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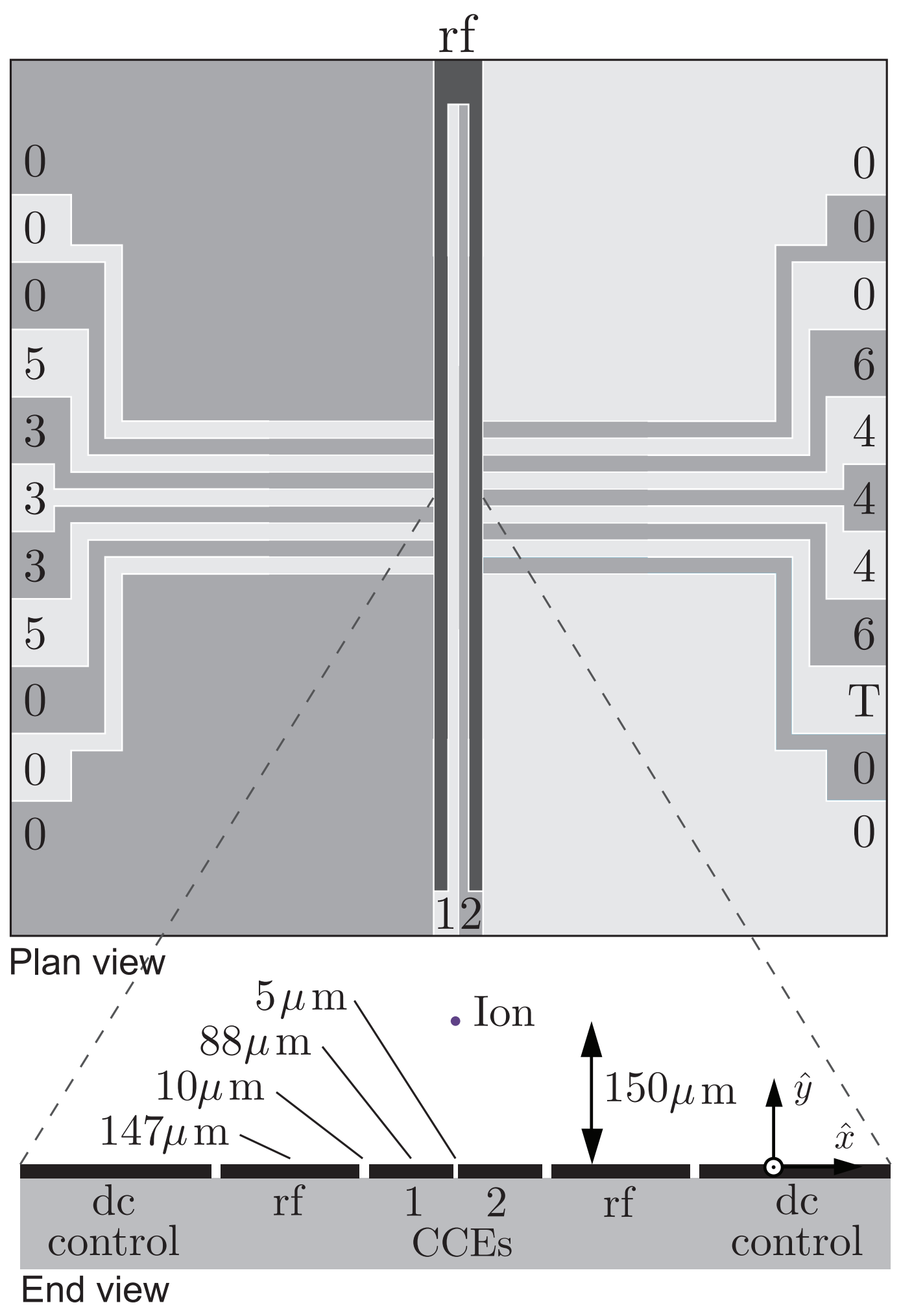
The Oxford planar ion trap project

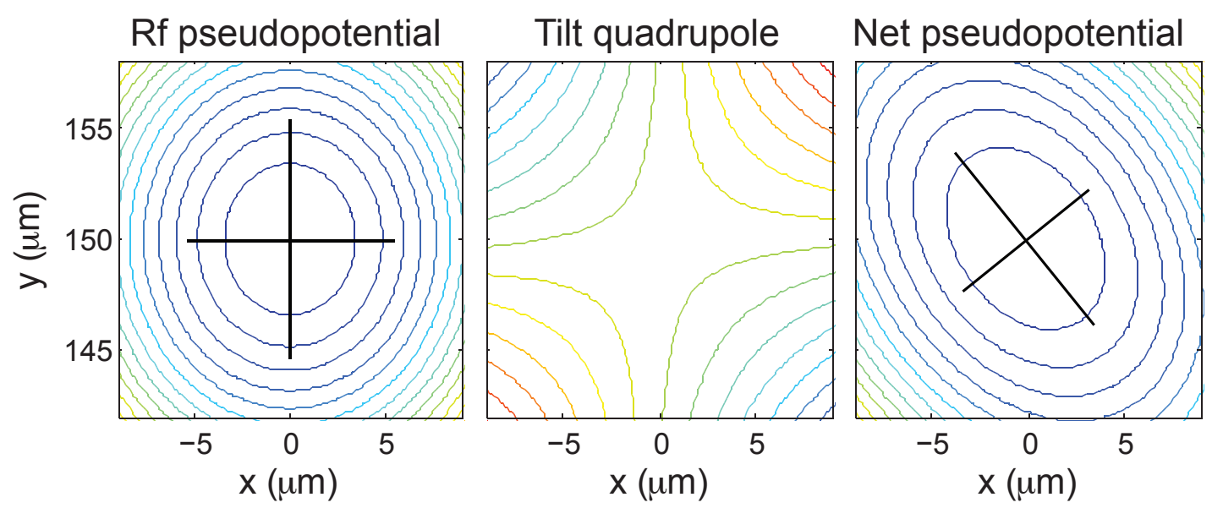
Ion Trap Quantum Computing Group - Department of Physics - University of Oxford

Design

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 scalable, and manufacturable in-house on short time scales allowing rapid testing and development of electrode geometries. We have fabricated a trap with a geometry similar to the proposed Sandia Mk2 (see below) as a proof of principle.

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





Our trap (left) is of a '6-wire' design. The split central control electrode (CCE) allows a static quadrupole (above, centre) to be applied at the ion's location with the dc electrodes. This tilts the radial normal modes so that the laser cooling beams couple efficiently to them (above, right).

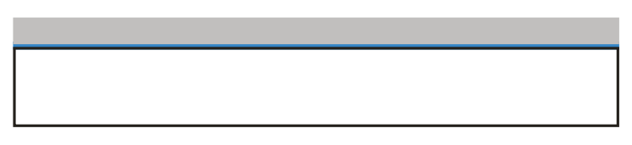
Parameter	V_1	V_2	V_3	V_4	V_5	V_6
Endcap	-1040	-1040	-3152	-3152	-235	-235
Tilt	-886	929	1117	-1030	1117	-1030
$\hat{x}$-Comp	0	0	-0.95	0.95	-0.95	0.95
$\hat{y}$-Comp	0.92	0.92	1.86	1.86	5.02	5.02

Using our model we develop four voltage basis sets (see table above, in mV) to allow independent control of four trap parameters (axial strength, tilt, x and y micromotion compensation).

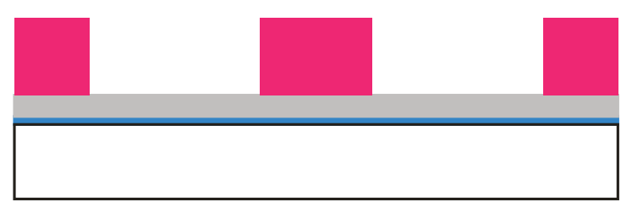
Fabrication

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

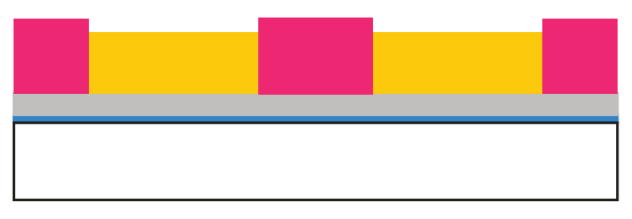
Substrate is 0.5mm thick polished quartz (10mm x 10mm)



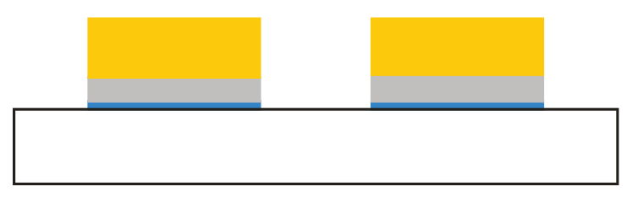
10nm titanium adhesion layer and 100nm silver seed layer evaporated onto substrate



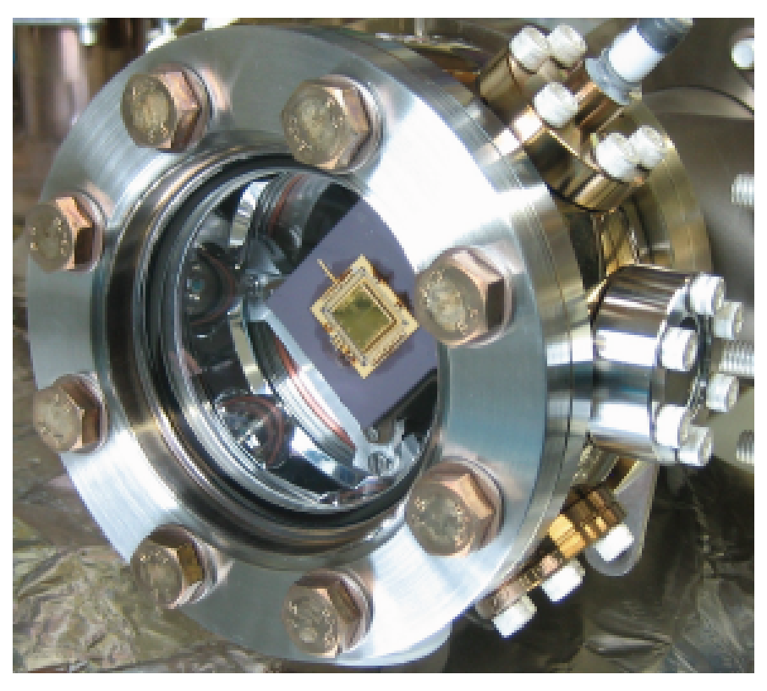
Approx 5µm thick photoresist spun on and electrode pattern lithographically defined



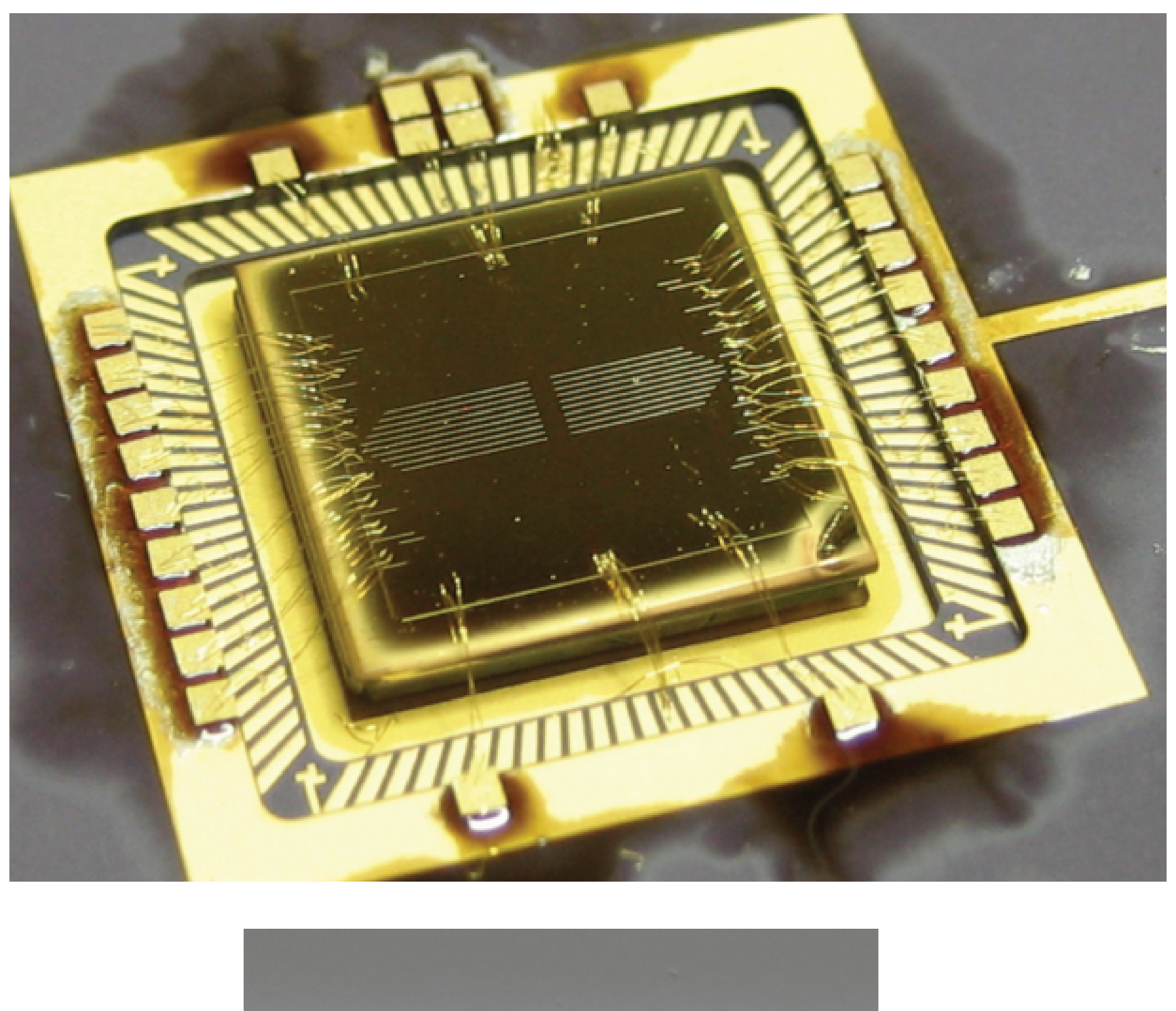
2.7 µm of gold electroplated from gold sulphite solution onto silver seed layer

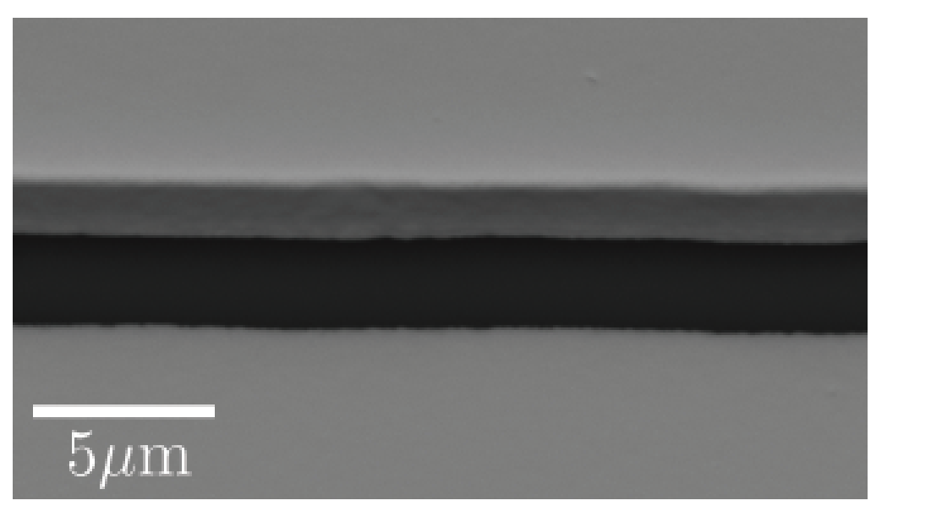


Photoresist removed with solvent. Silver etched (NH_4OH:H_2O_2) and titanium etched away with HF.



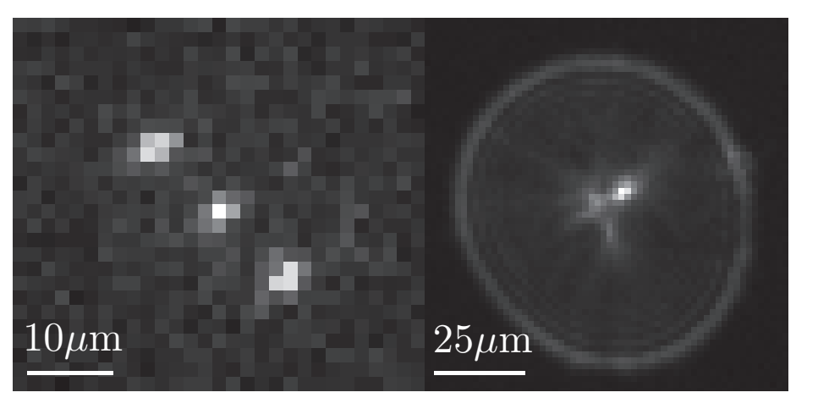
Trap under vacuum (left). Imaging is through the front window which is conductive (ITO coating) to prevent charging. The laser beams pass through the side windows and pass parallel to the trap's surface.





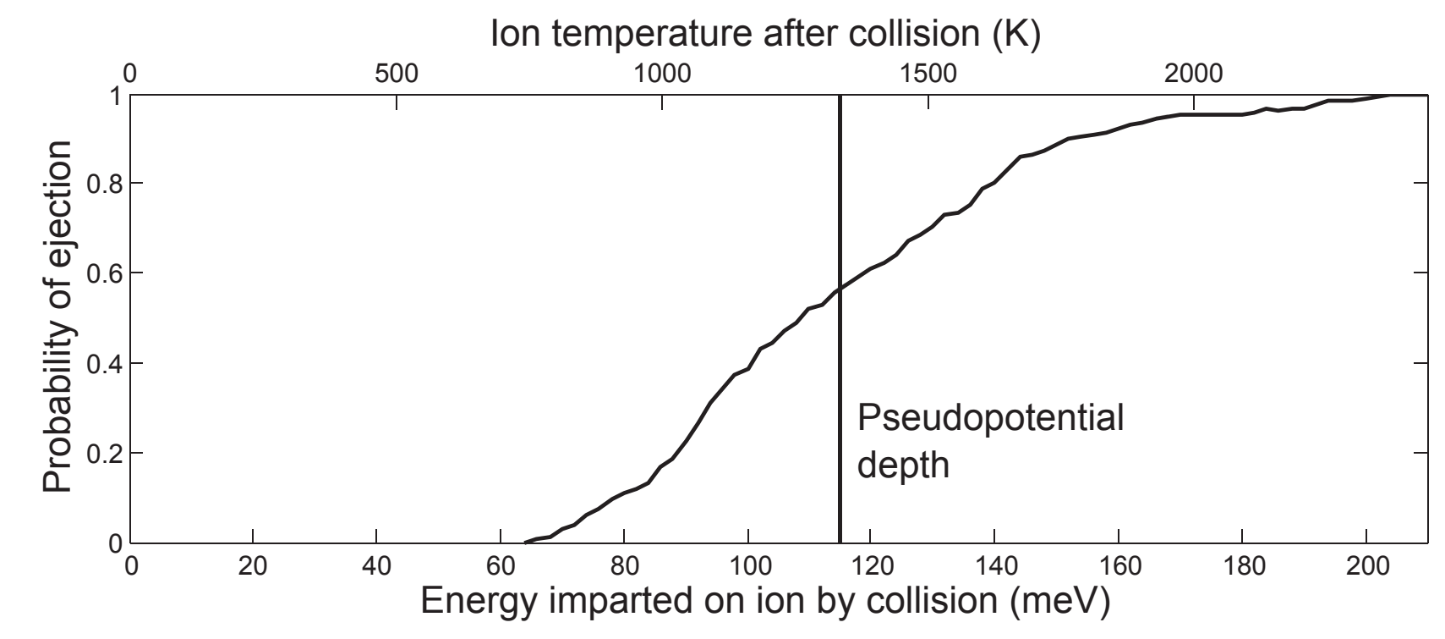
SEM image of an insulating electrode gap, angled to show gold thickness (above). The trap wire-bonded into a CPGA carrier (top). The carrier also includes single-layer 820pF filter capacitors for the dc electrodes.

Operation



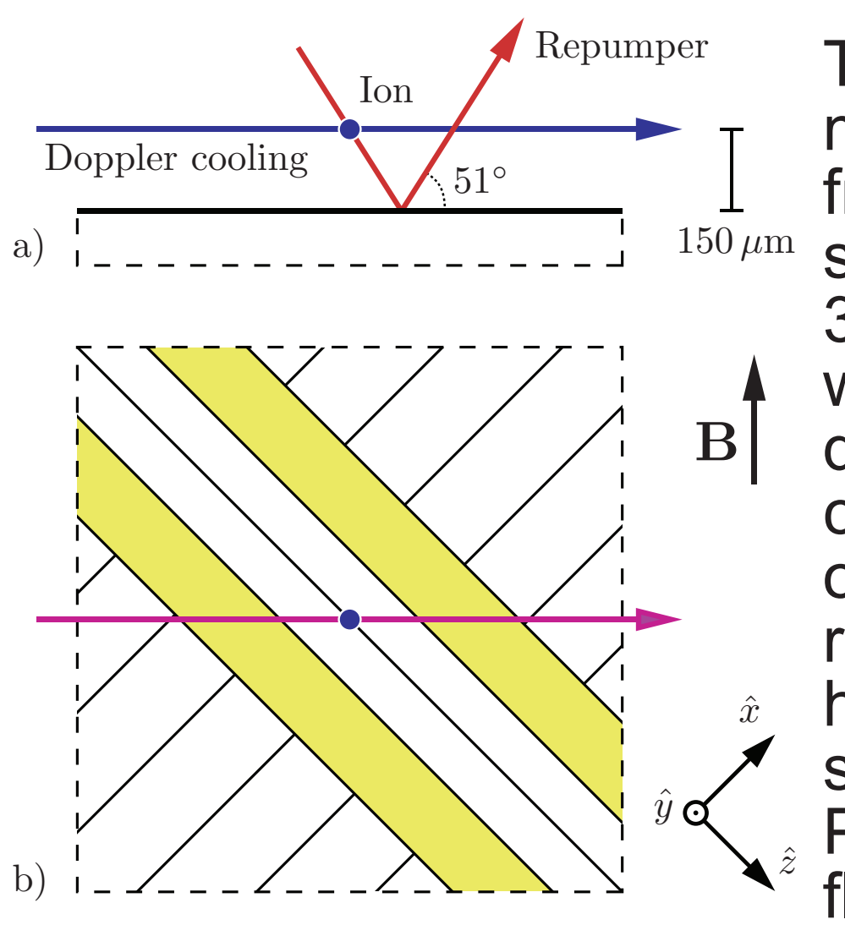
Up to three ions loaded (far left) using two-stage photoionization at 423 nm and 389 nm and the image of a single ion *reflected* in the gold electrode (left).

Ion-Surface Distance	150 µm
Rf Frequency	25.8 MHz
Rf Voltage Amplitude	112 to 223 V
Pseudopotential Depth	47 to 188 meV
Radial Secular Frequency	2.0 to 4.0 MHz
Axial Secular Frequency	300 kHz to 1.2 MHz
Ion Lifetime (typical)	5 min

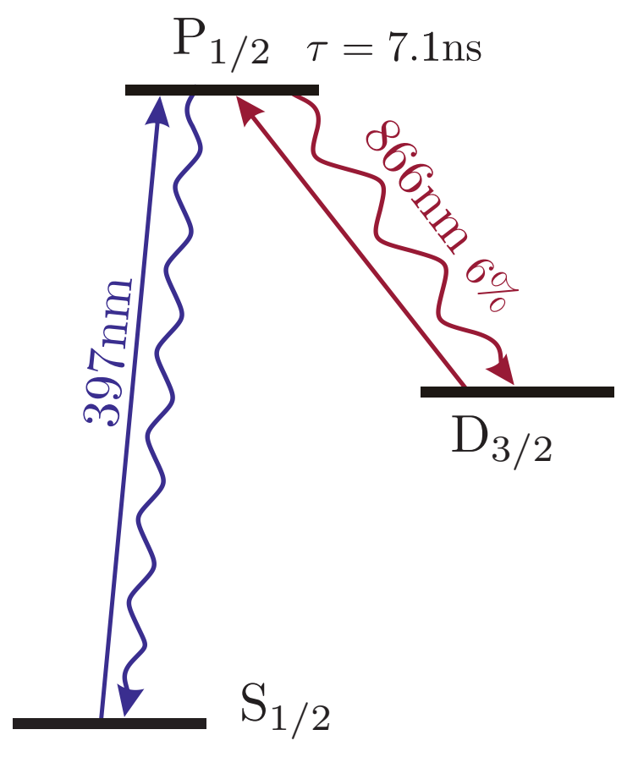


Loss rate is thought to be due to high pressure ($3x10^{-10}$ Torr). Numerical calculation of ejection probability based on ion trajectories is shown above.

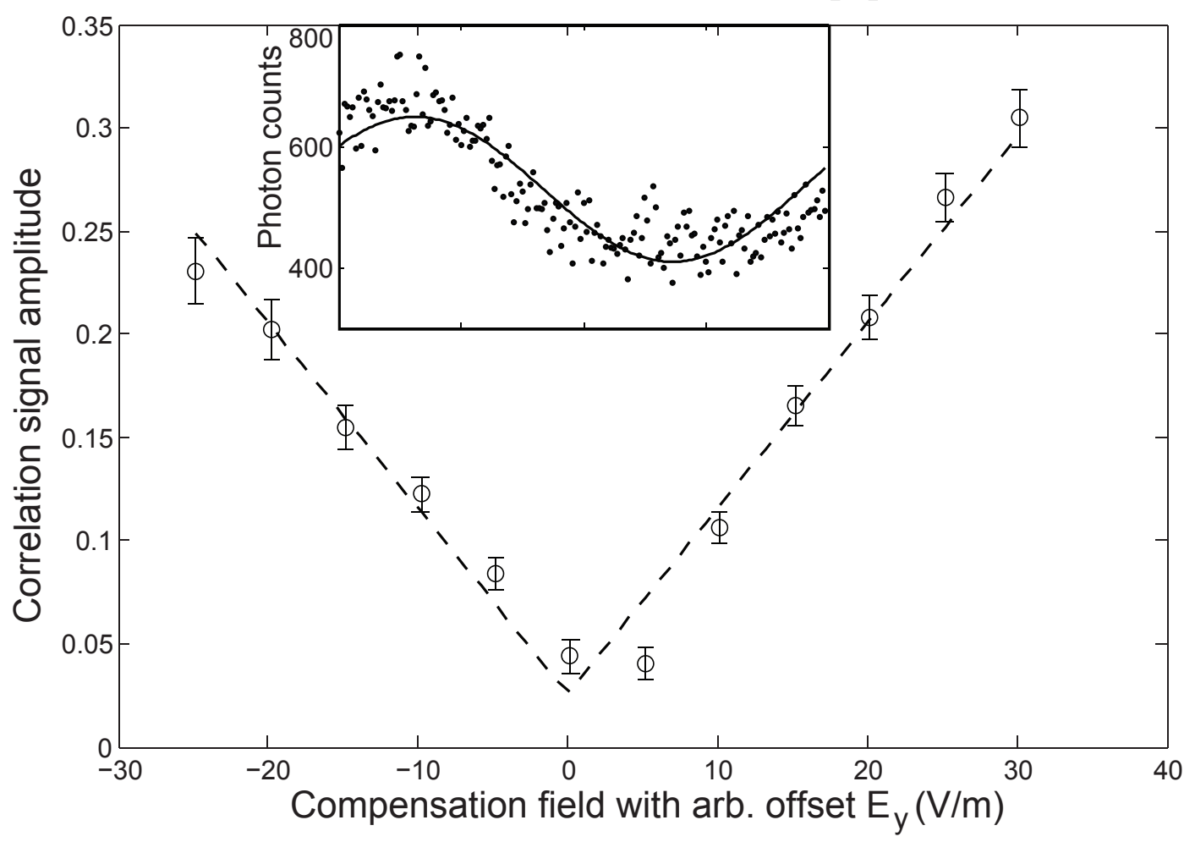
Micromotion Compensation



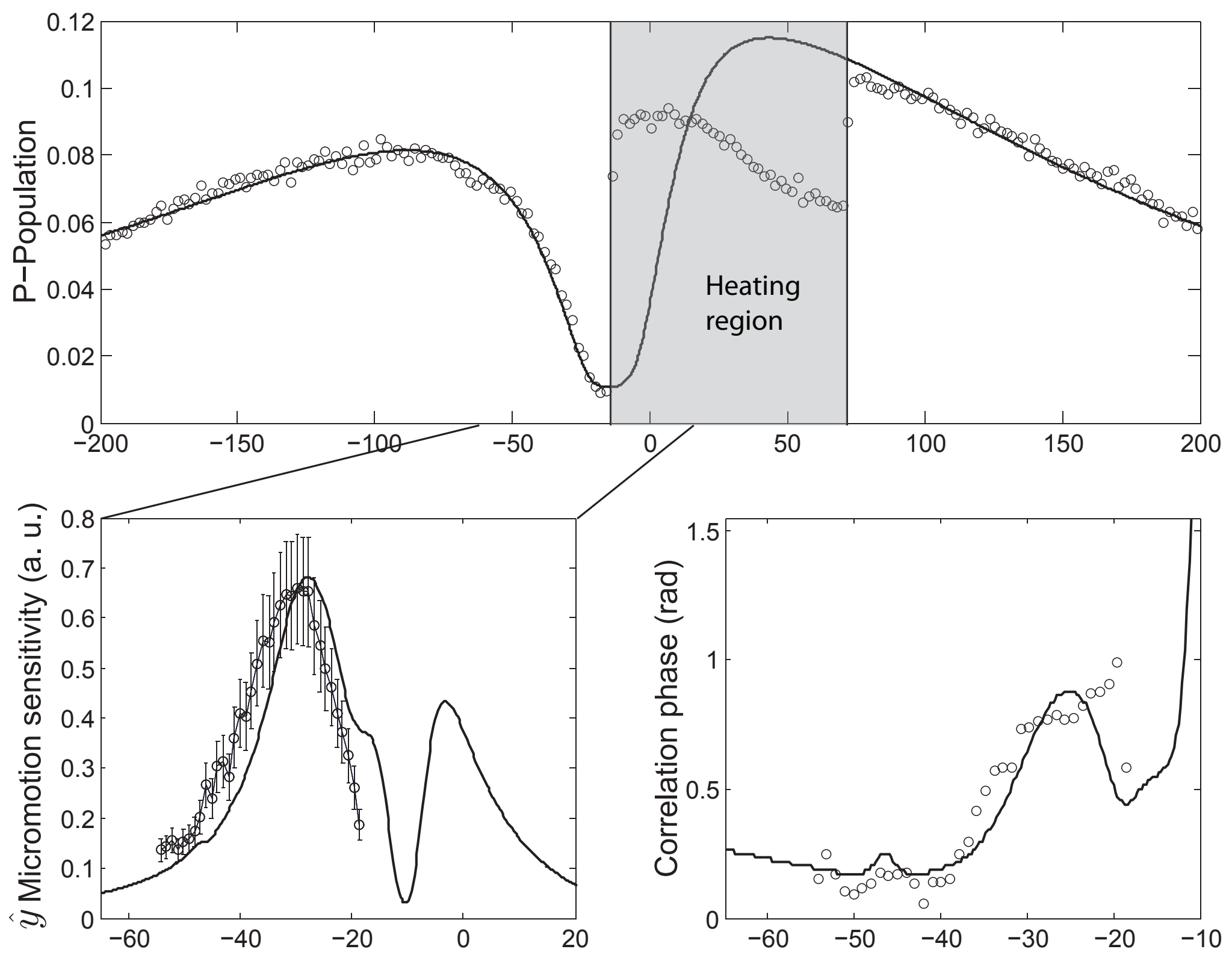
Trap rf drive causes driven micromotion when ion is displaced from rf null by stray fields. Doppler shifts cause correlation between 397nm ion fluorescence and trap rf which can be used for micromotion detection [3]. Beams in plane of trap cannot detect micromotion out-of-plane so we reflect 866nm repumper off trap (left). In regime of high repumper intensity the Doppler shifts of the repumper couple to the P-population and modulate the fluorescence



[3] Berkeland et al. J App. Phys. 83, 5025 (1998)

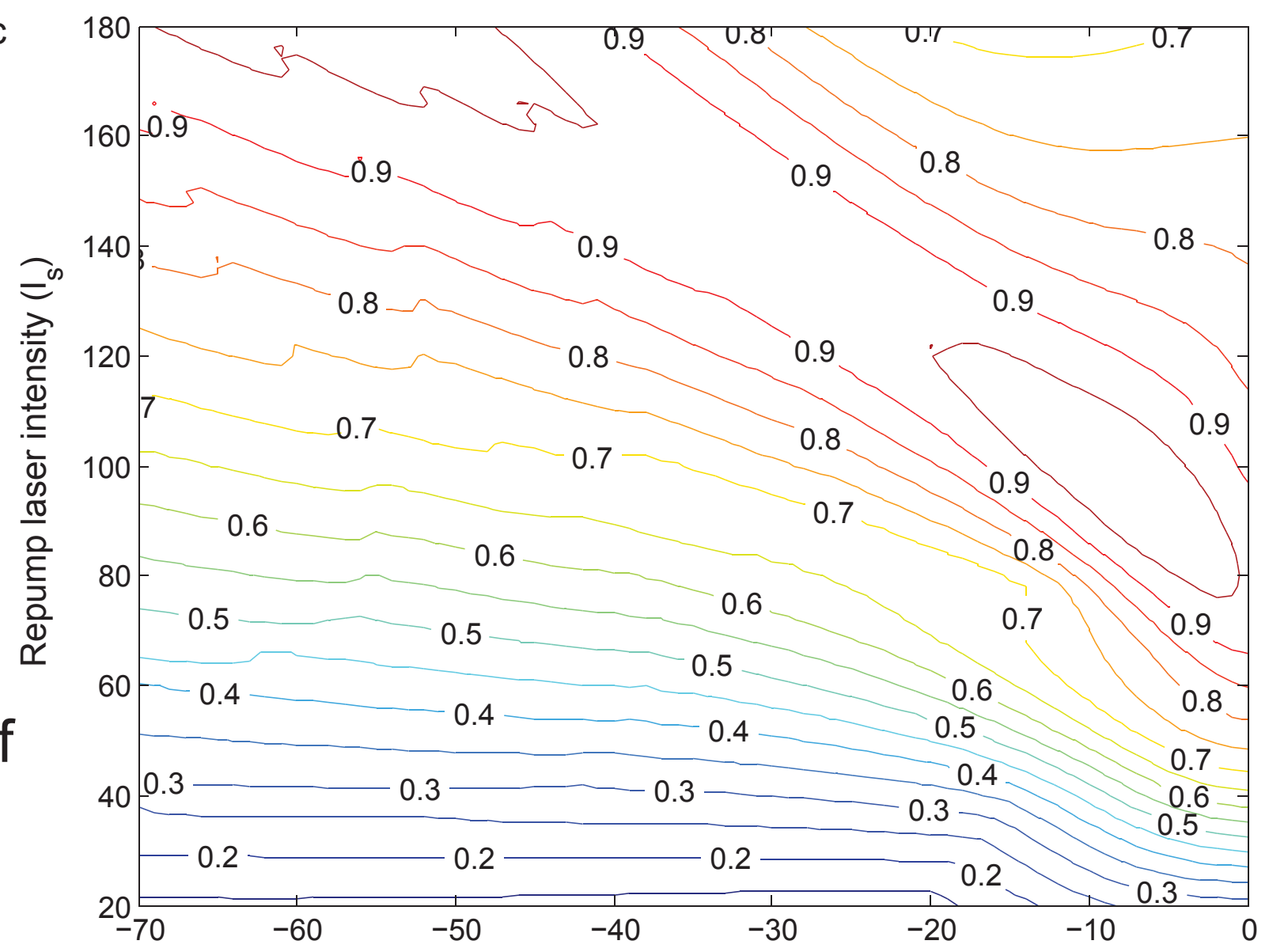


A typical rf correlation scan (inset, left). By applying a compensation field and monitoring the correlation scan we can null any micromotion (left).



By solving the Bloch equations for the steady state under repump laser modulation we can predict the optimal laser parameters. This contour plot (below right) shows the sensitivity to micromotion for different repumper laser intensities and cooling laser detunings as a fraction of the fluorescence rate. For all points the optimal repumper detuning is 10-20 MHz to the red of the cooling laser. The relative sensitivity drops off linearly with cooling laser intensity I_c but we set I_c to 1.5 saturations to achieve a good absolute sensitivity. The graphs to the left show a good experimental fit to our model.

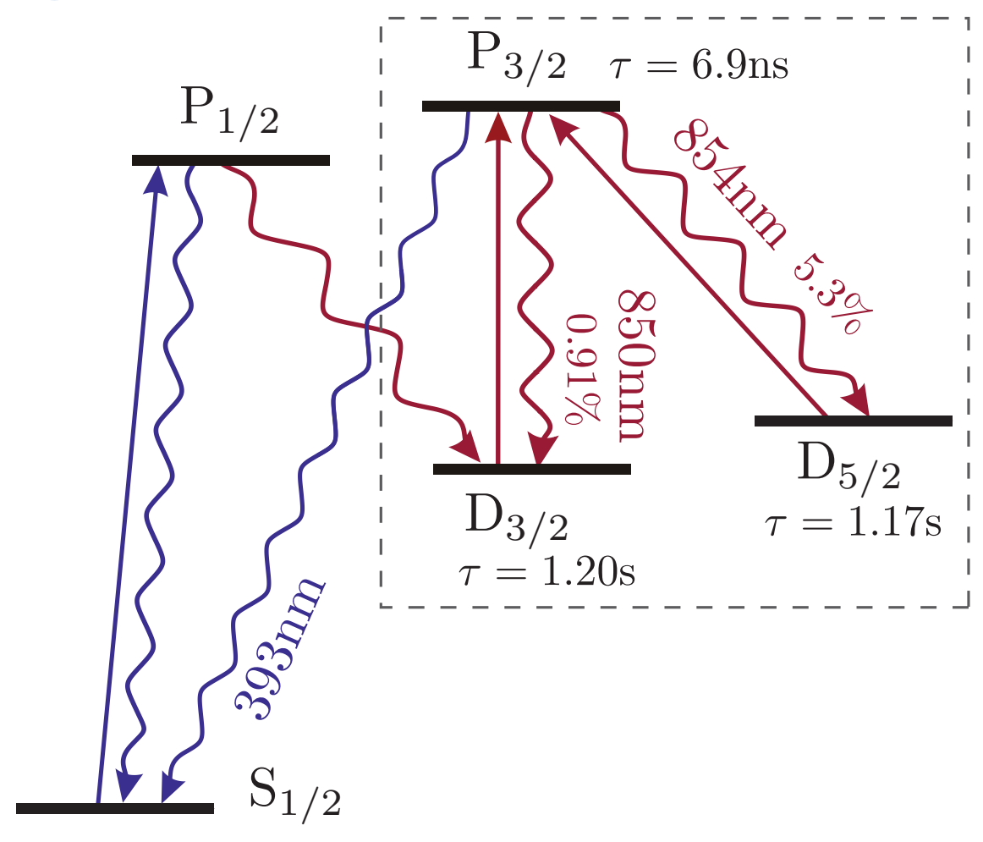
Using this method we are able to compensate stray fields out of the plane to within 3 V/m compared to 1 V/m in the plane (peak ion velocities of 0.3 and 0.1 m/s respectively). We note a gradual drift rate of approximately 10 V/m per hour, but no noticeable change on loading.

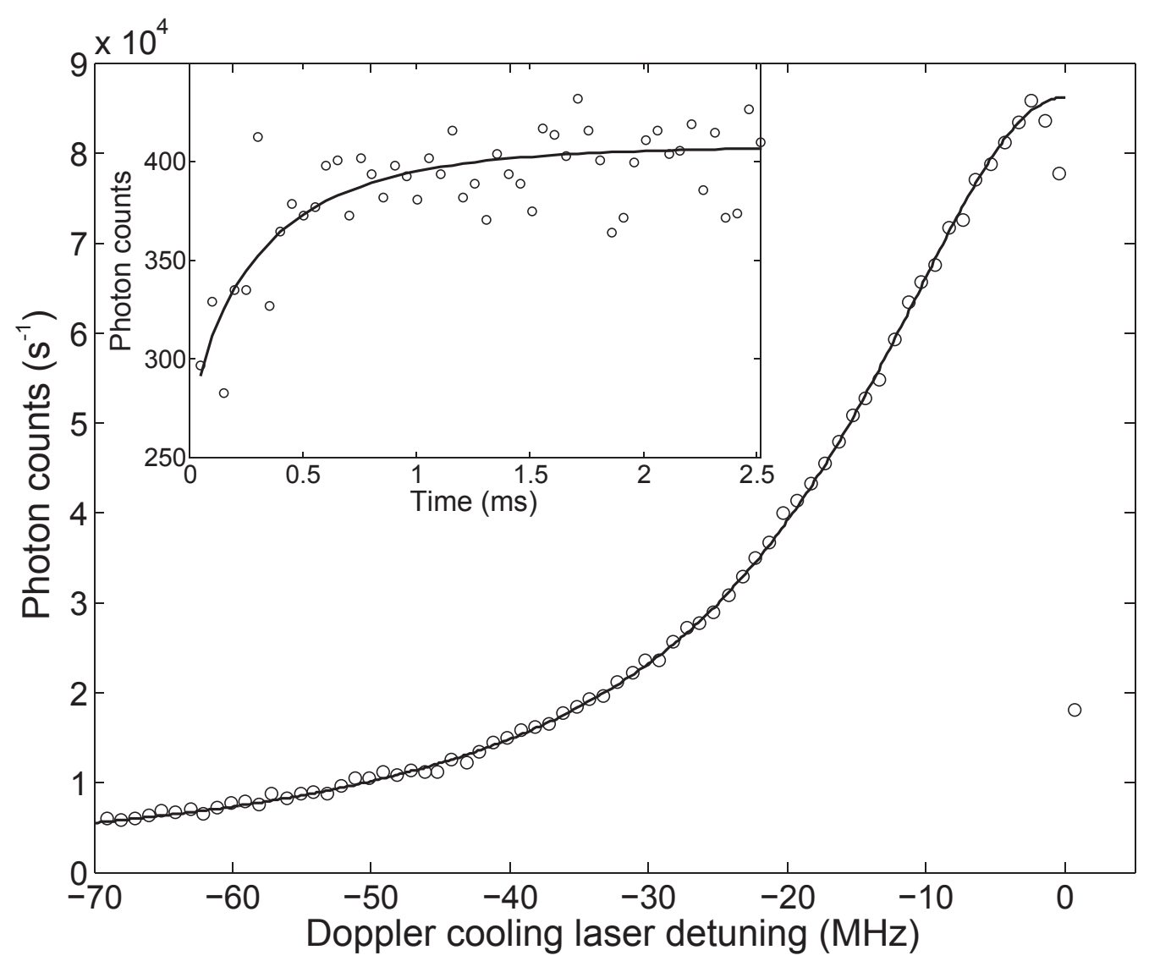


Heating Rates

We measure the motional heating rate of the trap using a Doppler re-cool method [4]. The ion is allowed to heat for 1 second and then the Doppler cooling laser is switched back on. Analysis of the ion's fluorescence as it cools back down allows us to determine its temperature. A typical re-cool curve is shown inset below.

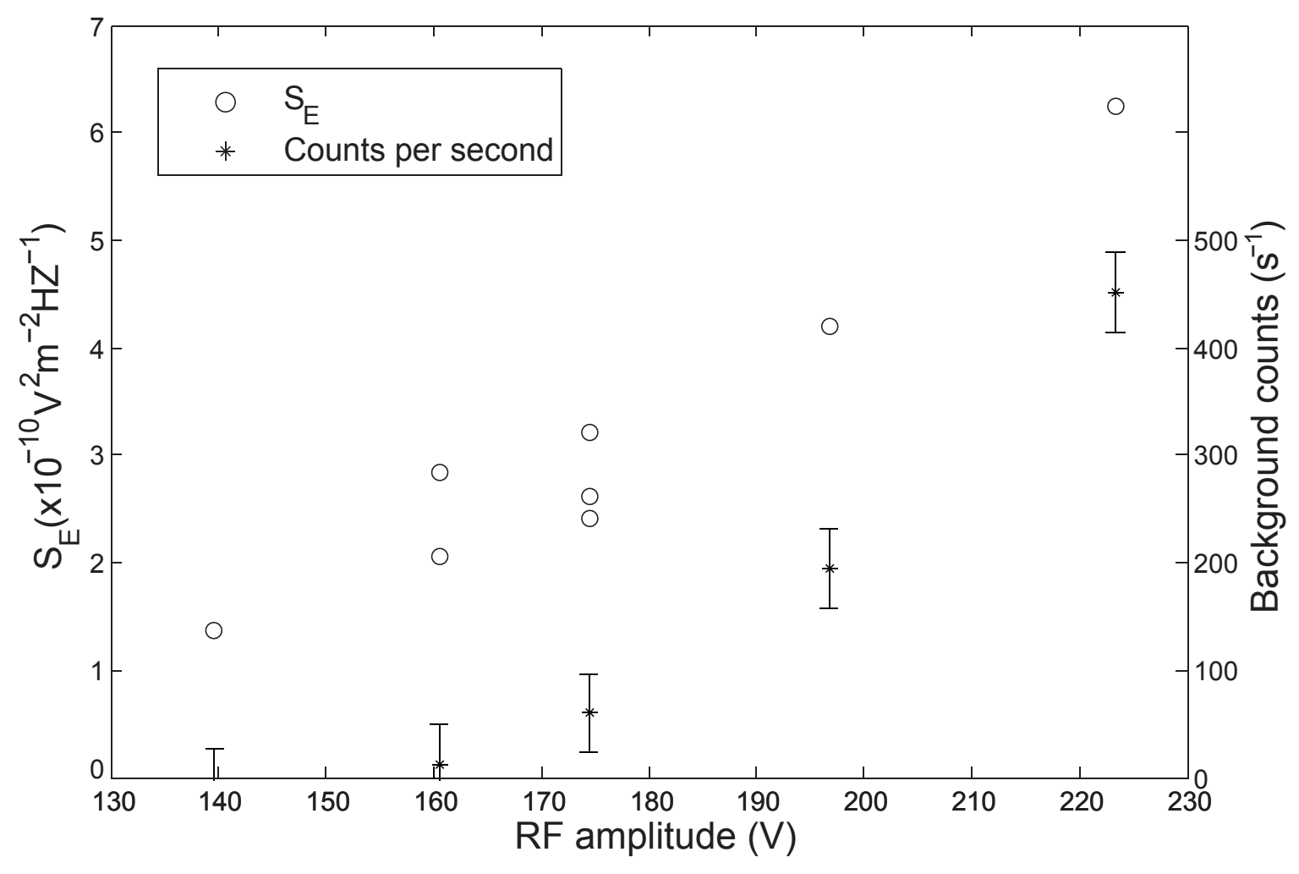
[4] Wesenberg et al. PRA 76, 53416 (1998)





The low-lying D-states in Ca^+ complicate analysis of this experiment if we repump out of them via the $P_{1/2}$ state due to coherent dark resonance effects. Instead we use the modified scheme above. As no laser connects the boxed levels to our fluorescing transition we can treat our system as quasi-two-level (see Lorentzian fit, left).

Before adequate heating rate data was taken an rf fault caused arcing which damaged the surface quality and lowered the breakdown voltage to around 150 V. We see clear evidence of electron emission from the increase in background photon counts at higher rf.

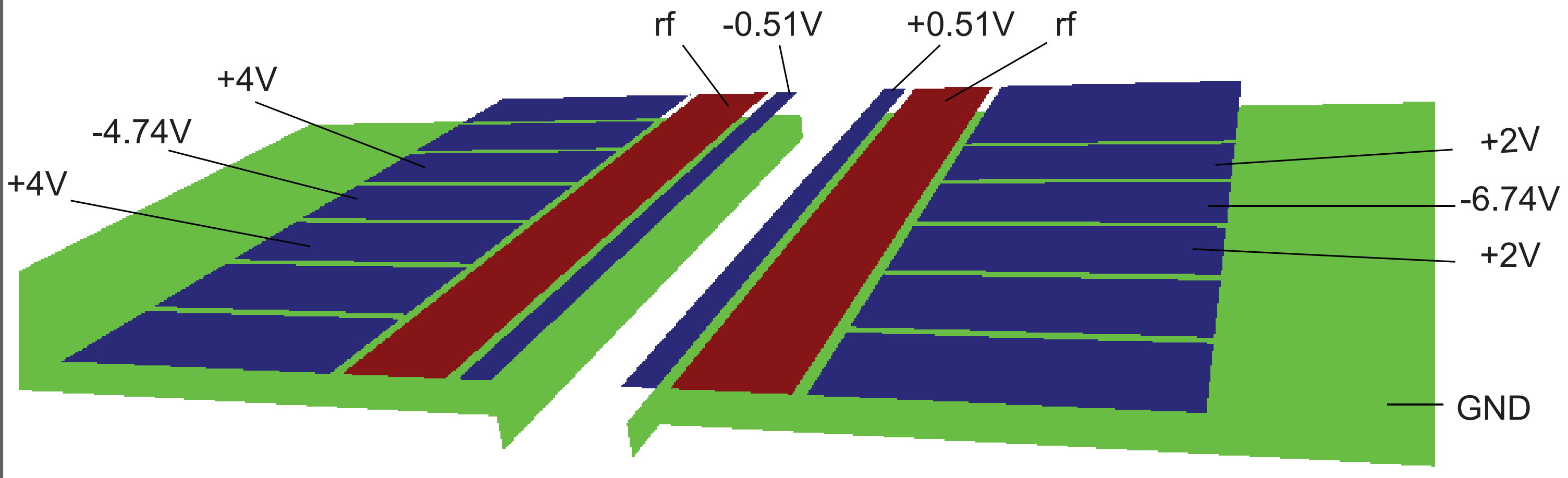


The electric field noise density S_E (above) is comparable to other traps of this size and corresponds to ~50 phonons of heating per ms at 500 kHz axial frequency.

e-print on the arXiv: Allcock et al.

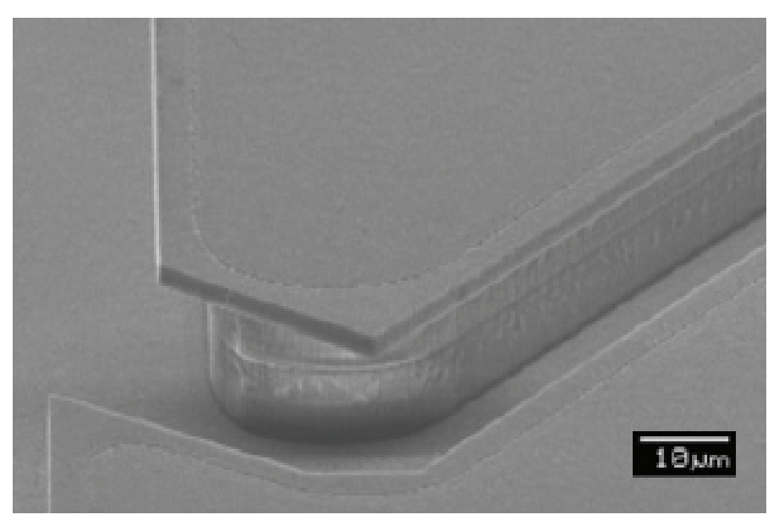
Mk2 Sandia Fabrication

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

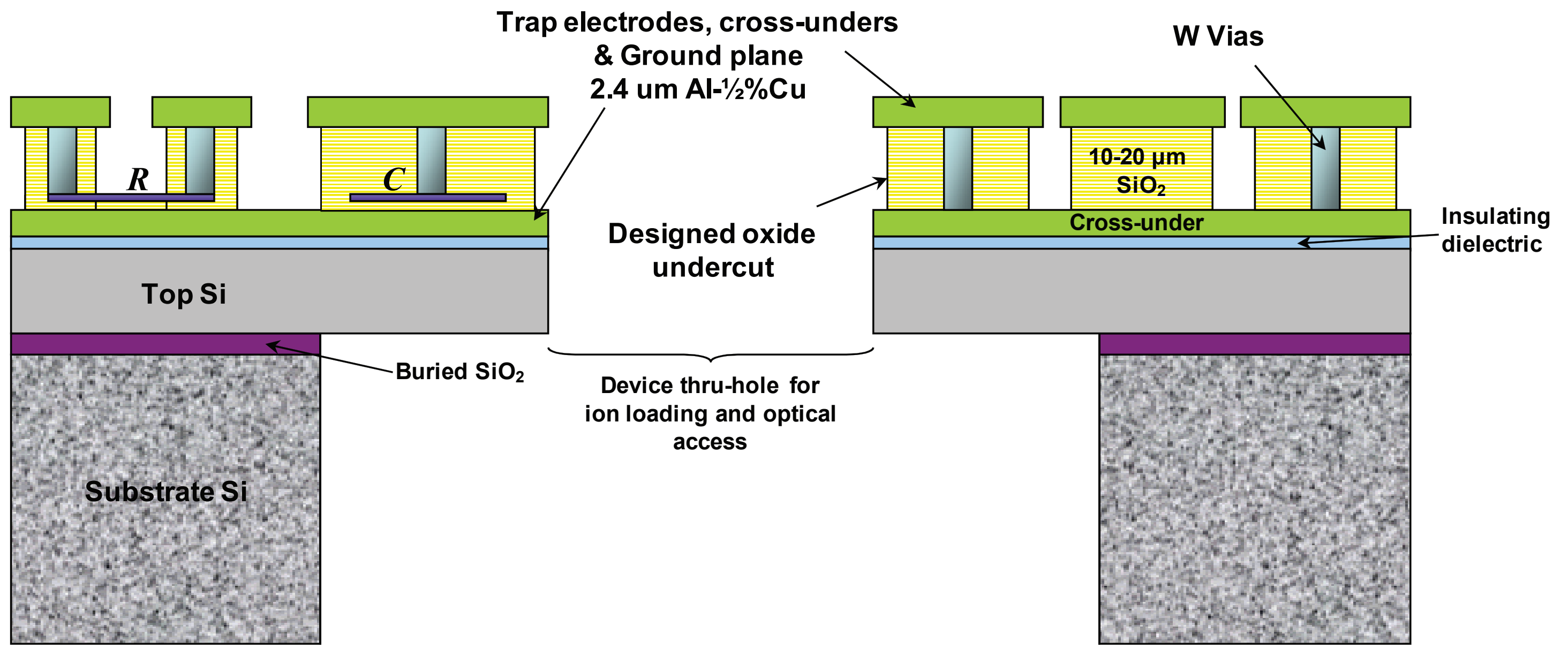


Above is an isometric view of a trap section and the required dc control voltages to trap an ion. The complete trap extends for 20 control electrode pairs. The ion sits directly above the 100µm wide slot. The central control electrodes are 70µm wide and all electrode gaps are 7µm.

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



A diagram (right) of the monolithic fabrication method that has been developed at the Sandia trap foundry. The SEM image (above) shows a fabricated electrode.



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 accommodate pre-aligned package of diffractive optics and fibres for laser delivery and fluorescence collection.

http://www.physics.ox.ac.uk/users/iontrap/ Department of Physics, Clarendon Laboratory, Parks Road, Oxford, OX1 3PU, United Kingdom d.allcock@physics.ox.ac.uk