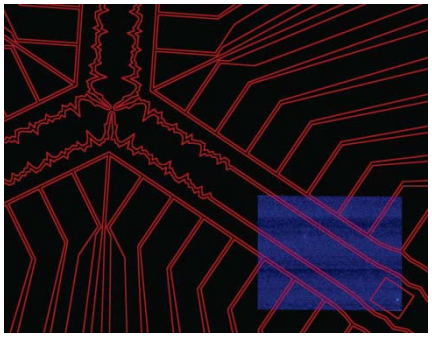
Etch rate 0.18 μm/min
Total Etch 22 μm

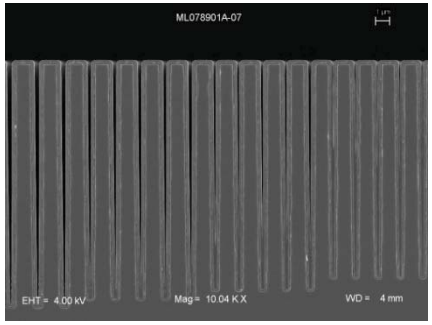
Thanks!


S4800 1.0kV 7.6mm x900 SE(U) 3/31/2011
50.0um








ML078901A-07
EHT = 4.00 kV
Mag = 10.04 K X
WD = 4 mm