Microfabricated Ion Traps for Quantum Simulations

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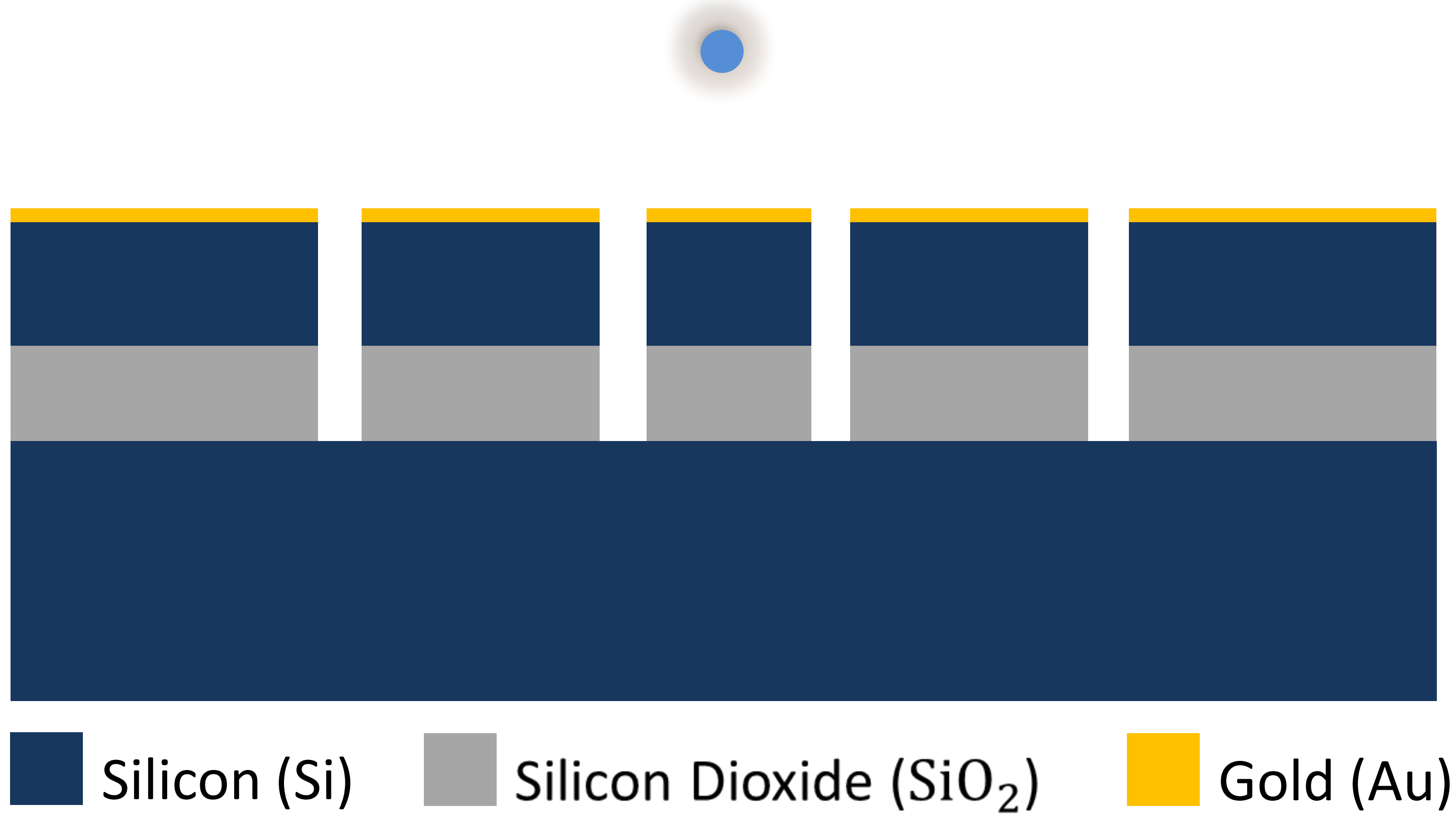
Two-Dimensional Ion Trap Array

- Simple Fabrication Process
- Extremely High Breakdown Voltage
- 2D Lattice Ion Trap
- Site to Site Shuttling

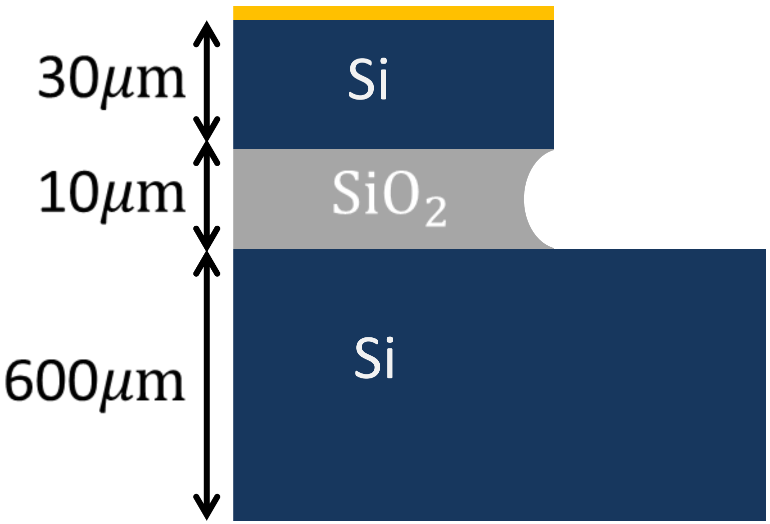
Two-Dimensional Ion Trap Array

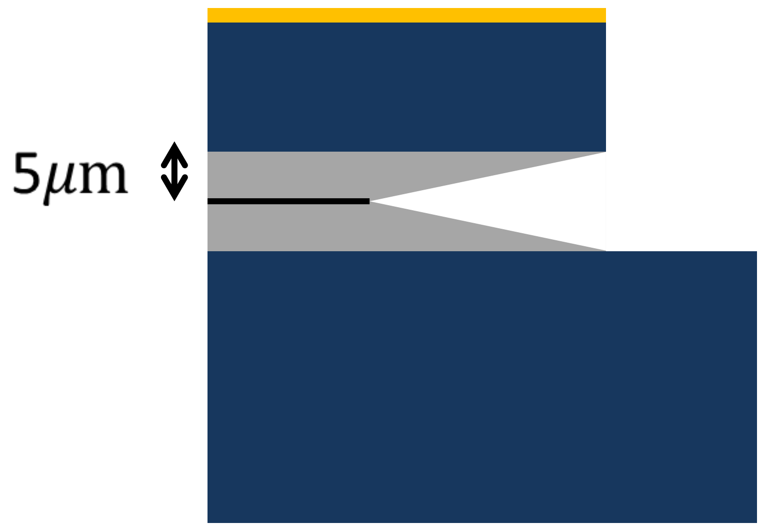
- Simple Fabrication Process



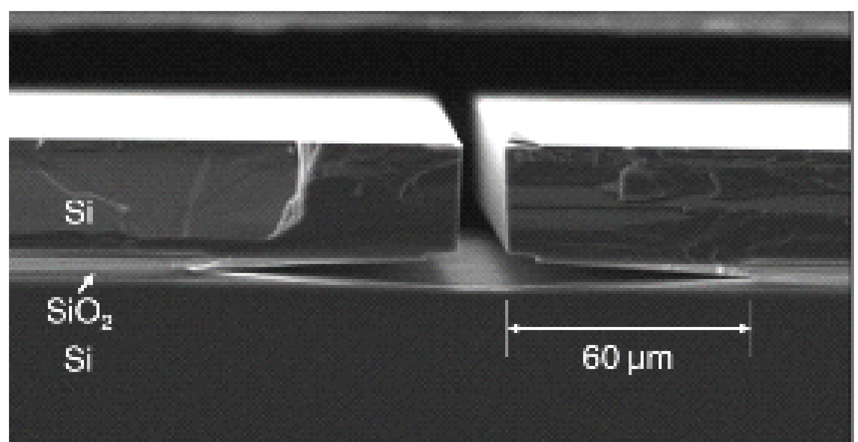
Two-Dimensional Ion Trap Array

- Extremely High Breakdown Voltage



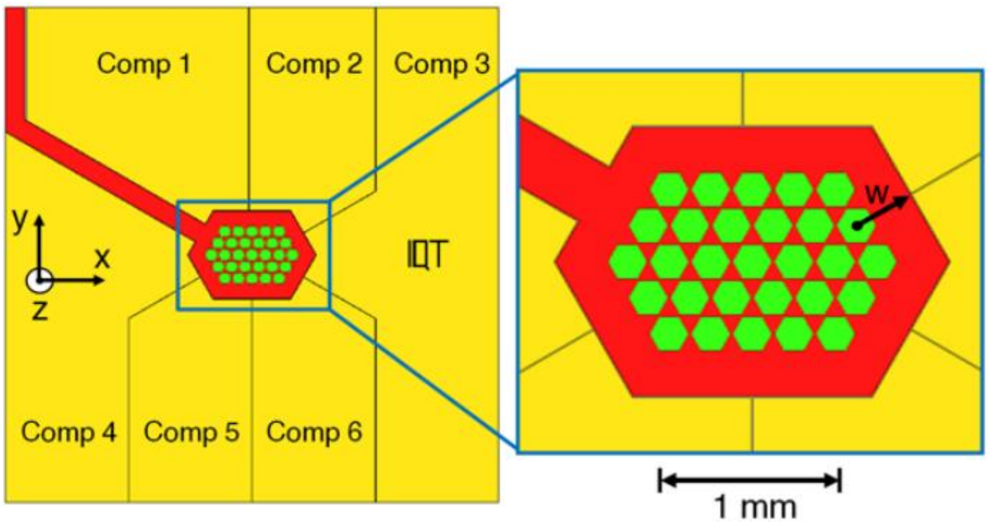


V_{DC} = 1298 V
V_{RF} = 1061 V



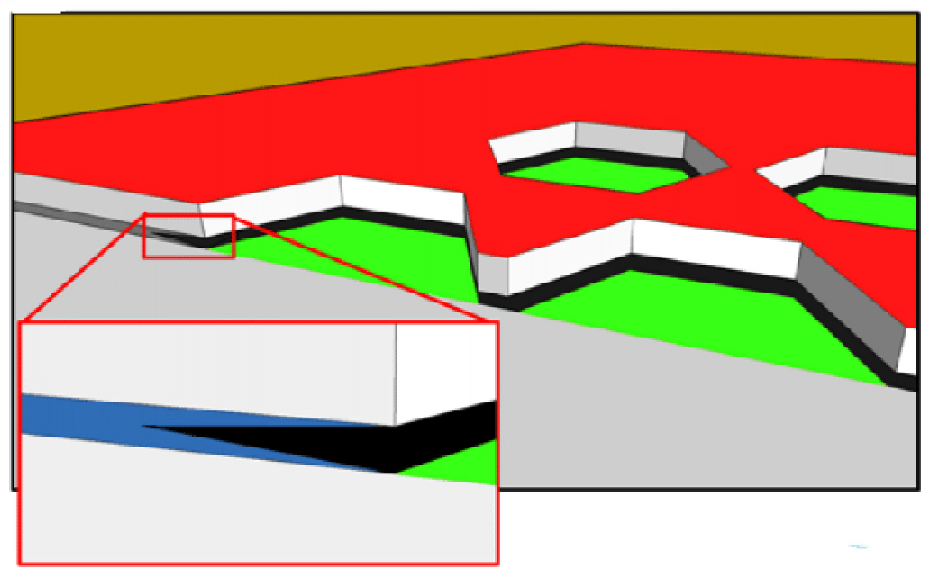
Two-Dimensional Ion Trap Array

- 2D Lattice Ion Trap



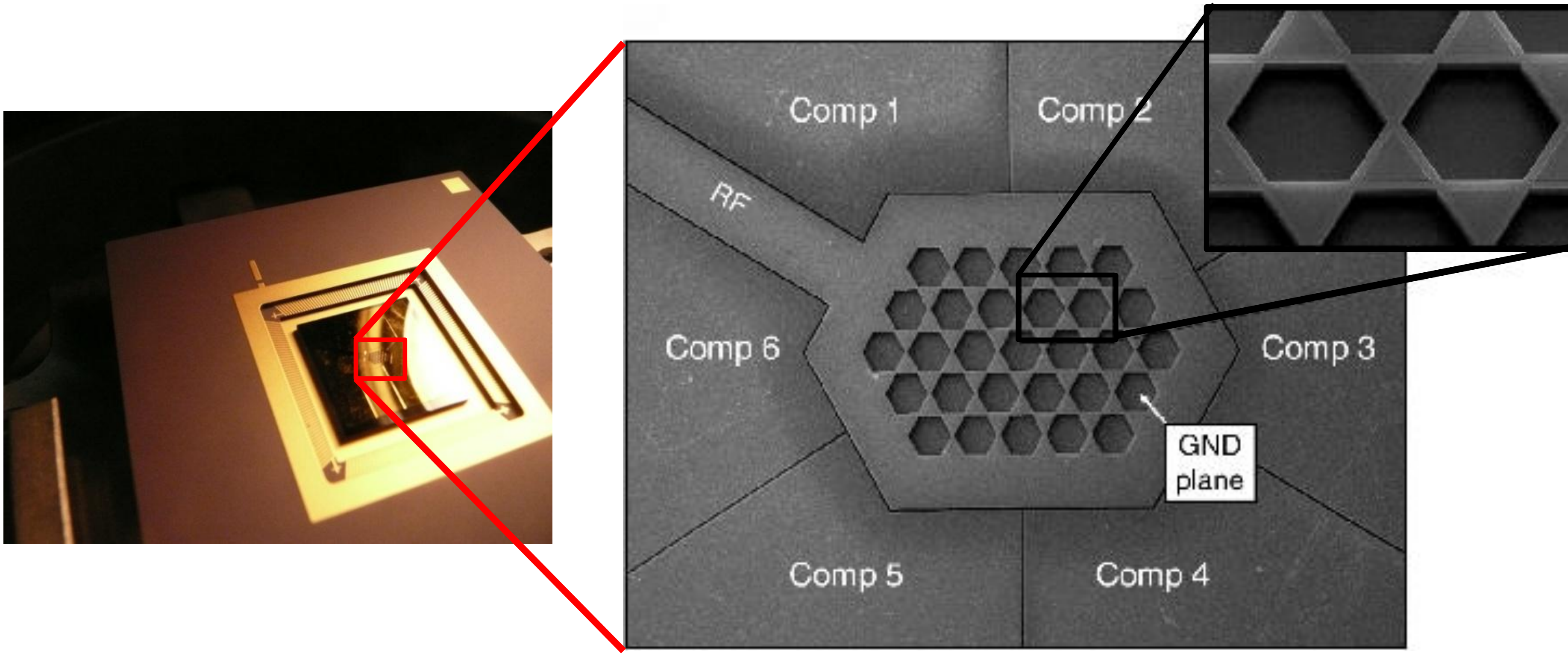
- Hexagon lattice with 6 nearest neighbours
- 270.5μm separation
- Scalable concept

- 156μm ion-electrode distance
- 60μm undercut



Two-Dimensional Ion Trap Array

- 2D Lattice Ion Trap



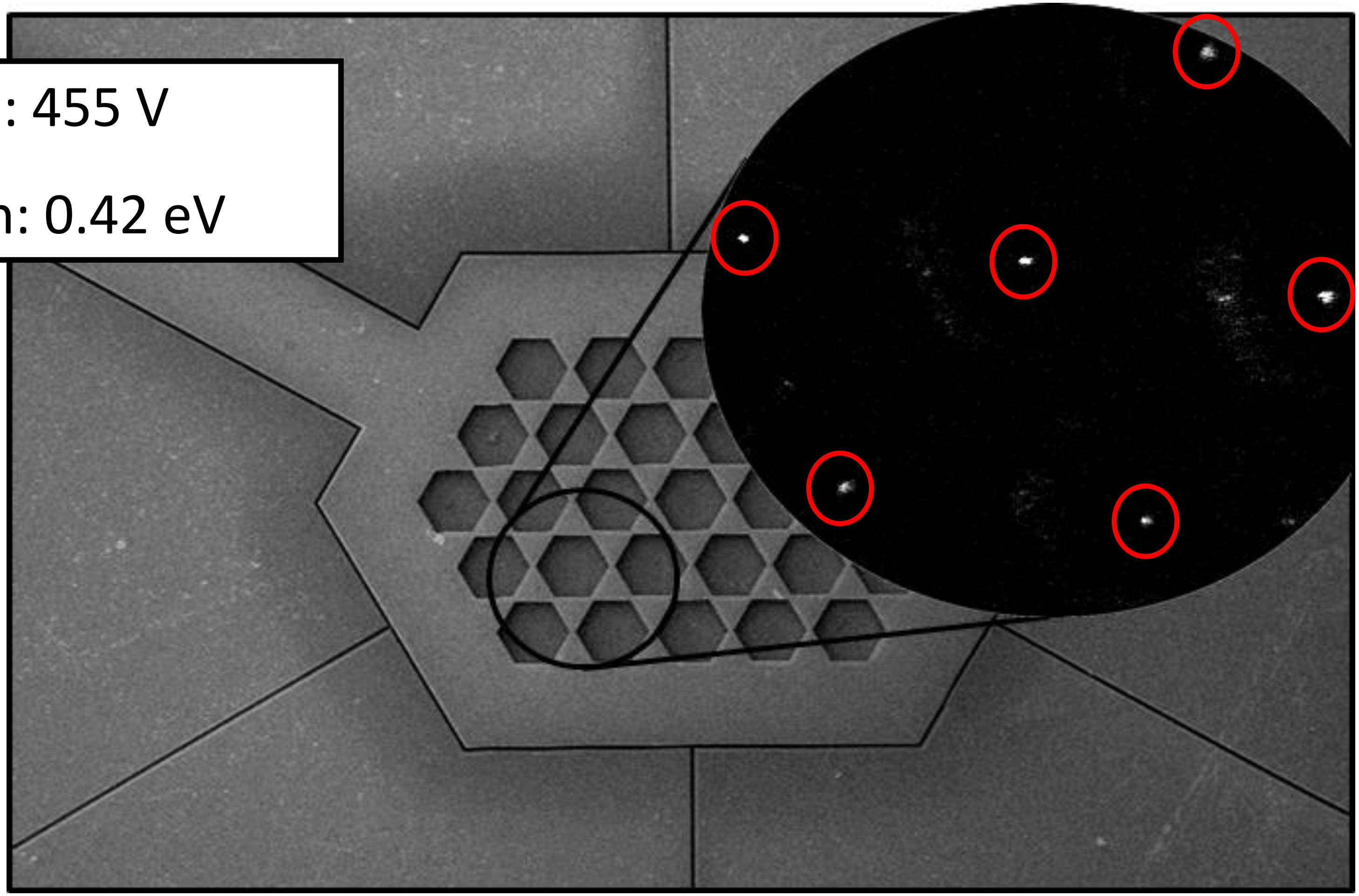
R. Sterling, H. Rattanasonti, S. Weidt, K. Lake, P. Srinivasan, S. C. Webster, M.Kraft and W. K. Hensinger, arXiv:1302.3781 [quant-ph]

Two-Dimensional Ion Trap Array

- 2D Lattice Ion Trap

RF voltage: 455 V

Trap depth: 0.42 eV



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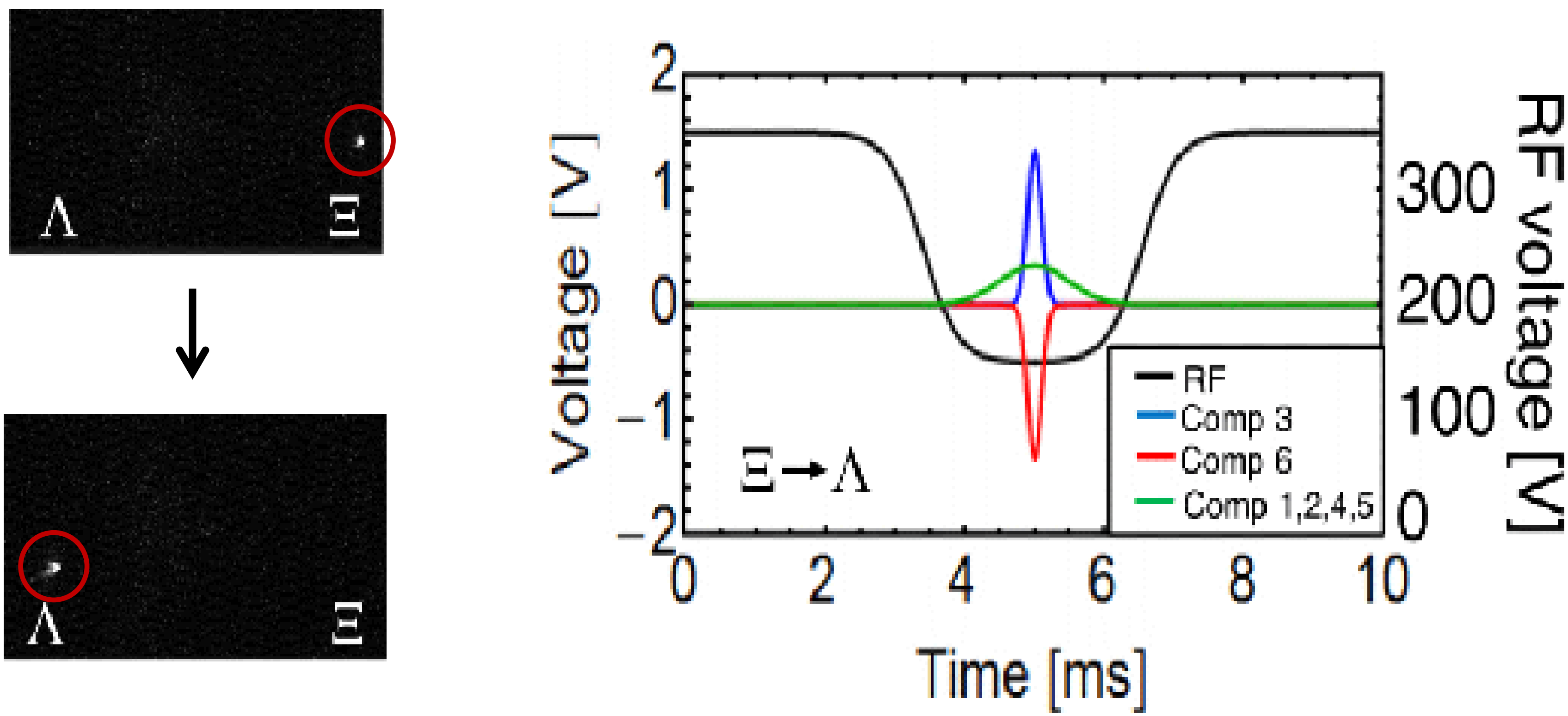
Two-Dimensional Ion Trap Array

- Site to Site Shuttling



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Optimization of Two Dimensional Ion Trap Arrays for Quantum Simulation

- Polygon Size and Separation
- Optimum Geometry $^{171}Yb^{+}$ Ions
- Fabrication Mask for Optimal Trap Design

Optimization of Two Dimensional Ion Trap Arrays for Quantum Simulation

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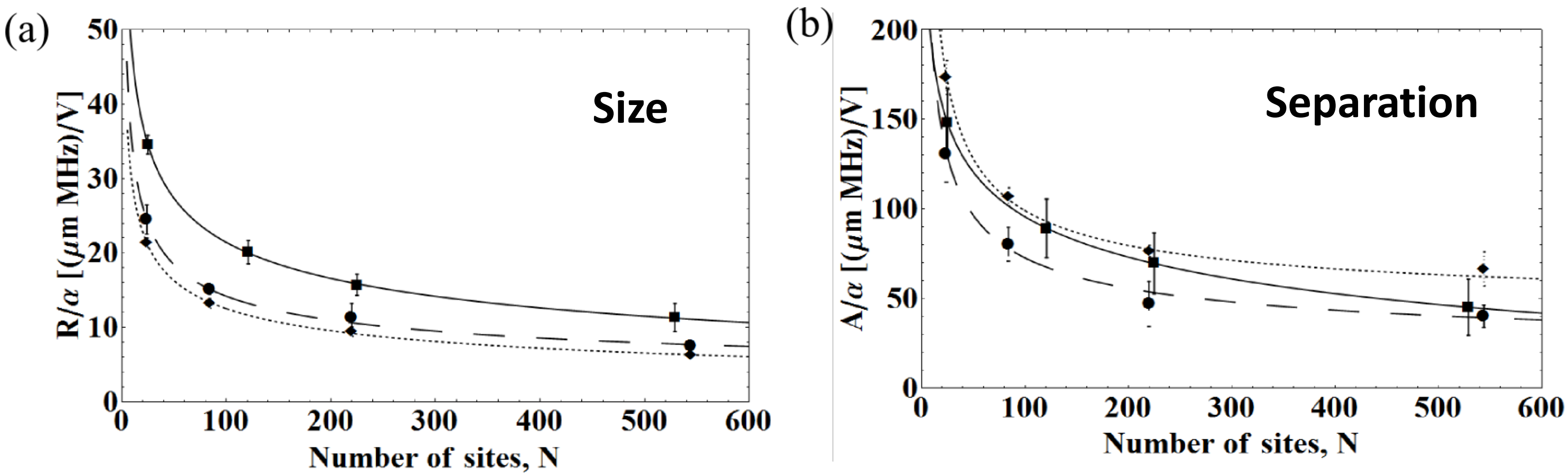

$$\alpha = {}^{V}/_{\Omega}$$

V= RF amplitude, Ω= RF Frequency

Lattice site radius and separation optimized highest interaction in square (squares), hexagonal (circles) and centre rectangular (diamonds) unit cell lattices and $^{171}Yb^{+}$ ions.

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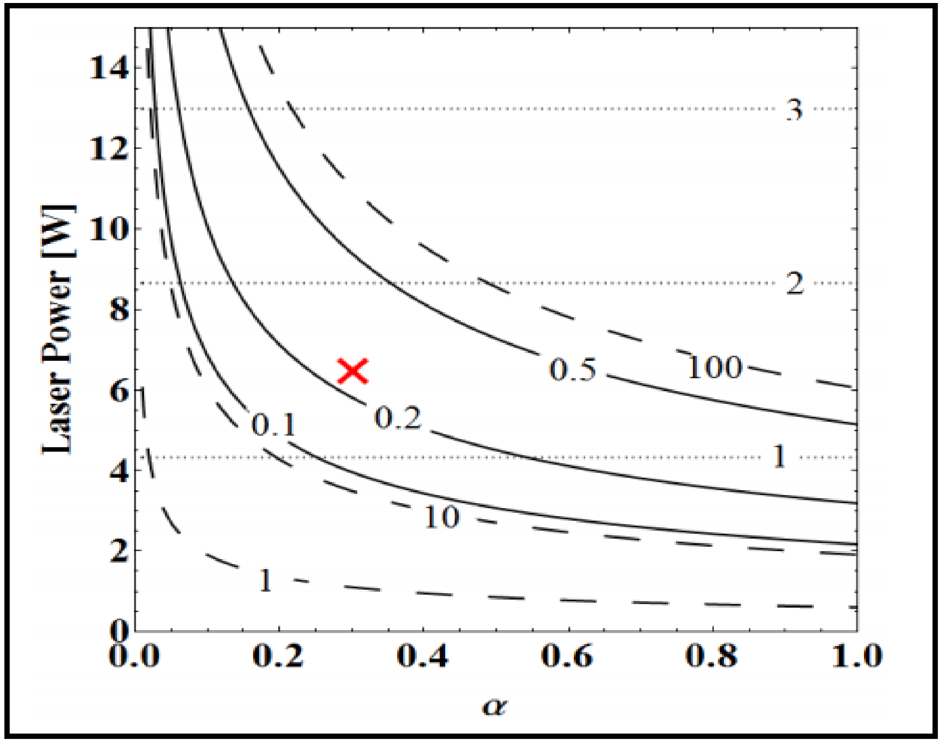
J. D. Siverns, S. Weidt, K. Lake, B. Lekitsch, M. D. Hughes and W. K. Hensinger, New J. Phys. 14, 085009 (2012)

Optimization of Two Dimensional Ion Trap Arrays for Quantum Simulation

Optimum Geometry $^{171}Yb^{+}$ Ions

- 30μm ion height
- 3x3 square unit cell ion trap array
- 14μm polygon radius
- 52μm separation



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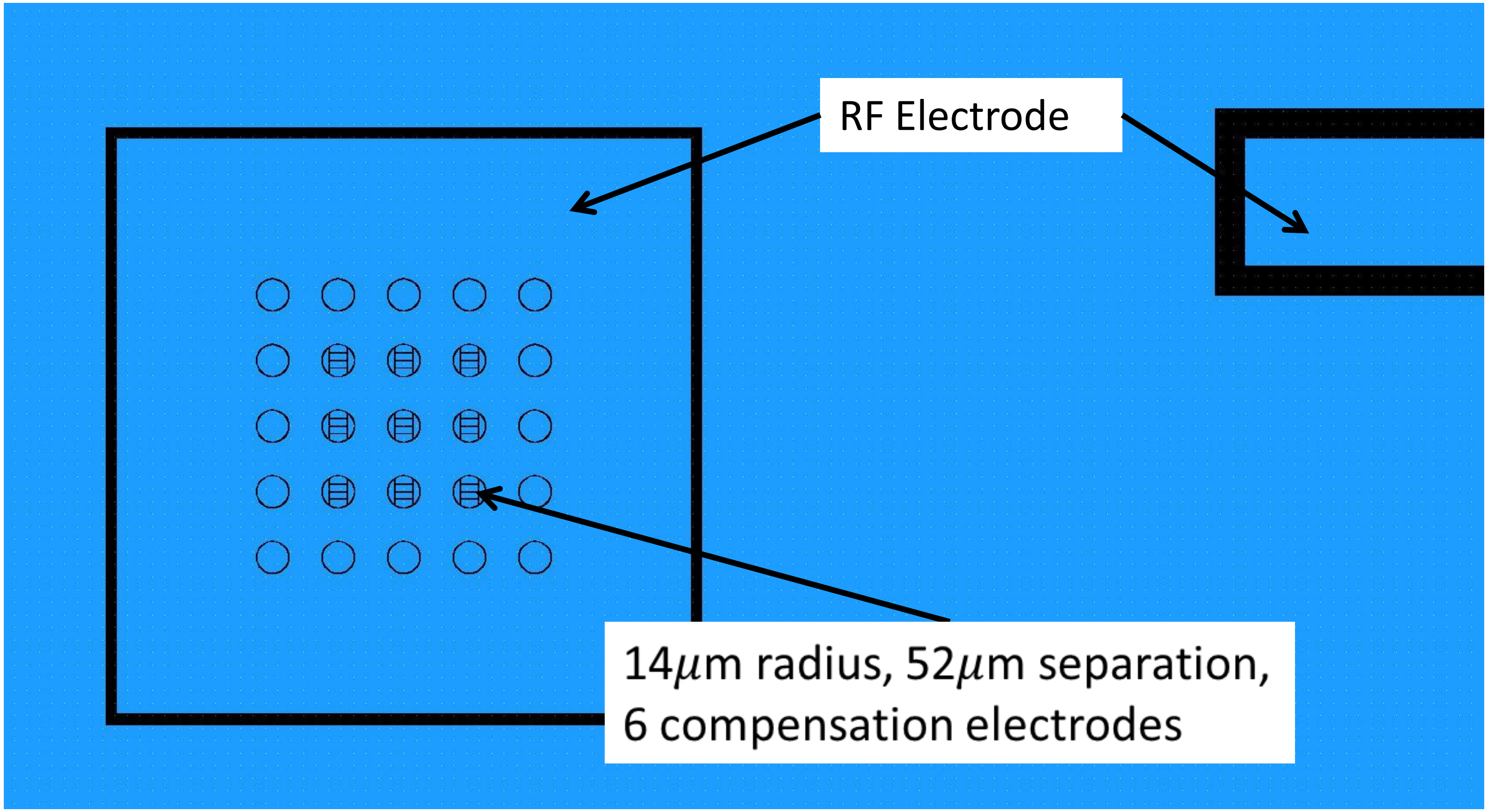
Optimization of Two Dimensional Ion Trap Arrays for Quantum Simulation

- Fabrication Mask for Optimal Trap Design

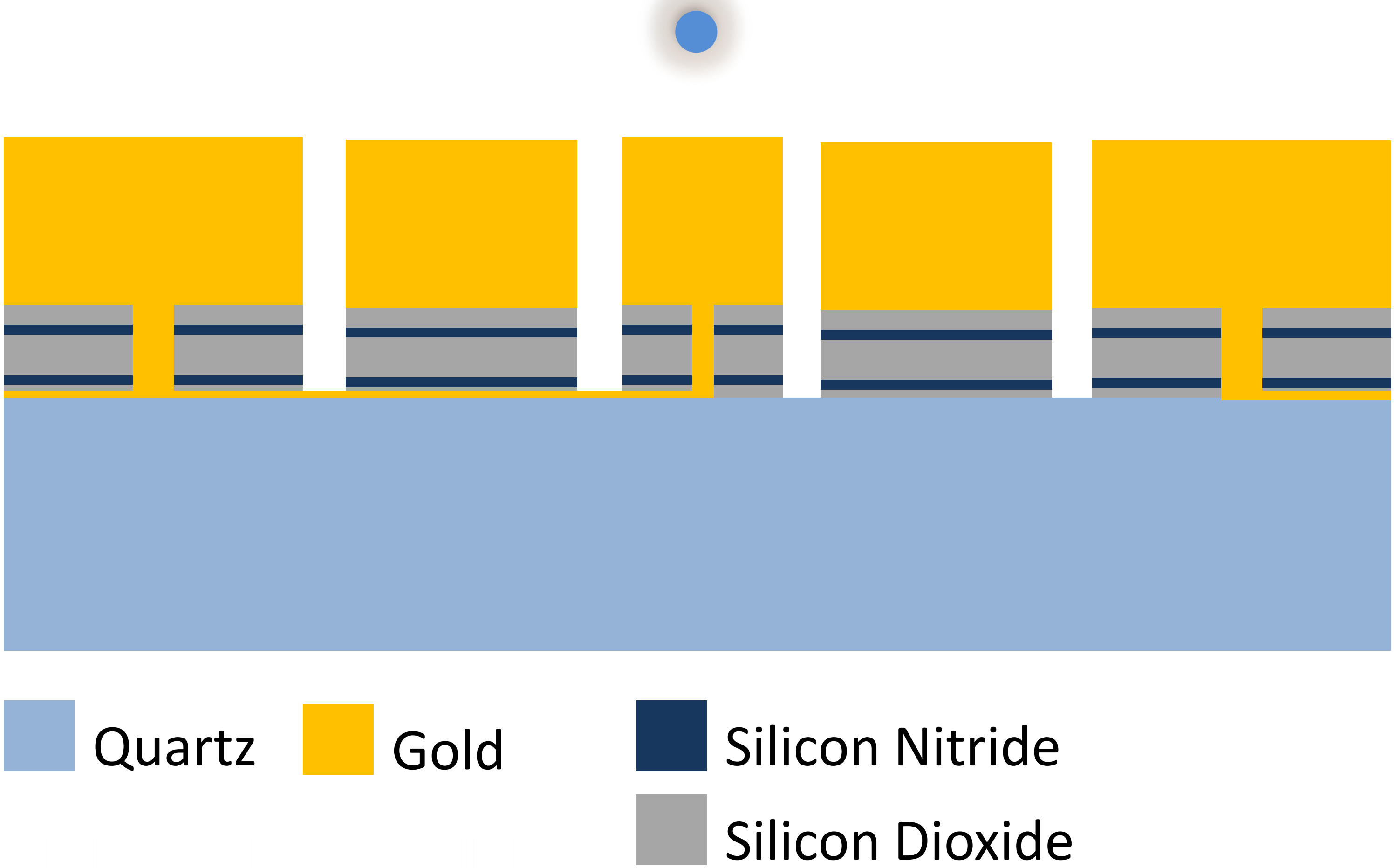


Advanced Microfabricated Ion Traps

- Multilayer Design with Buried Wires
- Isolated DC and RF Electrodes
- Ring Trap
- Y-Junction with Centre Segmented Electrodes
- Voltage Control System

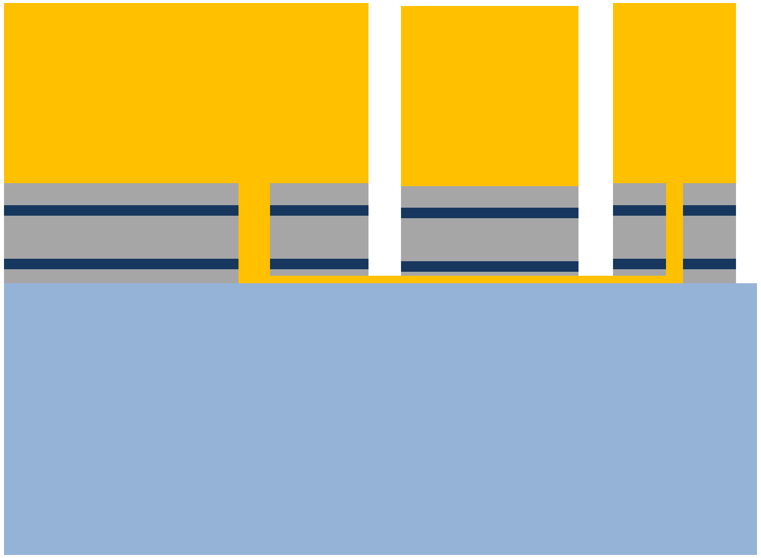
Advanced Microfabricated Ion Traps

- Multilayer Design with Buried Wires

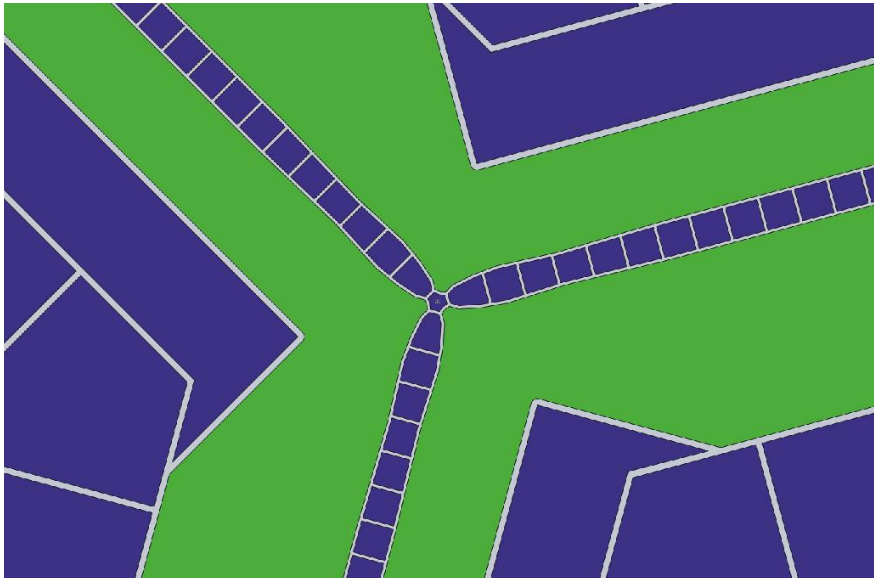


Advanced Microfabricated Ion Traps

- Isolated DC and RF Electrodes



Buried wires and vertical interconnect access (VIA) structures

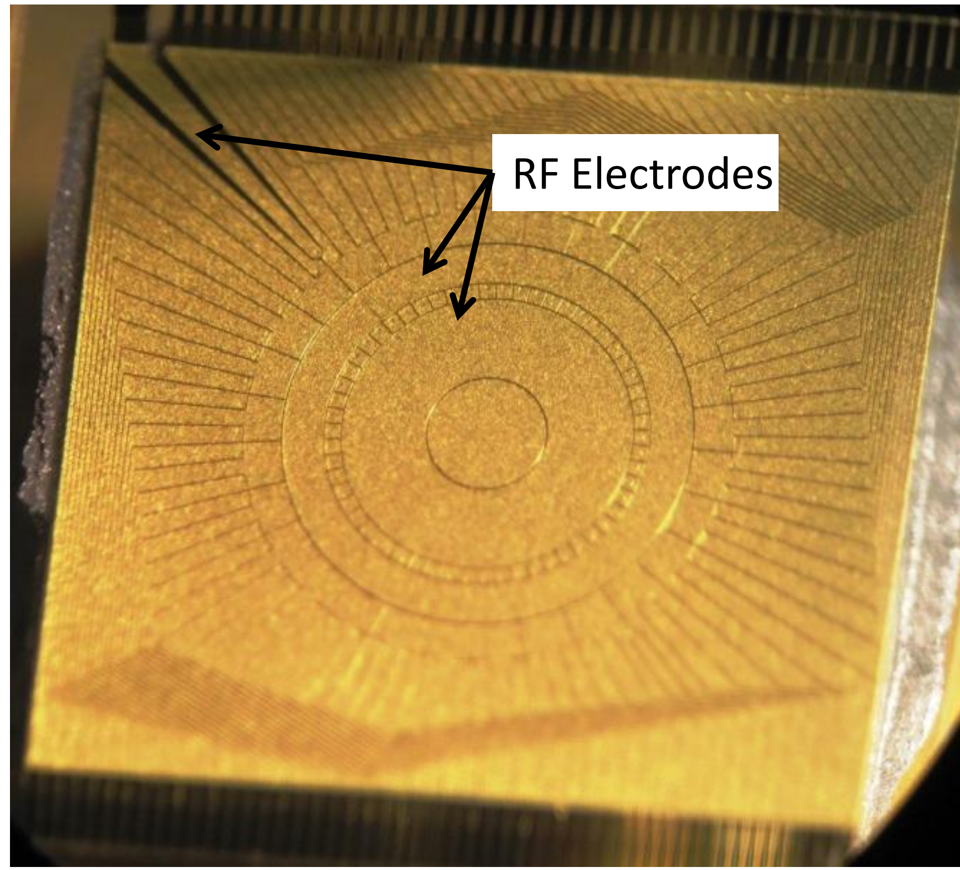


More advanced trap designs with isolated electrodes

Advanced Microfabricated Ion Traps

Ring Trap

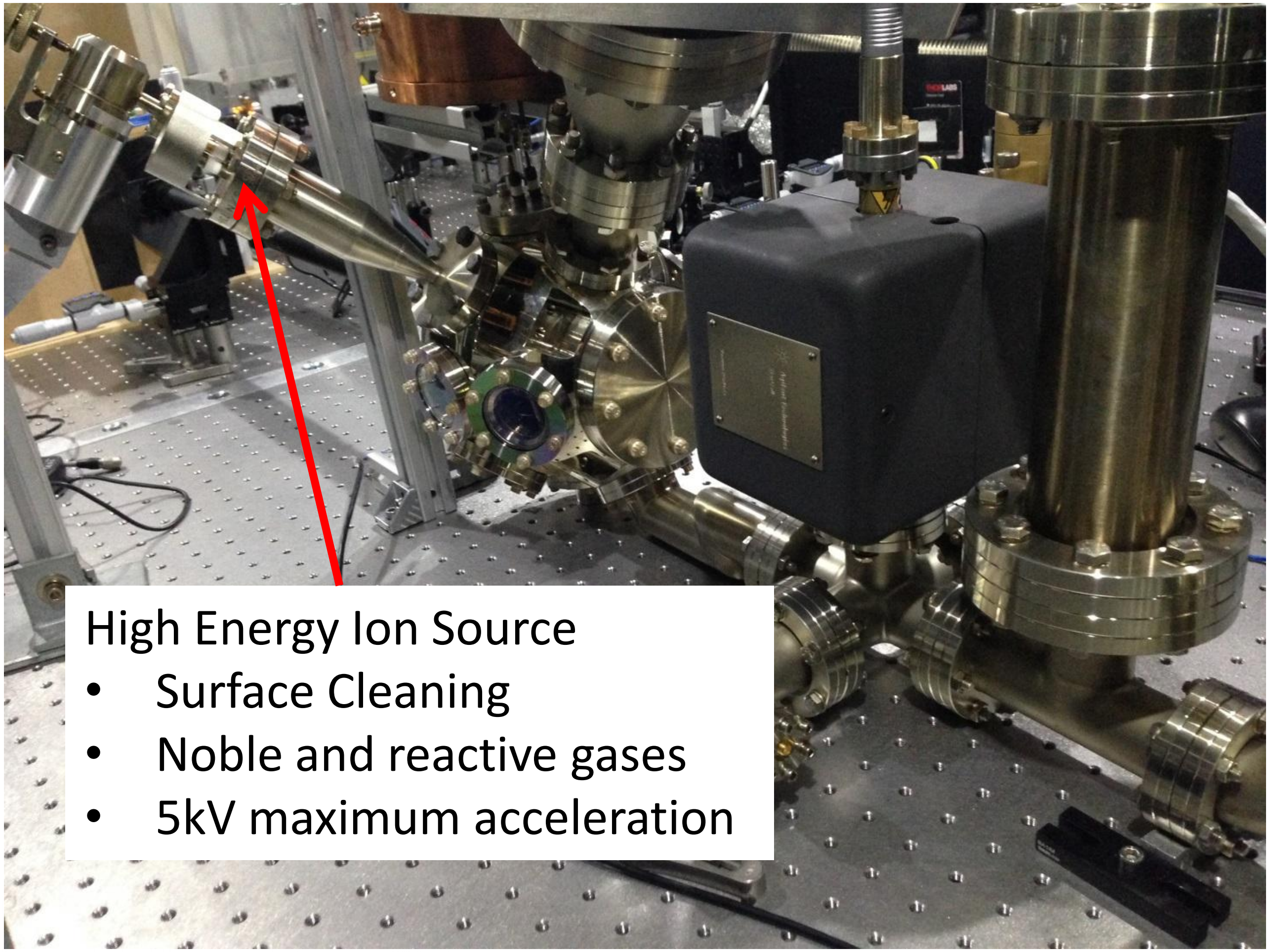
- Homogenous ion-ion spacing
- 1690µm radius
- 245µm ion-electrode distance
- Periodic Boundary Conditions
- Variety of experiments possible including Homogenous Kibble-Zurek-mechanism, Hawking radiation, space time crystals, superposition of quantum phase



M. D. Hughes, J. Maclean, C. Mellor and W. K. Hensinger

Advanced Microfabricated Ion Traps

- Ring Trap

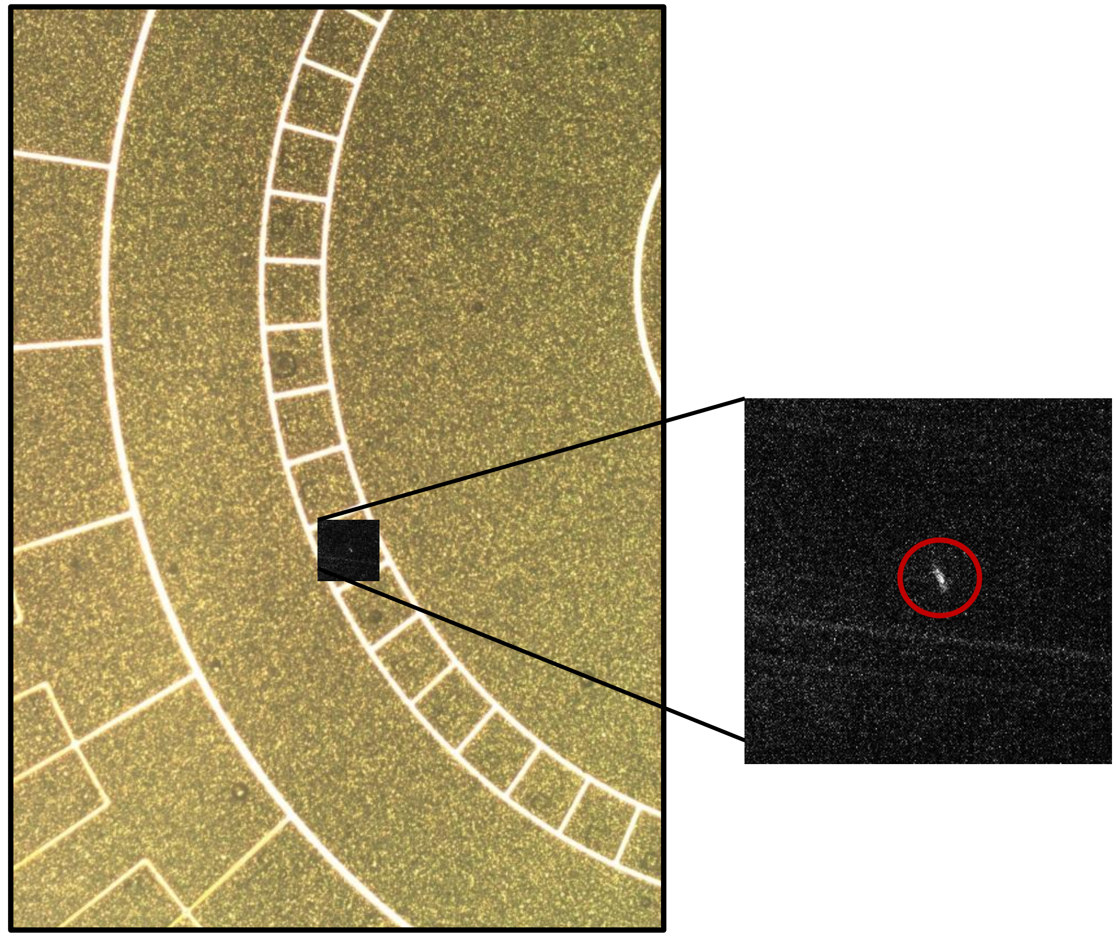


Advanced Microfabricated Ion Traps

Ring Trap

Simulated trap parameters:

- V_{RF} = 190 V
- $\Omega/2\pi$ = 13.6 MHz
- Trap depth = 0.1 eV
- $\omega_{r/z}/2\pi$ = 720 kHz
- $\omega_c/2\pi$ = 210 kHz



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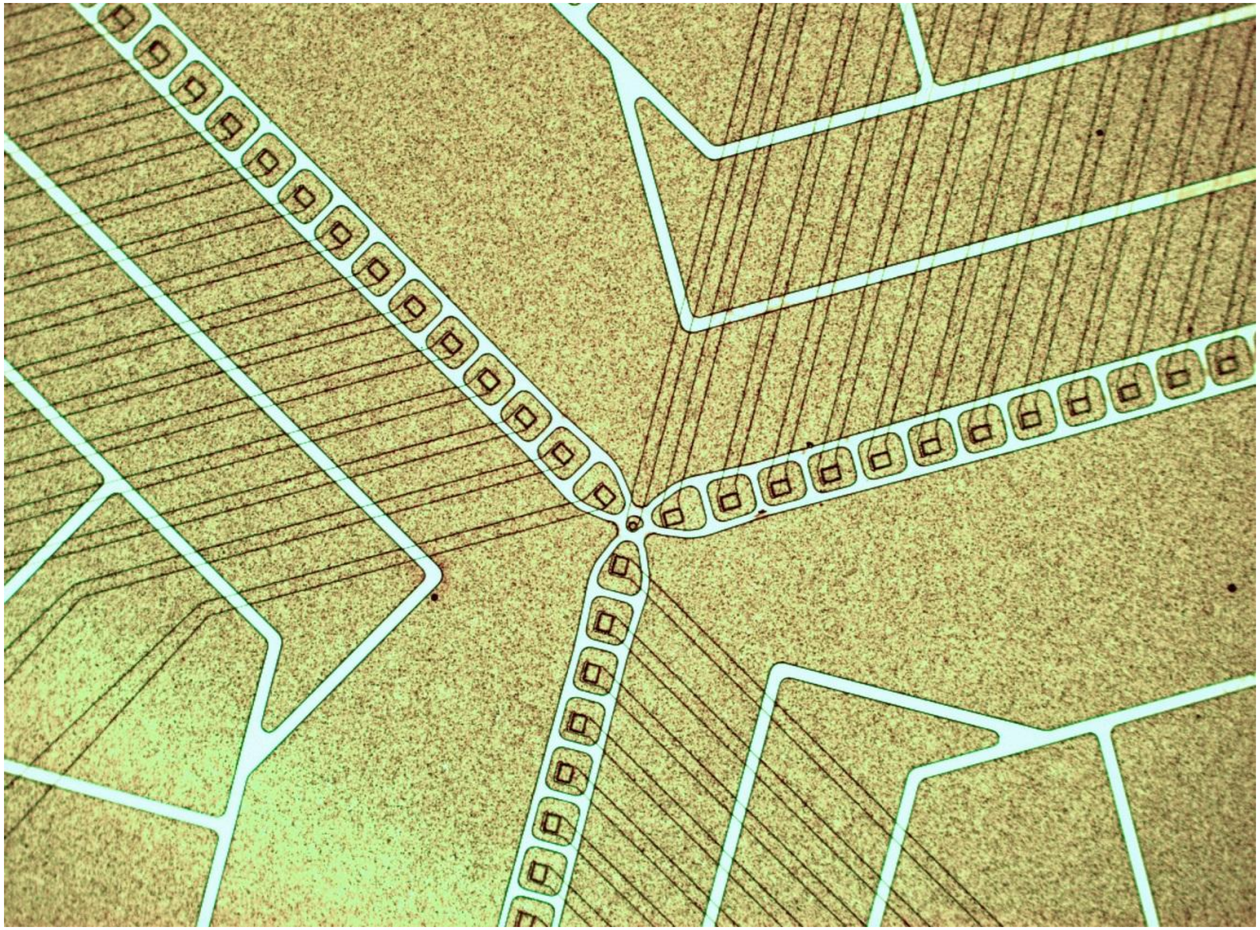
Advanced Microfabricated Ion Traps

- Y-Junction with Centre Segmented Electrodes



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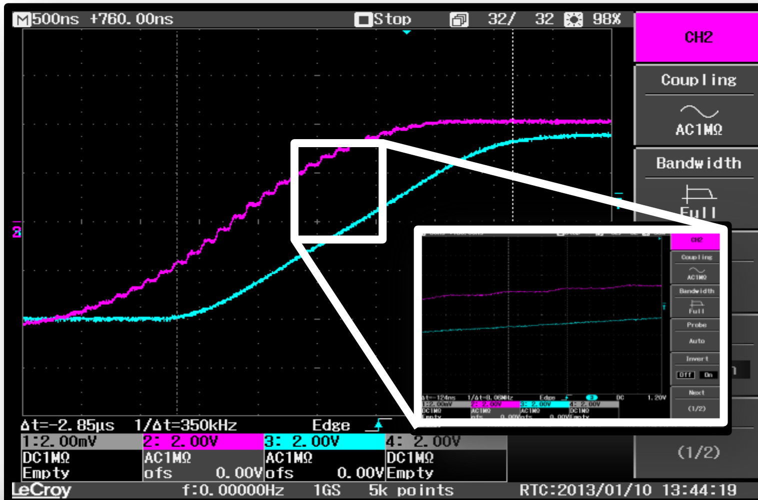
Advanced Microfabricated Ion Traps

Voltage Control System

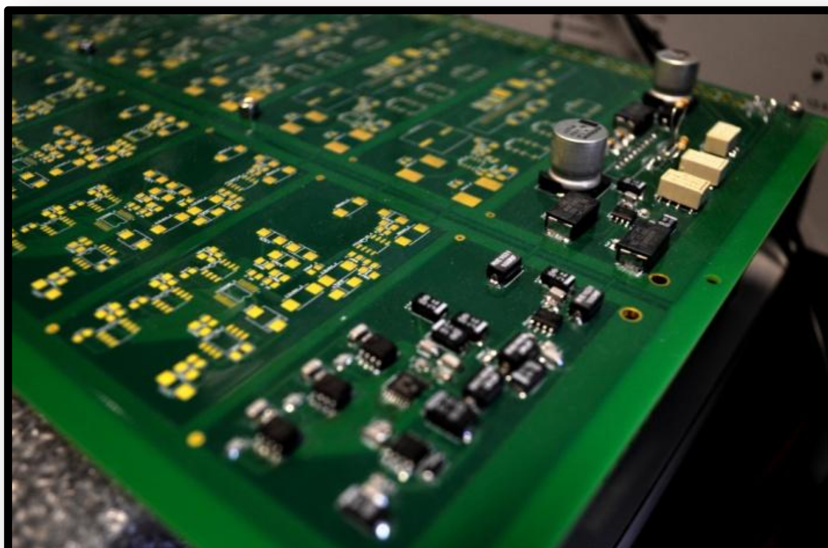
- 16 bit accuracy and 16MSPS update rate
- 90 channels
- Adjustable voltage range of ±100V and ±10V
- Low noise components and PCB design
- Digital, active and passive filters



Test Signal with 8MSPS update rate

Pink: Output from DAC

Green: Signal after active filter



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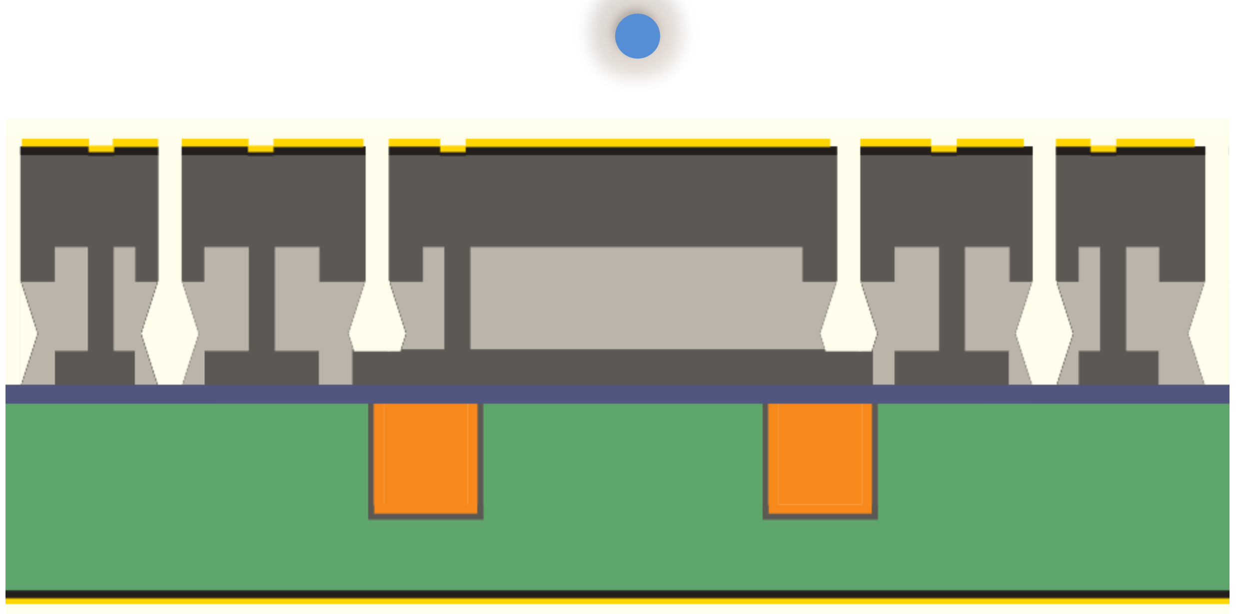
B. Lekitsch, G. S. Giri and W. K. Hensinger

Ion Traps with B-Field Gradient Structures

- Novel Fabrication Process
- Current-Carrying Wire Structures
- Thermal Transport System
- Advanced Trap Designs
- Microfabrication Results

Ion Traps with B-Field Gradient Structures

- Novel Fabrication Process

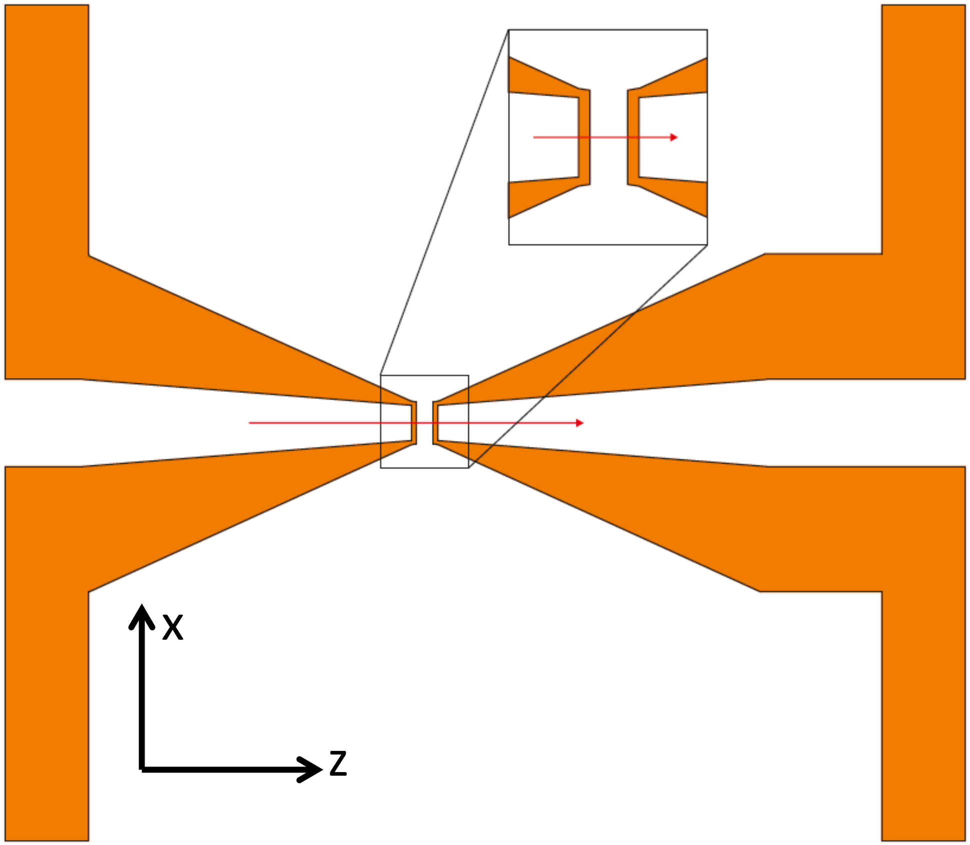


Diamond
Copper
Silicon Dioxide
Titanium
Gold
Silicon Nitride
Aluminium

Ion Traps with B-Field Gradient Structures

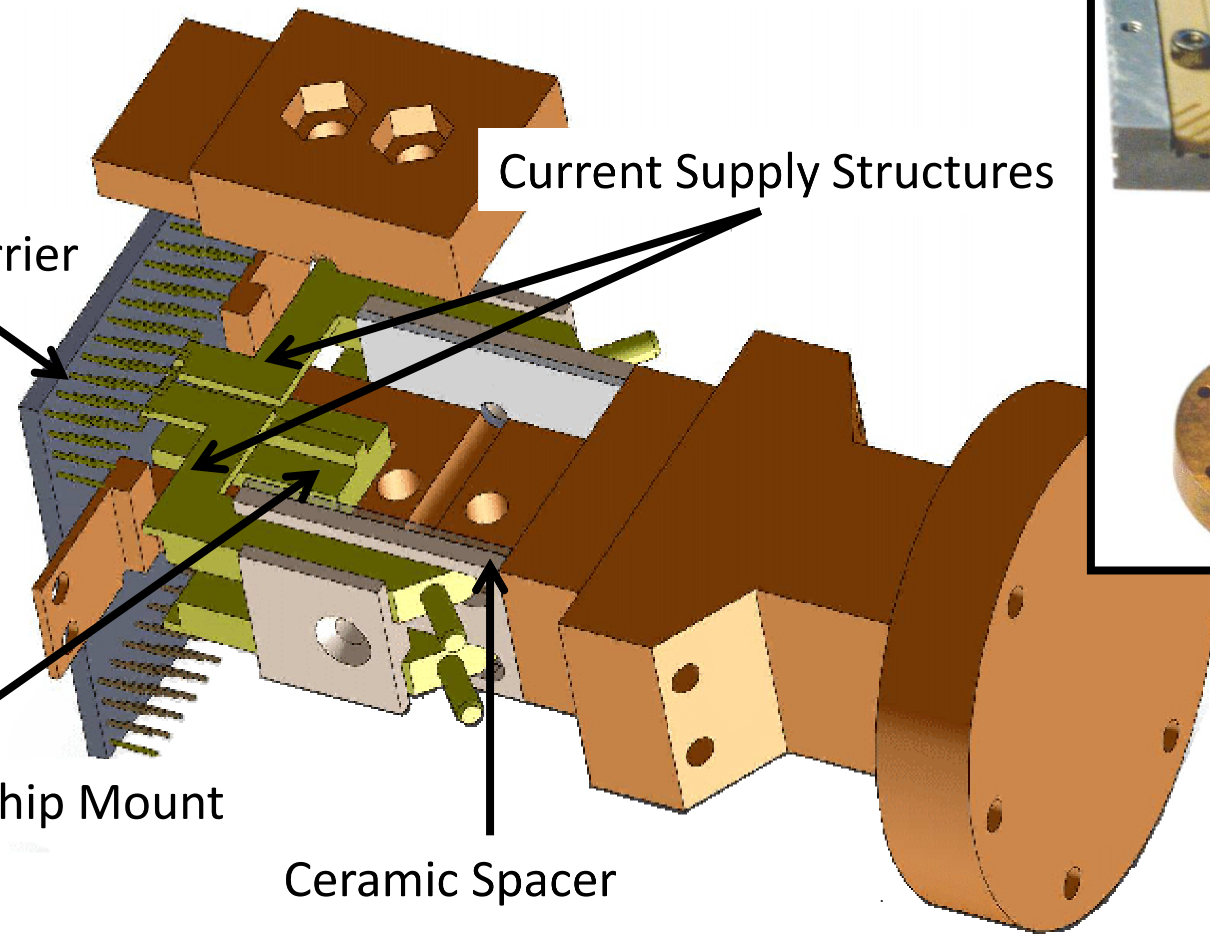
Current-Carrying Wire Structures

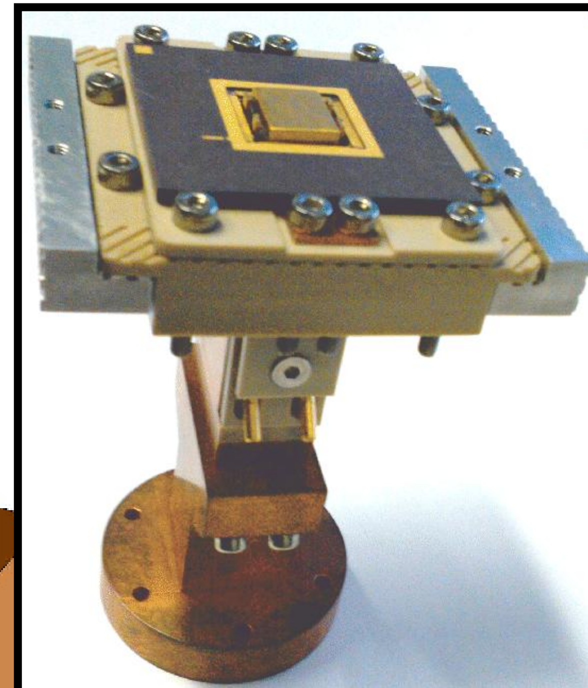
- 30µm thick and 40-1000µm wide
- Embedded in diamond substrate
- Gradients ~150 T/m for 12.5A at 60 µm ion height
- Traps with gradients along x and z direction are in production
- 5W of power dissipation



Ion Traps with B-Field Gradient Structures

- Thermal Transport System





Ion Traps with B-Field Gradient Structures

- Advanced Trap Designs

Trap	Ion height (um)	Current – carrying wires	Special Features
Linear trap	60	yes	
	120	yes	Loading slot
	165	-	Detection slot
	250	-	Large number of control electrodes
X-junction	100	yes	
	200	-	Loading slot
Ring trap	35	yes	
	100	yes	
3 x 3 array	30	-	
	50	-	
	100	-	

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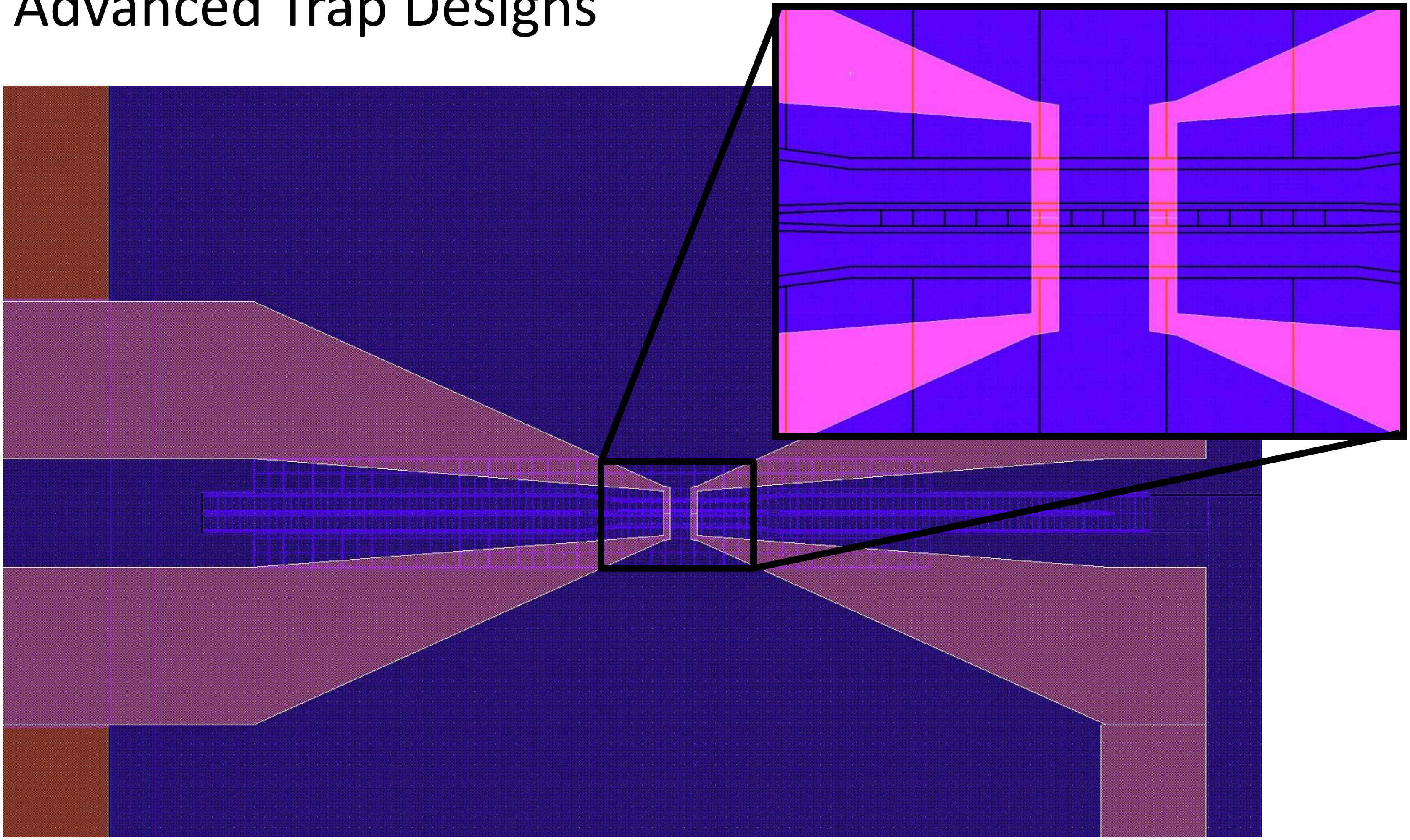

Linear trap design with current-carrying wires

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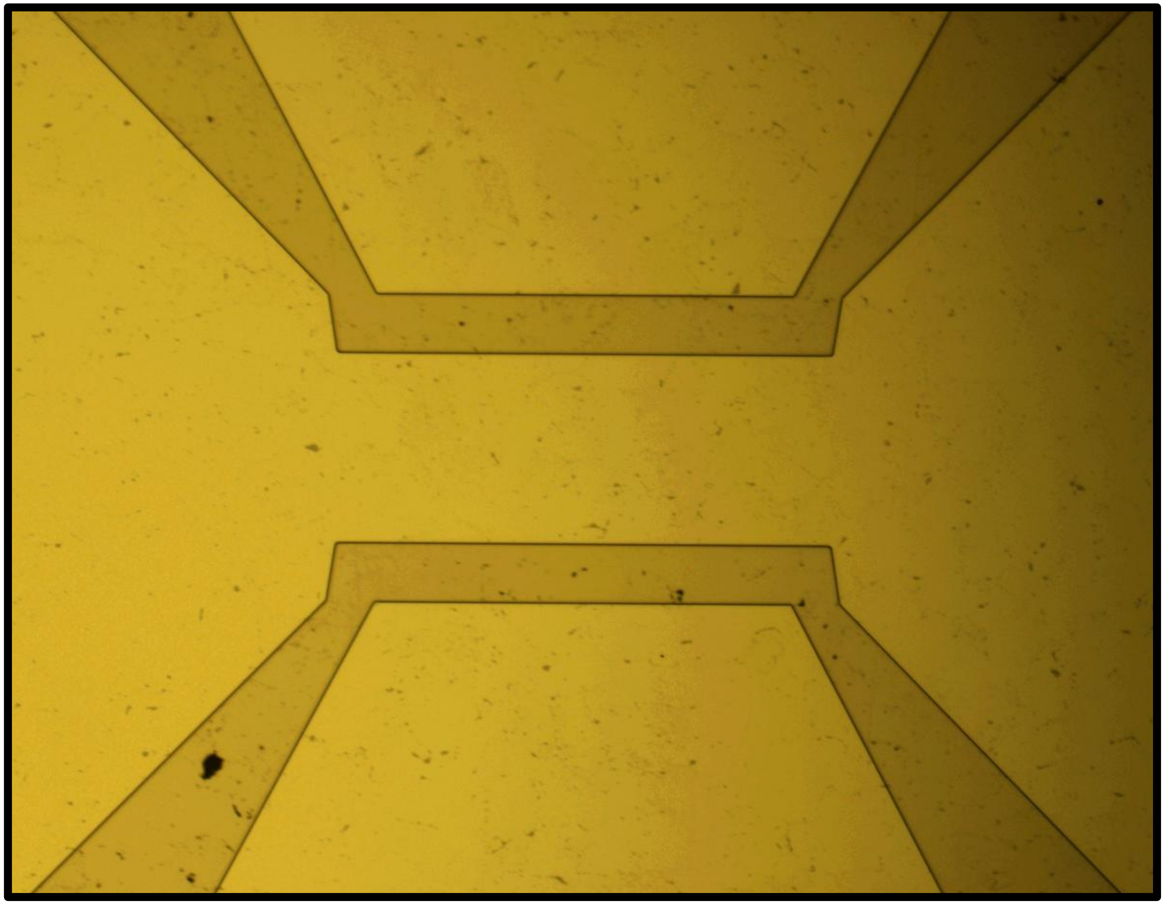
Ion Traps with B-Field Gradient Structures

- Microfabrication Results



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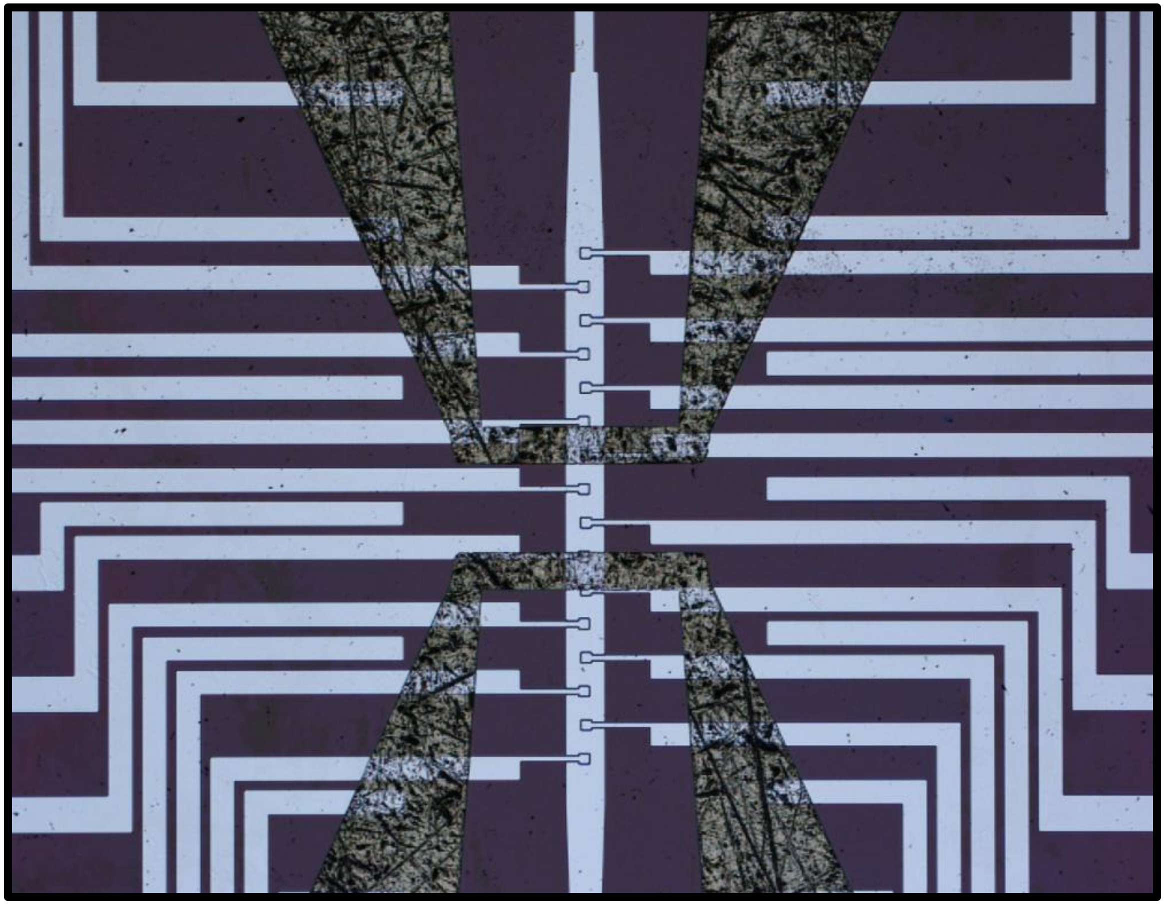

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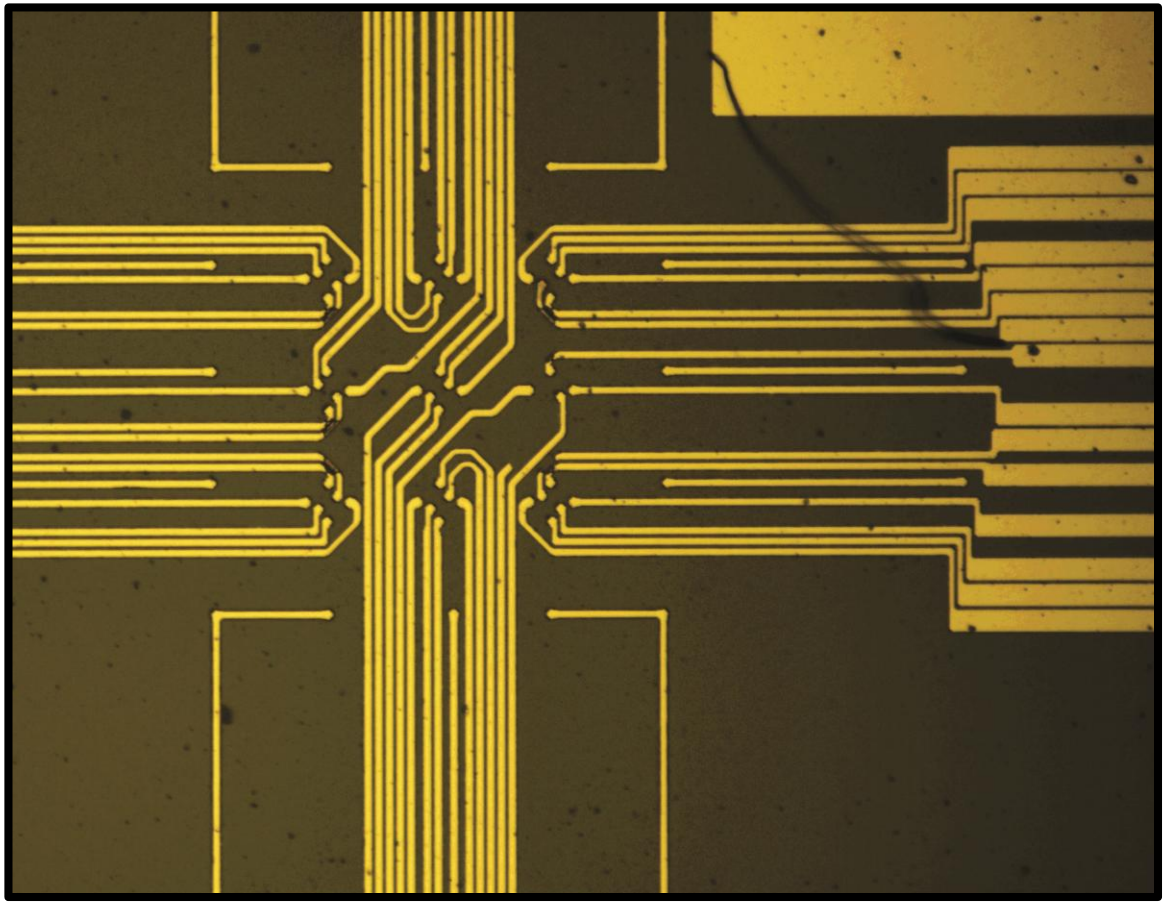

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Cryogenic Ion Trapping

- Cryogenic Vacuum System
- Ion Chip Mount with Permanent Magnets
- Ion Trap with Integrated Niobium Nitride High-Q Resonator
- Flat Multipole Ion Trap

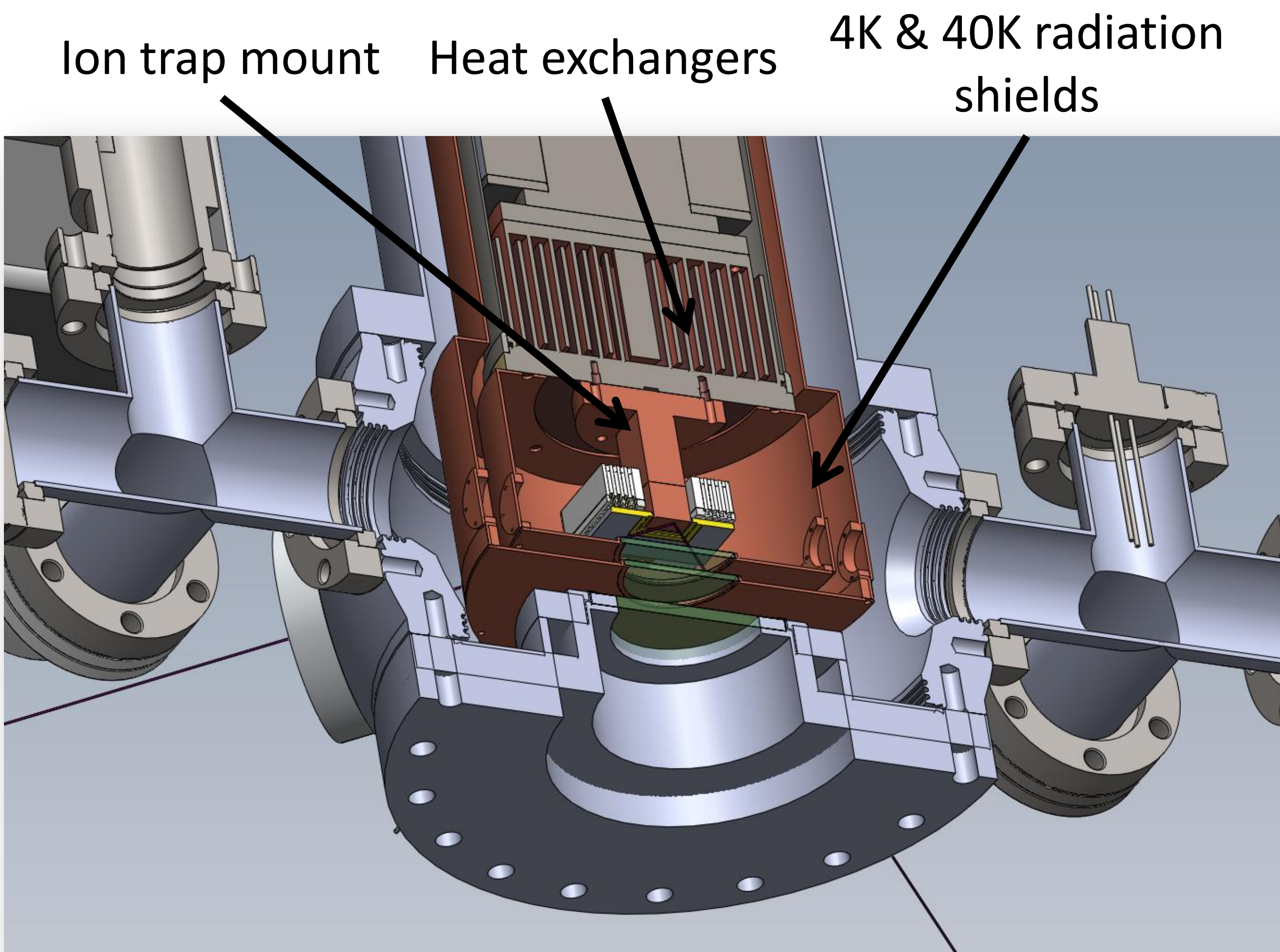
Cryogenic Ion Trapping

Cryogenic Vacuum System

- Gifford-McMahon cryocooler
- Ultra low vibration interface ~10nm
- Helium exchange buffer gas

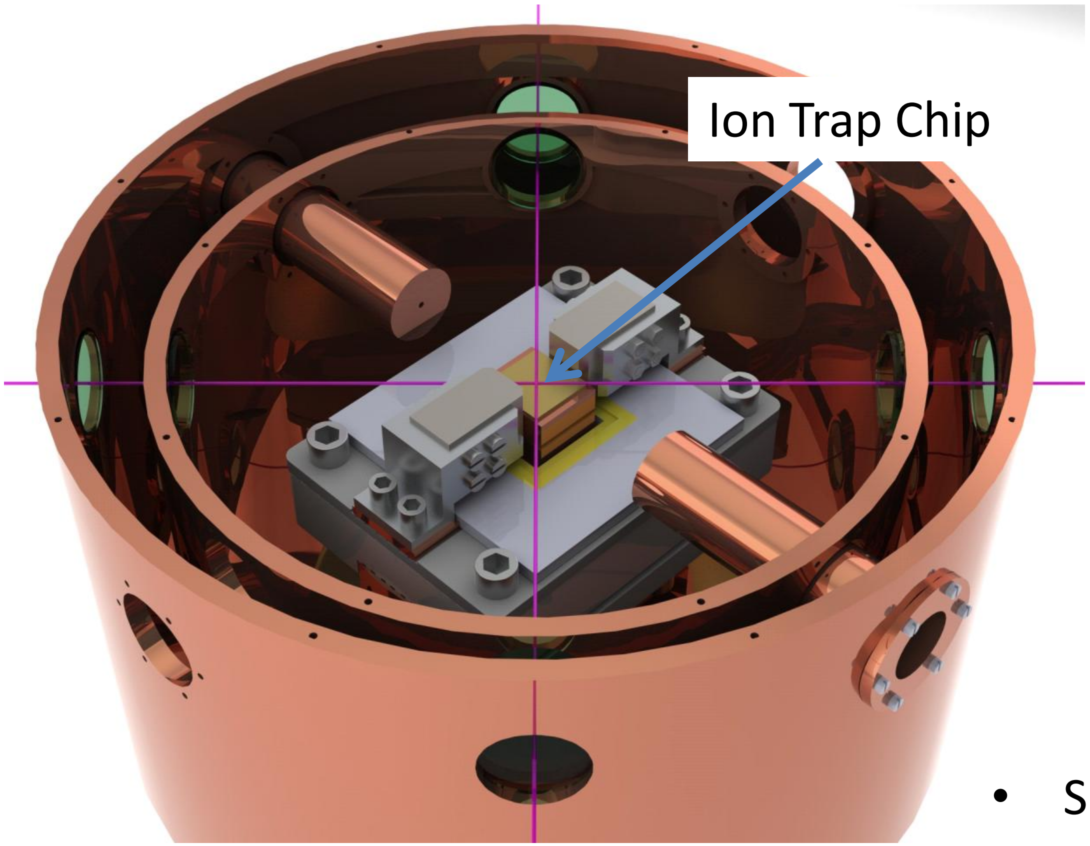
Cryogenic Ion Trapping

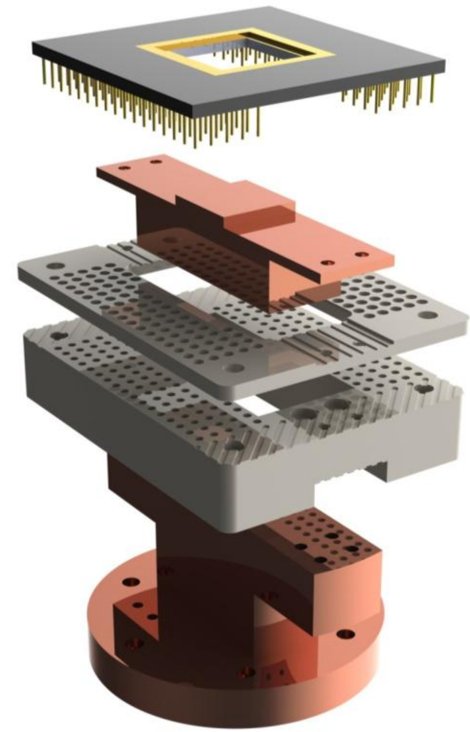
- Cryogenic Vacuum System



Cryogenic Ion Trapping

- Ion Chip Mount with Permanent Magnets

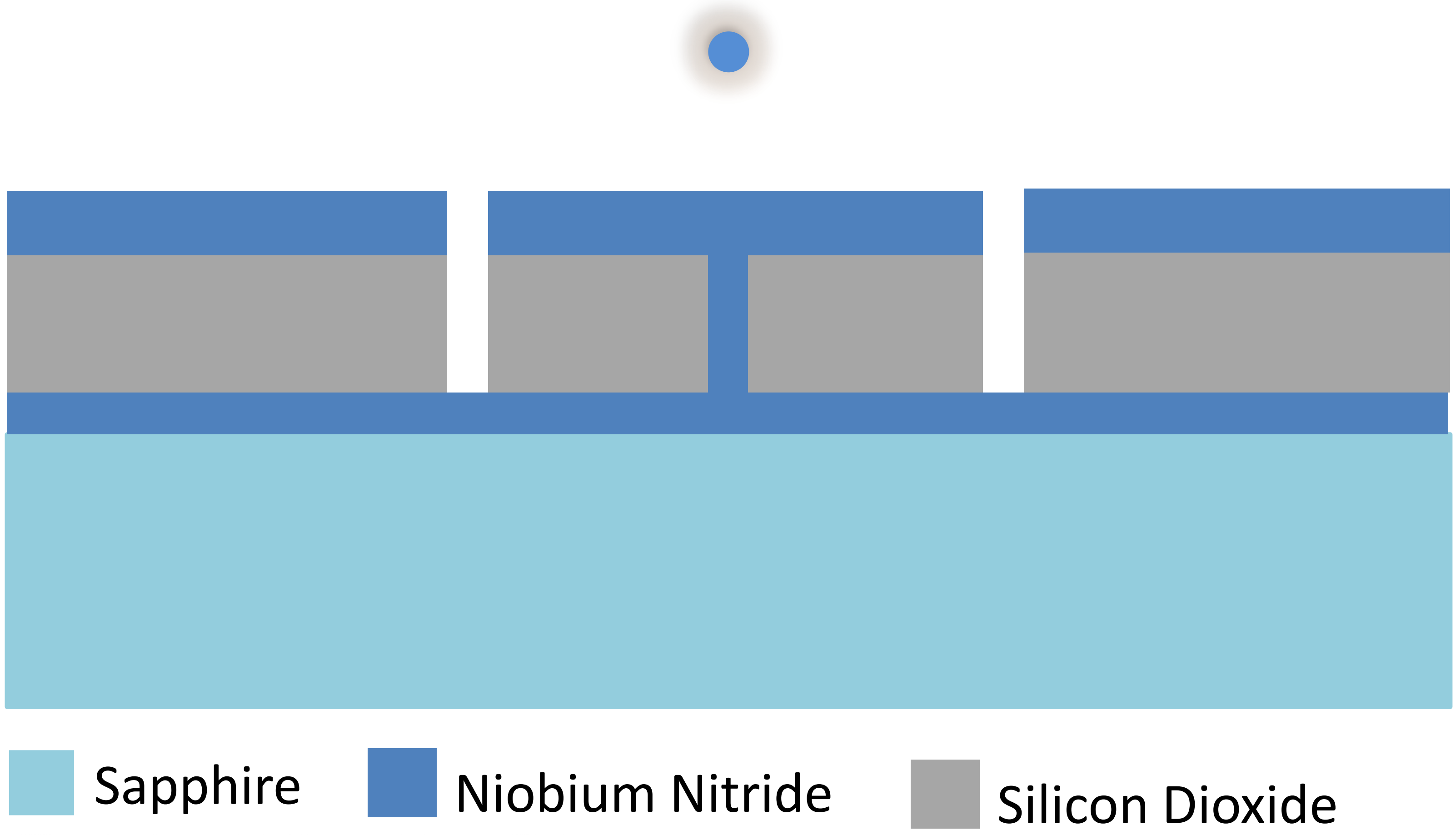




- Samarium Cobalt magnets
- Approximately 75 T/m gradient at the ions position

Cryogenic Ion Trapping

- Ion Trap with Integrated Niobium Nitride High-Q Resonator



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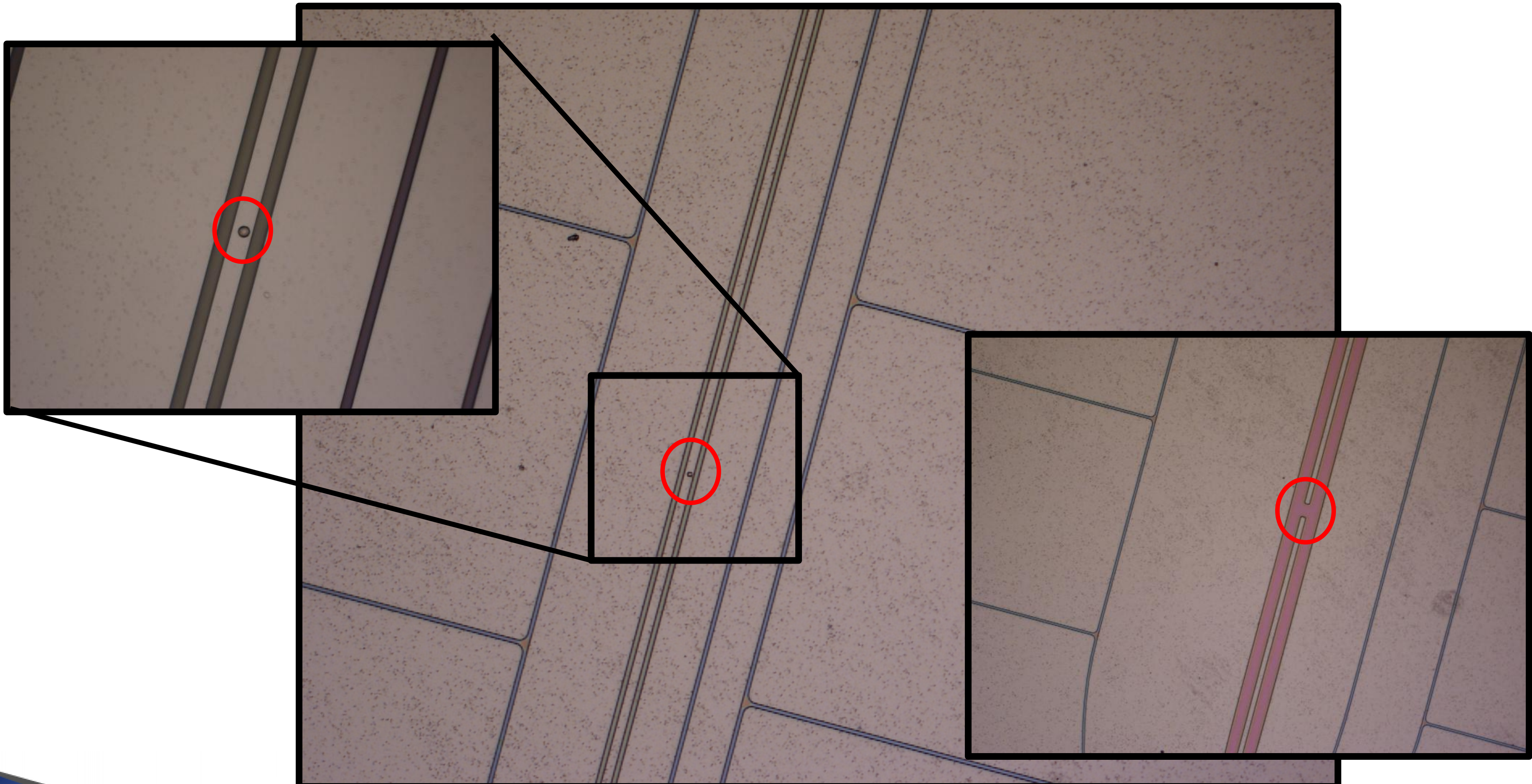

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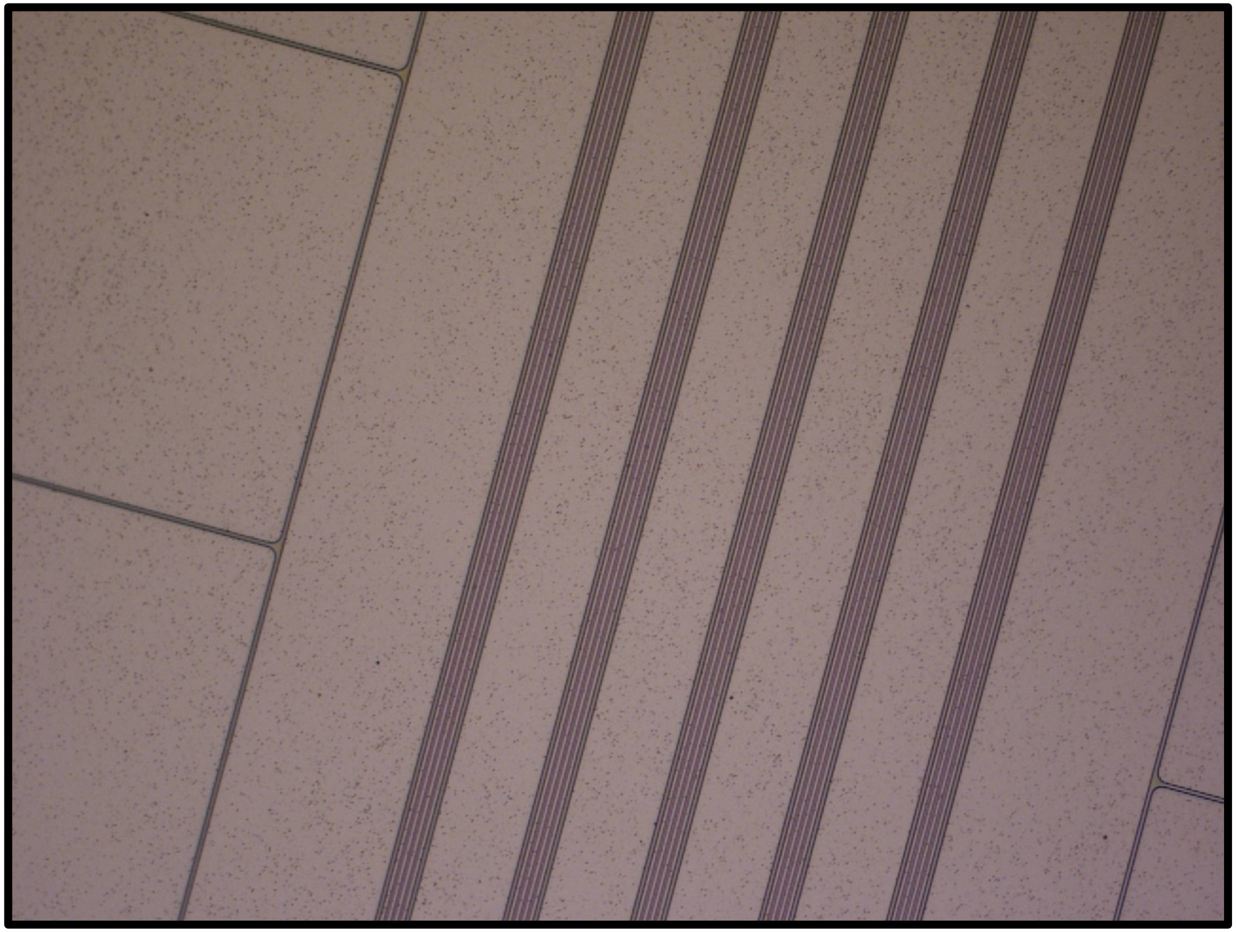
Cryogenic Ion Trapping

- Flat Multipole Ion Trap



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Summary

- Development of two-dimensional array and ring trap
- Variety of novel fabrication processes
- Advanced multilayered trap designs
- Cryogenic trapping and surface cleaning capabilities

The IQT Group

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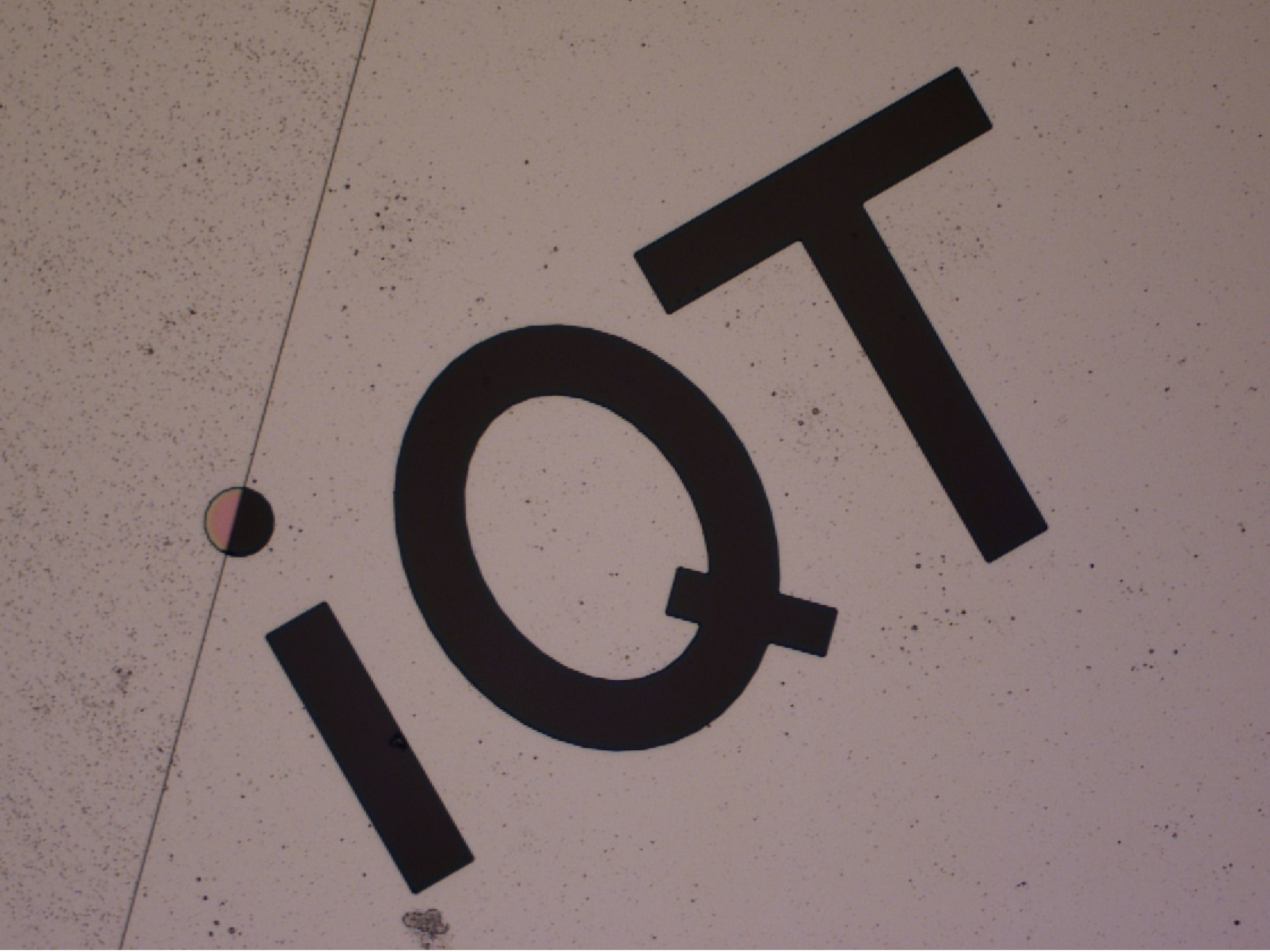
iQIT SEVENTH FRAMEWORK PROGRAMME

European Commission MARIE CURIE ACTIONS

IOTA cost European Science Foundation

The Nuffield Foundation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