Enhanced Light Collection from a Single Trapped Ion

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Abstract: We discuss two methods to improve the photon collection efficiency from trapped ions. This significantly improves the success probability of probabilistic photon entanglement schemes.

OCIS codes:

The collection of light from trapped ions is an integral part of the implementation of a trapped ion quantum computer. A high collection efficiency is crucial to quickly and faithfully read out the atomic state. Furthermore, new ways to scale a trapped ion quantum computer build on the entanglement of distant ions [1]. Here, remote entanglement of two ions is obtained by first entangling the electronic state of each ion with their emitted photons. The emitted photons are collected and directed to interferer on a beamsplitter. A coincidence detection at each output port of the beamsplitter heralds the success of the entanglement procedure.

However, the success probability scales with the square of the photon collection efficiency, and is currently extremely small. To date, these experiments are conducted in free space and are primarily limited by the solid angle of the lens and overlap of the spatial mode emitted by the ion with the Gaussian mode of the single mode fiber used to mode match the light from the two ions [2,3]. It is therefore of considerable importance to increase the amount of photons collected from trapped ions. We describe below the current efforts to improve the collection efficiency.

One method of increasing the collection solid angle is to place a reflector near the atom. Similar to [4], we will place a single trapped ion in the focus of a spherical mirror. The mirror has a radius of curvature of 5.08mm and reflectivity of >99.7% at 369nm (the $P_{1/2} \rightarrow S_{1/2}$ transition wavelength of ytterbium). With an ion placed at the focus of the mirror, ~15% of the solid angle emerges from the viewport of the vacuum chamber, a sevenfold enhancement over the current free space experiments.

Another method is to place the trapped ion in a high finesse optical cavity and use the Purcell effect to extract photons. We have a pair of mirrors with a 2.5cm radius of curvature and a finesse of ~5000. With a cavity spacing of 300μm, the mode waist is approximately w_0~ 15μm. The coherent coupling rate at the antinode is g~17MHz. The relevant dissipative rates are the cavity decay rate (60MHz) and spontaneous emission rate (19.7MHz), giving a single-atom cooperativity of C~0.24, which should give about 15% of the emitted light. The output of the cavity is a Gaussian mode which can be better mode matched to a single mode fiber. Overall, we expect a tenfold enhancement over the current experiments.

For both experiments, a small ion trap is necessary to shield the ion from stray charge buildup on the dielectric surfaces. We employ a 3-D RF quadrupole trap consisting of gold patterned on two laser-machined alumina substrates. Each substrate is mounted on independent translation stages, whereby the ion–electrode spacing can be varied *in situ*. The ion–electrode spacing will be chosen to be smaller than the ion–mirror spacing (150μm). The substrates are 127μm thick and machined to have three 100μm wide electrodes each. The outer electrodes provide the RF ground as well as DC control.

While a tenfold increase in photon collection results in an improvement of state detection from ~99% fidelity to ~99.9% [5], such an increase results in an improvement of two orders of magnitude in the probabilistic entanglement scheme.

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