Sideband heating of a single calcium ion trapped in a Penning trap: Preparation and coherence studies of a non-thermal state

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Previously, we have demonstrated the ground state cooling of a single trapped calcium ion in a Penning trap[1]. A trapped calcium ion is initially cooled to its Doppler limit by a red detuned 397 nm laser light (resonant with the $S_{1/2} \leftrightarrow P_{1/2}$ transition) [2]. The next stage of cooling is carried out through a resolved sideband cooling scheme. A resolved sideband cooling requires a narrow linewidth transition and also a narrow linewidth laser tuned to the first red sideband of the transition (i.e. $S_{1/2} \leftrightarrow D_{5/2}$ for a calcium ion). In an extension to that work, we report here the coherent manipulation, both within and outside the Lamb-Dicke (L-D) regime, of a single ion qubit. Coherence studies of a ground state cooled ion are carried out by observing the Rabi oscillations and Ramsey interference fringes, and the coherence time is measured to be 1.5 ms.

In contrast to sideband cooling we also show the results of the sideband heating on a ground state cooled trapped ion. Sideband heating is demonstrated by tuning the 729 nm laser to a blue sideband of the transition. This eventually drives the population to high phonon states. Due to the presence of minima of the sideband strength, the population gets confined to a few phonon states [3]. Such a spectrum is shown in Fig. 1, where the sideband heating is carried out on the first blue sideband. In the right part of the figure, a simulated histogram of the population spread as a function of sideband heating time is shown. It can be seen that initially the population spreads out and then gets confined around a phonon state n = 160. This is the phonon state at which the blue sideband strength ceases, thus leads to a population build up. Realisation of these quantum states are vital and can be very useful to demonstrate the quantum studies outside the L-D regime.

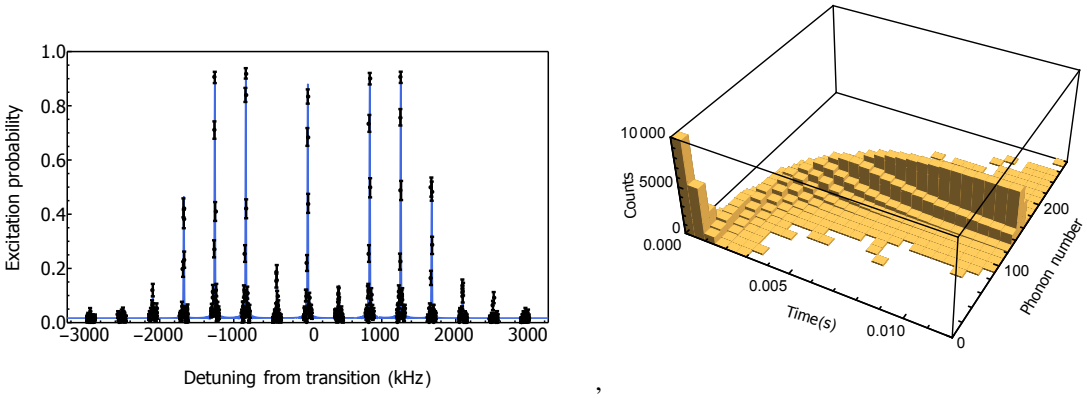

Fig. 1: Sideband heating of a calcium ion at 419 kHz axial frequency (Left). A simulated histogram plot of population in each phonon state as a function of time, where the sideband heating is carried out at the first blue sideband (Right).

Recently, we also have carried out the ground state cooling on ion Coulomb crystals (ICCs) [4]. The ground state cooling of an ICC is performed through a resolved sideband cooling scheme, similar to the single ion case. Due to the presence of multiple sidebands a complex cooling sequence was necessary and multiple laser frequencies are used repeatedly to efficiently cool the ions to their ground state. In future work we will carry out the coherence studies on such crystals.

References

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