SAND2012-5213P

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Diffractive Optical Elements: an Enabling Technology in Neutral-Atom Trapping Based Quantum Computing

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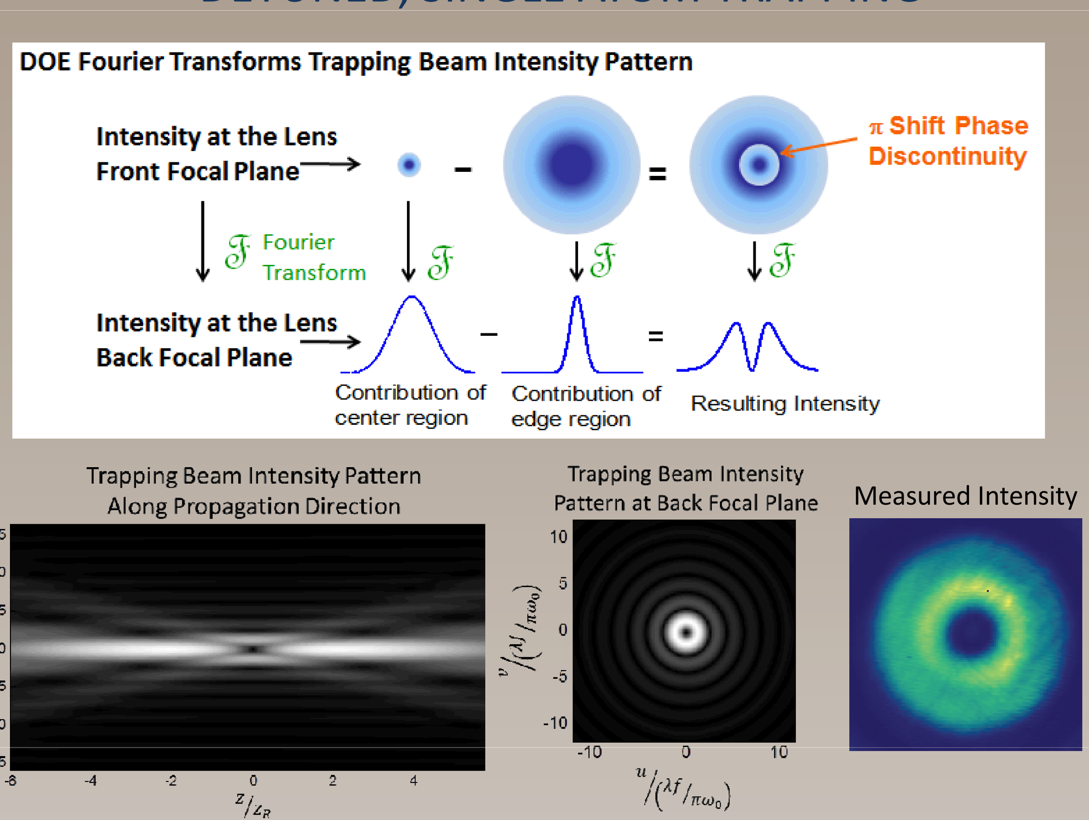
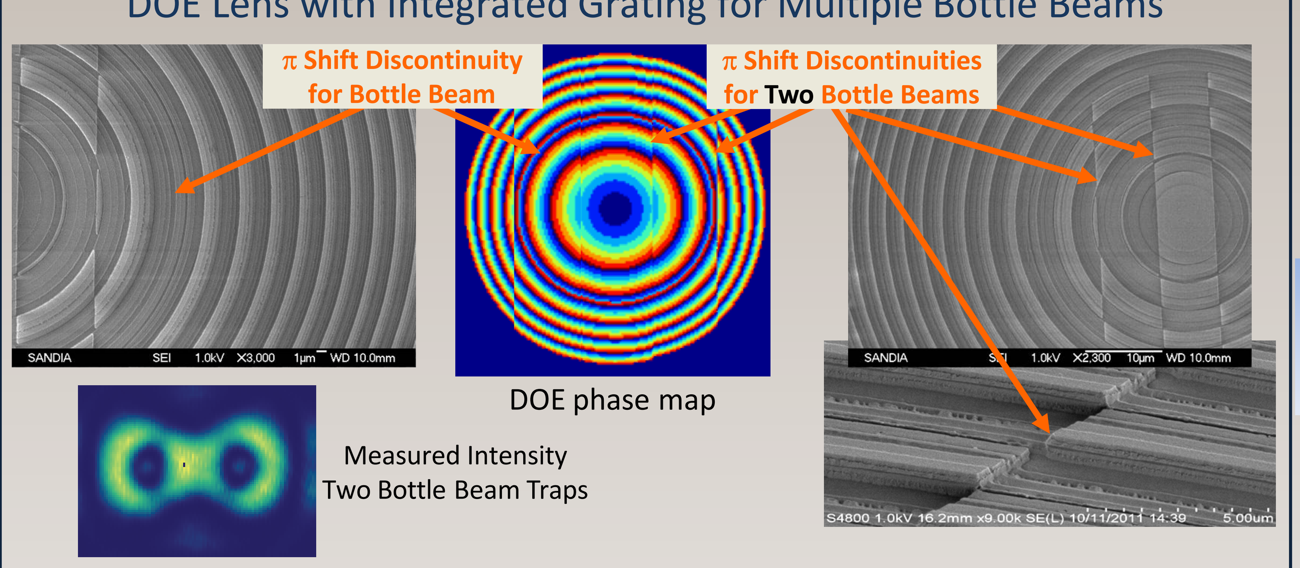
THREE DOE-BASED TRAP IMPLEMENTATIONS

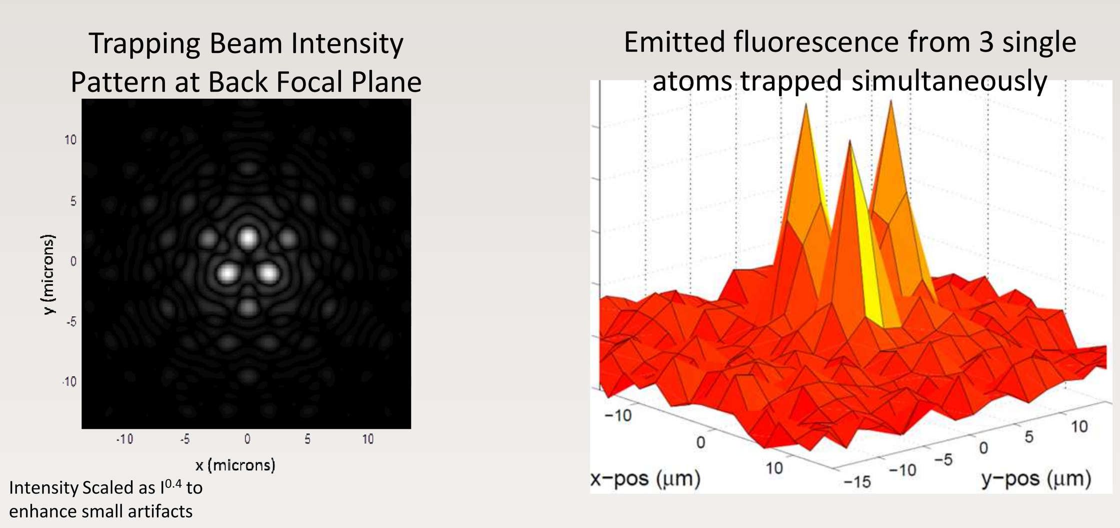
BOTTLE BEAM DOE WITH COLLECTION LENS FOR BLUE DETUNED, SINGLE ATOM TRAPPING



DOE Lens with Integrated Grating for Multiple Bottle Beams

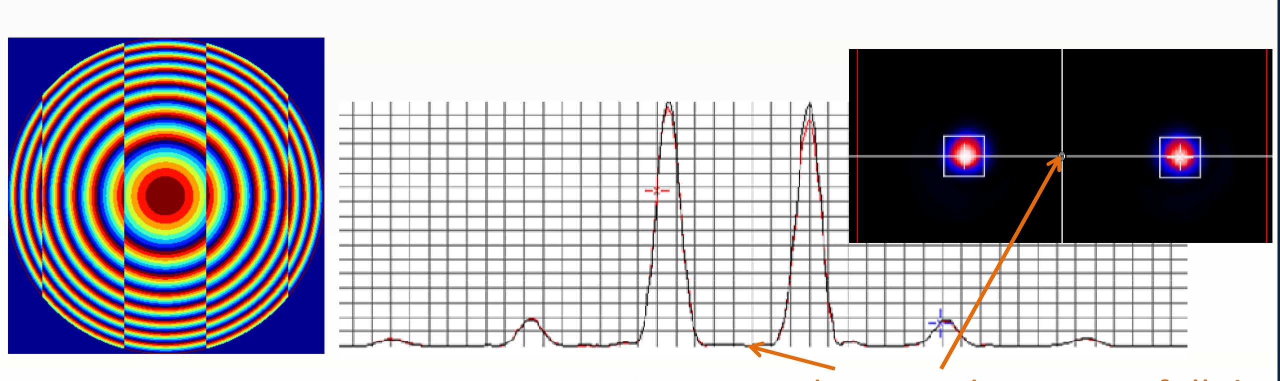


3-TRAP DOE FOR RED DETUNED, SINGLE ATOM TRAPPING



- Utilized, instead of suppressing, zero-order in a 4-level DOE, which makes overall grating efficiency higher; however, zero-order efficiency is VERY sensitive to etch depth. Any etch depth error makes the zero-order spot intensity different than the others.
- Successfully trapped single atoms in all 3 traps simultaneously; however, limitations due to anticipated non-uniformity in spot intensity.

2-TRAP DOE WITH INTEGRATED FOCUS FUNCTION



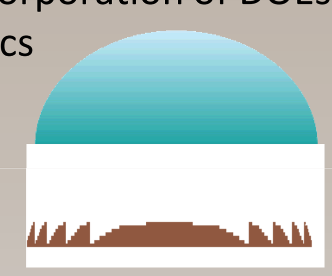
Suppressed zero-order successfully!

- Combines a lens function with a grating to realize 2 focused spots of equal intensity, at a precise lateral spacing
  - Eliminates need for mutual alignment of DOE and fast refractive lens

OPTICS IN QUANTUM TECHNOLOGIES

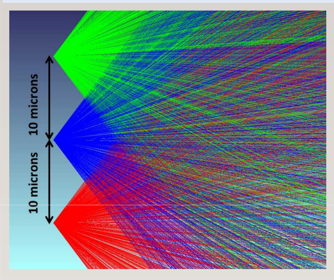
- Optics perform multiple functions in quantum technologies:
  - Tailoring an optical trapping field
  - Manipulating light for optimal excitation
  - Efficient, in-vacuum signal collection
  - Propagating the signal long distances with low loss
- Contribute to improved packaging and scalability
- Ultimately, in a determination of realizable quantum-technology configurations, the optical function is a critical enabling technology

ADVANTAGE OF DIFFRACTIVE OPTICAL ELEMENTS

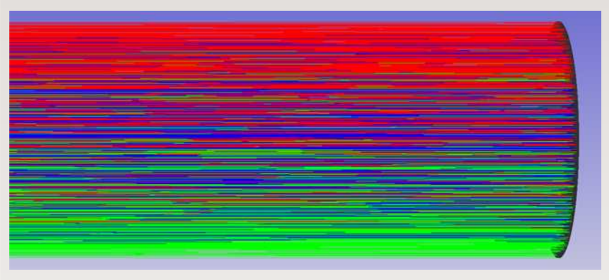


- A significant size advantage is conferred by the incorporation of DOEs as compared to refractive, bulk or even micro-optics
- DOE does not have surface sag
  - Occupies a smaller volume for the same NA
  - A smaller thickness can be used in a DOE, limited only by need for structural rigidity
- An array of 100% fill-factor, mutually aligned DOEs is as easily accomplished as a single lens due to lithographic definition
- Enables scaling

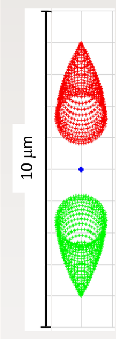
COLLECTION LENS DESIGN FOR LINEAR 1 X 3 TRAP ARRAY



Inside the quartz vacuum cell, fluorescence emission is collected from 3 Cs atoms, each separated by 10 μm



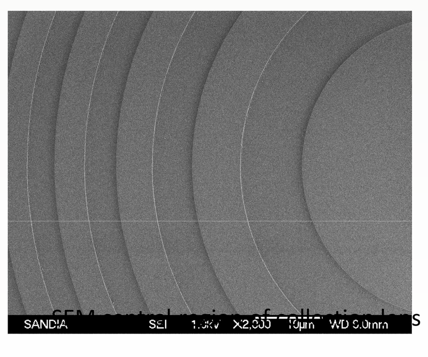
The DOE collects the emitted photons, and produces a collimated beam; the light from the 3 different atoms exits at slightly different angles



Focusing the 3 collimated beam produces 3 spatially separated spots that are coupled in to optical fiber. The DOE designs were optimized for fiber coupling efficiency

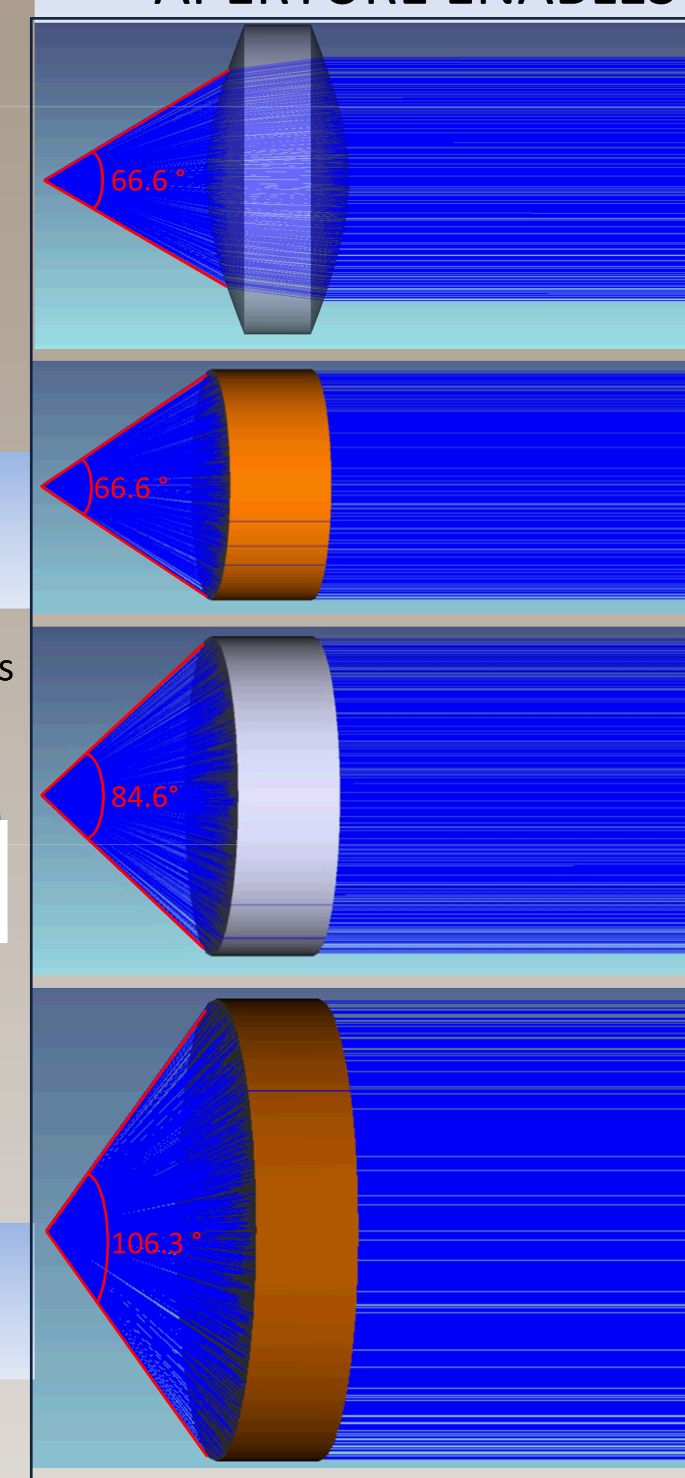
NOTABLE PROPERTIES OF THE DOE COLLECTION LENS REALIZED FOR THE 1 X 3 ARRAY

- Incorporated inside quartz vacuum cell
- Gold wings allow access for MOT beams
- Enables high collection efficiency
- DOEs occupy smaller volume than refractive options
- DOEs enables shorter distance to atoms
- The DOE matching the NA of the refractive is less sensitive to alignment than the refractive
  - The most aggressive DOE requires more careful attention to alignment
  - Alignment tools have been incorporated onto the wafer to aid with alignment



- Demonstration of 1 x 3 linear trap will establish pathway to a 3 x 3 array

COLLECTION LENS: LARGER NUMERICAL APERTURE ENABLES FASTER DATA RATES



Original refractive lens used for collection:
NA: 0.55
Working distance: 2.15 mm
Glass thickness: 1.9 mm

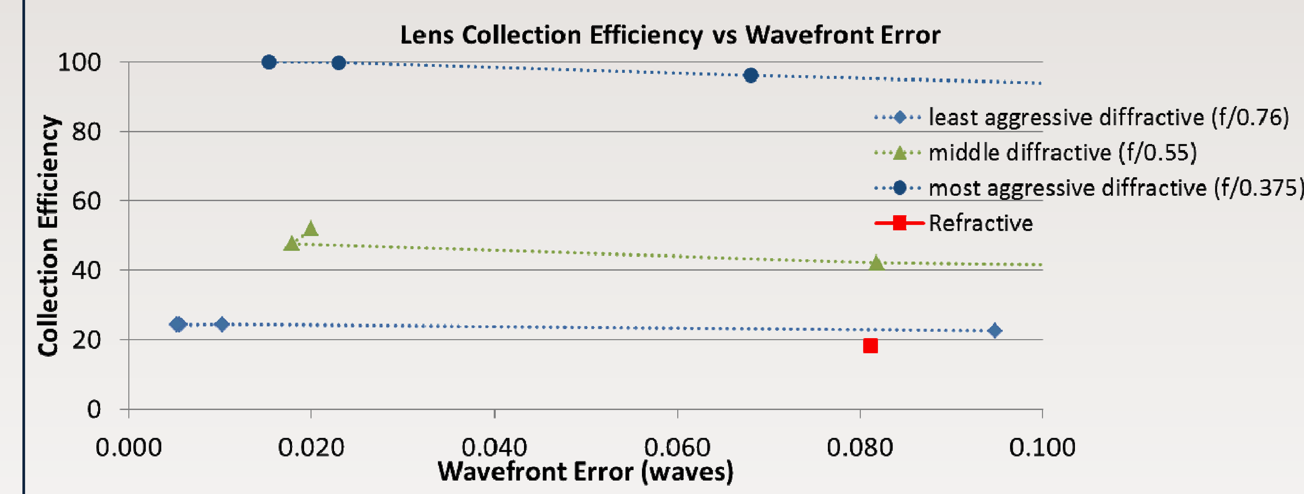
Diffractive design to collect same portion of the sphere as the refractive comparison
NA: 0.55

Diffractive design to occupy same physical space as refractive comparison. Improved collection angle.
NA: 0.67

Diffractive design twice as aggressive as refractive comparison.
NA: 0.8

Refractive/ Diffractive	Glass diameter (mm)	NA	f/#	% of sphere collected	Max Collection Efficiency*
R	4.5	0.55	0.76	8.23	18.2
D	3.3	0.55	0.76	8.23	24.3
D	4.5	0.67	0.55	13	51.9
D	6.7	0.80	0.38	20	100

* Normalized to most aggressive diffractive lens (NA 0.8)

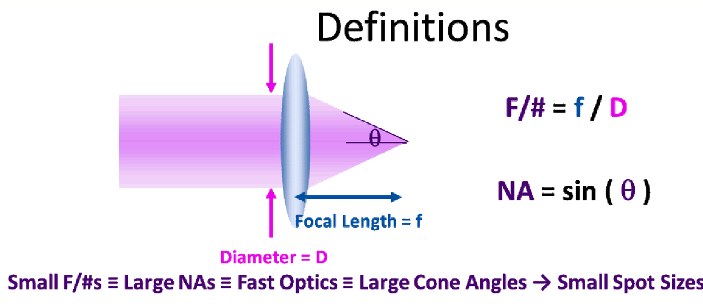


All 3 DOE options have less wavefront error and greater collection efficiency than the refractive comparison

SIGNIFICANT ACCOMPLISHMENTS

- Successfully trapped using DOE-generated, blue-detuned bottle beam
- Successfully trapped 3 single atoms simultaneously in 3-trap, 4-level DOE
- Smallest realized F/#s on integrated collection DOE of bottle beam trapping DOE
  - Presented at Photonics West, Jan 2012
- Implemented 2-trap DOE with integrated focus
- Pursuing parallel paths to simultaneously develop understanding of relevant physics and to advance DOE technology development toward higher order arrays

Definitions



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