Reactive Self-Tracking Solar Concentration

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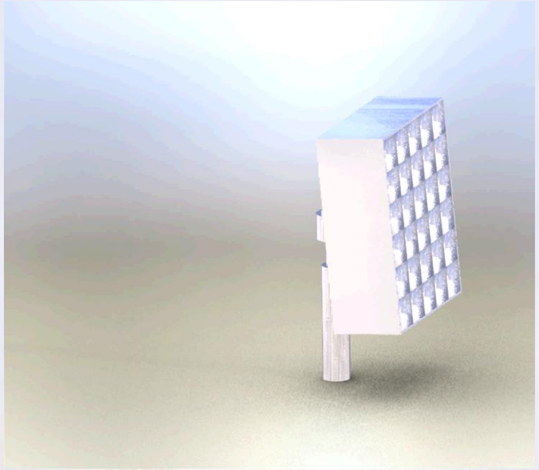
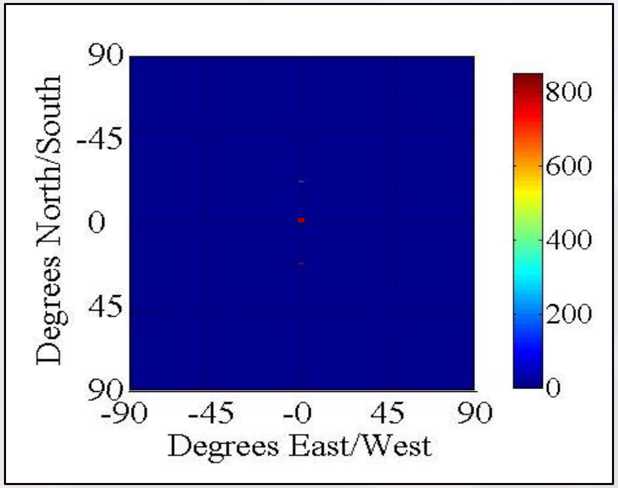
OSA Optics for Solar Energy (SOLAR)

Photo: Kevin Walsh, OLR

Concentrator Tracking - Motivation

2D Mechanical Tracking





Calculations are for a flat collector in San Diego, CA, tilted at latitude. Calculations based on A. Rabl. Active Solar Collectors and Their Applications.(Oxford University Press, New York, 1985)

Concentrator Tracking - Motivation

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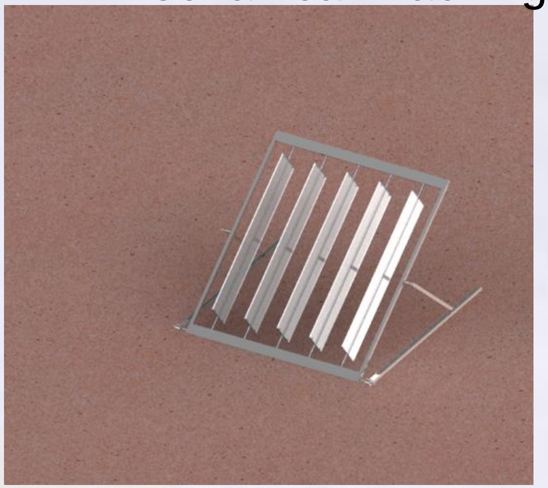
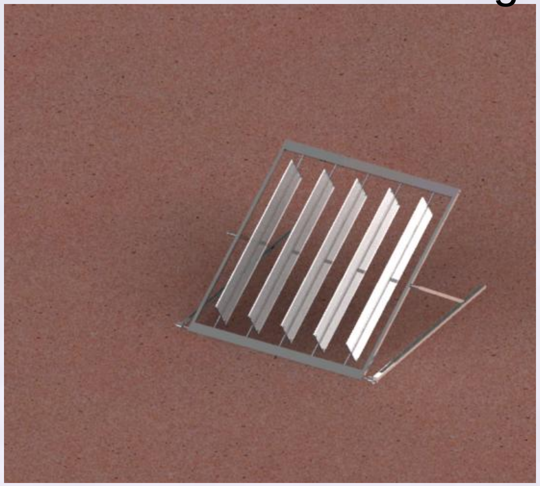
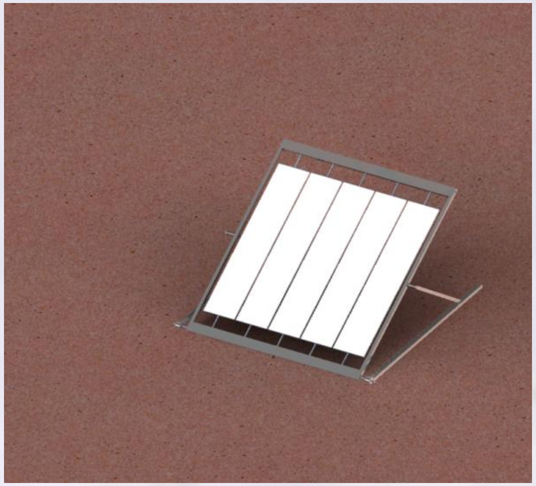
2D Mechanical Tracking

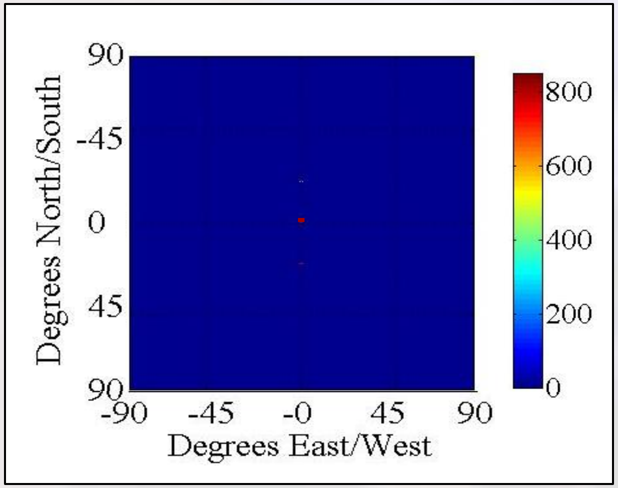


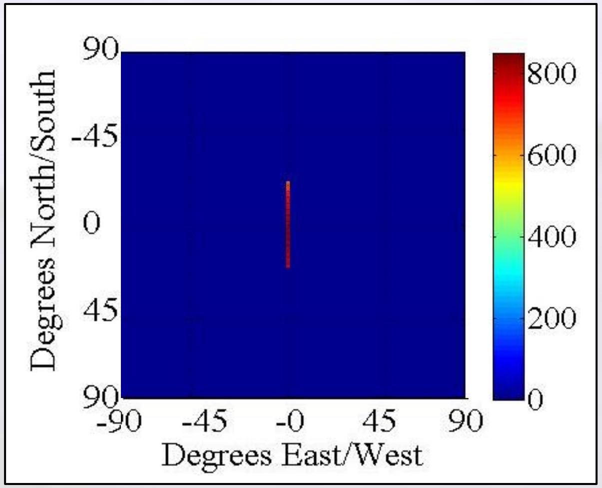
1D Mechanical Tracking

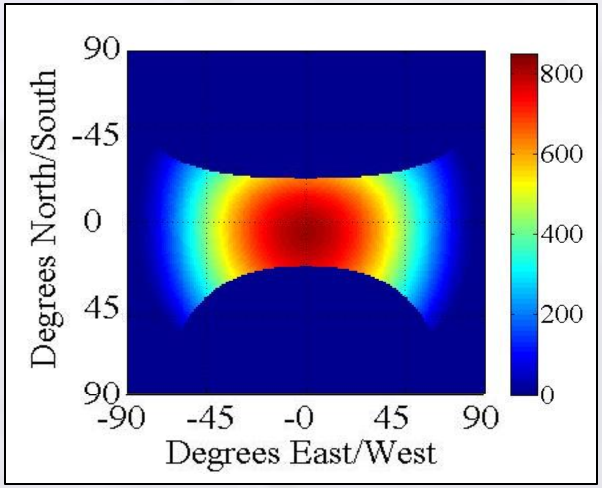


Static Collector









Goal: Use a material with a nonlinear response to light to minimize mechanical tracking needs.

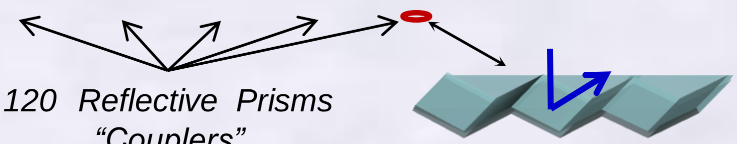
Calculations are for a flat collector in San Diego, CA, tilted at latitude. Calculations based on A. Rabl. Active Solar Collectors and Their Applications.(Oxford University Press, New York, 1985)

Planar Micro-Optic Solar Concentration

1mm

4mm

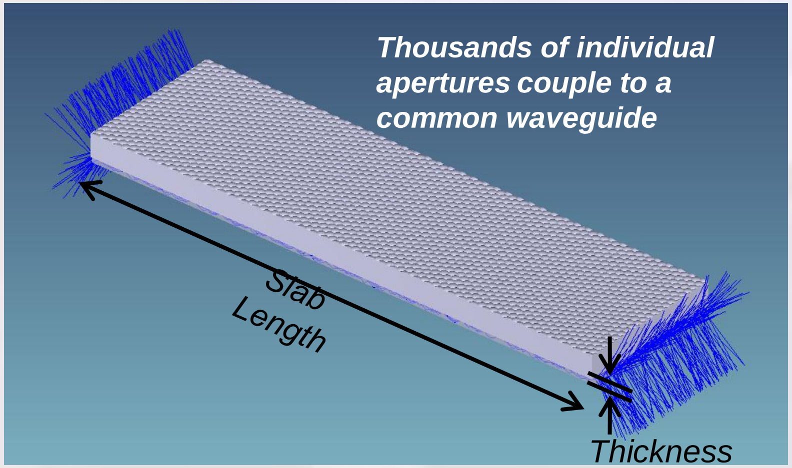
Concentrated Output



120 Reflective Prisms
“Couplers”
“Injection Features”

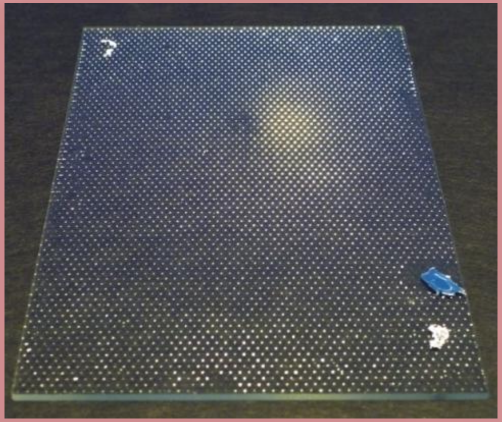
Coupled light striking another prism will decouple – dominant loss

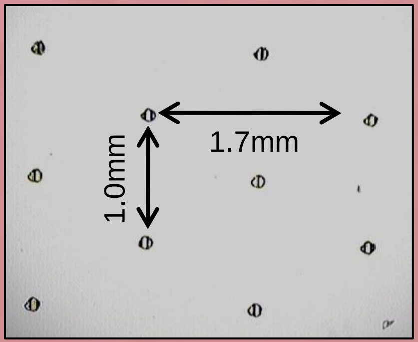
Concentrated Output

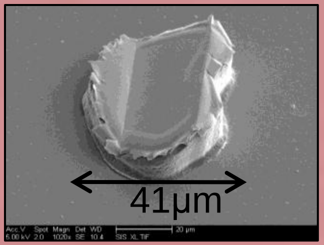


J. H. Karp et al, “Planar micro-optic solar concentrator,” Optics Express, 18(2) (2010).
J. H. Karp et al, “Radial coupling method for orthogonal concentration within planar micro-optic solar collectors,” OSA Optics for Solar Energy (2010)

Fabrication Results







Passive Prototype Performance

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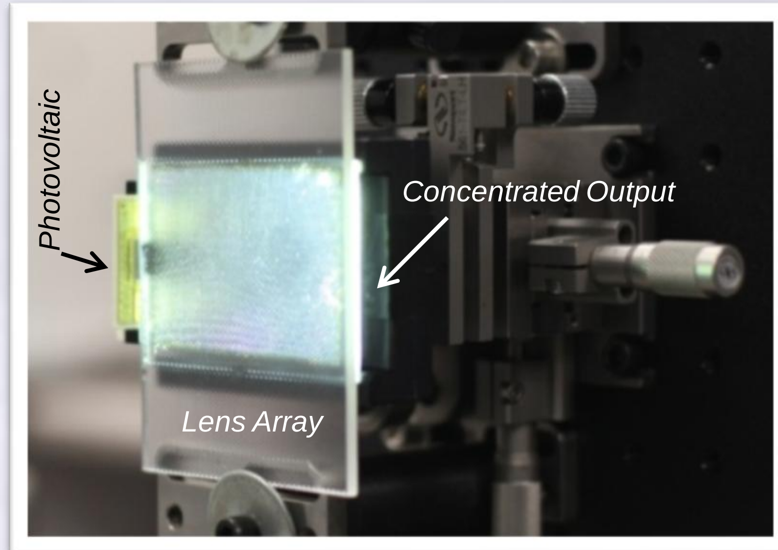
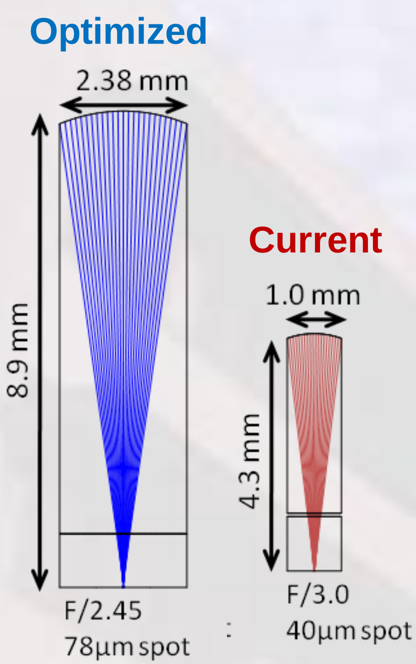
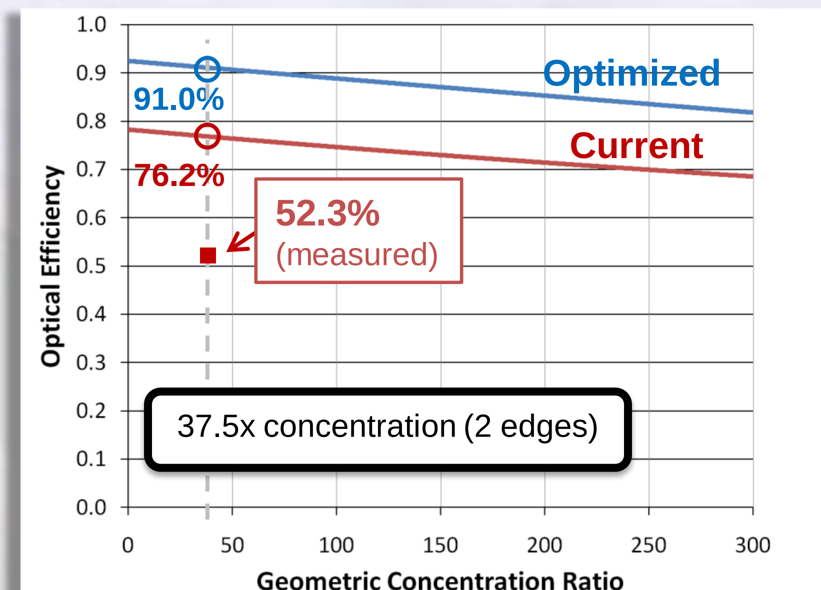
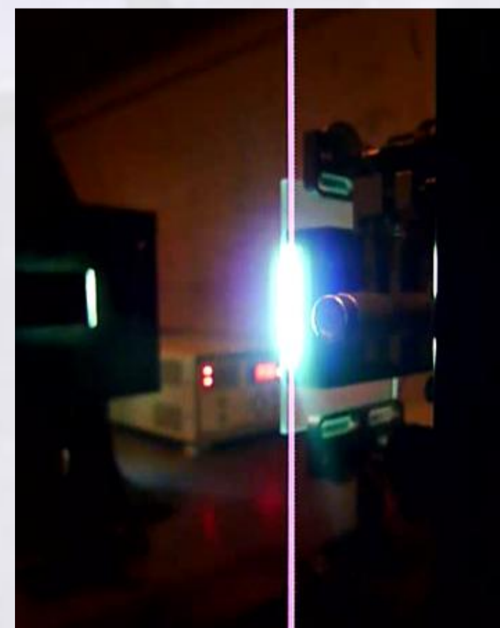


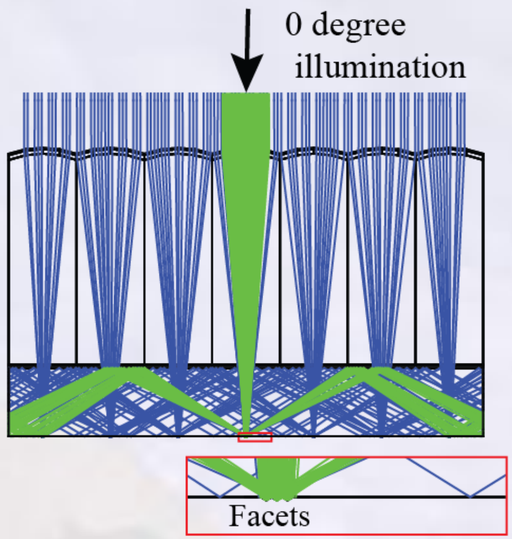




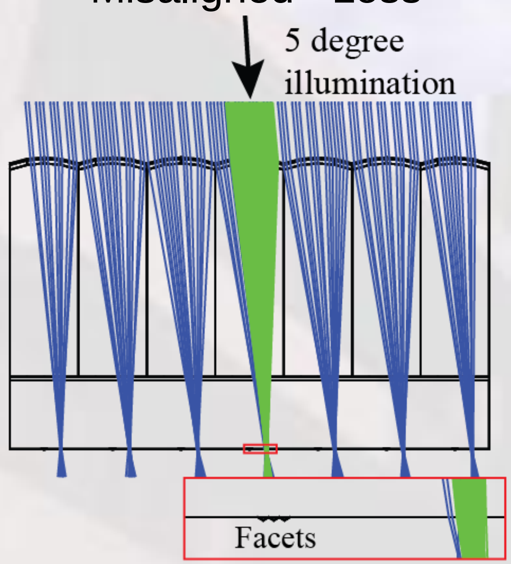


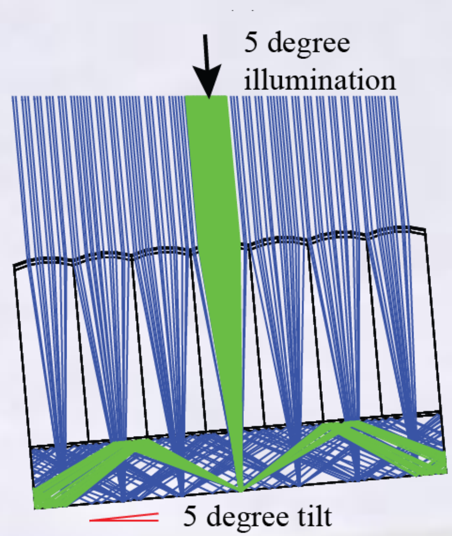
Mechanical Tracking

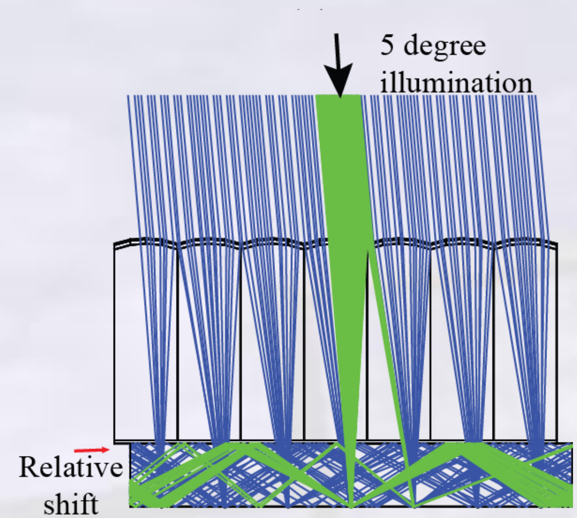
Aligned



Misaligned - Loss







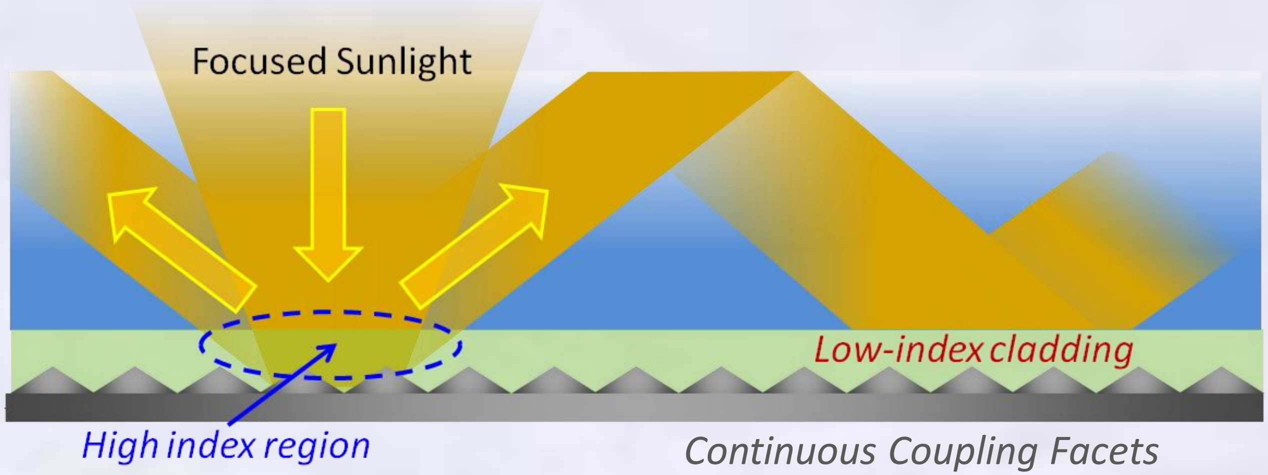
Large Scale Mechanical Tracking

- Typical for CPV systems
- High accuracy requirements
- Wind-Loading problems

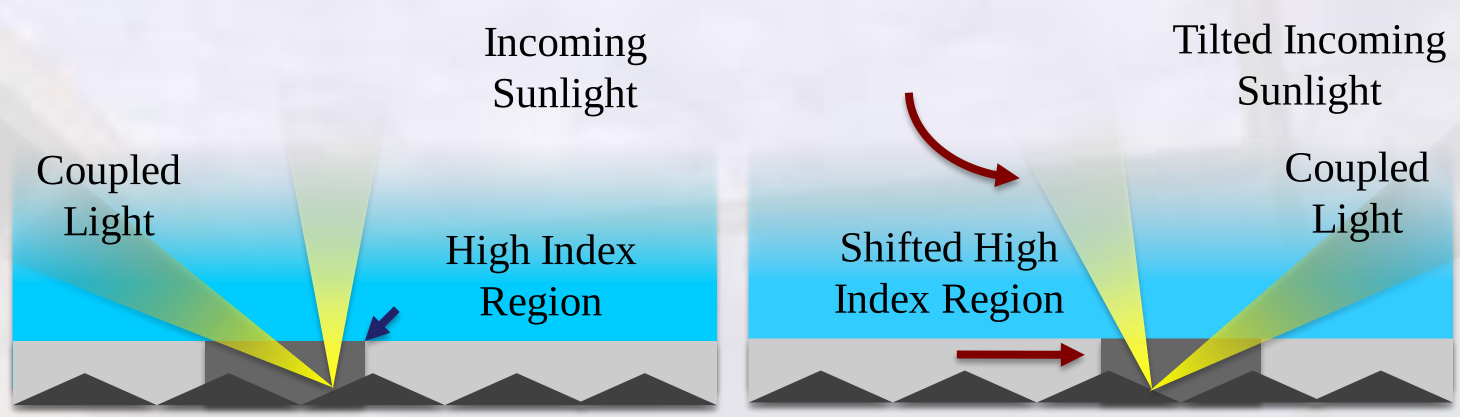
Mechanical Micro-Tracking

- Moving one optical element relative to the other allows tracking of large angle with small motions
- J. Hallas et al, "Lateral translation micro-tracking of planar micro-optic solar concentrator," Proc. SPIE 7769, 776904 (2010).

New approach: Reactive Tracking



Create nonlinear response to focused sunlight



Reactive Tracking

- Coupler relocates in response to sunlight
- Cladding index material response
- Spot moves less than 60 um/minute for a 4mm lenslet/slab distance

Angle-range Optimized Lens Design

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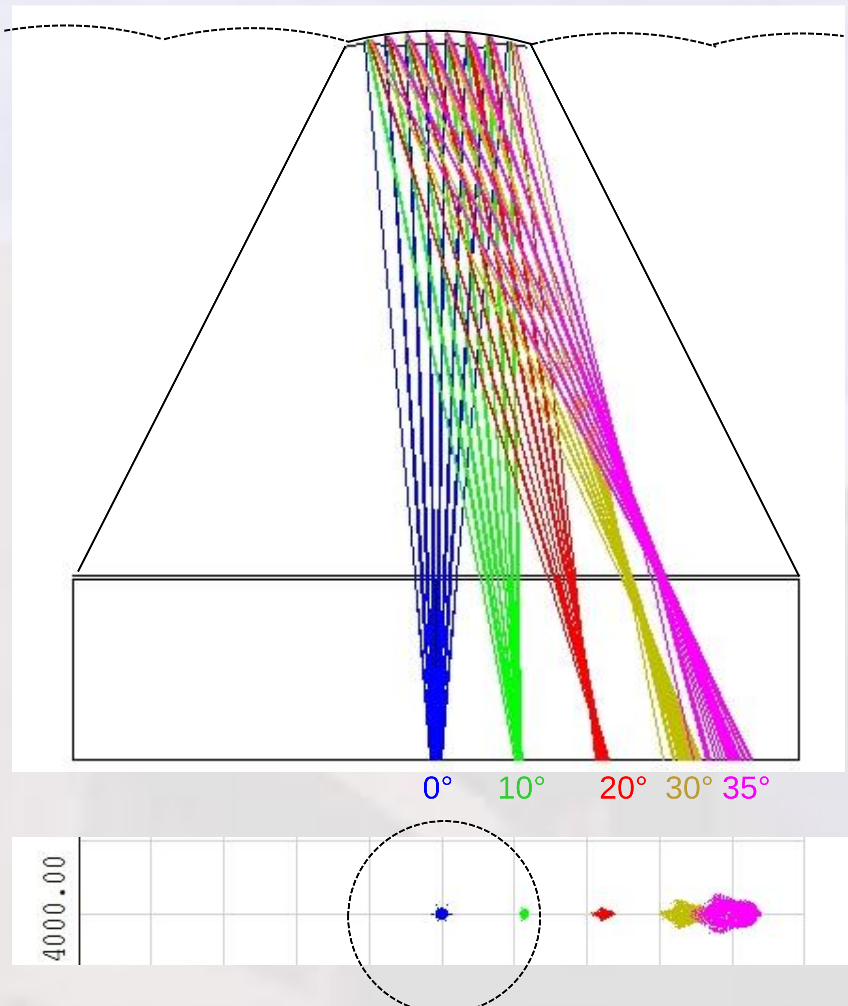
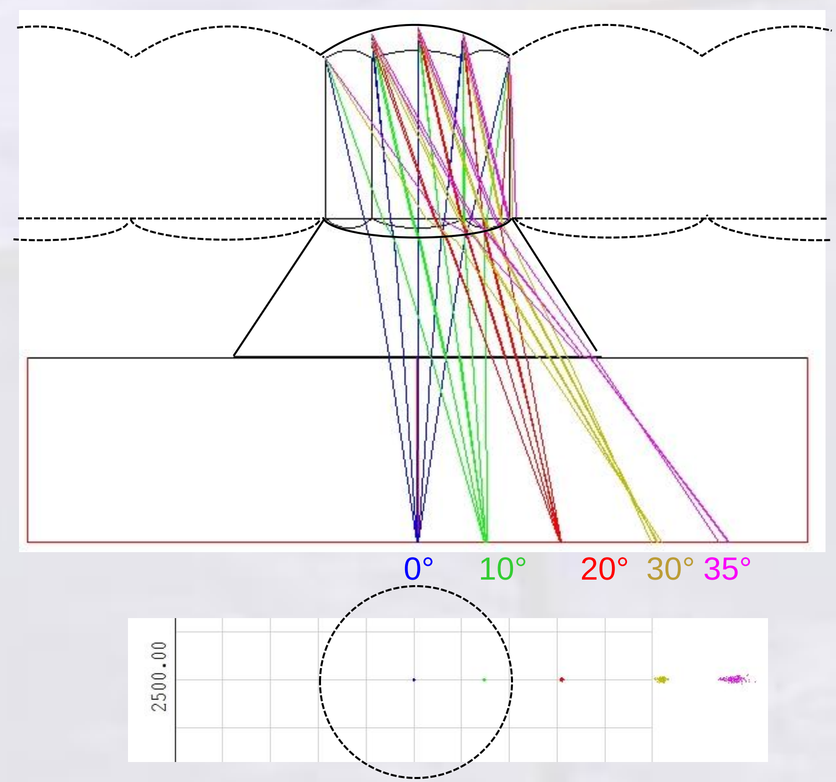
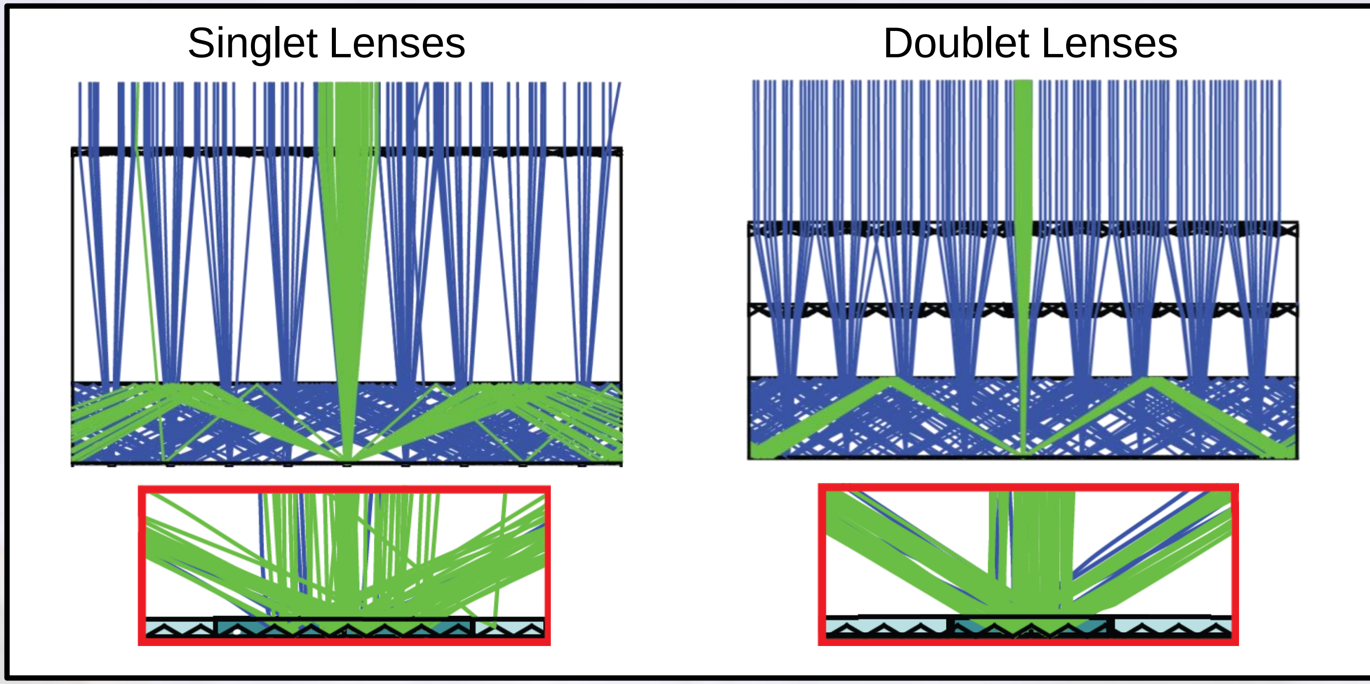
- Acrylic asphere lens
- F2 Glass Waveguide
- Off-Axis performance falls off
- Easy to fabricate

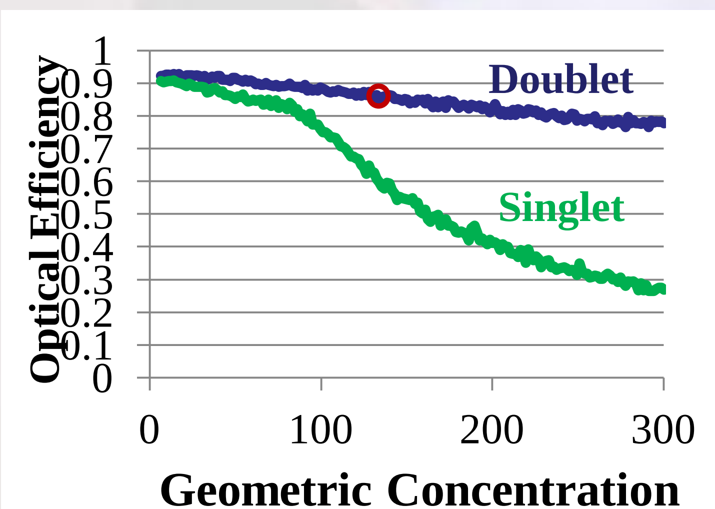


- Acrylic and polycarbonate asphere lenses
- F2 Glass Waveguide
- Improved off-axis performance; smaller spot sizes overall
- More difficult to fabricate
- Vignetting at Extreme Angles



Simulated Results – On-Axis

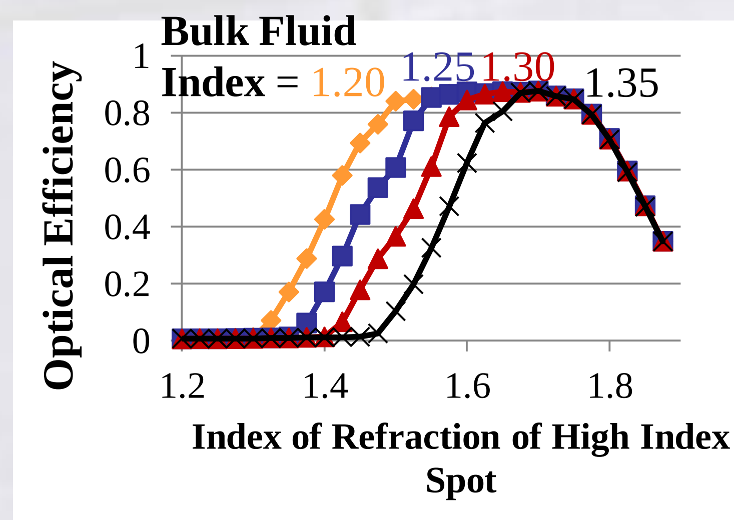




At 128x geometric concentration

Singlet: 65% On-Axis Efficiency – 83x effective concentration

Doublet: 86% On-Axis Efficiency – 110x effective concentration



Simulated Results – Off-Axis

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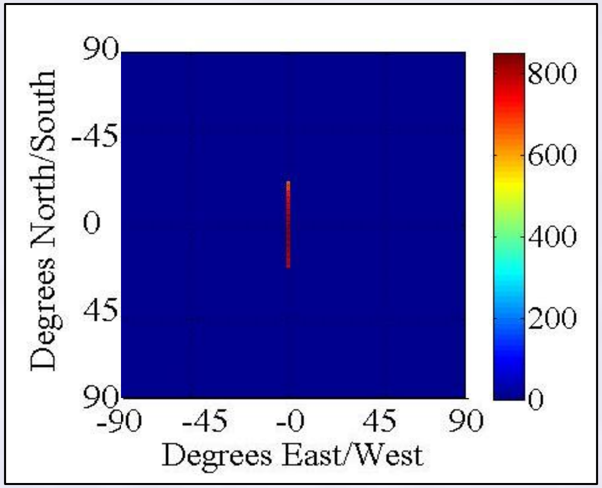
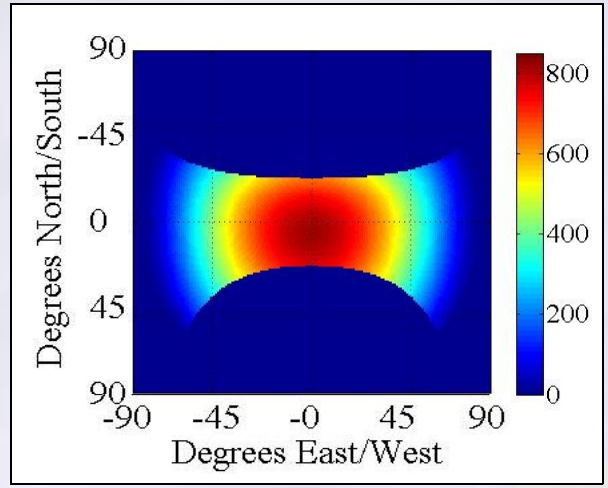
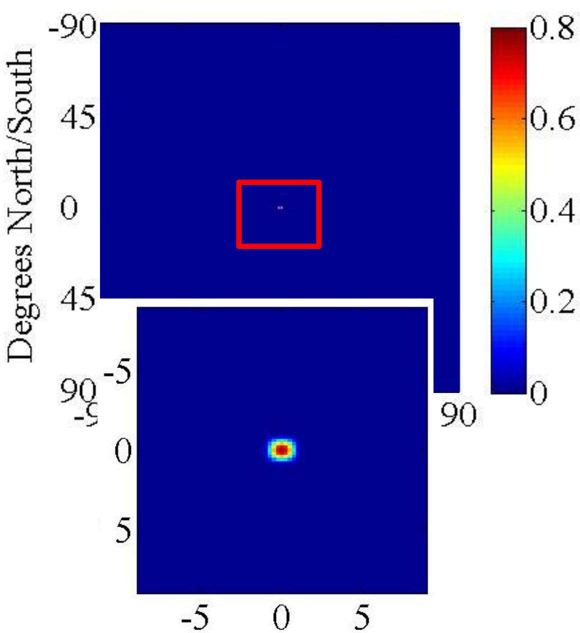
1D Polar Tracking



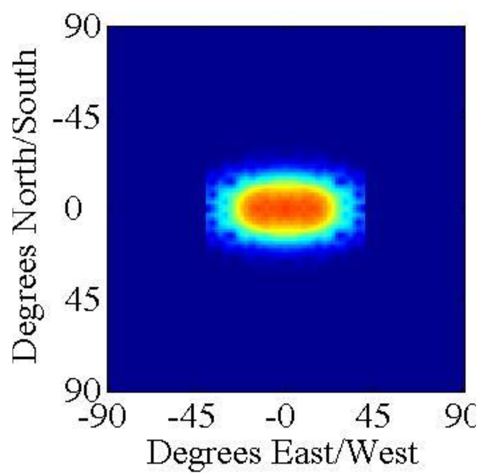


Static Panel

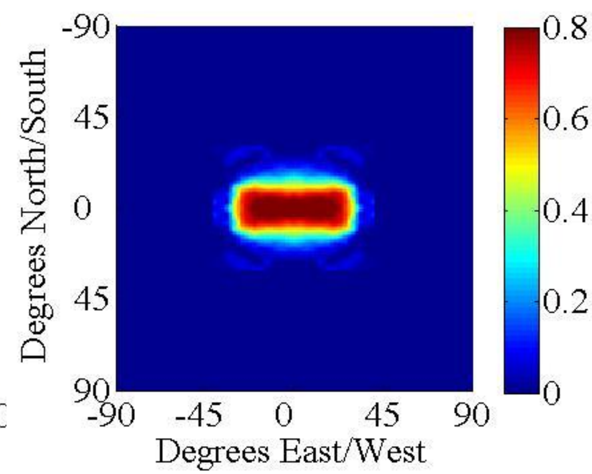
Passive Design



Reactive Singlet



Reactive Doublet



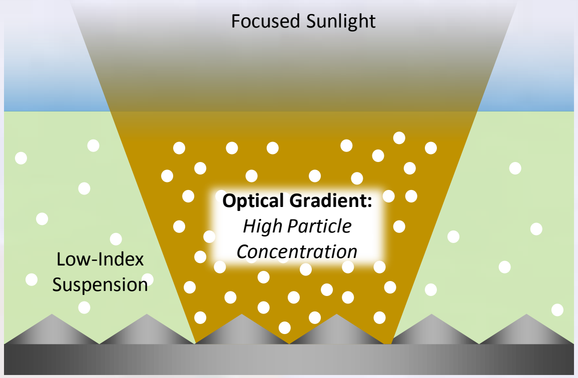
Accepted Annual Energy:

25% - Static Panel
60% - 1D Polar Tracking

28% - Static Panel
83% - 1D Polar Tracking

Nanofluidic design concepts

Index response can be achieved through localized trapping of high index particles in a low index suspension

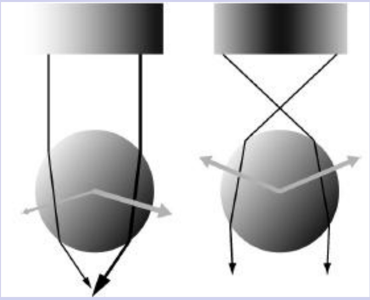


Direct Trapping Design

Optical trapping of particles

Ideal solution since no extra components are needed

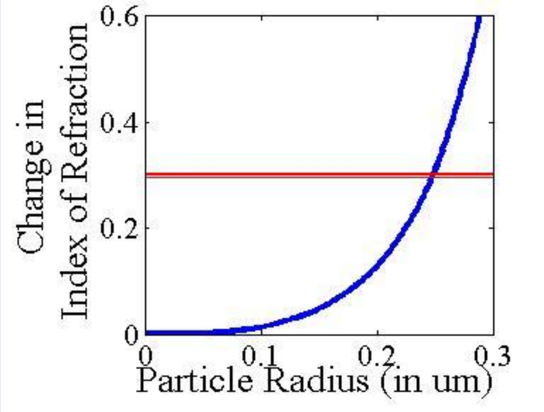
Optical Tweezers



K.C. Neuman and S.M. Block, "Optical trapping.," *The Review of scientific instruments*, vol. 75, Sep. 2004, pp. 2787-809.

- As light refracts through a sphere, it changes angle. Through conservation of momentum, the particle will move in the opposite direction

•Particles large enough for the needed index change would cause scattering and fail to stay in suspension



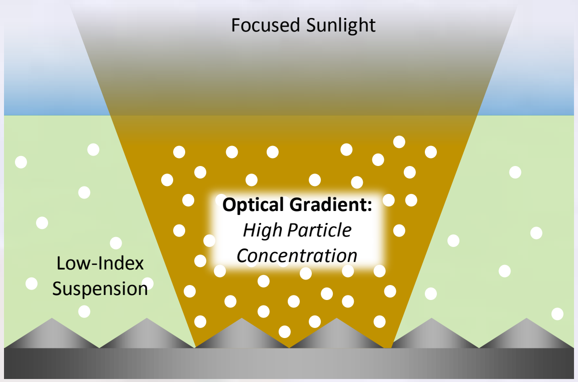
Nanofluidic design concepts

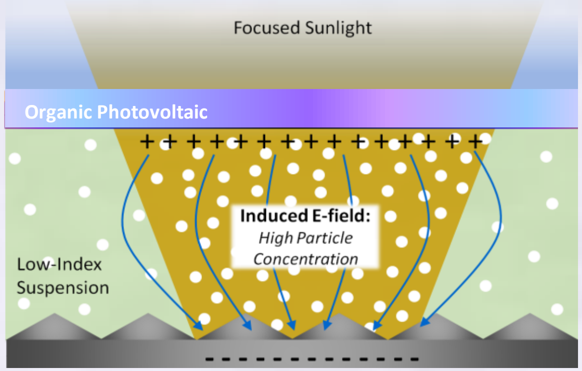
UCSD Photonics

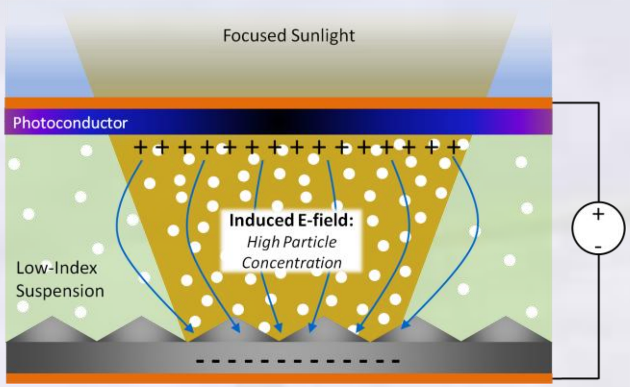
Index response can be achieved through localized trapping of high index particles in a low index suspension

Optically-induced dielectrophoresis

Same trapping force with 100,000 times less optical intensity compared to optical trapping





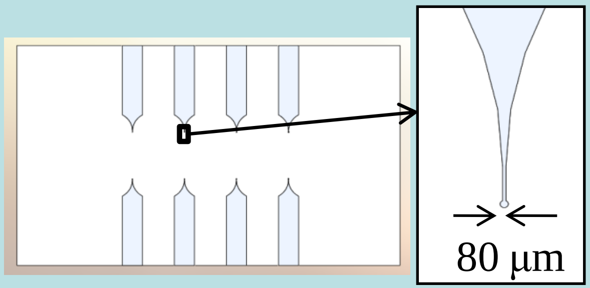


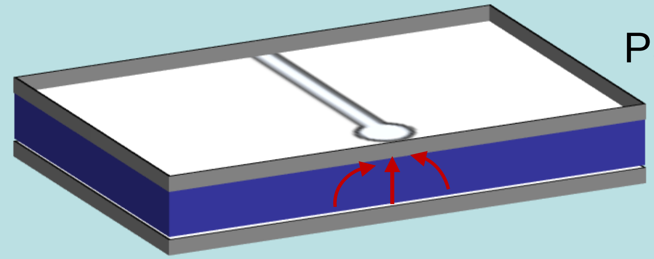
Direct Trapping Design	Photovoltaic Design	Photoconductor Design
Optical trapping of particles	Electro-optical trapping of particles	Electro-optical trapping of particles
Ideal solution since no extra components are needed	Requires photovoltaic layer and additional processing, but no external power	Requires photoconductor layer and external power
Won't work		

P.Y. Chiou et al "Massively parallel manipulation of single cells and microparticles using optical images.," *Nature*, vol. 436, Jul. 2005, pp. 370-2.

Reactive Materials Testing

Patterned Indium Tin Oxide Electrodes
(a Transparent Conducting Oxide)





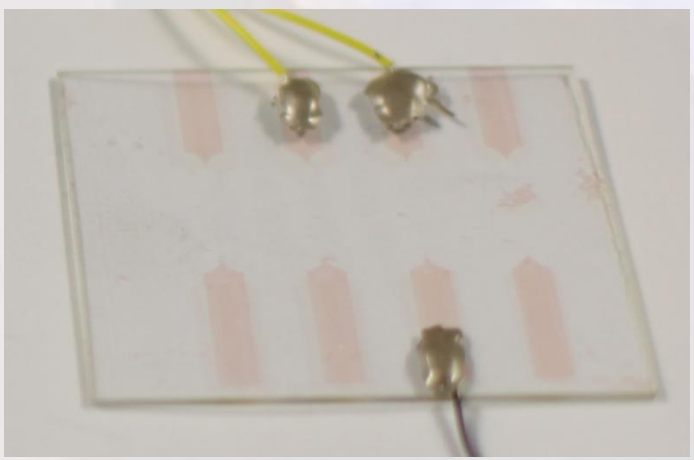
Patterned ITO Slide

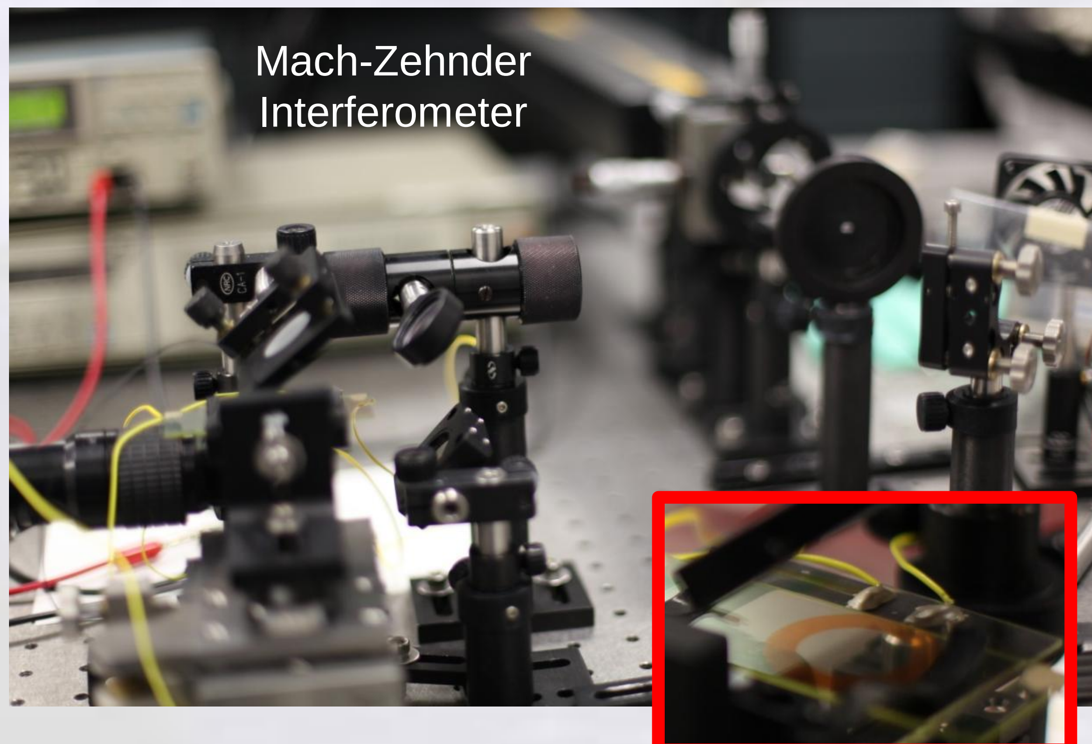
Colloid Under Test

Solid ITO Slide

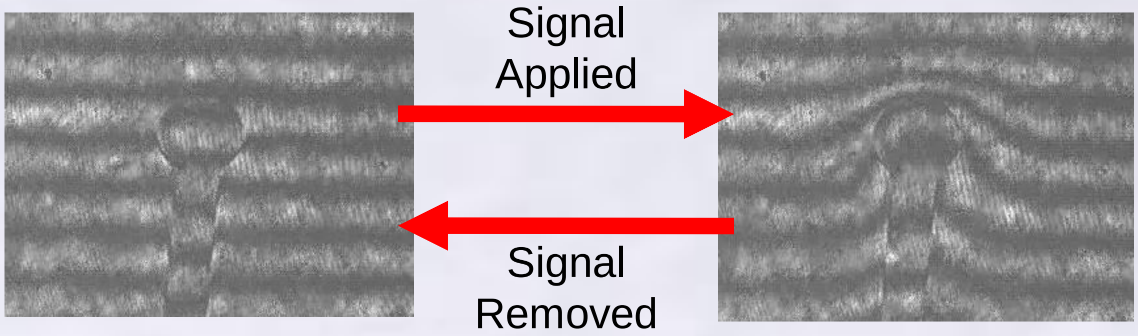
Induced Non-Uniform Electric Field attracts high index particles

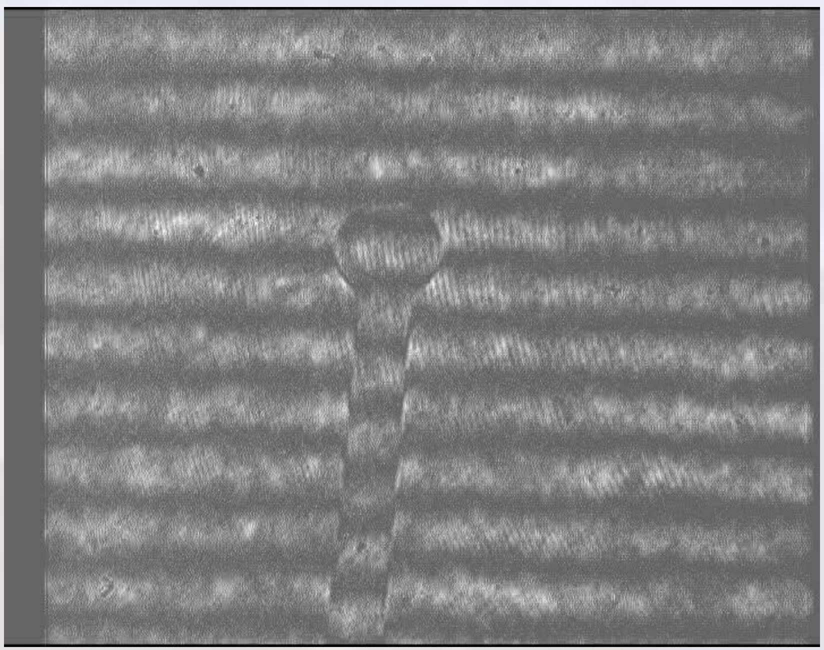
ITO Coated Slides
~30 Ω/□ sheet resistance





Results



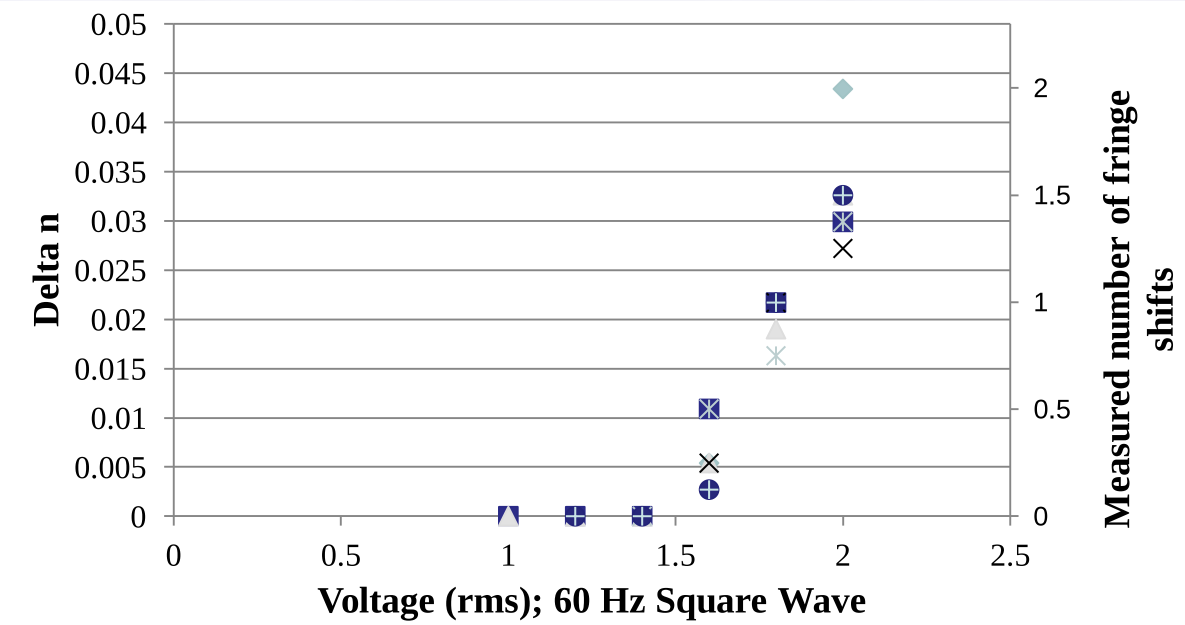


60 nm Polystyrene Spheres in Water
(10% by volume)

2 Volts rms 60 Hz Square Wave
Applied for 60 seconds

Fast, Reversible Index Change Demonstrated

Results



Average change in index = .033

2.3x increase in concentration (10% to 23%)

Equivalent increase for titanium dioxide in perfluorotriamylamine (FC-70 from 3M) would result in a .141 change

Conclusions

- Self-tracking reactive concentration could enable a wide acceptance angle for concentrator systems without precision tracking requirements.
- Wide-angle lenslet design works, given sufficient change in index of refraction
- While direct optical trapping won't work, DEP trapping can
- Initial experiments with aqueous polystyrene demonstrate DEP-induced change in index of refraction
- Additional materials work must be done in collaboration with industry and/or academic partners to produce the necessary change in index of refraction

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Thank you,

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