A Lithographic Dual Rf Ion Trap for Multiplexed Quantum Computing

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Developing a practical quantum computer requires perhaps hundreds of interacting "qubits". Cirac and Zoller[1] proposed a physical scheme to implement quantum computing with a string of ions which are held in a single linear rf trap. Two internal states of each ion make a quantum bit or qubit. The application of a laser field couples the qubits to a common quantized vibrational mode of the trap. Gate operations proceed between qubits by way of this common vibrational mode which acts as a data bus. The Cirac/Zoller scheme provides a good starting point for quantum operations but as the number of ions increase several difficulties are encountered. The addition of each ion to the string adds a common axial vibrational mode. Soon it becomes nearly impossible to spectrally isolate the desired vibrational mode from the others. In addition, as ions are added to the trap, the axial trap strength must be decreased in order to maintain a linear string of ions. A weaker trap makes Doppler and sideband cooling less effective. It is also a challenge to individually address ions with laser beams when they are in a long string. To avoid these problems we plan to implement a multiplexing scheme based on several few-ion qubit registers[2]. Here, entangling gate operations are performed on only a few ions at a time in a particular trap; then the ions are electrostatically shuttled between traps to communicate their quantum information.

In a first step towards realizing a multiplexed quantum computer we have constructed a dual linear ion trap, the unit cell of this scheme. The trap is constructed with a stack of alumina wafers with laser machined slots and evaporated gold traces that create the correct electrode geometry. These lithographic techniques allow the trap to be made small and are easily expandable to larger arrays. The dual trap is a simple extension of a single linear trap. In a linear rf trap the static potential electrodes are segmented for axial confinement. Instead of just three segmented electrodes, the case for a single trap, our dual trap has five. Axial confinement at two separated places occurs when the outer two and middle segments are biased at about 10 volts above the other two segments. Lowering the potential on the middle electrode segment permits two initially separated ions to be combined together in one trap. This trap will be the test bed for the basic ion manipulations needed for a multiplexed quantum computer.

Several experiments are planned with this apparatus. First, the shuttling of ions between the traps can be tested. The ions can be entangled[3] in one trap and separated. We can check to see if they maintain internal state (qubit) coherence after separation. This can include a test of Bell's inequalities with the ions. Our near 100% state detection efficiency eliminates the "fair sampling" hypothesis required in other experiments[4]. Ultimately, we plan to trap two different atomic species in the trap, with one species continuously laser-cooled. This sympathetic cooling allows the vibrational modes to be recooled after ion shuttling without destroying qubit coherence. Finally, it should be possible to implement "scalable" quantum teleportion schemes, where an unknown quantum state of an ion in trap 1 is *deterministically* teleported to an ion in trap 2.

Additional design changes were made with this trap with the goal of reducing vibrational mode heating. Our previous results show a strong decrease of heating rates with increased trap size[5]. The scaling suggests that the heating is due to fluctuating microscopic patch-potentials. For this reason, the average linear dimension of our dual trap is about 30% bigger than our previous linear trap. One source for the patch-potentials is beryllium from our ovens coating the trap electrodes. The gradual increase over time in the heating rate that we have seen with our traps correlates with the slow build-up of beryllium on the trap electrodes. In this new trap design the electrodes are shielded from the beryllium oven by an additional baffle plate which closely covers the electrodes. This design will allow us to test this hypothesis. Heating measurements will be presented.

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