Scaling and suppression of motional decoherence in an adjustable ion trap*

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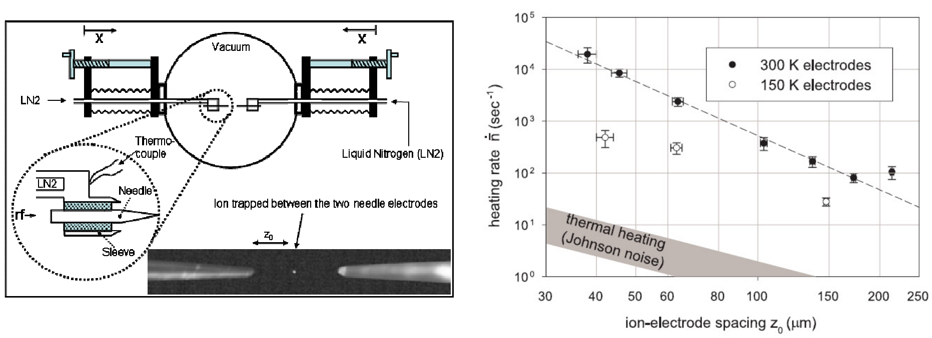
Heating of the motional states of trapped ions may be a source of decoherence for many quantum logic gate schemes[1]. Heating data from previous experiments[2,3] indicates that the magnitude of observed heating is significantly larger than expected from thermal (Johnson) noise and is thought to originate from microscopic "patch" potentials[4]. Using data from previous experiments it is difficult to study this anomalous heating in a controlled way, because of comparisons across different trap structures, materials, surface qualities, and ion species.

In order to investigate this anomalous heating and to provide a scaling with electrode proximity, we have constructed an ion trap[5] that permits continuous variation of the electrode-ion spacing. The "needle" shaped tungsten electrodes provide a quadrupole trap and can be moved via external translation stages. The needle tips are approximately spherical with a radius of 3µm and supported by a conical shank of half-angle 4°. Each surrounding cylindrical grounded sleeve of inner diameter 3.0 mm is recessed 2.3 mm from the needle tip and electrically isolated from the needles with an alumina tube. We are able to trap over the range of ion-electrode distances of 23 to 250µm. Fig. 1(a) shows a schematic drawing and an ion trapped between the two needle electrodes. The needle electrodes can be cooled to a temperature of approximately 150K via contact with a liquid Nitrogen reservoir.



(a) (b)

Fig. 1:
(a) Schematic diagram of the ion trap apparatus with translation stages that allow variable ion-electrode spacing. The inset shows an ion trapped between two needle electrodes.
(b) Axial heating rate as a function of distance z from trapped ion to each needle electrode, for warm (solid points) and cold electrodes (open points).

In order to measure decoherence of ion motion, a single $^{111}Cd^{+}$ ion is first laser-cooled to near the ground state of motion through stimulated-Raman sideband cooling. The mean number of motional quanta is determined by measuring the ratio in the strength of the stimulated-Raman first-order upper and lower sidebands. Motional decoherence is measured by inserting a delay time (up to τ = 50 ms) after Raman cooling but before the sideband probe. Figure 1(b) shows several measurements of heating rates at various values of the distance z between the ion and the needle electrodes indicating a $\sim z^{-3.5}$ scaling.

When the electrodes are cooled to ~150K the measured heating rate is still two orders of magnitude higher than expected from thermal noise, as shown in the Fig. 1(b). However, the ion heating rate is suppressed by an order of magnitude for a decrease in electrode temperature by only a factor of two, suggesting that the anomalous heating observed in ion traps may be thermally driven and activated at a threshold temperature, and that further cooling to 77 K or lower may even quench this anomalous heating completely.

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