Reactive Self-Tracking Solar Concentration
Katherine Baker, Jason Karp, Justin Hallas, and Joseph Ford
University of California San Diego
Jacobs School of Engineering
Photonic Systems Integration Lab

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OSA Optics for Solar Energy (SOLAR)
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)
Goal: Use a material with a nonlinear response to light to minimize mechanical tracking needs.

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Passive Prototype Performance

Xe arc lamp solar simulator

Photovoltaic Lens Array

Concentrated Output

Optimized

Current

Optimized Current

Optimized (measured)

37.5x concentration (2 edges)

Geometric Concentration Ratio

Optical Efficiency

91.0%

76.2%

52.3%

(40μm spot)

(78μm spot)

(4.3 mm)

(8.9 mm)

2.38 mm

8.9 mm

F/2.45

78μm spot

F/3.0

40μm spot

UCSD Photonics
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
New approach: Reactive Tracking

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

- 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

Singlet Lenses

Doublet Lenses

Optical Efficiency vs. Geometric Concentration

Bulk Fluid Index = 1.20, 1.25, 1.30, 1.35

Index of Refraction of High Index Spot

11/21/201
Simulated Results – Off-Axis

1D Polar Tracking

Passive Design

Accepted Annual Energy:

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

Reactive Singlet

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

Reactive Doublet

Degrees North/South

Static Panel

Accepted Annual Energy:

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

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

Degrees East/West
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


- 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

Change in Index of Refraction

![Graph showing change in index of refraction against particle radius](image-url)
Nanofluidic design concepts

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**
- Optical trapping of particles
- Ideal solution since no extra components are needed
- *Won’t work*

**Photovoltaic Design**
- Electro-optical trapping of particles
- Requires photovoltaic layer and additional processing, but no external power

**Photoconductor Design**
- Electro-optical trapping of particles
- Requires photoconductor layer and external power

Patterned Indium Tin Oxide Electrodes (a Transparent Conducting Oxide)

ITO Coated Slides ~30 Ω/□ sheet resistance

Mach-Zehnder Interferometer
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
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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kabaker@ucsd.edu

psilab.ucsd.edu