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Segmented Ion Traps for Quantum Computing

Ion Trap Quantum Computing Group - Department of Physics - University of Oxford

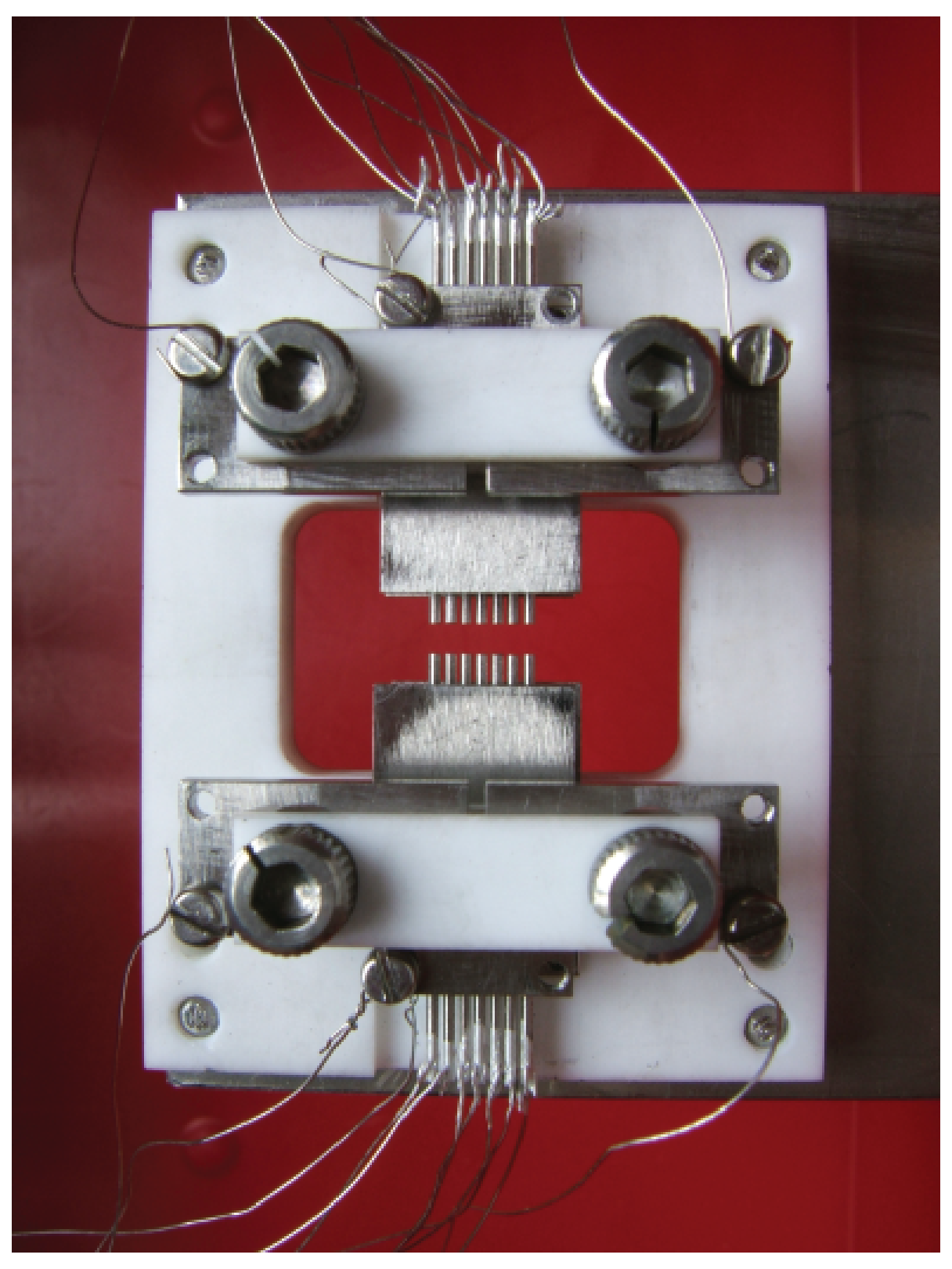
Intermediate Scale Trap

Designed to investigate separation of ions in a regime where ion-electrode distances are large enough to give low motional heating, with a geometry optimised for a high octupole coefficient for a given breakdown voltage.

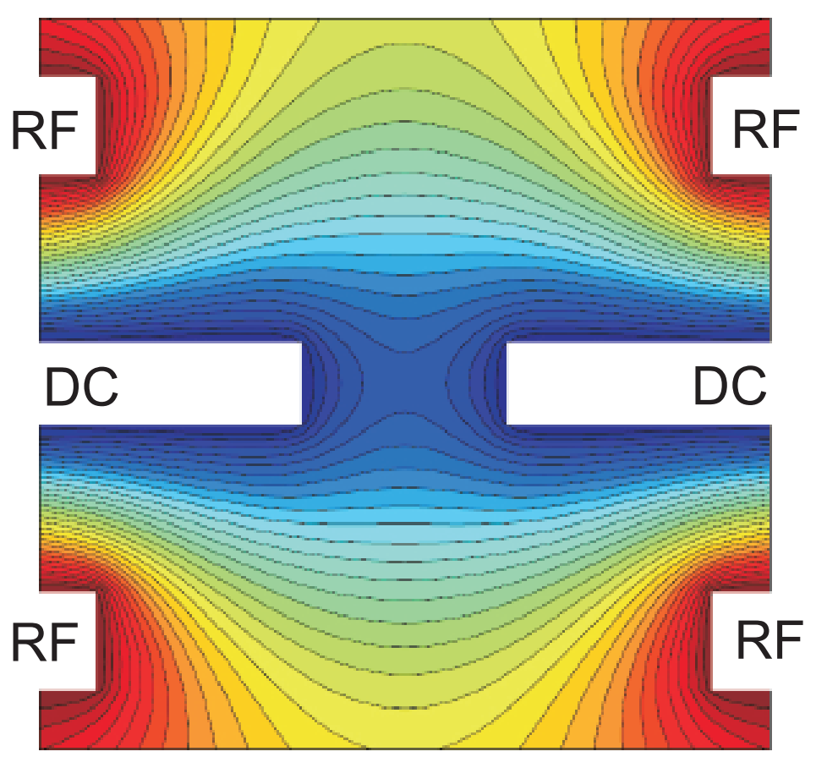
Fabricated by Uni. Liverpool (S. Taylor & B. Brkic)

Demonstrated:
- Photoionization loading
- Ion storage time of >1day
- Secular frequencies measured by electrode 'tickling'
- Doppler cooling and crystallisation of up to 3 ions
- Micromotion compensation via RF correlated photon counting
- Heating rate by doppler re-cool method with preliminary data giving O(1K/s)

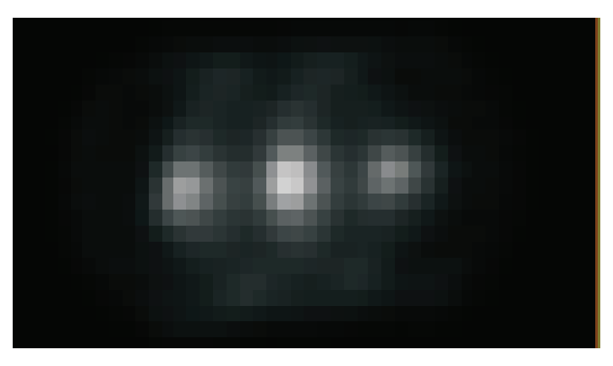
Future:
- Sideband cooling and heating rate measurement
- Ion shuttling and separation



RF field potentials in cross-section of the trap.



Ion-Electrode Distance	700μm
RF Drive	5.8 Mhz @ 300V_{pp}
Trap Depth	4.8eV
Radial Secular Freq.	1.6MHz

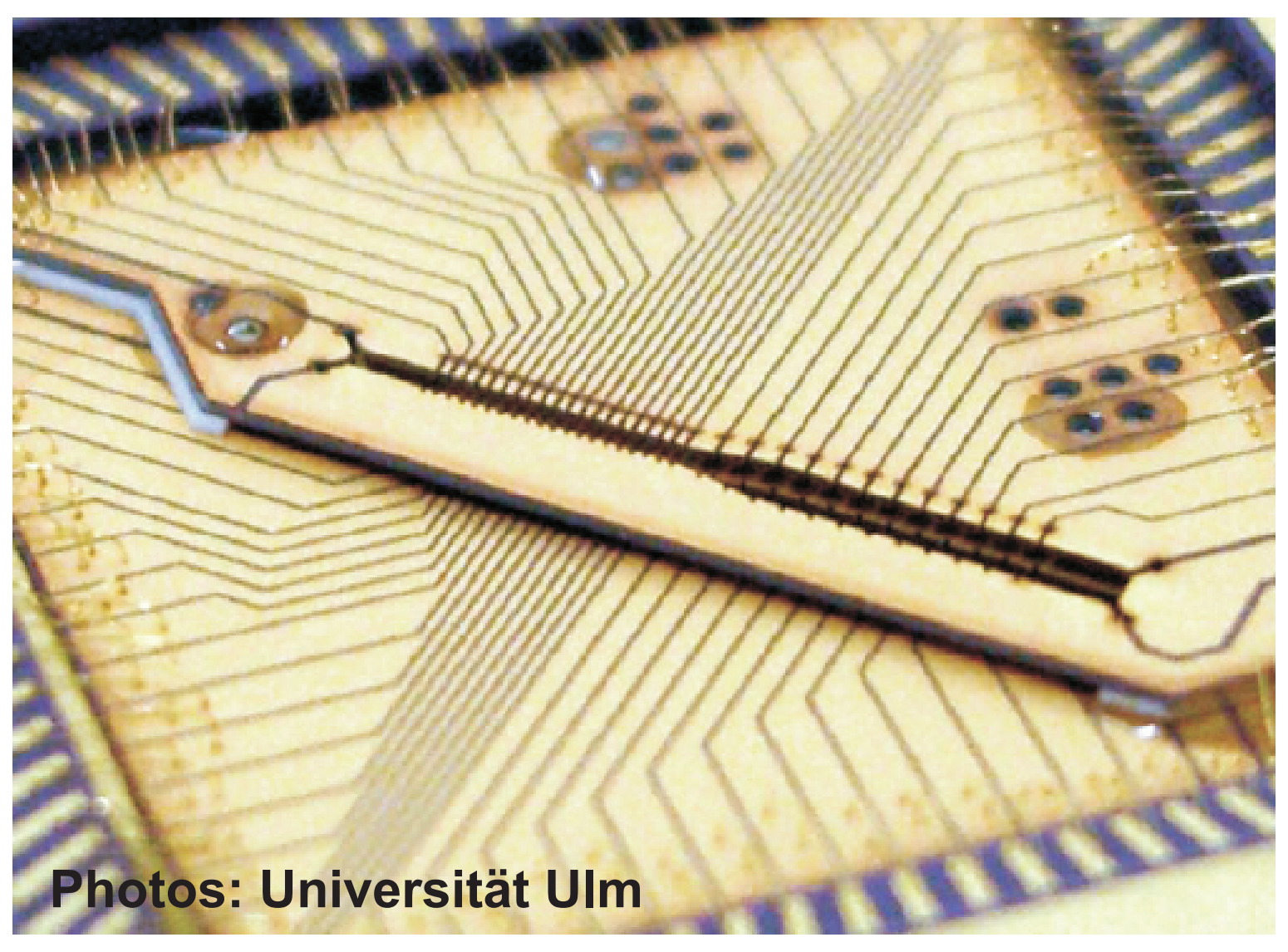


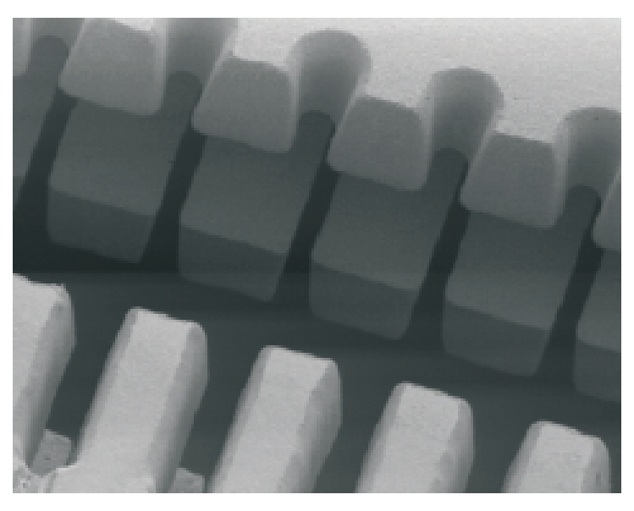
Three ion crystal (left) loaded with ~1MHz radial and ~400kHz axial frequencies.

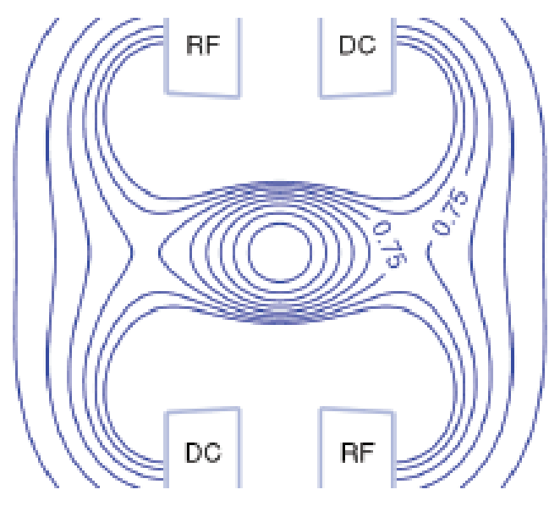
EU Microtrap Project

A collaboration between National Physical Laboratory (UK) and the Universities of Aarhus, Innsbruck, Oxford, Siegen and Ulm. Aimed at developing an EU technology capability in trapped ion microstructures for application to quantum information science.

Photos and parameters below from working prototype of the project's first trap at Ulm University. See Schulz et al. New Journal of Physics 10 (2008) 045007 for details.

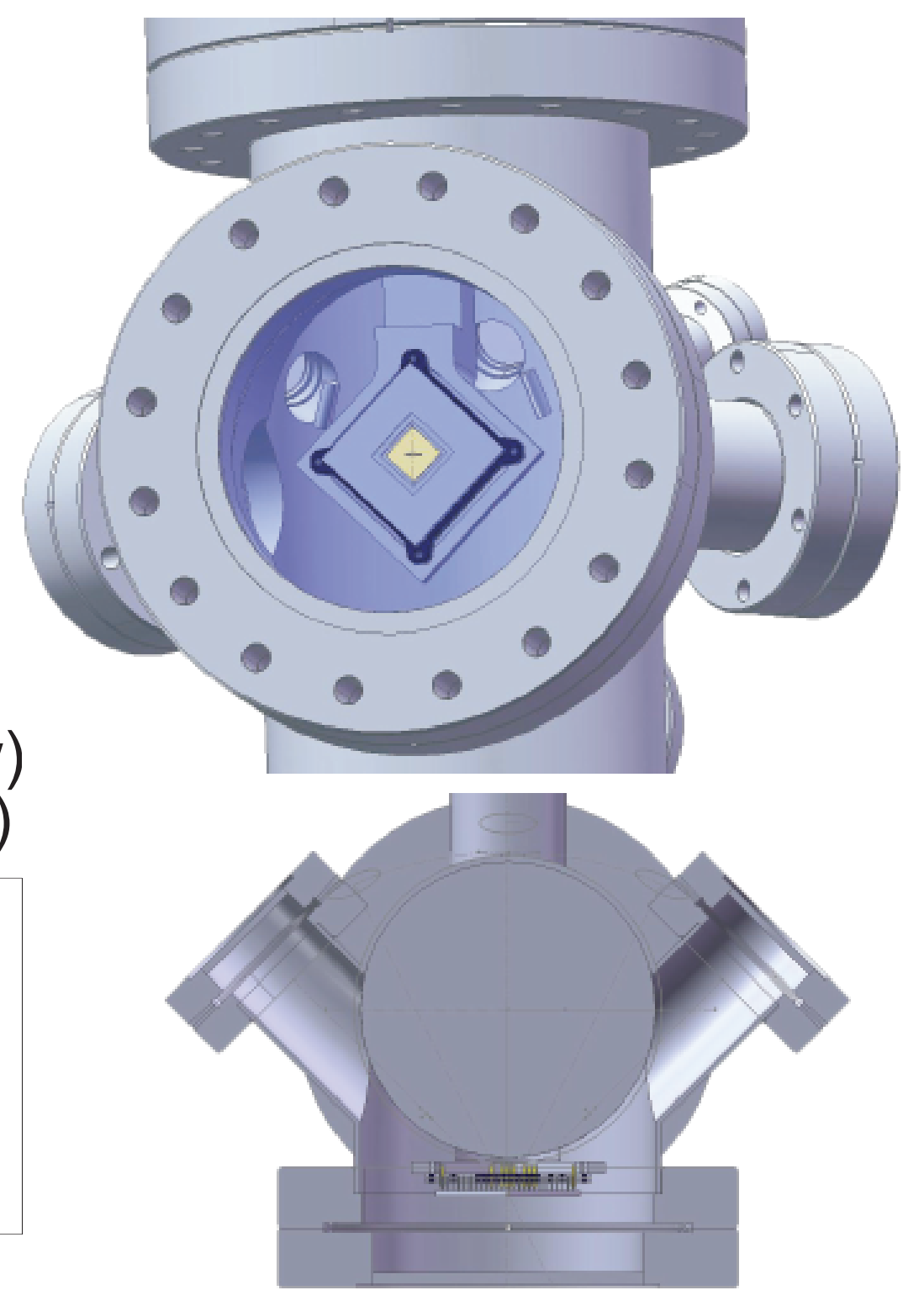






- Ti/Au (10μm) on Al_2O_3 wafer (400μm) cut with femtosecond laser
- Three wafers stacked, glued and wire-bonded to package
- 500μm wide storage zone (Ulm's results below)
- 250μm wide processing zone (awaiting results)

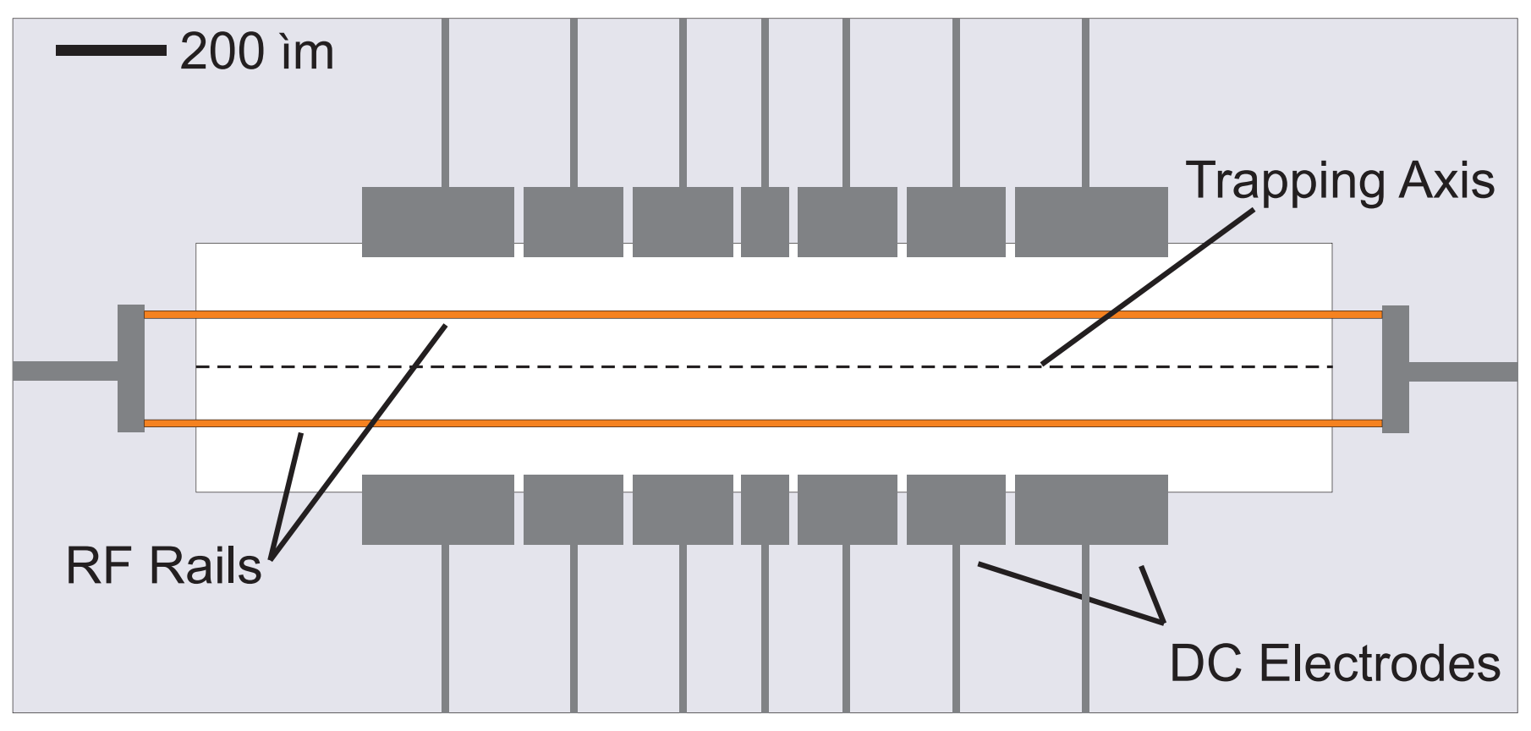
Ion-Electrode Distance	250μm
RF Drive	24.8 MHz, 140V
Trap Depth	755meV
Radial Secular Frequency	1.26 MHz
Heating Rate	2.1(3) quanta/ms

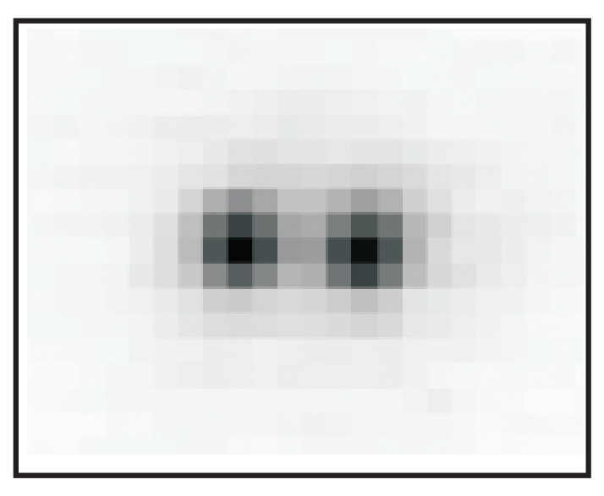


Oxford trap and vacuum system (below) currently under construction

Sandia Mk1 Planar Trap

Trap, designed and fabricated by Sandia National Laboratoies (Matt Blain) under DTO module 4 project.
Materials: tungsten on silicon, with gold coat on backplane
1 r.f. electrode pair and 14 d.c. electrodes around a 2mm x 0.4mm vacuum slot





Two ion crystal (above). Separation is ~9.6um and the lifetime was ~1minute with cooling.

Ion-Electrode Distance	99.5μm
RF Drive	27.25 MHz, 60V to 110V
Trap Depth	68meV
Radial Secular Frequency	~ 3.5 MHz
Axial Secular Frequency	~ 300 kHz

General observations

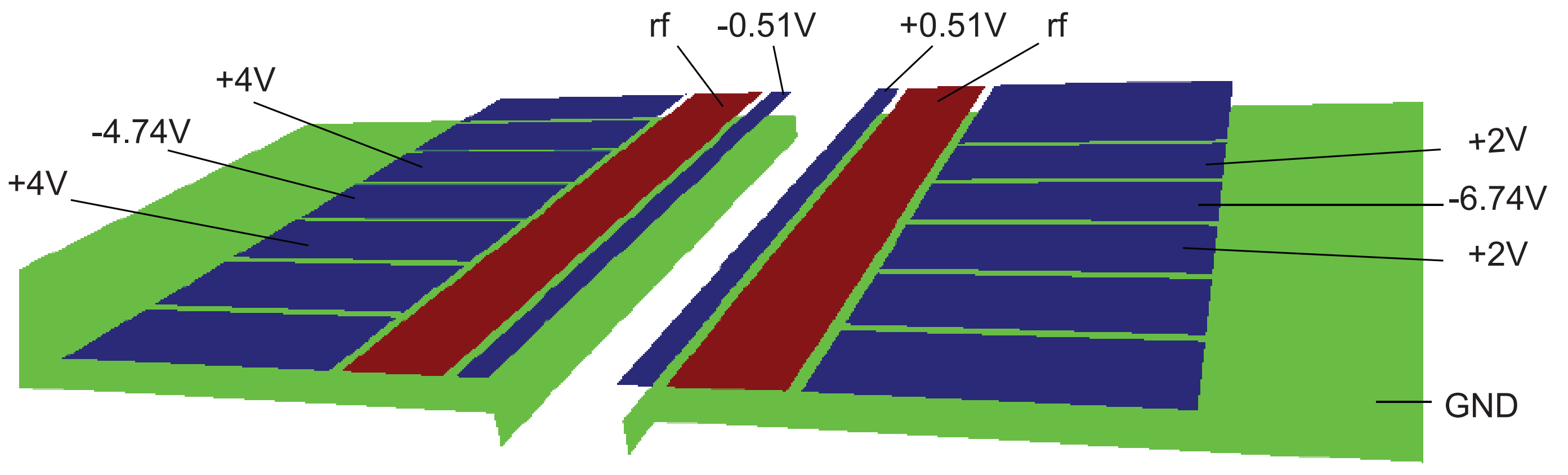
- One and two Ca^{40} ions loaded by photoionisation.
- Doppler cooling with co-propagating 397 nm & 866 nm laser beams.
- Single ion lifetime is hours with cooling, seconds without.
- Ions shuttled ~360μm from trap centre in either direction.
- Heating rate of 49(9) K/s measure using Doppler recool method.

Issues

- Exposed silicon charges up when exposed to light, moving ion off rf null.
- Combination of exposed dielectric and electrode materials thought to lead to the very high heating rate.
- 'Suspended rf rail' design does not lend itself to current thinking on junction design.
- Cooling lasers (which must pass through the slot) do not couple to the radial vibrational mode in the plane of the trap.

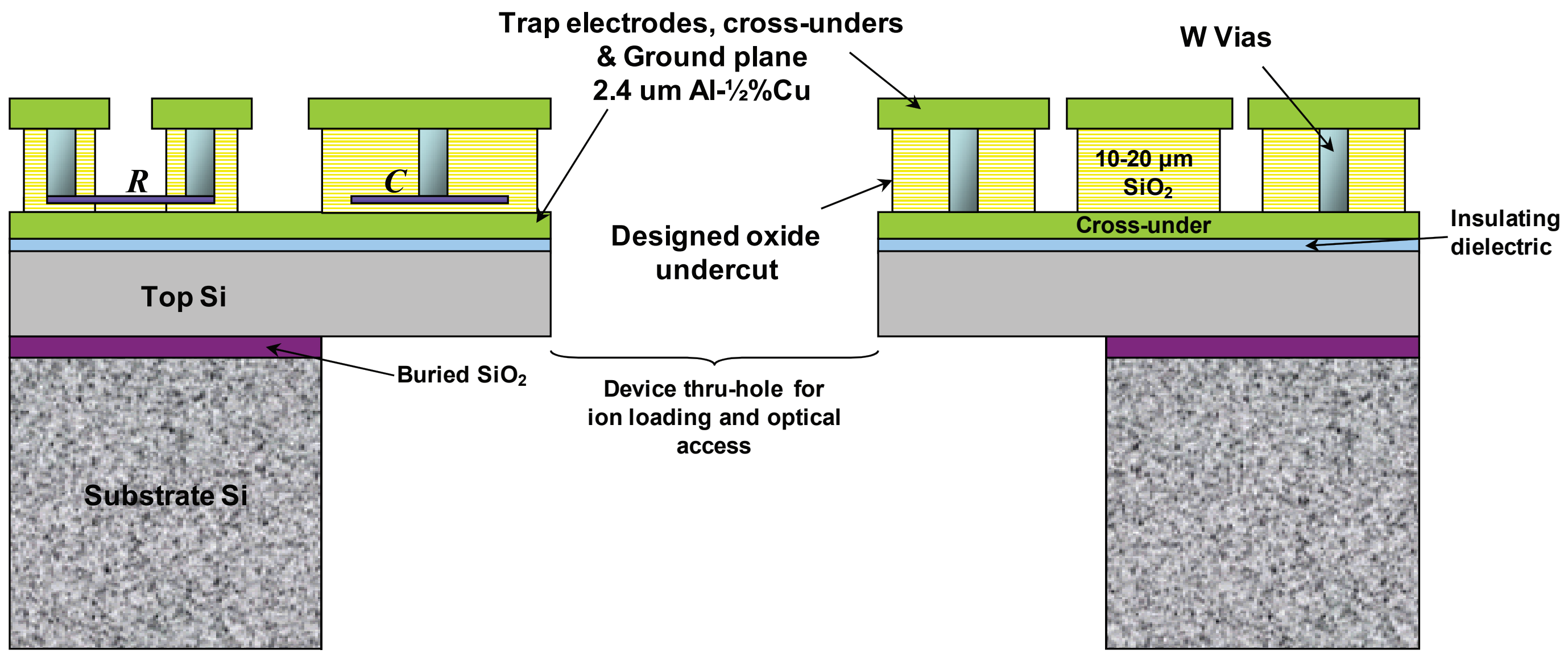
Sandia Mk2 Planar Trap

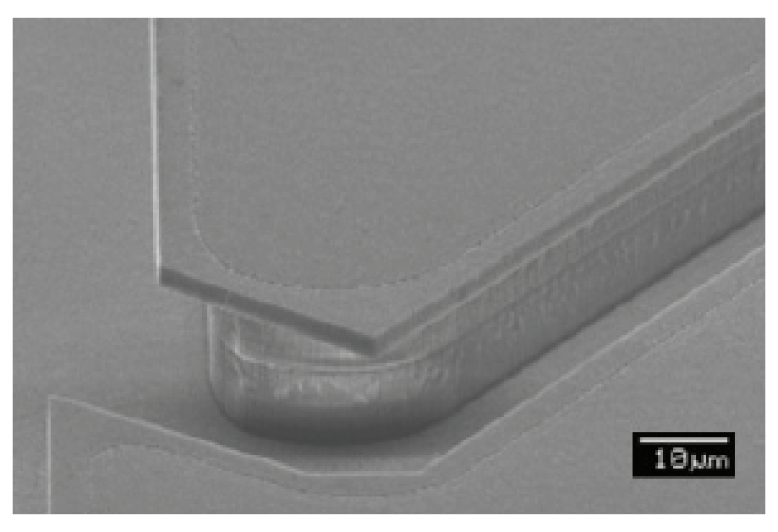
Fabrication underway at Sandia National Laboratoies (M. Blain & D. Stick) funded by iARPA. Design and testing input from Oxford and Innsbruck (W. Hänsel).



Above is an isometric view of a trap section and the required dc control voltages to trap an ion. The complete trap extends for 20 control electrode pairs. The ion sits directly above the 100μm wide slot. The control electrodes at 70μm wide and all electrode gaps are 7μm.

Below is a digram of the monolithic fabrication method that has been developed for the Sandia trap foundry. The SEM image (right) shows a fabricated electrode.





Ion-Electrode Distance	93.9μm
RF Drive	40 MHz, 200V
Trap Depth	190meV
Radial Secular Frequency	5.5 MHz
Axial Secular Frequency	750kHz

Features

- Ion 'sees' no dielectric or exposed semiconductor.
- Trap can be evaporatively coated with different metals to investigate effects of surface composition on ion heating.
- Split central electrode allows rotation of trap principle axes for efficient laser cooling even in a symmetric design.

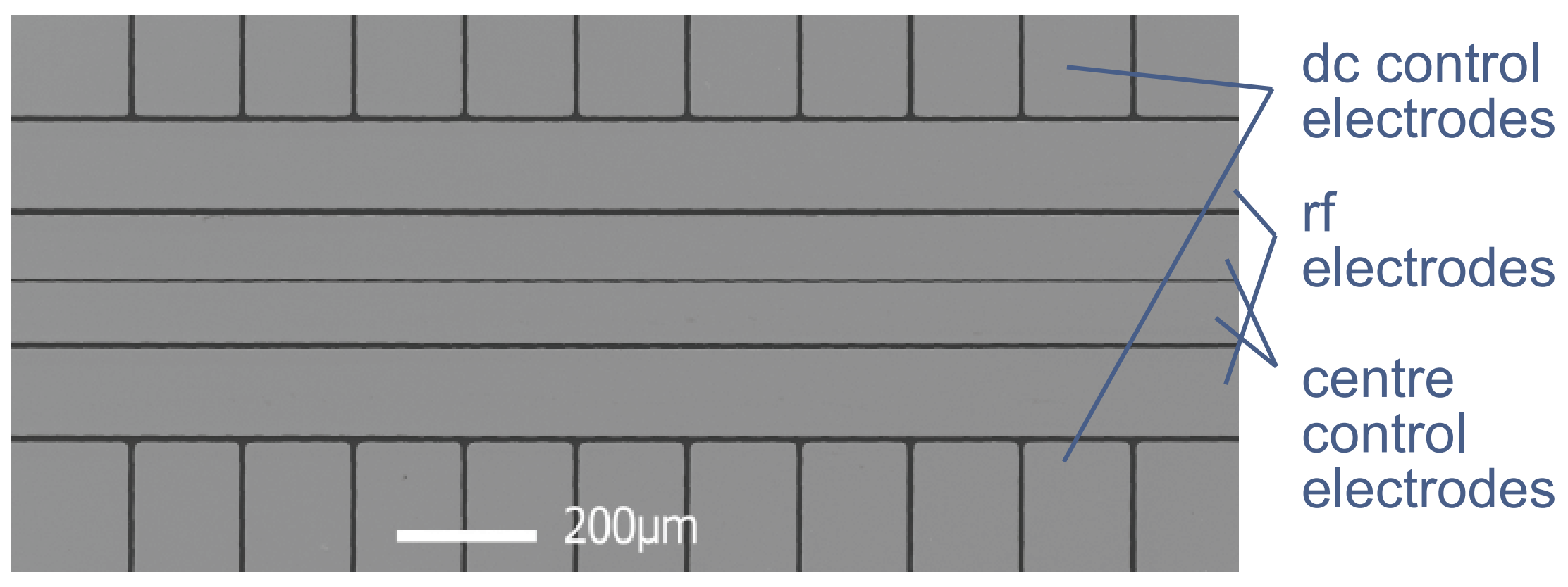
Future Developments

- Slot designed to accomodate pre-aligned package of diffractive optics and fibres for laser delivery and fluorescence collection.
- Geometry is compatable with currently envisioned 'near-ideal junctions'
- Integration of filters into the trap structure is possible with this fabrication technology.

The Oxford Planar Trap

Planar traps based on a simple metal patterned substrate have recently been demonstrated at NIST [1] and MIT [2] with promisingly low heating rates measured. This type of trap is inherently easily scalable. Furthermore these particular traps are designed to be manufactured in-house on short time scales to allow rapid testing and development of new electrode geometries. The first trap we've fabricated has a geometry similar to that of the proposed Sandia Mk2 to test some of the proposed trap parameters.

[1] Seidelin et al. PRL 96, 253003 (2006)
[2] Labaziewicz et al. PRL 100, 013001 (2008)

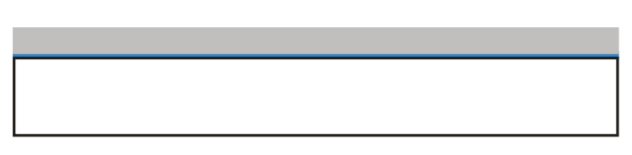


SEM image of the trapping region (above). The ion is directly above the 5μm gap between the centre control electrodes. All other gaps are 10μm.

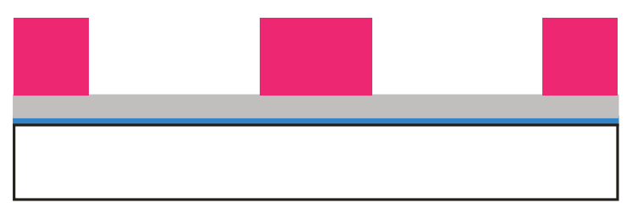
Ion-Surface Distance	149μm
RF Drive	35 MHz, 200V
Trap Depth	82meV
Radial Secular Frequency	~ 3.5 MHz
Axial Secular Frequency	~ 1 MHz

Fabrication Process
Based on MIT method. See thesis of J. Labaziewicz (2008).

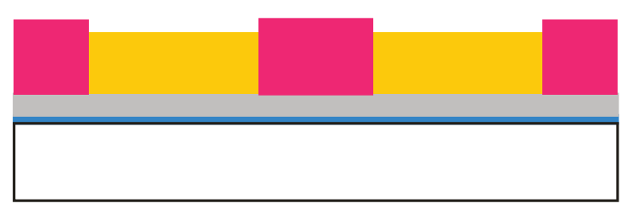
Substrate is 0.5mm thick polished quartz (10mm x 10mm)



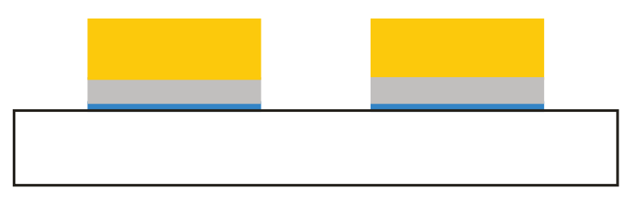
10nm titanium adhesion layer and 100nm silver seed layer evaporated onto substrate



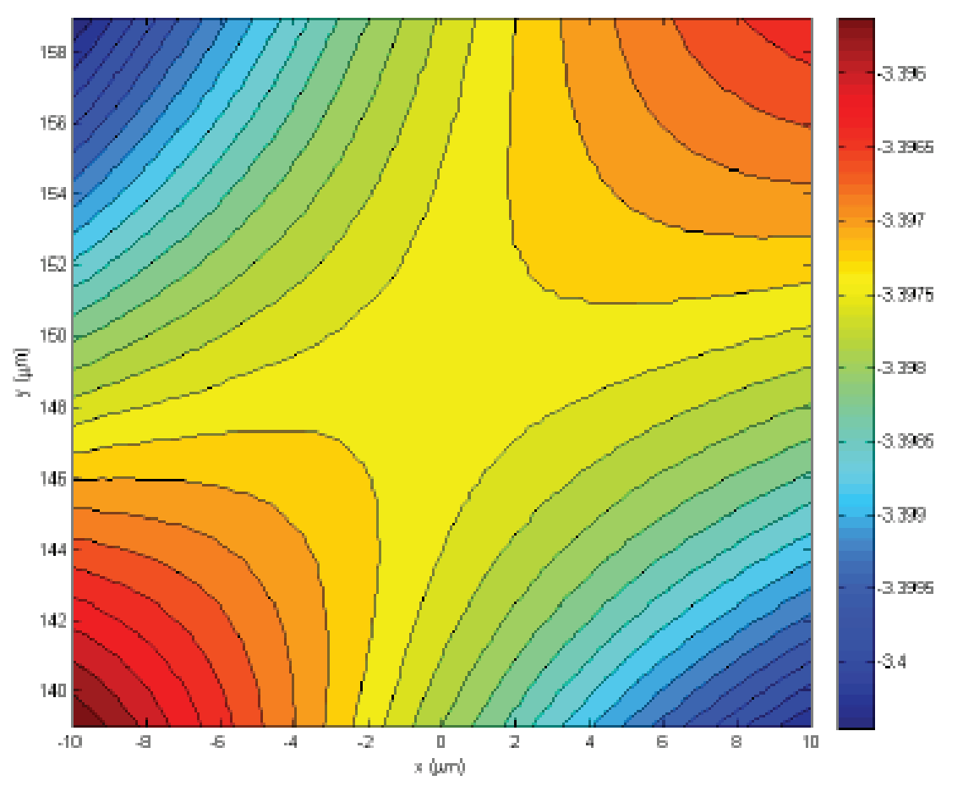
few μm thick photoresist spun on and electrode pattern lithographically defined



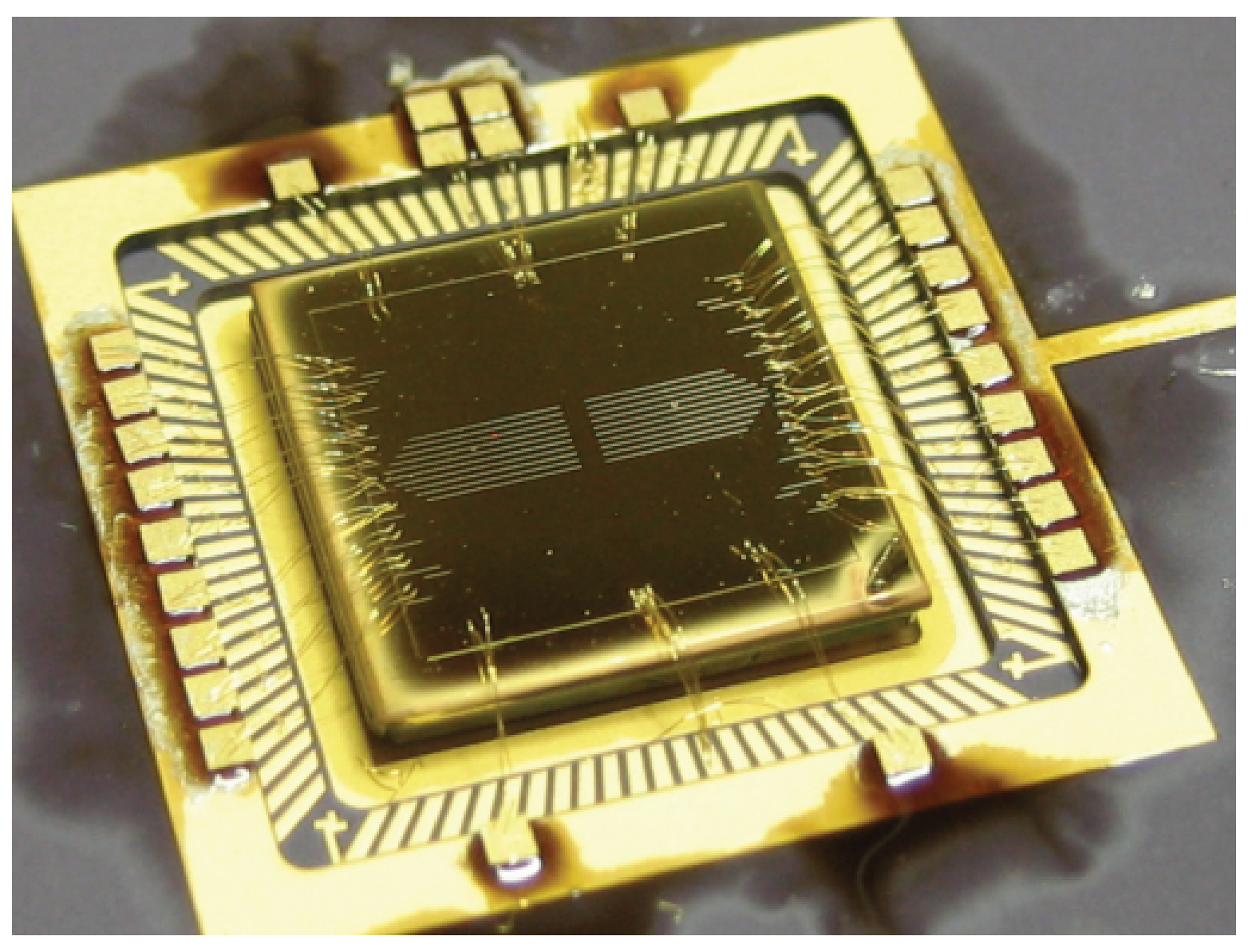
2.7 μm of gold electroplated from gold sulphite solution onto silver seed layer

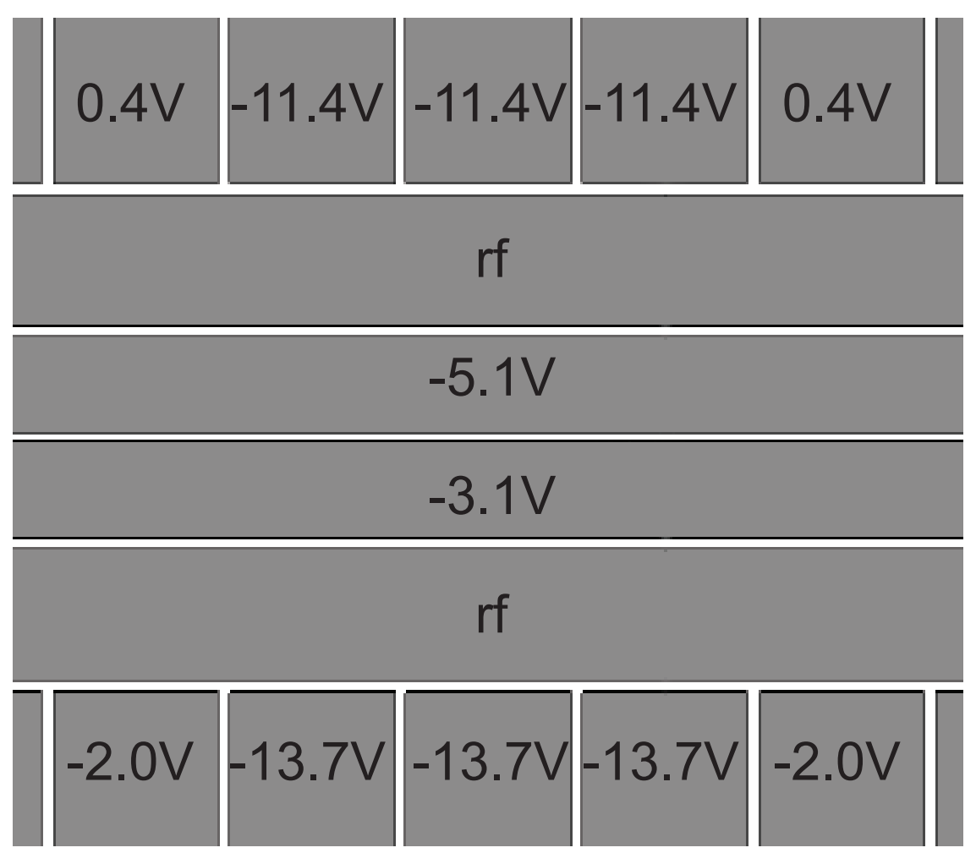


Photoresist removed with solvent. Silver etched ($NH_3OH:H_2O_2$) and titanium etched away with HF.



Trap has been wire-bonded into a CPGA carrier (below). The carrier also includes single-layer 820pF filter capacitors for the dc electrodes.

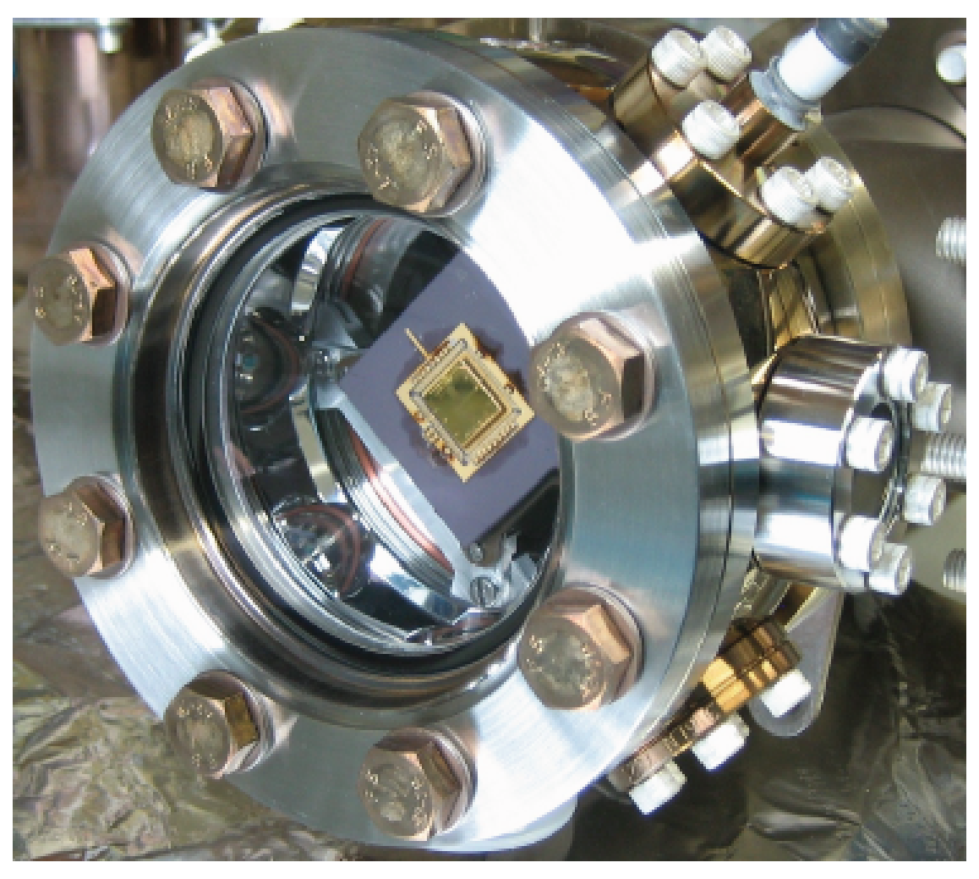




Trap is of a '6-wire' design. The split central control electrode allows a static quadrupole (above) to be applied at the ions location with the dc electrodes (left). This tilts the radial normal modes so that the laser cooling beams couple efficiently to them. Modelling of the trap is done using both a numerical boundary-element method and an analytical Biot-Savart method [1].

[1] Wesenberg PRA 78, 063410 (2008)

Trap under vacuum (below). Imaging is through the front window which is conductive (ITO coating) to prevent charging) The laser beams pass through the side windows and pass parallel to the trap's surface. Neutral fluorescence has been observed and trapping attempts are underway.



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