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A double junction segmented ion trap with integrated optical delivery

INTRODUCTION

Ion traps are a robust and promising platform for quantum information processing and for the implementation of a quantum computer. However, major challenges exist in scaling these systems to the level required for full-scale quantum computing. I will describe work concerned with addressing two of these challenges; namely connecting multiple trap zones in more than one dimension, and integrating laser light delivery into the trapping structures.

MOTIVATION

In the last few decades, the limitations of classical computation have motivated scientists to turn to quantum computation. In the attempt of identifying the key requirements for a quantum system to be a viable quantum computer, the Di Vincenzo criteria were formulated [1]. Trapped ions satisfy all of the Di Vincenzo criteria. There is, however, an important criterion on which research is still open: that the system can be scaled to a large number of qubits while still satisfying all other criteria [2]. One approach towards scalability [3] is that of creating a trap with several trapping regions. This allows gates to be performed on a small numbers of ions, and that gates can be performed in parallel on ions stored in different regions of the processor. In this scenario, linear traps present a limitation: as the ions are arranged in a linear string, it is challenging to arbitrarily entangle two ions separated by a long string of other ions. In order to achieve order switching on a large number of ions and thus transfer of quantum information, junction traps have been proposed [3].

Our work focuses on pursuing the scalability requirement, by the creation of a double-junction ion trap. The trap geometry and the electric fields provide control over the motion of the ions, while laser light is used to perform quantum gates and state detection. Our trap introduces new features to improve both the ion motion control and the ion manipulation.

TRAP DESIGN

The trap is made of a stack of silica glass wafers: two host the junction trap structure, the middle wafer is used for optical integration and outer wafers hold shim electrodes for stray electric field compensation. There are three experimental zones and a total of 145 electrodes. With an electrode to ion distance of 185 μm, driving the trap at 90 MHz allows us to achieve secular frequencies of 3.7 (Ca) and 16 (Be) MHz. Tapered electrodes allow for an optical access angle of 45°.

We concentrate our design efforts on the junction region. Here, we find that open bridges, as well as closed bridges, can be used to minimise the residual axial field (axial presudopotential barriers), which the ions encounter when approaching the junction. We are able to optimise the junction geometry to achieve pseudopotential barriers below 0.2 eV. We also investigate the excess micromotion contribution from the finite size of electrodes and from electrode gaps. We find that gaps create a residual oscillatory axial electric field, with amplitude of 200 V/m, which is attenuated when the segmentation is only present on the dc fingers.

There are two main novel features in our design: first, the use of selective subtractive 3D printing technology to fabricate the wafers. This technology offers a way of incorporating the alignment of the wafers into the trap structure, minimising misalignment and providing a way to create larger arrays of traps. Secondly, the integration of optical delivery via micro-lensed optical fibres to achieve focused beam spots$<20\mu$m at a working distance of 400 μm. An integrated shim electrode will compensate for their charging.

SUMMARY

We are finalising the design and fabrication of a novel segmented 3D ion trap featuring two X-Junctions and delivery of light integrated within the trap wafers. This work will be useful in investigating approaches to scalability of quantum computers.

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[2] D. Kielpinski, C. Monroe, and D. Wineland, Architecture for a Large-Scale Ion-Trap Quantum Computer, Nature 417, 709711 (2002).
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Summary

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