Resolved sideband cooling of a single Sr^+ ion

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Trapped ions are of great interest in quantum information processing (QIP) as shown by recent experiments using $^{9}Be^+$ [1] and $^{40}Ca^+$ [2]. The ideal starting point for efficient coherent manipulation of both internal and external degrees of freedom is an ion in the ground state of the trapping potential. This may be achieved by resolved sideband cooling [3] in which the lower motional sideband of a narrow transition is driven. Strontium is an attractive candidate for such applications due to the narrow 5s $^2S_{1/2}$ – 4d $^2D_{5/2}$ electric quadrupole transition at 674 nm. With analogous electronic structure, the resolved sideband cooling scheme used in $^{88}Sr^+$ is similar to that demonstrated in $^{40}Ca^+$ [4].

A single $^{88}Sr^+$ ion has been trapped in a radio-frequency endcap trap [5]. The ion is first Doppler cooled on the 422 nm dipole transition and then sideband cooled on the 674 nm quadrupole transition (fig 1a). Doppler cooling was initially limited by a large anomalous heating mechanism. Similar heating observed in work using Ba^+ [6] was attributed to coating of the trap electrodes by impurities from the atomic source used to load the trap. A new oven, based on that developed in Ref. [6] has been constructed to overcome this problem. By tuning a narrow (4 kHz) probe laser to the $^2S_{1/2}$ (m_j = -1/2) – $^2D_{5/2}$ (m_j = -1/2) transition and varying the pulse duration of the probe radiation incident on the Doppler-cooled ion, damped Rabi oscillations are observed (fig 1b). The damping is due to the ion's thermal distribution over motional states of the trap and implies an average vibrational quantum number $\langle n_z \rangle \sim 20$ in the axial direction after Doppler cooling [7].

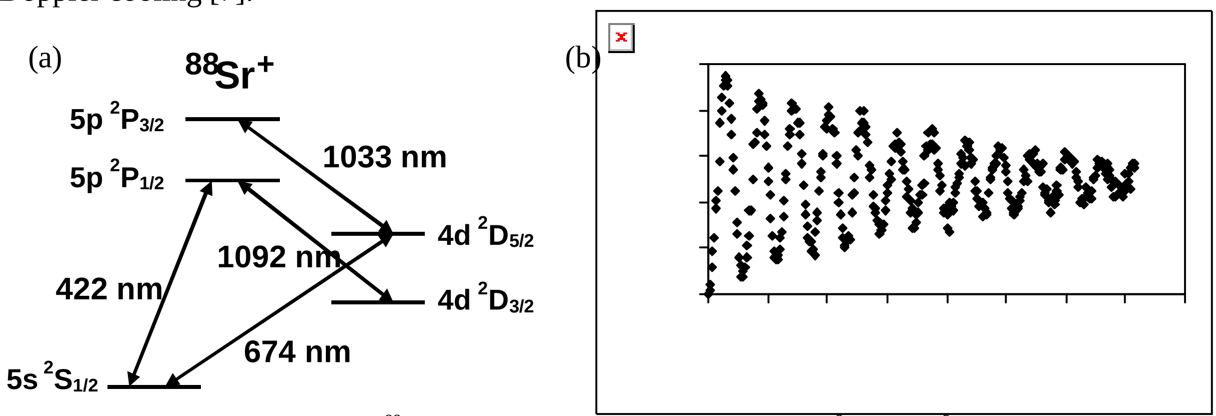

Fig. 1. (a) Energy levels of $^{88}Sr^+$. The ion is Doppler cooled on the 5s $^2S_{1/2}$ – 5p $^2P_{1/2}$ transition at 422 nm, with 1092 nm radiation preventing optical pumping into the $^2D_{3/2}$ state. (b) Rabi oscillations on the $^2S_{1/2}$ (m_j = -1/2) – $^2D_{5/2}$ (m_j = -1/2) transition after Doppler cooling.

When sideband cooling on a lower motional sideband of the quadrupole transition, the cooling rate will be limited by the long lifetime of the $^2D_{5/2}$ state. The $^2D_{5/2}$ level is therefore mixed with the short-lived 5p $^2P_{3/2}$ level using a quencher laser at 1033 nm. The $^2S_{1/2}$ (m_j = -1/2) – $^2D_{5/2}$ (m_j = -5/2) transition is then chosen for sideband cooling order to achieve a closed cooling cycle. The presence of 1033 nm light during sideband cooling results in an AC Stark shift of the $^2D_{5/2}$ state which has been characterised (fig 2).

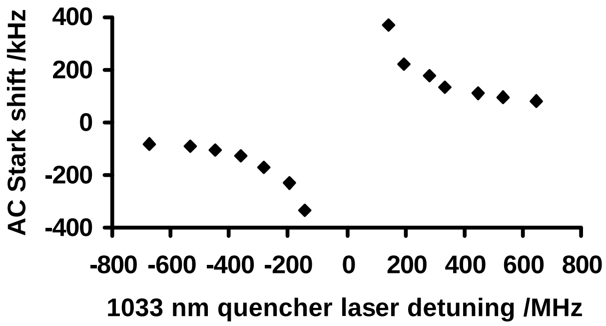

Fig. 2. AC Stark shift of the lower radial sideband of the $^2S_{1/2}$ (m_j = -1/2) – $^2D_{5/2}$ (m_j = -5/2) transition

Resolved sideband cooling when driving the lower axial sideband of the $^2S_{1/2}$ (m_j = -1/2) – $^2D_{5/2}$ (m_j = -5/2) transition has recently been observed as an asymmetry in absorption on the upper and lower sidebands, see fig 3. Preliminary work using a 5 ms sideband cooling pulse has resulted in cooling in the axial direction to $\langle n_z \rangle \sim 0.1$.

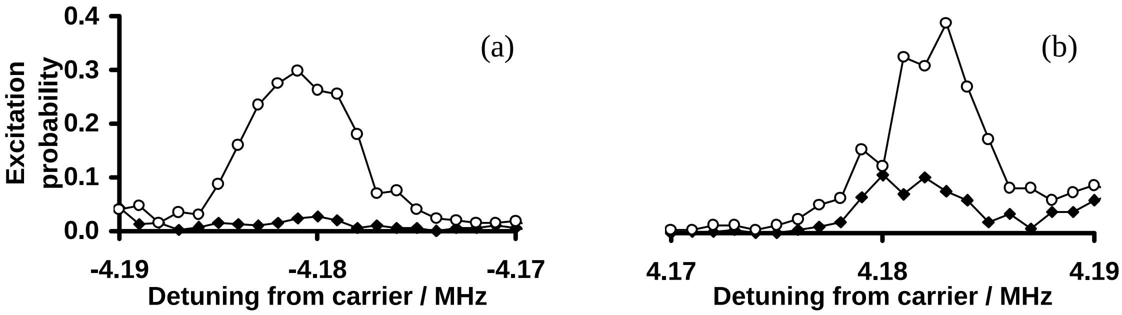

Fig. 3. Absorption spectra on both upper (b) and lower (a) axial sidebands of the $^2S_{1/2}$ (m_j = -1/2) – $^2D_{5/2}$ (m_j = -5/2) transition, before (open circles) and after (filled circles) resolved sideband cooling.

References

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