Optimisation of a microfabricated surface trap geometry for use in quantum simulations

R. C. Sterling[1], J. D. Siverns[1], P. Srinivasan[2], H. Rattanasonti[2] , M. Kraft[2] and W. K. Hensinger[1]

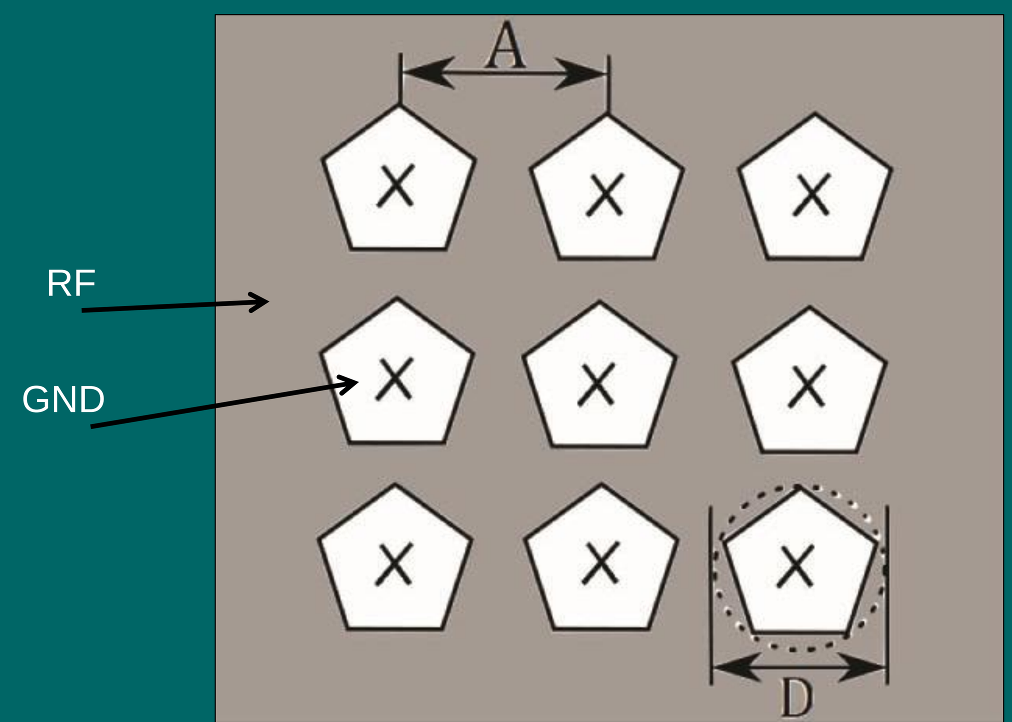
[1] *Ion Quantum Technology Group, Department of Physics and Astronomy, University of Sussex, Brighton, East Sussex, BN1 9QH*
[2] *School of Electronics and Computer science, University of Southampton, Highfield, Southampton, UK SO17 1BJ*

Introduction

Ions confined in surface trap arrays have been shown to be a promising system with which to perform quantum simulations[1-4]. The internal states of the ions provide a controllable and measurable[5] system in which to model the evolution of many body spin-1/2 systems.

Devices of this nature would facilitate the simulation of many body systems without the hindrance of exponential scaling with the systems size[6], paving the way for applications of quantum information processing far beyond that of current classical computers.

The basic structure of the microtrap lattice consists of many radio frequency (rf) ring electrodes, with an rf grounded centre. These rings are arranged into a regular lattice structure as shown below:



By controlling the number of sides of each polygon, the diameter of the polygon, D, and the ion-ion separation, A, optimisation of the trap parameters and quantum simulator suitability can be achieved.

Simulator theory

The coupling rate between adjacent ions is given by:

$$J = \frac{\beta F^2}{m\omega^2}$$

Where m is the mass of the ion, ω_i is the secular frequency, F is a state dependant force mediated by a laser and β is derived from the ratio of the change in coulomb interaction to the change in restoring force, given by:

$$\beta = -\frac{e^2}{2\pi\varepsilon_0 m\omega^2 x^3}$$

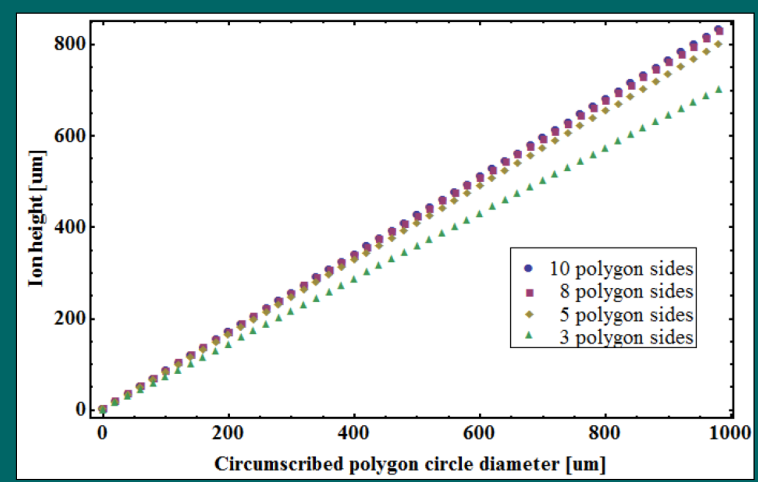
Where e is the charge of an electron. To ensure that the interaction takes place before decoherence the interaction time, T_J, must be smaller than the dominant decoherence process. The parameter K_{sim} is a ratio of interaction time to decoherence time and maybe used to optimise lattice parameters.

$$T_J = \frac{\hbar}{J} \qquad K_{sim} = \frac{T_n}{T_J}$$

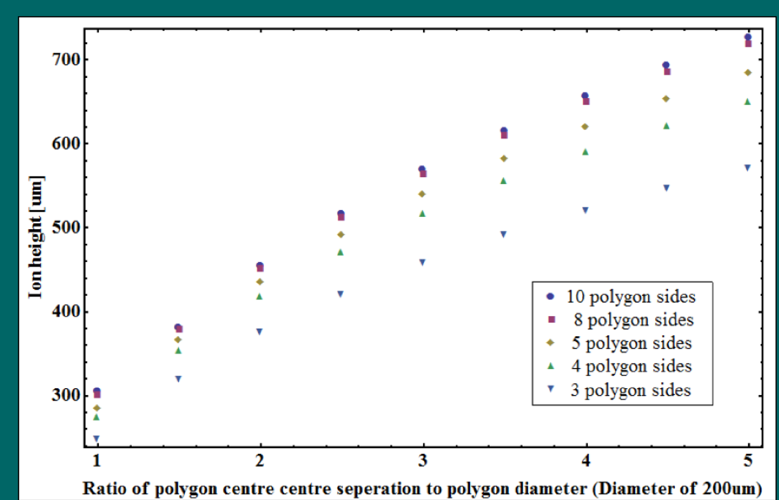
Geometry properties

The optimisation of the trap parameters have to enable an interaction which occurs faster than the decoherence, as well as ensuring the trap depth and secular frequencies remain practical for experiments: trap depths > 0.1eV, secular frequencies >100 kHz and ion height >50 µm.

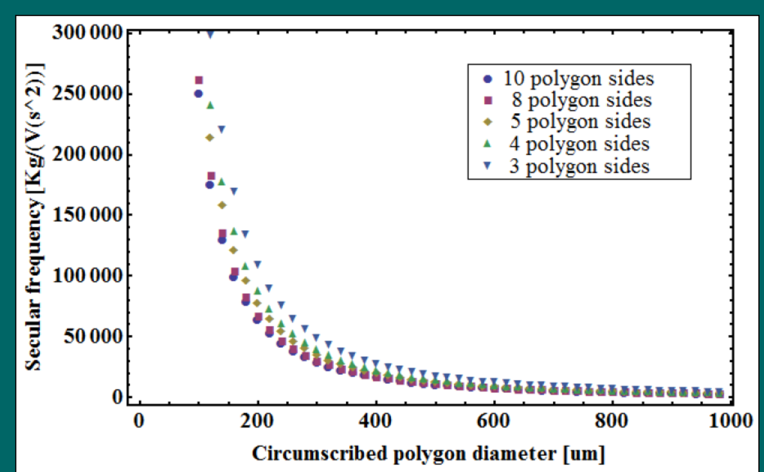
The electric fields were analytically solved using a Biot-Savart-like law[8]. The circumscribed diameter of the polygons, D, the polygon separation, A and the polygon side number were all varied. The relationship between these parameters and the ion trap height, secular frequency and trap depth were plotted.



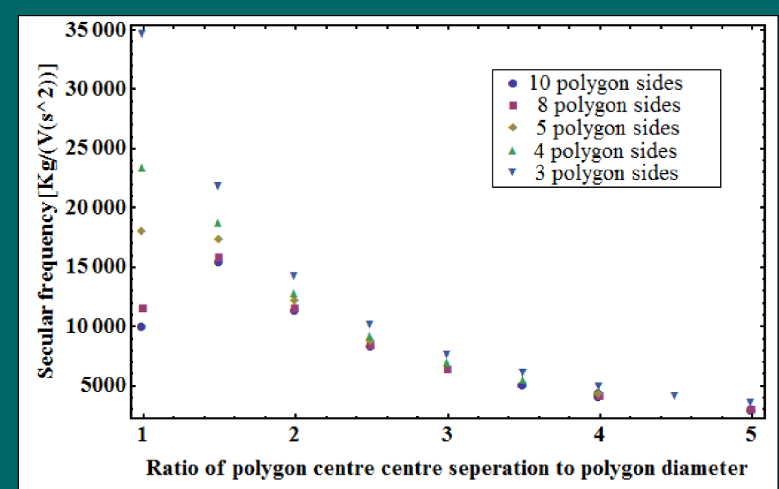
Left shows the height of the rf nil above the surface of the polygon array, h, against the circumscribed diameter of the polygon, D. This was repeated for several different polygon side numbers, n. The polygon separation, A, was kept constant at $\frac{5}{4}$D.



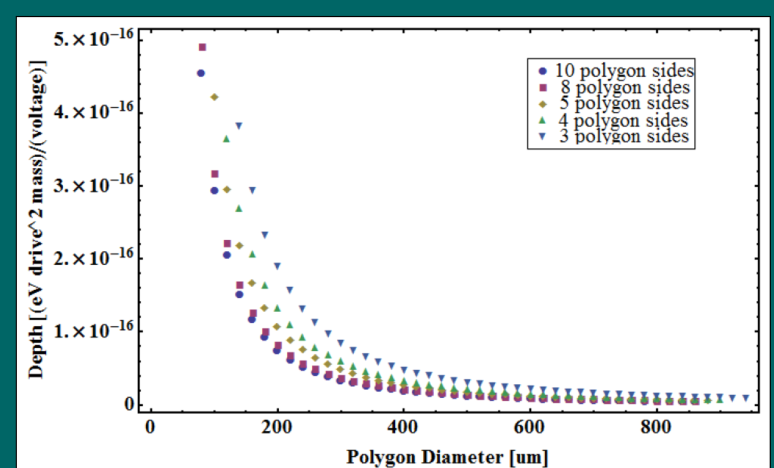
Right shows the height of the rf nil about the surface of the polygon array, h, against polygon separation, A, given as a ratio of separation to polygon diameter. The polygon diameter was kept constant at D = 400 µm.



Left shows the radial secular frequency of the trapped ions against the polygon diameter, D. The polygon separation was kept constant at $\frac{5}{4}$D.



Right shows the secular frequency of the ions against polygon separation, A, given as a ratio of the separation to the polygon diameter. The polygon diameter was kept constant at D = 400 µm.



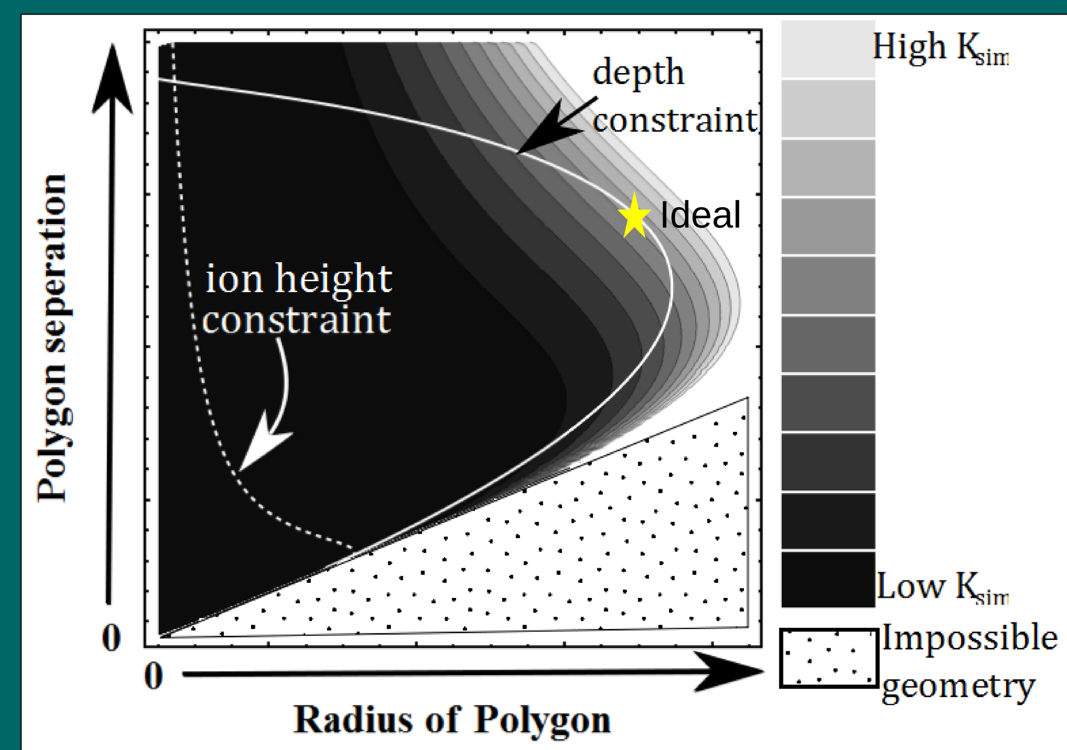
Left shows the trap depth against the polygon diameter, D. The polygon separation was kept constant at $\frac{5}{4}$D.

Optimised design

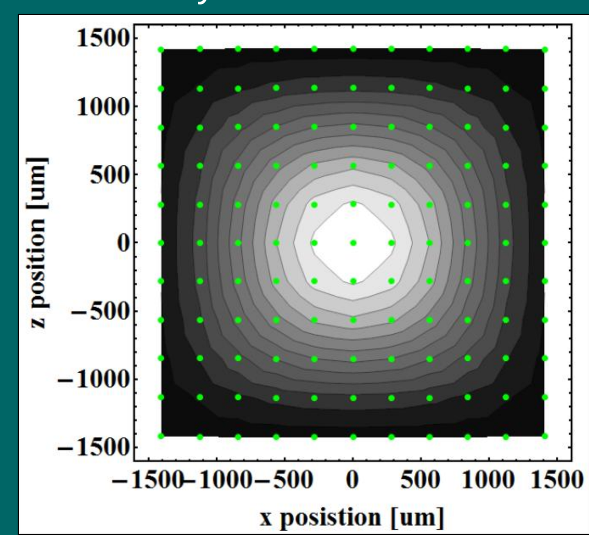
Optimisation can be achieved by calculating the electric field from an array of polygons and by varying the polygon side number, n, polygon diameter, D and the inter polygon separation, A.

The heating rate of the ion was then calculated as the relationship to ion-electrode distance, h is know, and scales as h^{-4} [7].

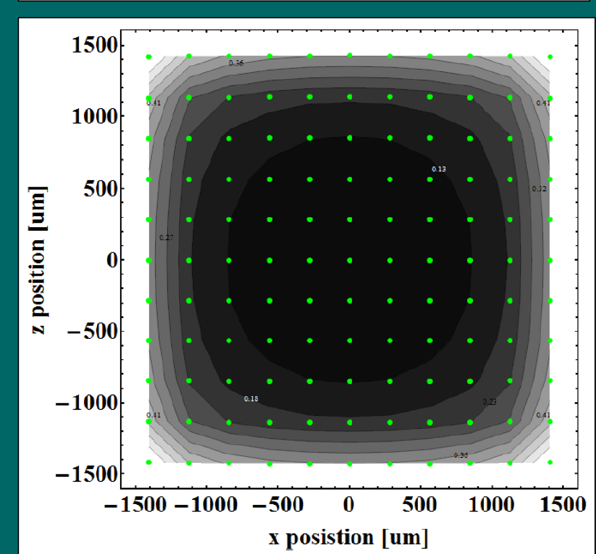
The interaction time can then be calculated from the simulated ion secular frequency and combining this with the decoherence time K_{sim} can be found. Plotting the values of K_{sim} along with experimental constraints on trap depth, secular frequency and ion height we get the follow plot:

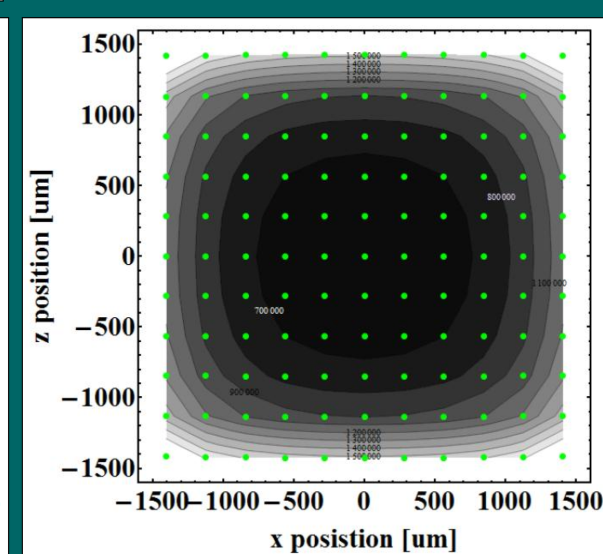


For $^{171}Yb^+$ with an rf amplitude of 200 V at 15 MHz drive frequency, the trap depth, secular frequency and K_{sim} were then calculated in an 11x11 array.



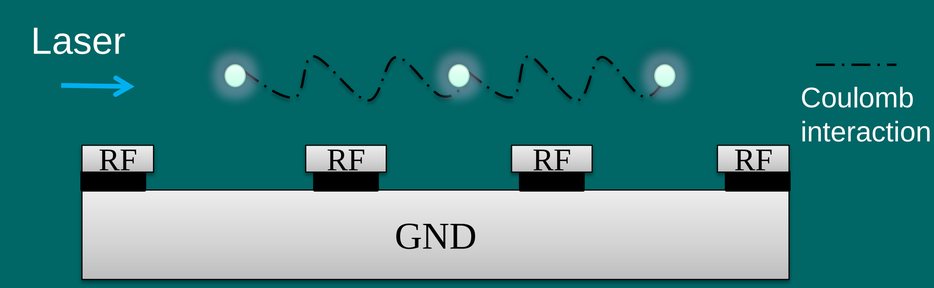
Left shows a K_{sim}/F^2 contour plot with contour lines of 0.5×10^{36} N^{-2} up to 6×10^{36} N^{-2}. The ions are marked by a green dot. *Bottom left* shows trap depth contours of 0.05eV up to 0.5eV at the edge. *Bottom right* shows secular frequency contours of 0.1MHz up to 1.5MHz at the edge.



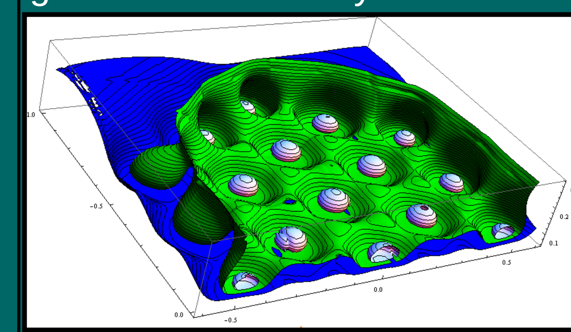


1st microfabricated lattice

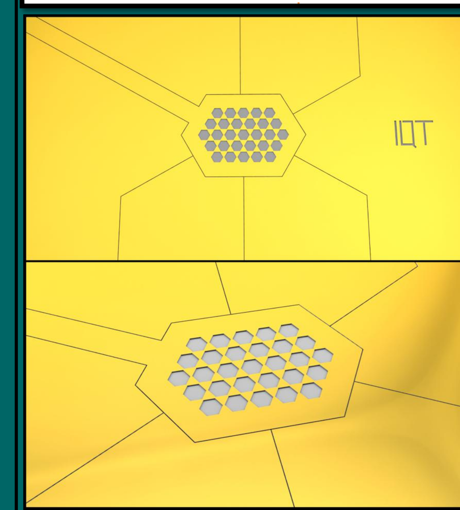
By etching away islands to expose the conductive handle layer electrically connected isolated islands can be created. This is useful when trying to create 2D lattices as the handle layer can be used as ground electrodes.



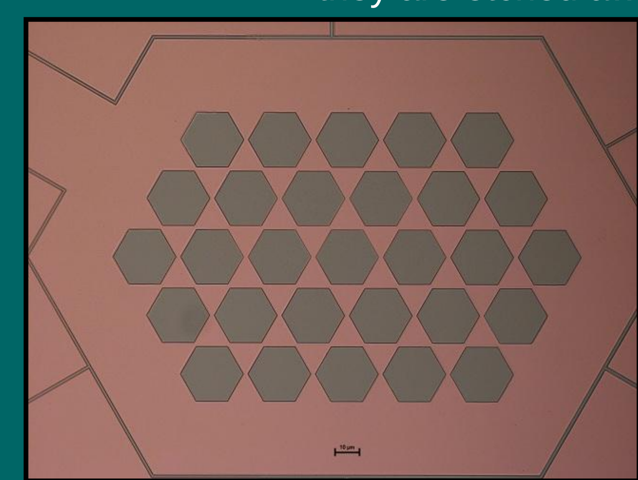
Progress:
The trap is fabricated from a Silicon-on-insulator wafer, the grounded centres are produced by etching the top level of silicon and exposing the grounded handle layer.



Contours: white 0.1eV, green 0.2eV, blue 1eV



Left shows drawings of the proposed ion trap lattice. It comprises of 29 trap sights and is surrounded by 6 compensation electrodes. *Below* shows the trap lattice during fabrication, the grey hexagons are the exposed top silicon layer, before they are etched away.



1) R. Blatt and D. J. Wineland *Nature*, 453:1008-1015
2) D. Porras and J. I. Cirac *Phys. Rev. Lett*. 92(20):207901
3) I. Buluta and F. Nori, *Science*, 326:108-111
4) K. R. Brown, R. J. Clark, T. Lin and I. L. Chuang, *Journal of applied physics,* 105(013114)
5) D. Leibfried, R. Blatt, C. Monroe and D. J. Wineland, *Rev. Mod. Phys.,* 75(1):281-324
6) R. P. Feynman, *Int. J. Theor. Phys.,* 21(467)
7) Q. A. Turchetter, D. Kielpinski, B. E. King, D. Leibfriend, D. M. Meekhof, W. M. Itano, C. Monroe and D. J. Wineland, *Phys. Rev. A,* 61(6):063418
8) M. H. Oliveira and J. A. Miranda, *Eur. J. Phys*. 22 (2001) 31-38