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Imaging trapped ions with an integrated microfabricated optic

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Abstract. We have integrated a microfabricated phase Fresnel lens (PFL) with an ion trap and used it to image a 174\textsuperscript{Yb}\textsuperscript{+} ion. The observed collection efficiency was 4.1 ± 1.3%, in agreement with a predicted performance of 4.6% based on optical characterization and suitable for use in quantum computing. A maximum signal to background scatter noise of 23 ± 4 was measured near saturation intensity (s=0.7). The depth of focus was 11 µm and the field of view in excess of 100 µm across.

Keywords: Phase Fresnel Lens, Trapped Ion Quantum Computing
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Trapped ions are a leading system for implementing quantum computers due to their long coherence times and strongly controllable interactions. Small scale quantum computations have already been realized in trapped ions [1] and a roadmap exists for achieving large scale quantum computing [2] through the development of microfabricated multi-zone traps [3]. Arrays of microfabricated phase Fresnel lenses (PFLs) have many properties [4] which make them an attractive alternative to conventional refractive optics for coupling light into and out of trapped ions in such a processor. These diffractive optics can achieve large numerical apertures (NA) exceeding 0.9 while maintaining diffraction limited performance [5] at the near ultraviolet wavelengths found in trapped ion systems.

APPARATUS

The PFL was fabricated by electron-beam lithography on a fused silica substrate. The e-beam patterning defined a series of rings corresponding to contours of $\pi$ phase steps for an ideal point source $f= 3$ mm from the lens with a wavelength of $\lambda = 369.5$ nm. This is the wavelength of the $S_{1/2}$-$P_{1/2}$ cycling transition in Yb\textsuperscript{+}. The rings were etched to a depth of 390 nm, shifting the optical path length in the etched zones by $\lambda/2$. This pattern was extended to a diameter of 5 mm giving the lens an NA=0.64, corresponding to 12% of the total solid angle. The lens has previously demonstrated focusing to a subwavelength spot size of $w_0 = 350 \pm 15$nm with a 30+/−1% overall diffraction efficiency (37% ideal for binary optic) [4]. As illustrated in Figure 1 the PFL was mounted inside a UHV vacuum chamber with a needle type ion trap. An RF quadrupole was formed near the focal point of the PFL by applying an AC potential of 1800 V\textsubscript{pp} at
20 MHz to two tungsten needles with a tip to tip spacing of 200 µm. $^{174}$Yb$^+$ was loaded into the trap by isotope selective photo-ionization from an atomic beam. The ions were then laser cooled using our existing all diode laser systems [6].

**RESULTS**

We measured the on resonance ion scattering rate as a function of laser power to determine the collection efficiency. In the saturated regime (s=4.7) count rates up to $22,600 \pm 260$ /sec/ion were observed. Fitting the data gives an estimated maximum count rate $25608 \pm 2330$ /sec. Accounting for the quantum efficiency of our detector (28 ± 7%) and the transmission efficiency of our optical system (laser linefilter T=25 ± 5%, all other optics combined T=90%) we observed collection efficiency of $> 3.6 \pm 1.1\%$ and estimate an actual collection efficiency of $4.1 \pm 1.3\%$. This is in agreement with our previous estimate for this PFL of 4.6% [4]. Switching to a multi-level/blazed PFL groove structure would likely at least double the diffraction efficiency [7] and push the collection efficiency near 10%. As alignment sensitivity is crucial to successfully interfacing large microfabricated arrays of ion traps to arrays of PFLs we have also quantified the imaging volume. Here we define the bounds of the imaging volume as when the observed spot size doubles. The observed depth of focus was 11 µm and the field of view in excess of 100 µm across for an ion with an observed 1/e$^2$ spot width of 6.5 µm. The spot size is limited by ion motion [8]. A common problem in using PFLs in optical systems is the introduction of scattered light from unwanted diffractive orders. Ion traps are particularly sensitive to stray scattered light due to the relatively small photon signal.
levels. We have not observed that this is a significant problem as we were able to obtain a signal to background scatter noise ratio of $23 \pm 4$ near saturation intensity ($s=0.7$). This is in an environment where our laser cooling beam $1/e^2$ diameter of $80 \mu m$ is only 2.5x smaller than the needle spacing of $200 \mu m$.

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REFERENCES