

# Novel tracking of a planar micro-optic solar concentrator

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C3P Presentation on  
November 3, 2010



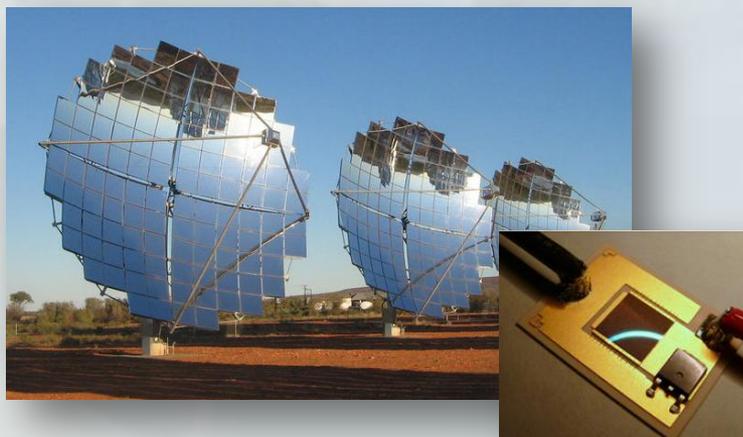
## Silicon: 14-17% efficiency

- Mono- or polycrystalline
- >90% market share
- Limited spectral response



## Thin Film: 7-12% efficiency

- CdTe, CIGS, a-Si
- Mass fabrication on flexible substrates
- Reduced material and manufacture costs



## Multi-junction: >41% efficiency

- Broad spectral response – material stack
- Small area, expensive fabrication
- **Pair with concentrating optics**
  - **Large collection aperture**
  - **Reduced systems costs**



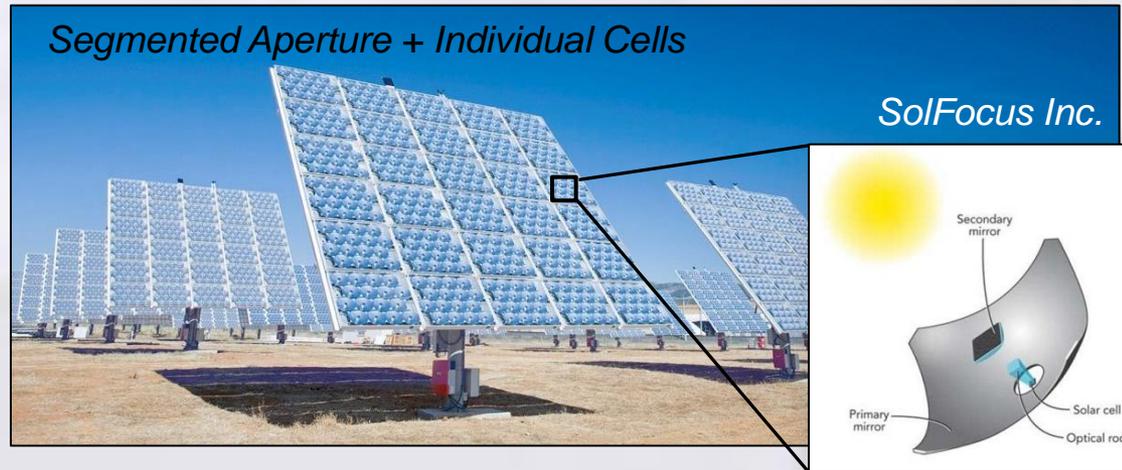
October, 1934  
"Power from the sun"



Solar thermal using circulating oil



November, 2010: Same basic structure



Solar electric using photovoltaic devices



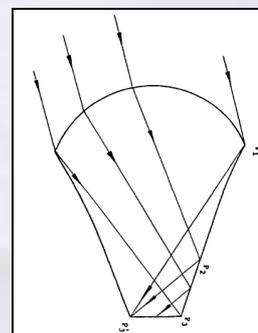
## 1. Primary Focusing Optic

- Performs light concentration
- Large collecting lens or mirror
- Trend towards multiple apertures

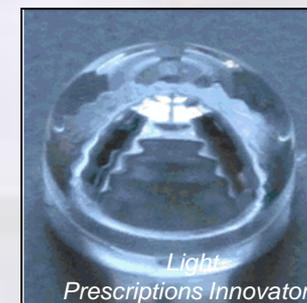


## 2. Secondary Homogenization Optic

- Mounted between primary and PV cell
- Uniform illumination for high efficiency
- Non-imaging optical design



Xiaohui Ning, Appl. Opt. 26, 1987



## 3. Mechanical Tracking

- Alignment for direct insolation
- Angular acceptance defines tracking accuracy
- Wind loading and environmental stability



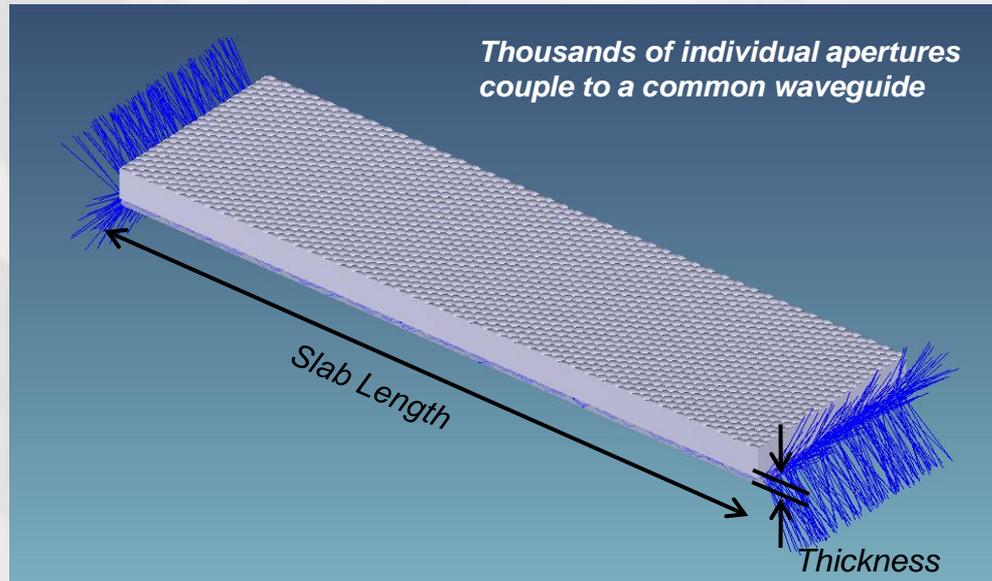
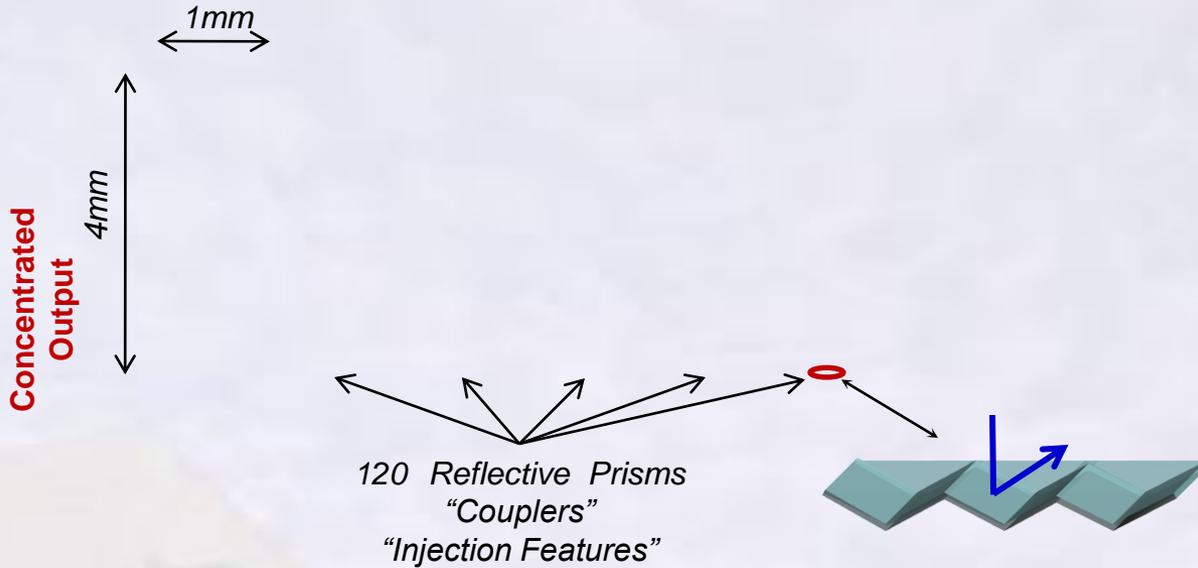
Flatcon System Tracking



Concentrix Solar



# Planar Micro-Optic Concentration



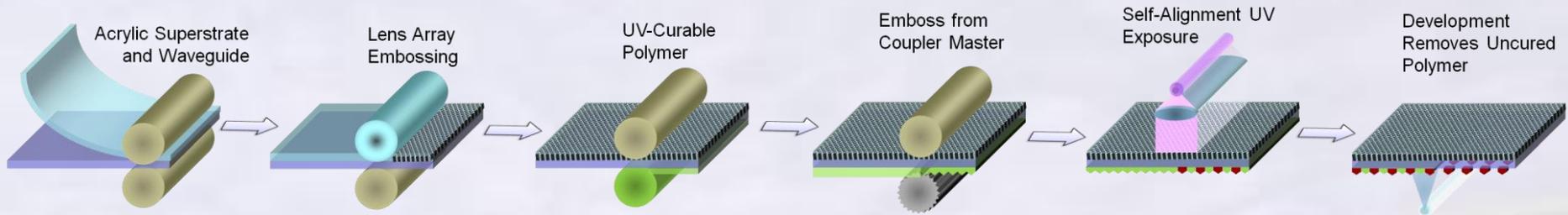
### Geometric Concentration Ratio

$$C_{geo} = \frac{\text{Slab Length}}{2 * (\text{Slab Thickness})}$$

J. H. Karp, E. J. Tremblay and J. E. Ford, "Planar micro-optic solar concentrator," *Optics Express*, Vol. 18, Issue 2, 1122-1133 (2010).

## Low-cost manufacturing process

*Continuous roll processing on flexible or rigid substrates*

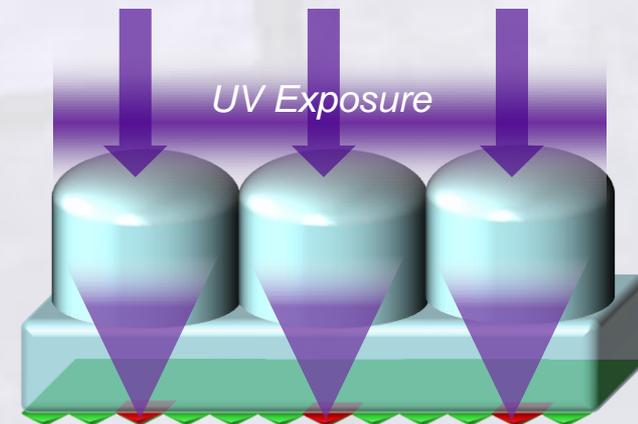


**Injection features must be matched to lens array**  
**Critical Alignment Tolerance**

- *<10 $\mu$ m lateral alignment tolerance*
- *<0.01 $^\circ$  (0.2mrad) rotational alignment*

### One Solution: Self-alignment

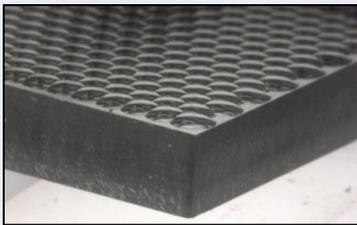
- Mold prism structure in UV-curable photopolymer
- Expose through lens array to cross-link localized prisms
- Cured regions remain part of the final device



*Coupling features created by exposing through lenses*

- Lens Array:

- F/3.0 focal ratio
- Hexagonal packing
- UVT acrylic



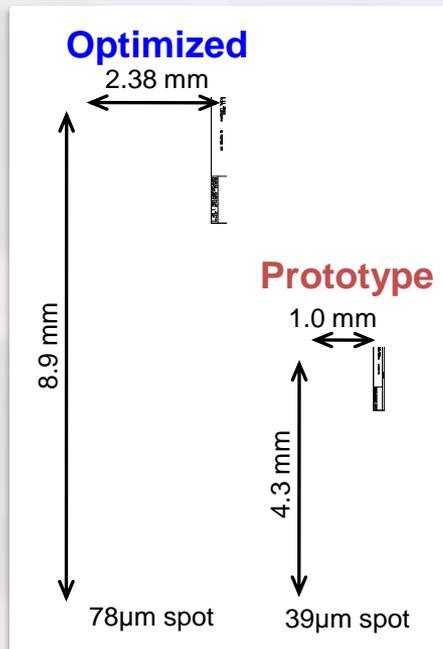
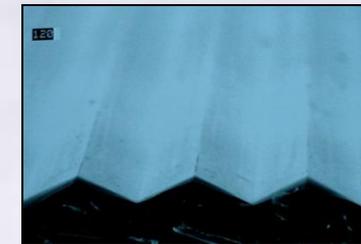
- Waveguide:

- Microscope slide (75mm x 50mm)
- BK7 float glass

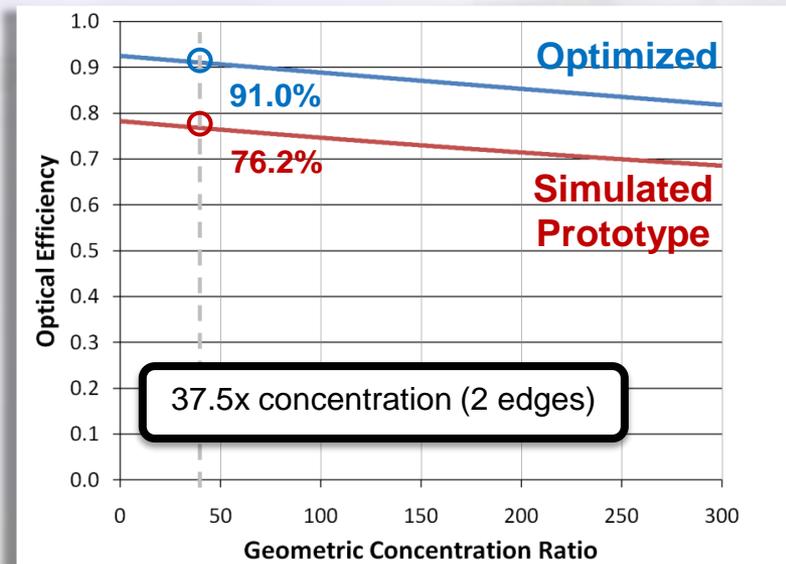


- Prism Mold:

- 120° symmetric prisms
- 50µm period, 14.4µm deep
- Molded in SU-8 Photoresist

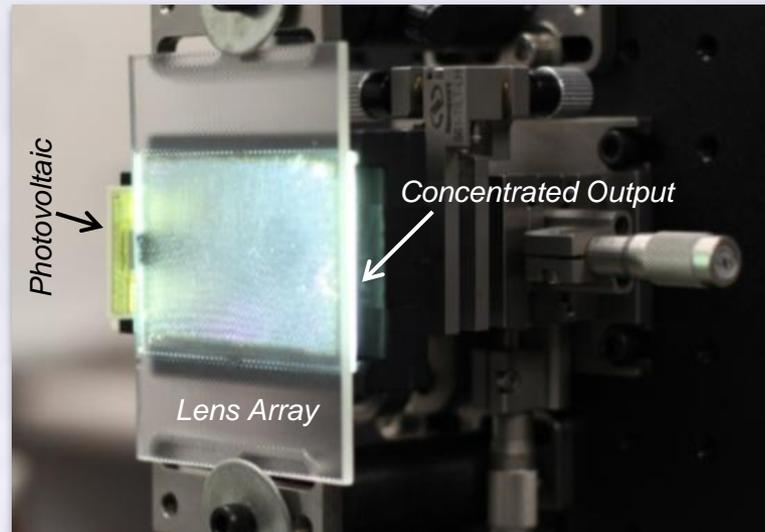
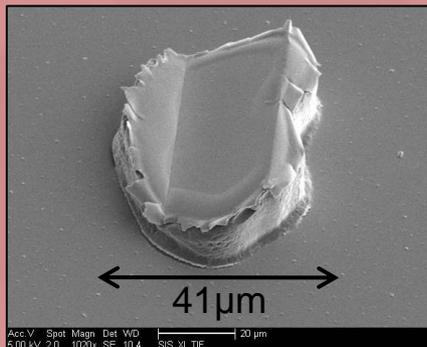
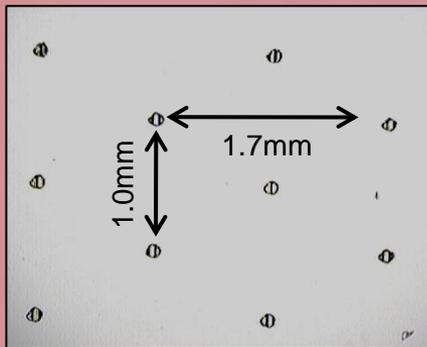
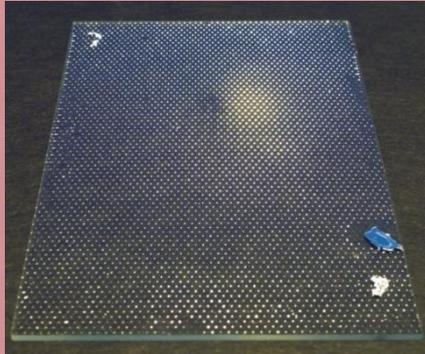


## Simulated Ray-trace results





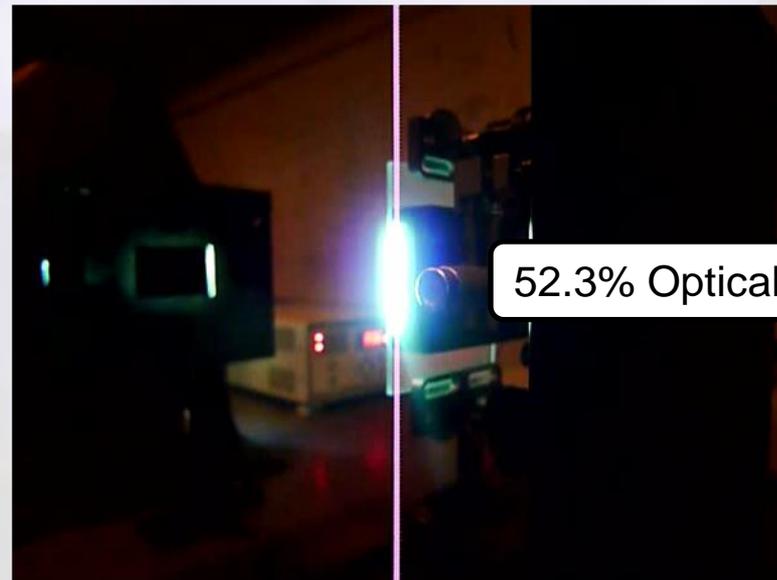
## Fabrication Results



Xe arc lamp  
solar simulator

Six-axis  
alignment stage

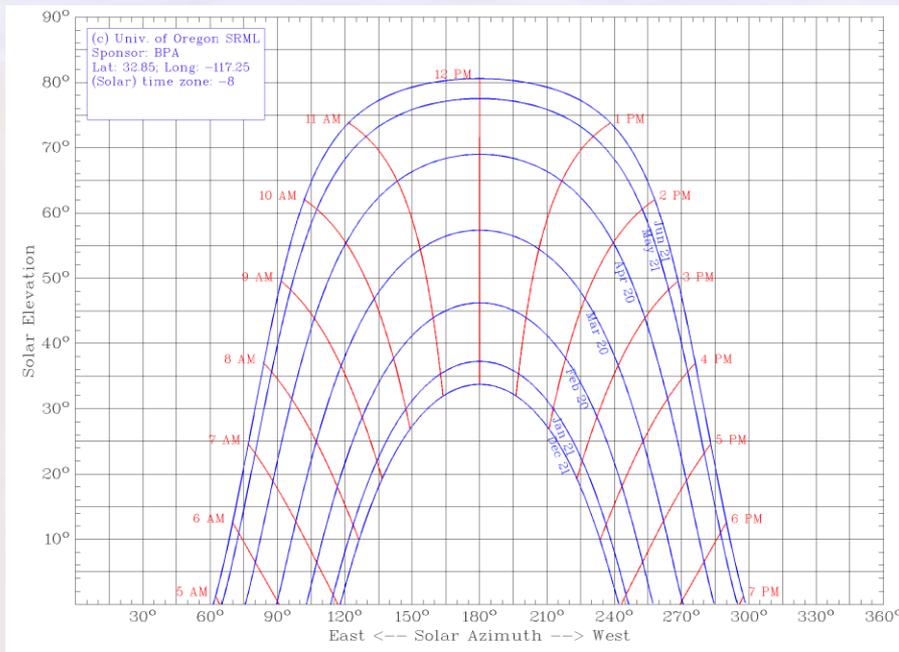
Multi-junction  
PV cell



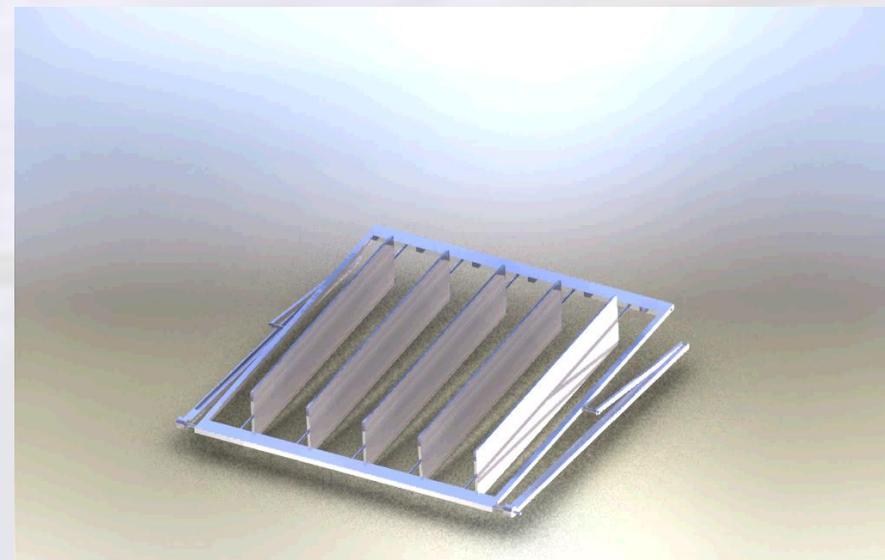


## High-concentration systems (>100x) require 2-axis tracking

**Sun chart:** Plots solar elevation and azimuth angles

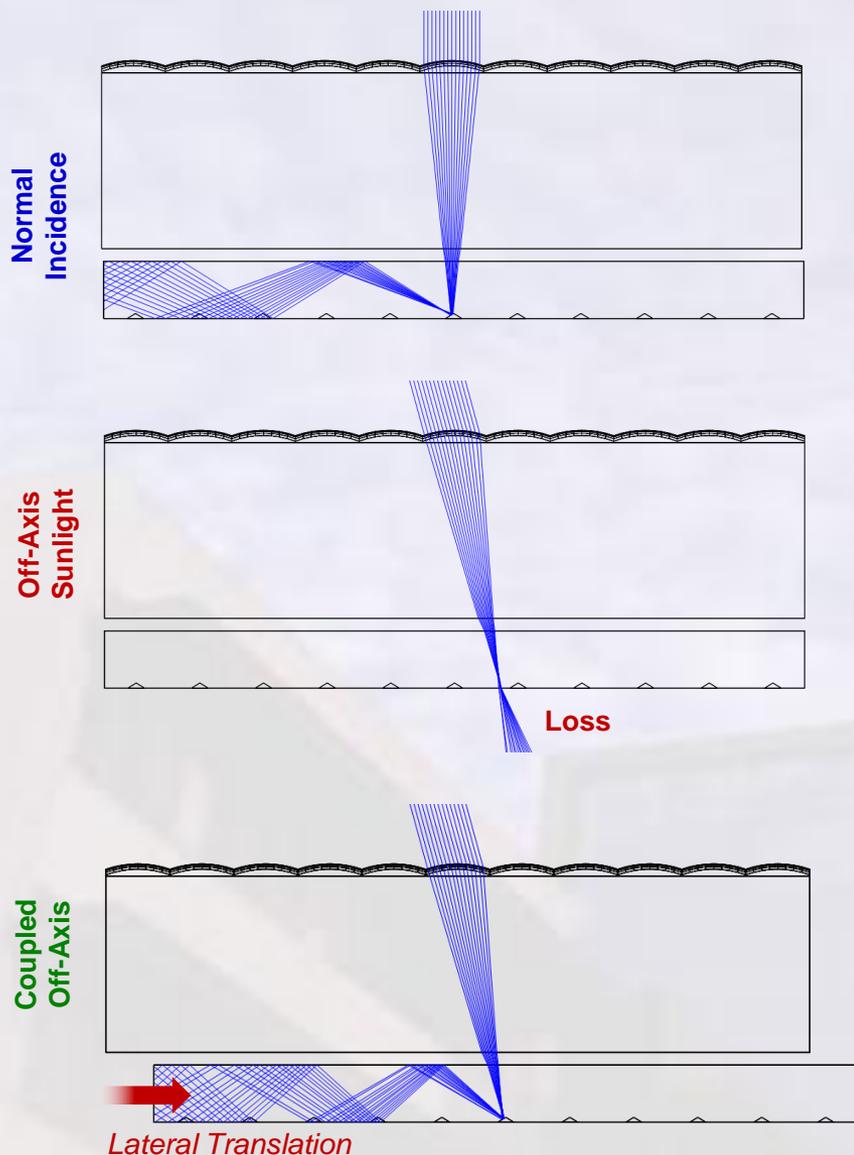


**Louvered 2-axis tracking system**





*But this geometry allows us to approach tracking differently...*



**Simple lateral translation yields 2-axis tracking**

Allows precision motion to be housed within a fixed frame

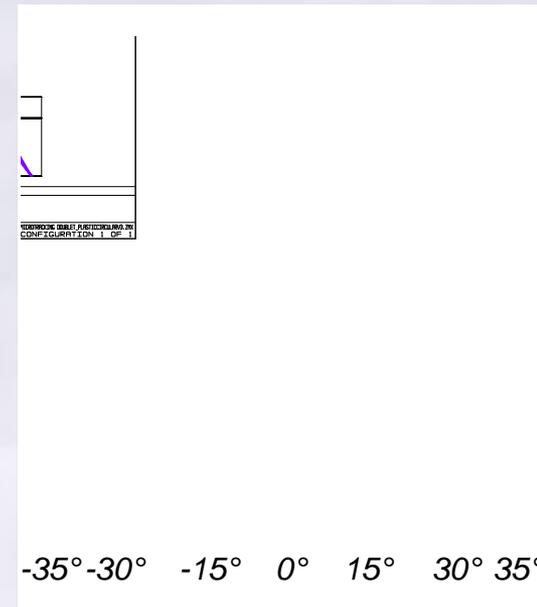
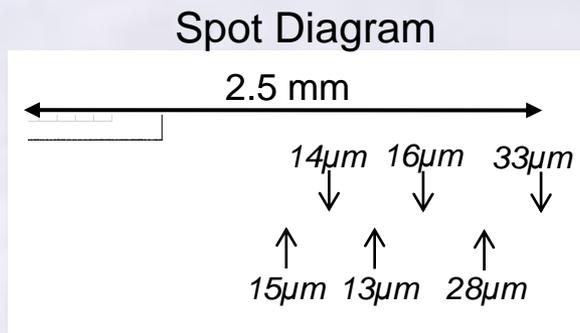
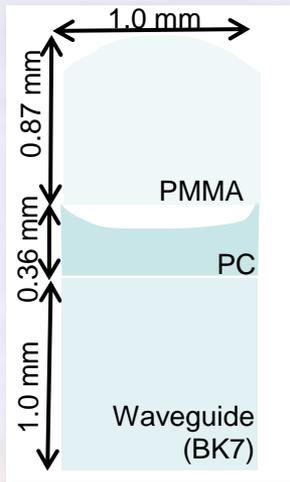
## Micro-tracking Requirements

- Wide-angle lens array
- Efficient coupling and propagation
- Precision motion (*1-2mm translation*)
  - *Total translation is independent of system aperture*



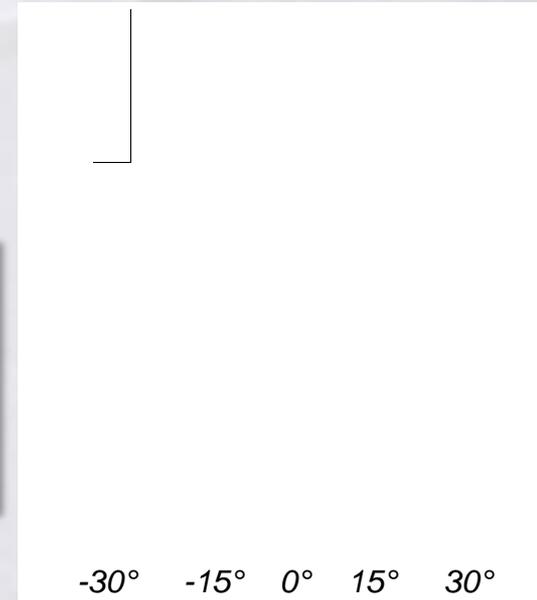
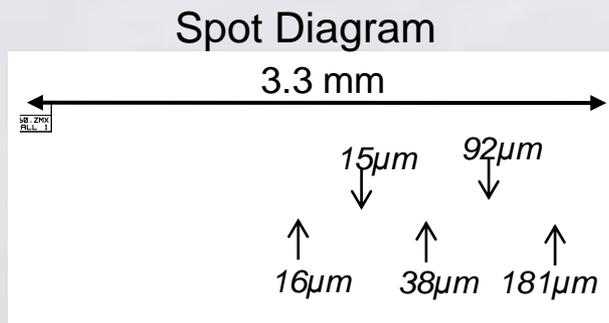
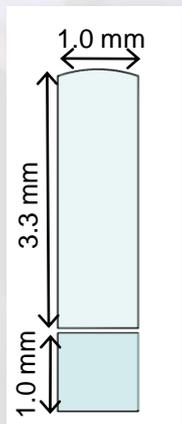
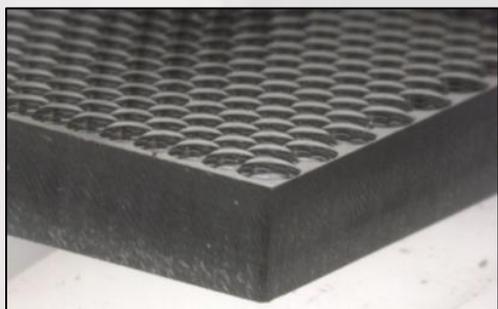
## Doublet microlens

- Near 100% aperture efficiency required
- Large acceptance angle with minimal growth in RMS diameter



## Single microlens (current prototype)

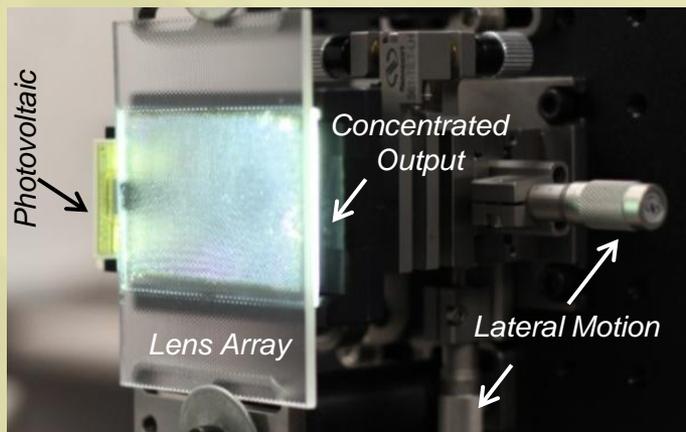
- Significant aberrations lead to 100x increase in spot area over 60° field



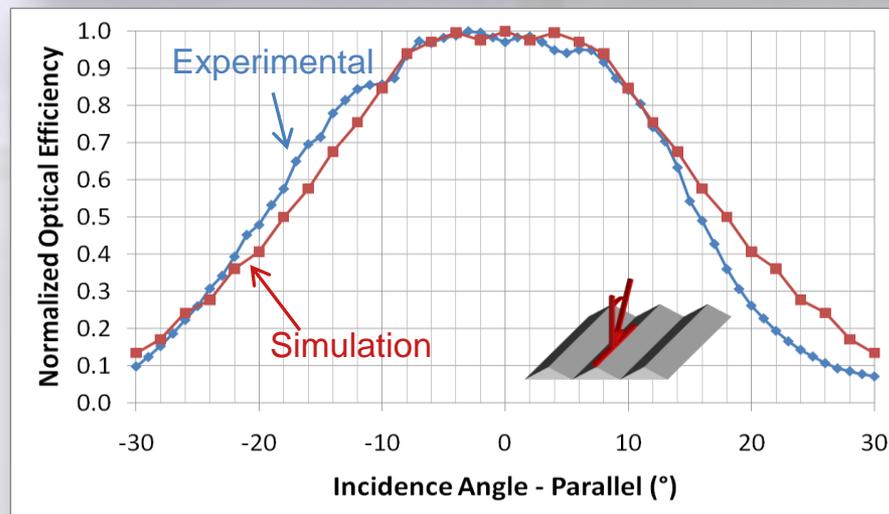
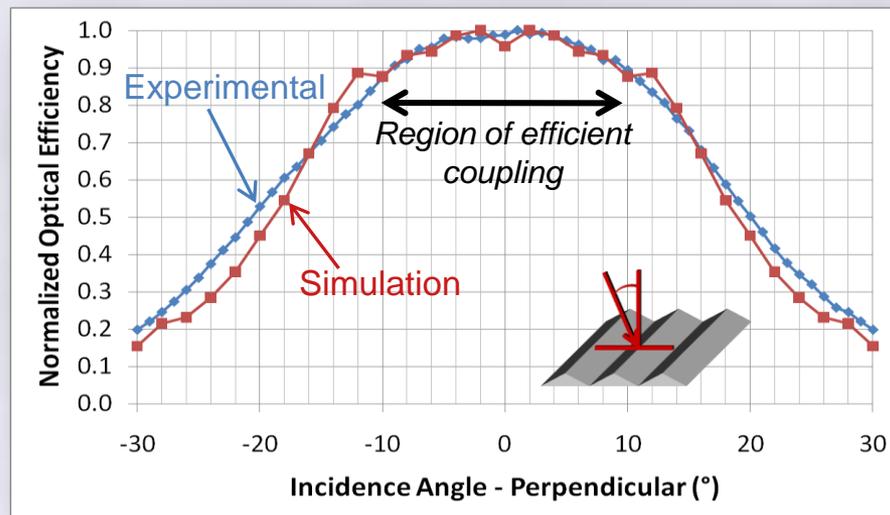


## Experimental Setup

- Xe arc lamp solar simulator ( $\pm 0.26^\circ$ )
- Digital rotation stage
- Multi-axis lateral translation stage



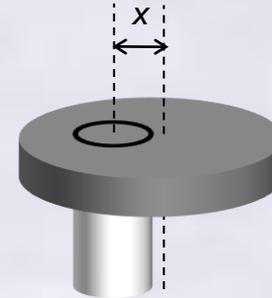
J. M. Hallas, J. H. Karp, E. J. Tremblay and J. E Ford, "Lateral translation micro-tracking for planar micro-optic solar concentrators," Proc. SPIE 7769, 7769-03 (2010).



**Efficient coupling limited to  $\pm 10^\circ$**   
**- Poor off-axis lens performance**

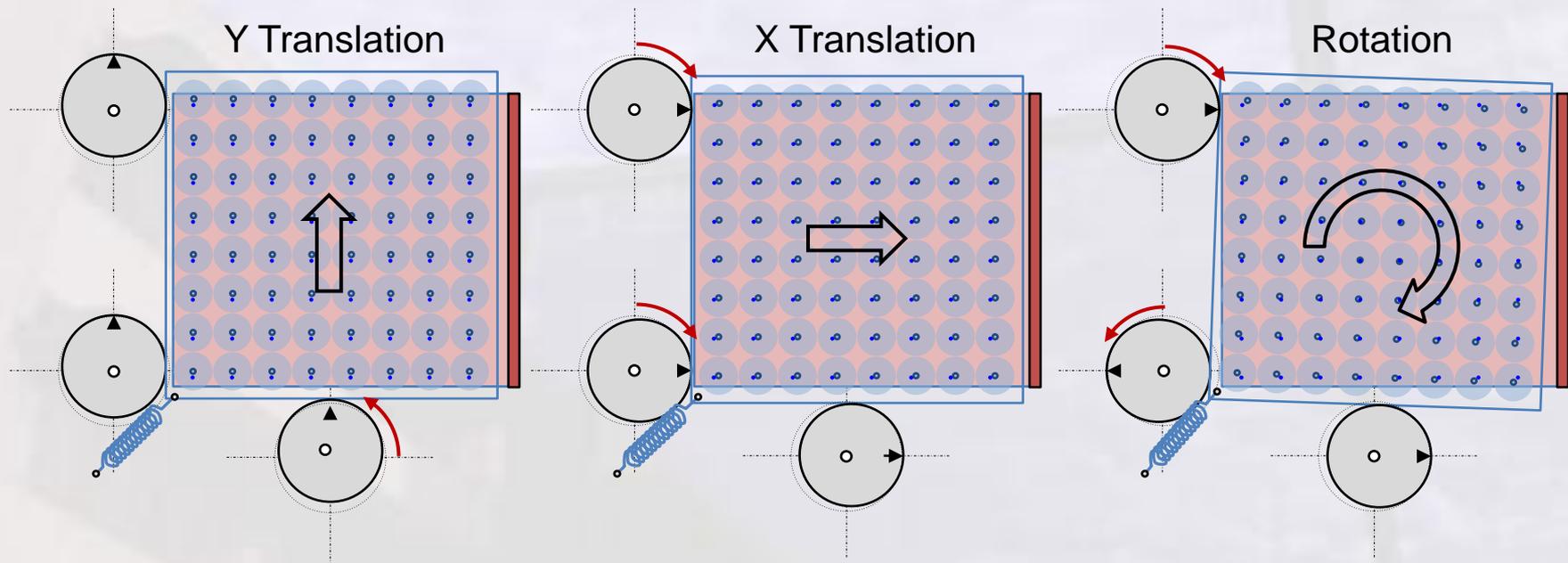
## De-centered rotational cam

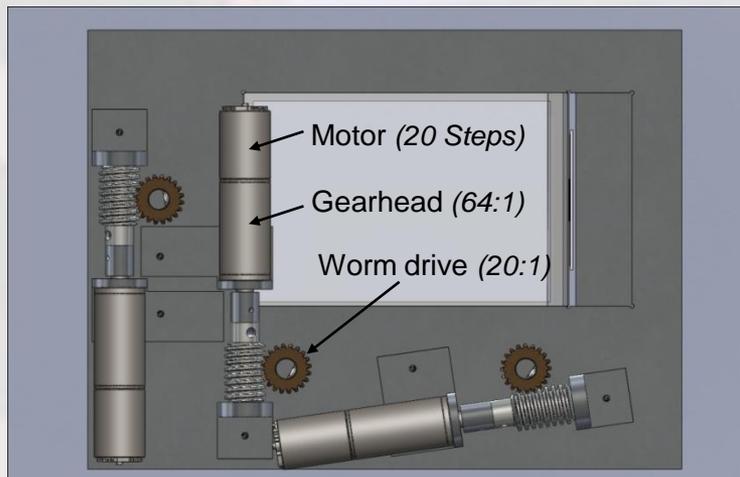
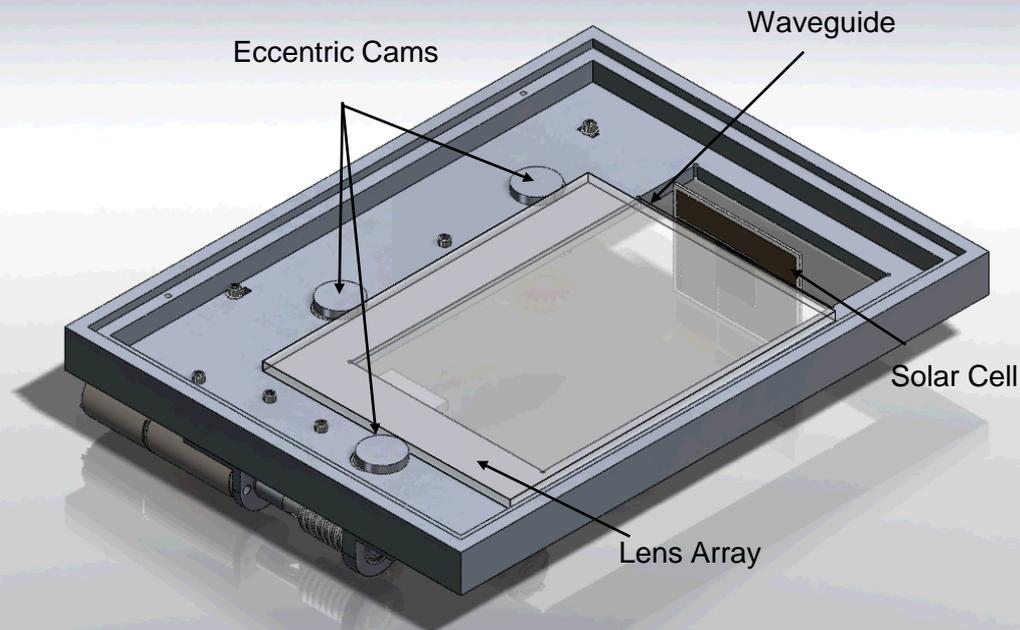
- 2x lateral translation
- Precise motion using gear reduction



## 3-axis motion in one plane

- X (2-cams) and Y (1-cam) lateral translation
- Pair of cams provide rotation through asynchronous motion
  - Critical alignment for large waveguides





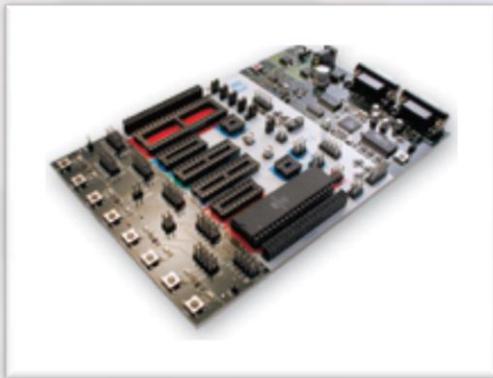
## 4mm total lateral translation

- 25,600 steps
- 0.16 $\mu$ m translation per step
- 0.0003 rotation per step

**Similar setup drives much larger systems**



# Fabricated platform



Micro-controller  
development board





- Planar micro-optic concentrators are a new direction for solar concentrators
- Experimental work successful in proving concept
- Next task:  
Prove systems are manufacturable, durable and work at predicted efficiencies



***Thank You***

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