Optical Characterization Of A Phase Fresnel Lens For Trapped Ion Quantum Computing

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Abstract

To efficiently collect light from ions in a trapped ion quantum computer, a lens with a high numerical aperture is advantageous. Using phase Fresnel lenses with large working distances and high numerical apertures, we can couple a large fraction of the fluorescence from an ion into a single optical propagation mode (TEM00). We have optically profiled a phase Fresnel lens with a numerical aperture of 0.64 and a focal length of 3 mm. A 350±15 nm beam waist and a beam quality M^2 of 1.08±0.05 was measured near the diffraction limit.

Introduction

Through the use of a quantum computer, the factorization of large numbers can be streamlined. One leading technology is trapped ion quantum computing. Trapped ion quantum computers use the ground states of ions trapped in an RF trap as their qubits. Depending on which of the ground states the ion is in, readout occurs when photons are scattered by an ion. By increasing the probability of collecting a photon, a faster quantum state measurement with greater signal to noise can be made.

While ions posses long decoherence times and high fidelity readout, the entanglement of spatially separated ions is challenging. Through the use of entanglement between an ion and an emitted photon, ion-ion entanglement over large distances can be achieved. In a single ion-photon system the probability of coherently coupling a photon into a single optical mode is proportional to the ion-photon entanglement rate. For ion-ion entanglement, the entanglement rate goes as the square of the coherent coupling efficiency. Using high numerical aperture phase Fresnel lenses, we can improve the probability of coherently coupling a photon, increasing the probabilities for ion-photon and remote ion-ion entanglement (Streed-09A).

Small Spot Focusing Quality

Profiling of the phase Fresnel lens was conducted using a knife edge beam profiler to accurately measure beam waists (Chapman-07). Translating the razor perpendicular to the optic axis, we obtained values for the beam waist w(z), the $1/e^2$ waist radius, as a function of the distance z along the optic axis. Fitting Eq. (1) to the experimental values of w(z) allows us to estimate an M^2 and w_0 for the focused beam. An ideal Gaussian beam has an M^2 equal to 1.

$$w(z) = w_0\sqrt{1+\frac{M^4\lambda^2 z^2}{\pi^2 {w_0}^4}} \quad (1)$$

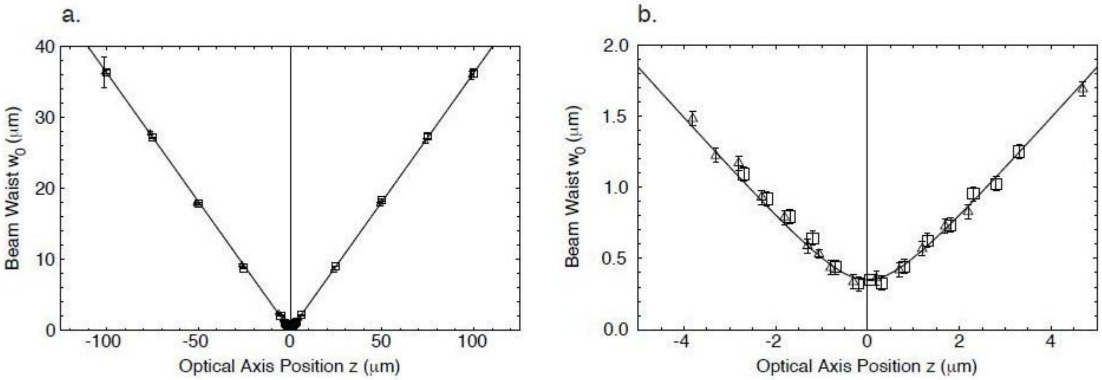

Figure 1: Open boxes represent data points while the line represents the fit from Eq. 1. a) Beam waist size as a function of position along the optical axis b) detail of the focusing region from a.

The fit in the above plot provided the following results. w_0 is the minimum beam waist, M^2 is the beam quality factor and θ is the half angle divergence. For further applications regarding the PFL, please refer to Streed-09B.

Table 1: **Measured Beam Parameters**

Variable	Value
w_0	350±15nm
M^2	1.08±0.05
θ	348±1 mrad

Position Dependant Diffraction Efficiency Measurements

Unlike conventional lenses, PFL's have differing diffraction efficiency depending on the spatial location on the lens. Reducing the input beam waist allows the diffraction efficiency of the different spatial locations to be measured. Translating a razor perpendicular to the propagation direction in front of a power meter allowed each of the diffraction modes to be blocked in a controlled fashion. This allowed for the power in each of the diffraction modes to be measured.

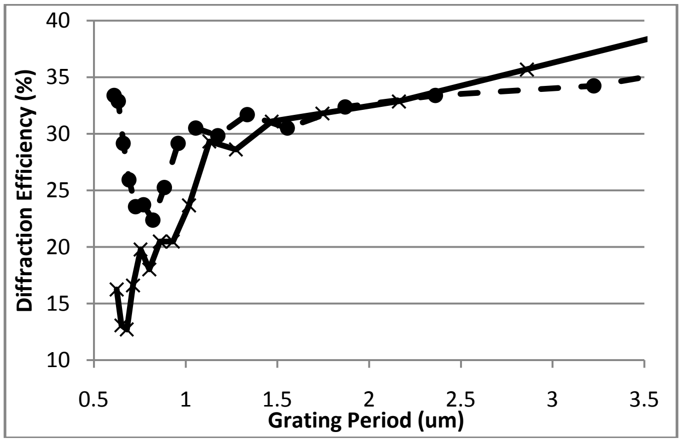

Figure 2: Measured diffraction efficiency as a function of grating period. Circles are S polarised, Crosses are P polarised. Curves are trend lines and do not represent a fit to the data.

At small grating periods feature sizes are on the order of a wavelength. In this regime the light is undergoing vector diffraction and exhibits strong polarization dependence. The effect of S and P polarization at low grating periods was observed as large differences in the measured diffraction efficiency. At grating periods larger then 1.5 µm, the light undergoes scalar diffraction which is polarization insensitive.

Conclusion

Using a submicron knife-edge beam profiler, we have demonstrated that diffraction limited spots can be created using a high numerical aperture phase Fresnel lens. This implies that a PFL can collect and collimate light from a single ion in a coherent fashion making them a good candidate to be used as a high efficiency collection optic in a trapped ion quantum computer. Profiling the position dependent diffraction efficiency of the PFL showed two different regions where both vector and scalar diffraction were the main contributing factors to the diffraction efficiency.

Acknowledgments

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