Microtracking and self-adaptive solar concentration

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Overview

- **collector field challenges**
  - wind-loading, environmental susceptibility
  - infrastructure
- **minimizing the tracking requirement**
  - microtracking
  - collection optic design
  - solar thermal & concentrating PV
  - waveguide coupling
  - putting it all together
- **eliminating the tracking requirement**
  - self-adaptive concentrator responses

Linear CSP collector field

Motivating challenges:

- cost: significant tracking infrastructure
- wind loading: tracking error, collector field damage
- reliability: movable HTEs currently prone to failure

Opportunities for paradigm shift:

- minimize or even eliminate active tracking → *static* collector field
  - immune to wind loading
  - no moving parts → reliable, low installation & maintenance costs
- lower cost components → glass to plastic

Can we do this and maintain optical performance of a parabolic trough?

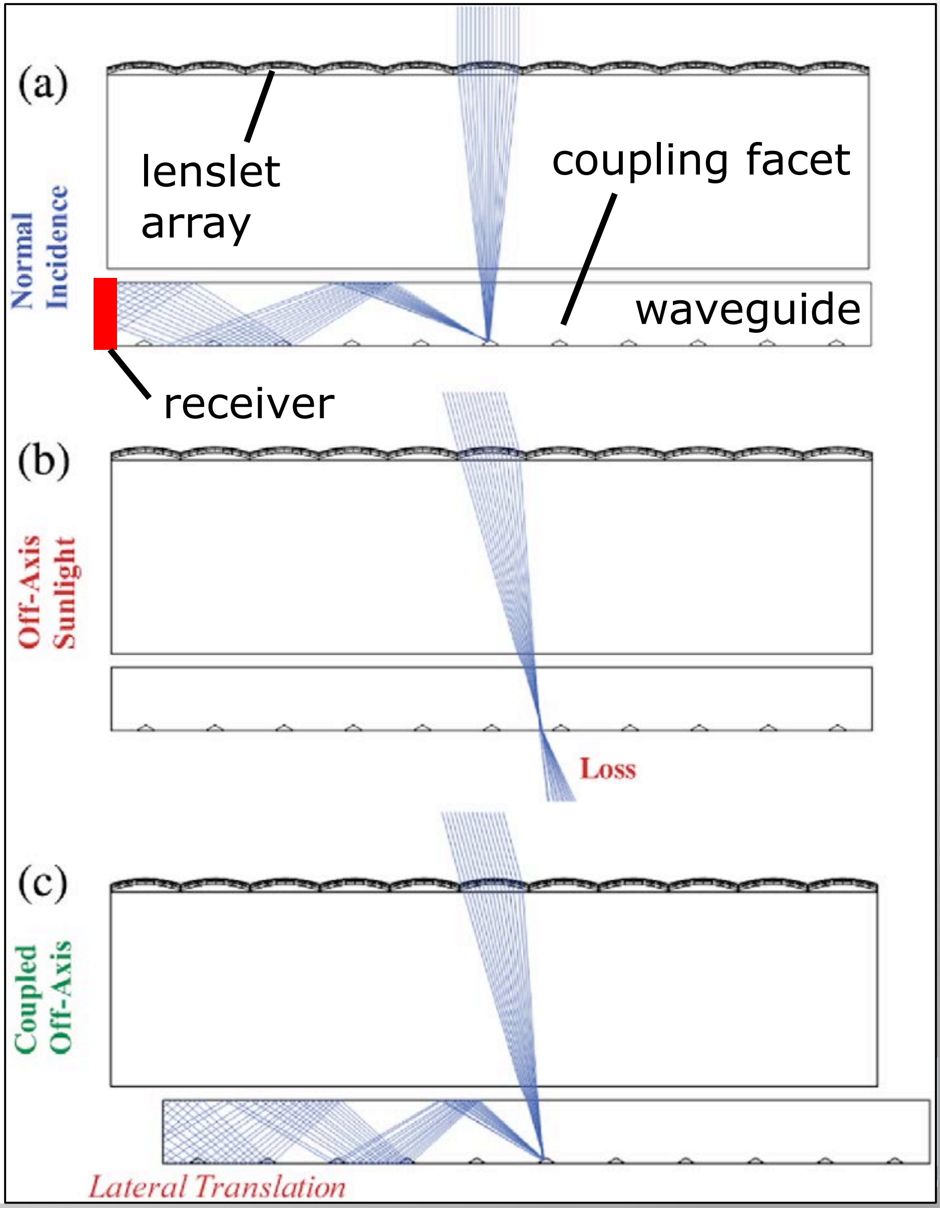
Microtracking

Advantages

- minimal tracking response:
    - ~1 cm of lateral translation required
    - tracking unaffected by wind
- potential for low cost:
    - plastic optics
    - flat glass sheet for waveguide

Design considerations

- tight focal point over <u>wide</u> angle in-plane
    - minimize coupling features → outcoupling loss
- maximum scattering into waveguide
- maximize transmission to HTE

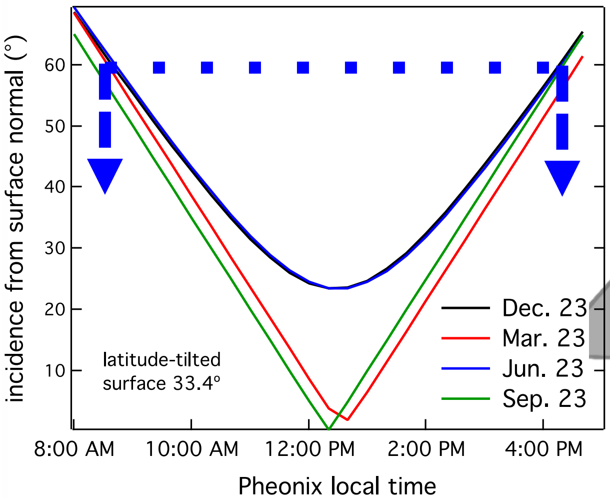


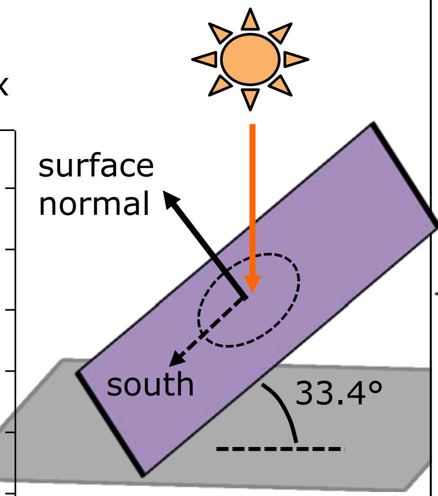
J.M. Hallas et. al. Appl. Opt. **51**, 6117 (2012)

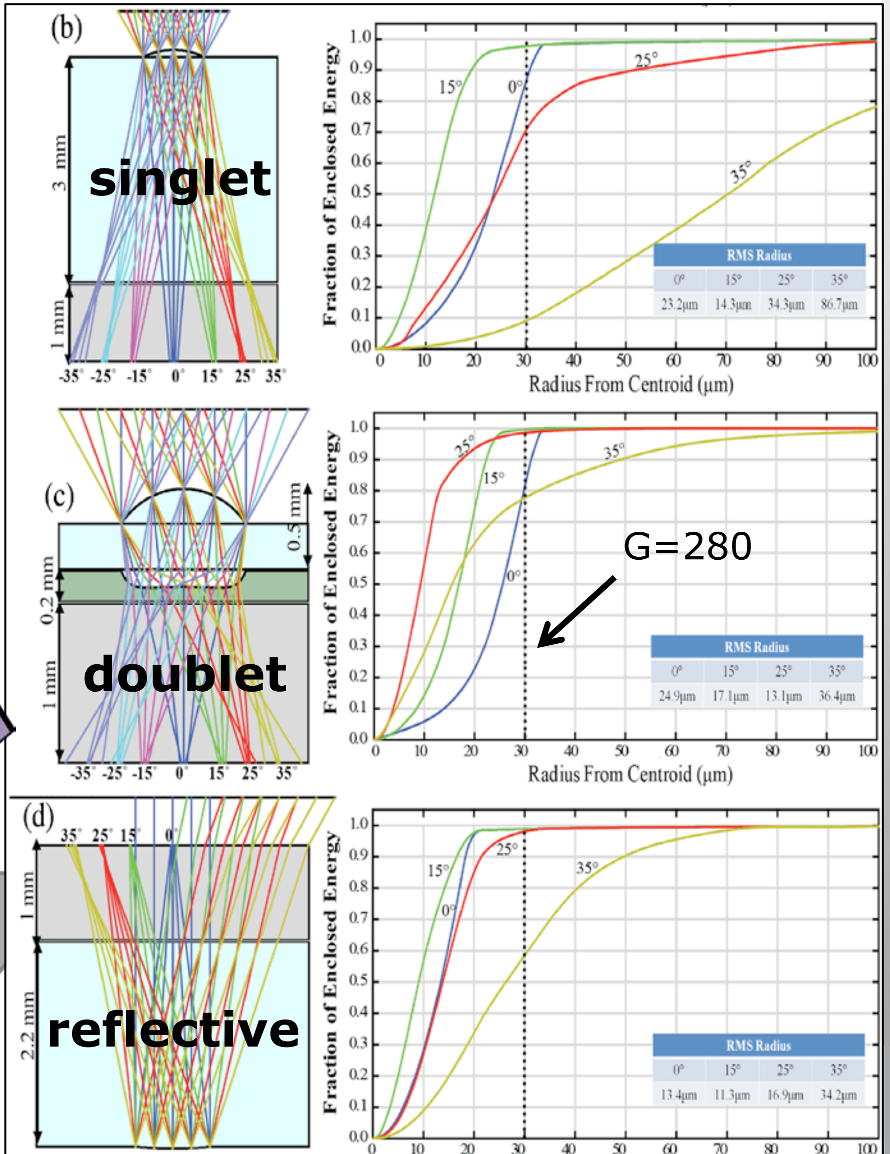
Oblique angle performance

- Petzval surface not flat
  - ✘ poor performance at oblique incidence
- 8 hrs/day collection requires ±60° acceptance

Solar incidence from normal on latitude-tilted surface in Phoenix







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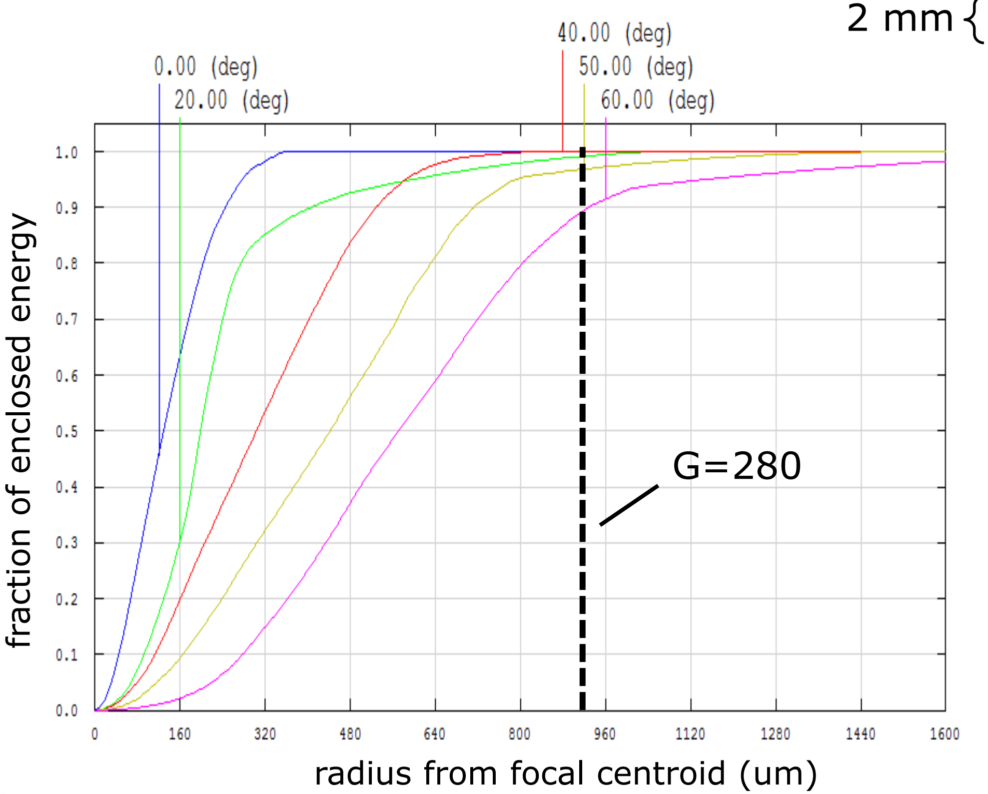
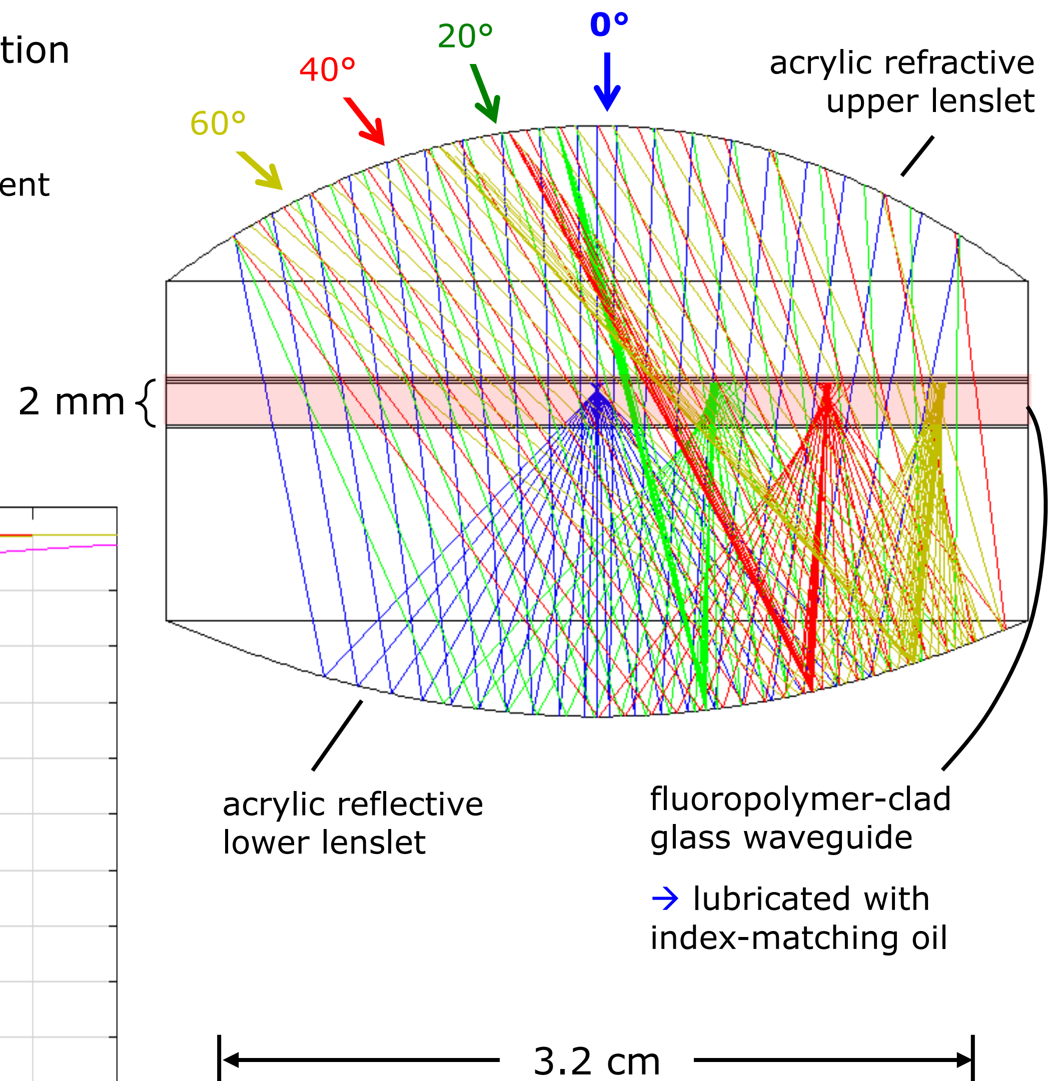
Folded collection optic

- refractive & reflective: Petzval cancellation
- **strengths:**
  - *dramatic* off-angle efficiency improvement
  - simple, inexpensive, compact
  - near monolithic → reliable

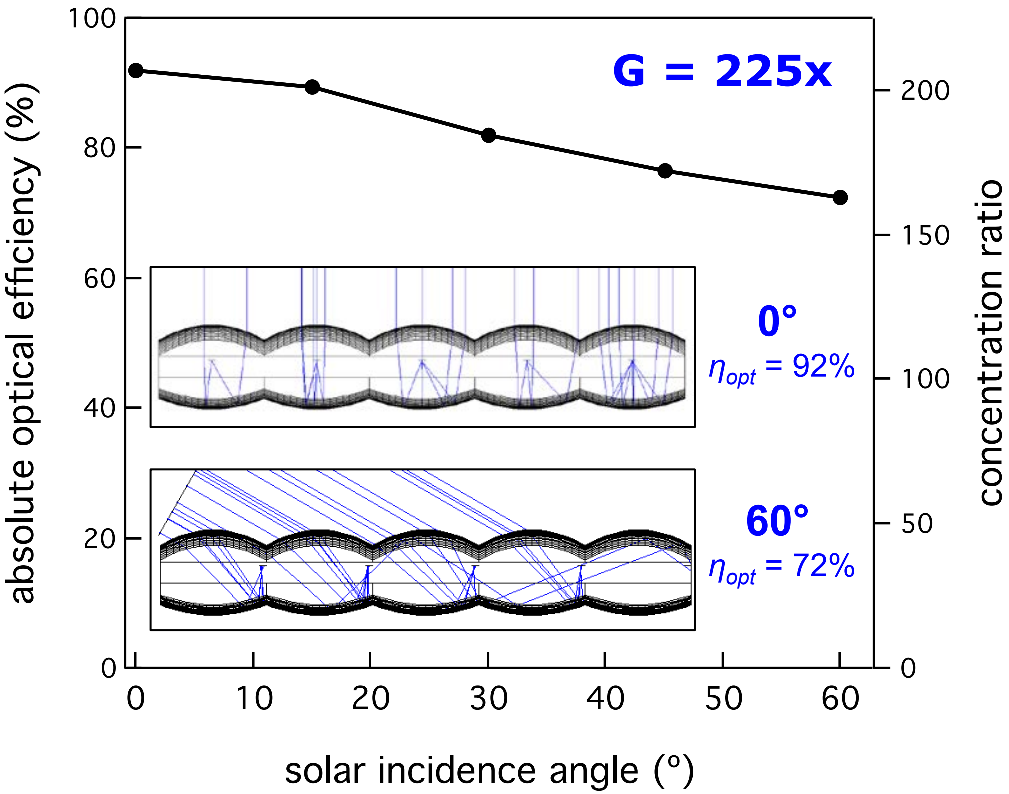


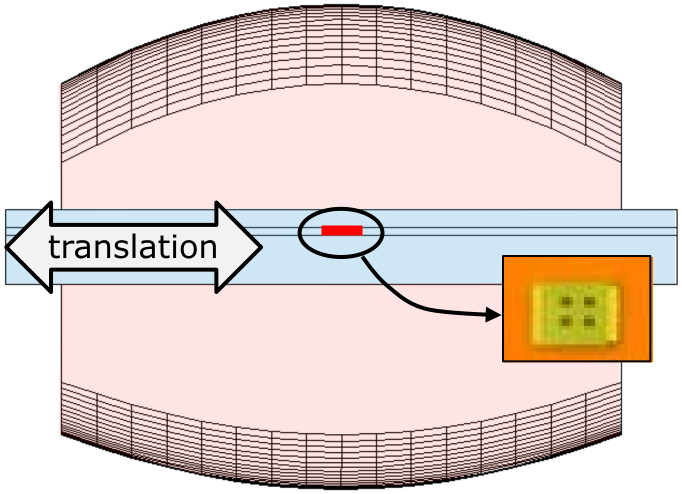


Digression: microtracking + microcells

→ **great potential for CPV**

- 10x10 array of 15mm square lenslets
- 1mm square GaAs solar cells embedded between glass
- 400 – 900nm unpolarized sunlight





advances over current CPV:

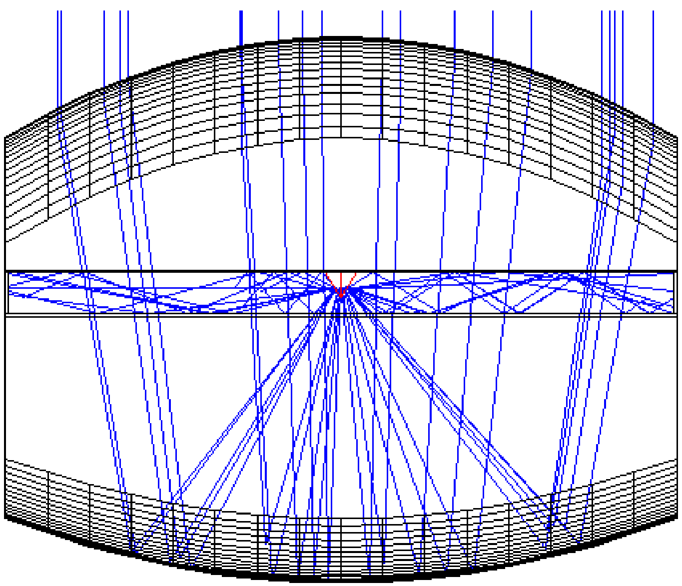
- minimal tracking infrastructure:
  - <1 cm lateral motion
  - *building integrateable* CPV
- immune to wind-loading
- inexpensive: *all plastic optics*
- minimal heat loading

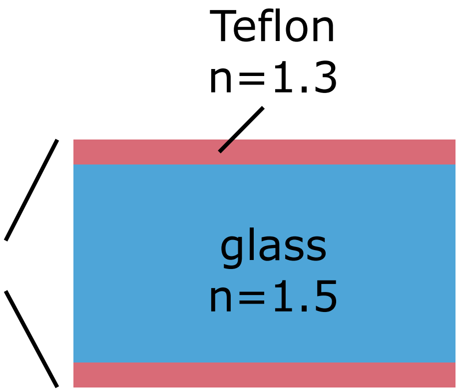
X. Sheng et. al. *Adv. Energy Mater*. (2013)

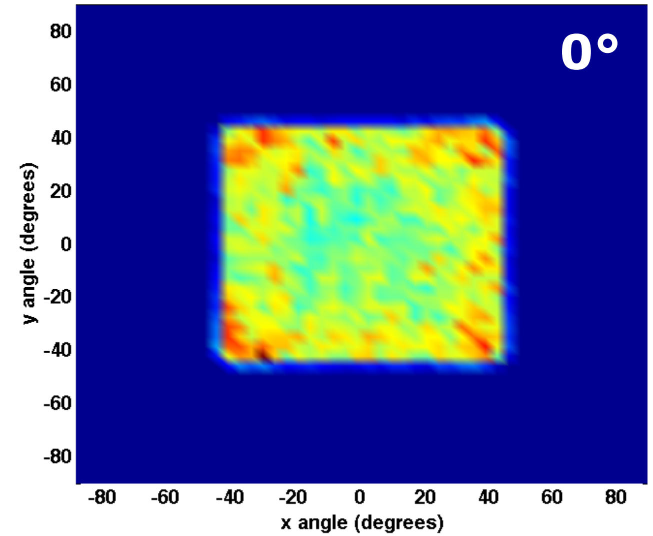
Waveguide coupling

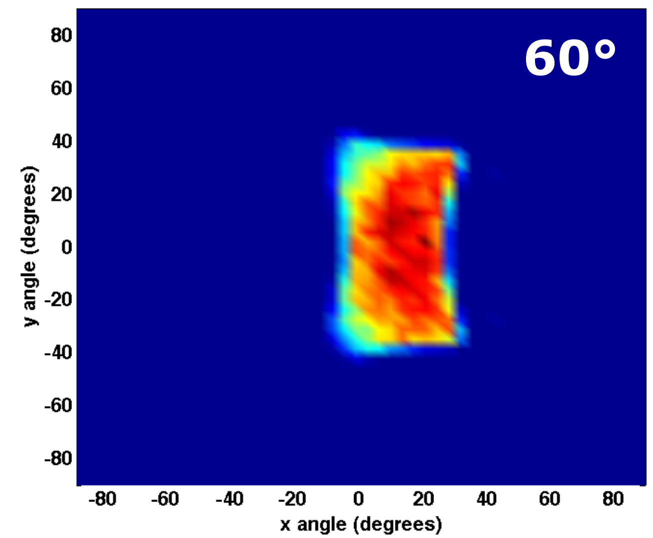
→ redirect collected light into confined modes

- light at focus: confined within ±45°
  - → must be scattered >63° critical angle
- simple conical indentation:
  - → 91% incoupling at 0°
  - → 80% incoupling at 60°



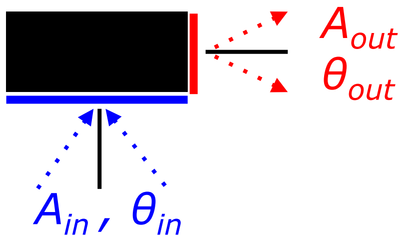


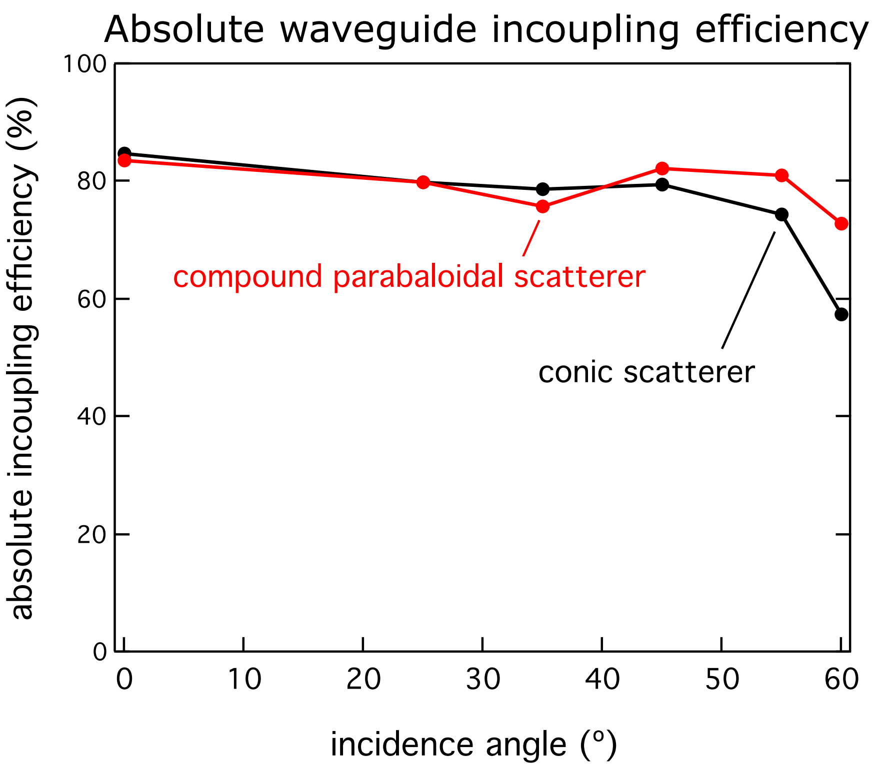


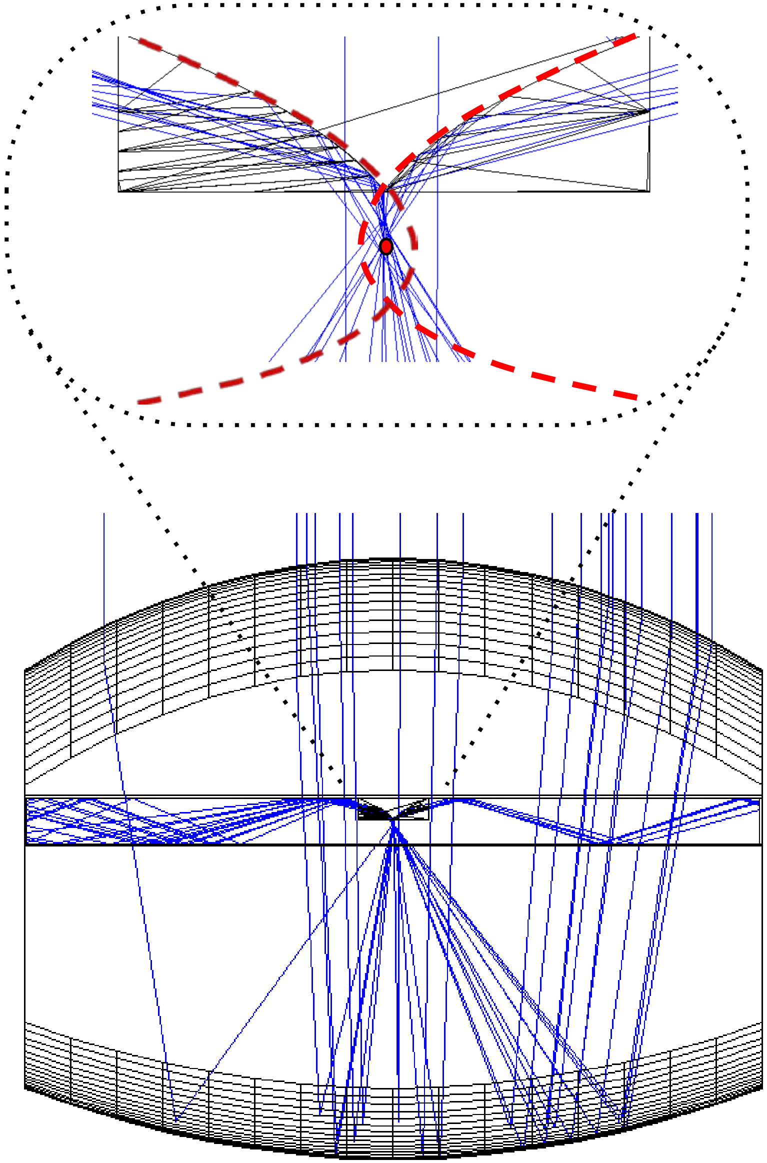


A nonimaging problem

- maximum radiation transfer:
  → nonimaging optics → angle transformer

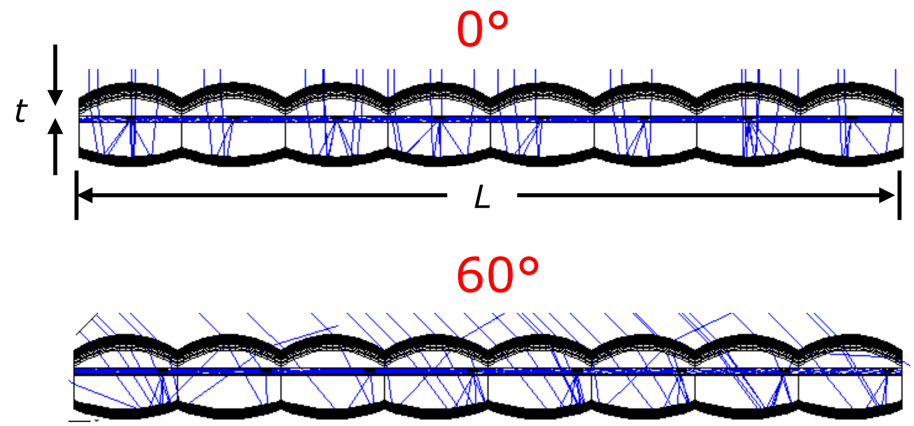


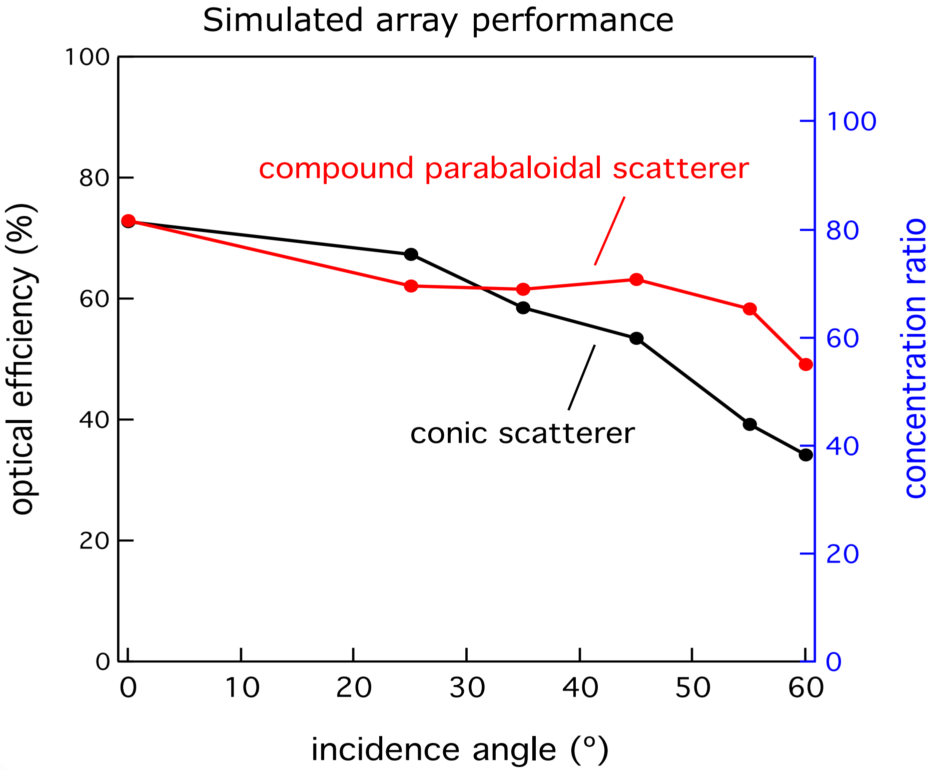


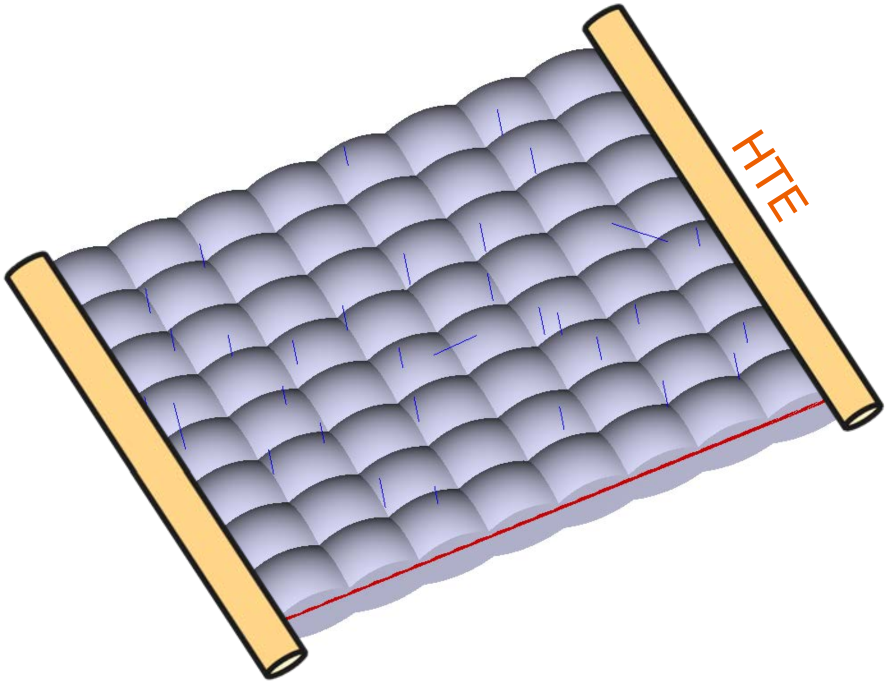


Putting it all together

- geometric gain: G = L / 2t
- optical efficiency: $\eta_{opt} = P_{inc} / P_{edges}$
  - 2 mm glass sheet, L=0.45 m: G = 112x
  - concentration ratio: CR = G x η_{opt}
- optics scale invariant → larger size

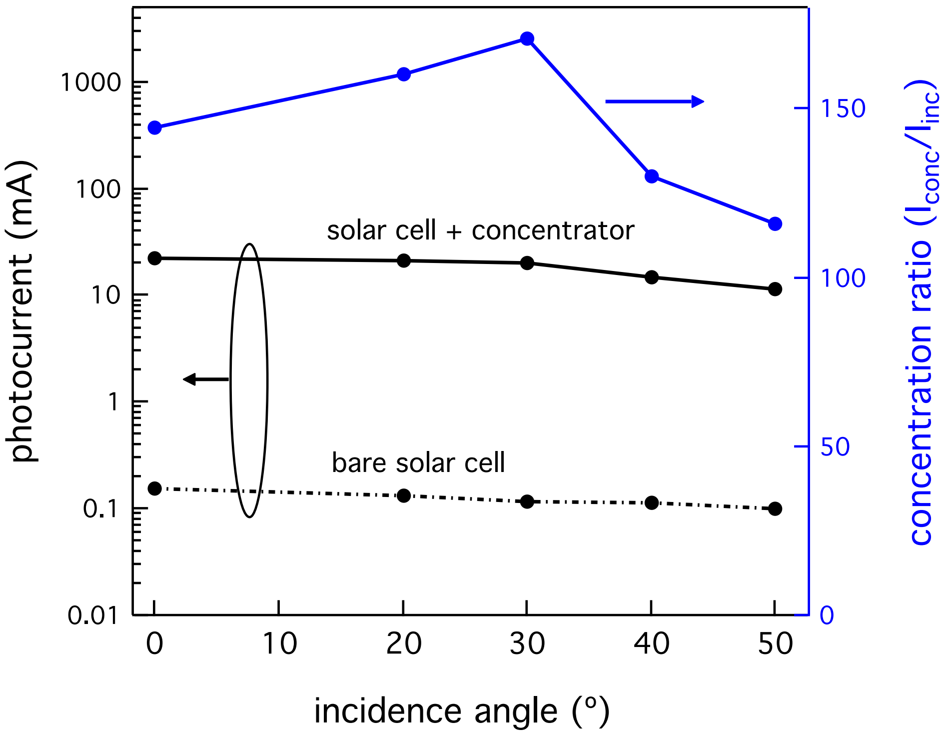


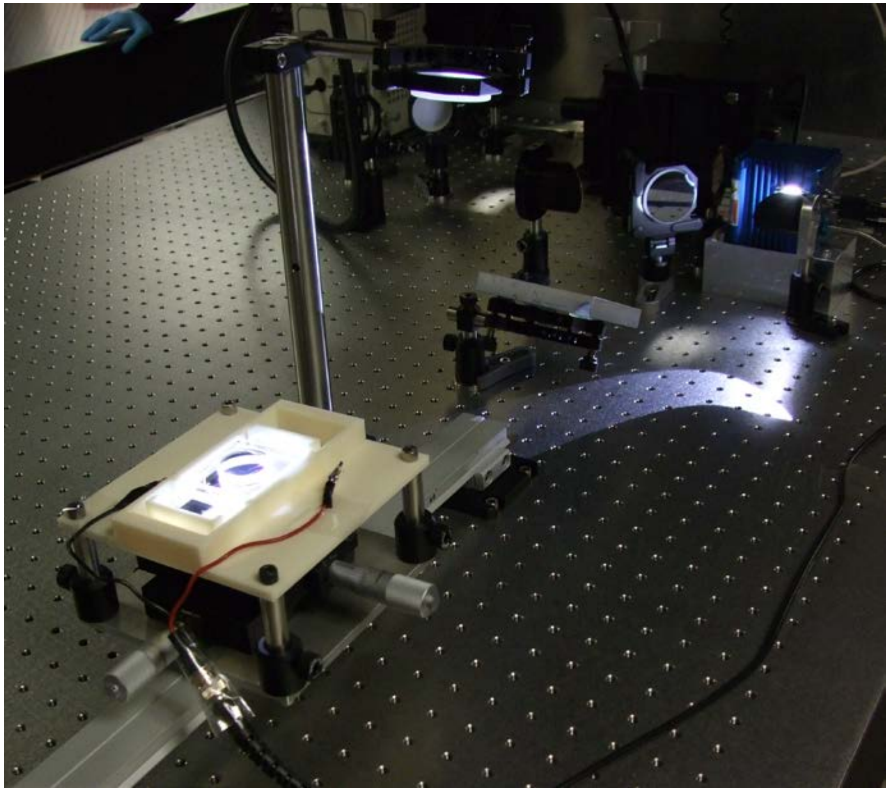




Collection optic initial testing

- off-the-shelf 30 mm spherical lenses
  - spaced by glass sheets
- ~2 mm^2 Si photovoltaic cell
- manual micrometer adjustment
- simulated AM1.5D illumination



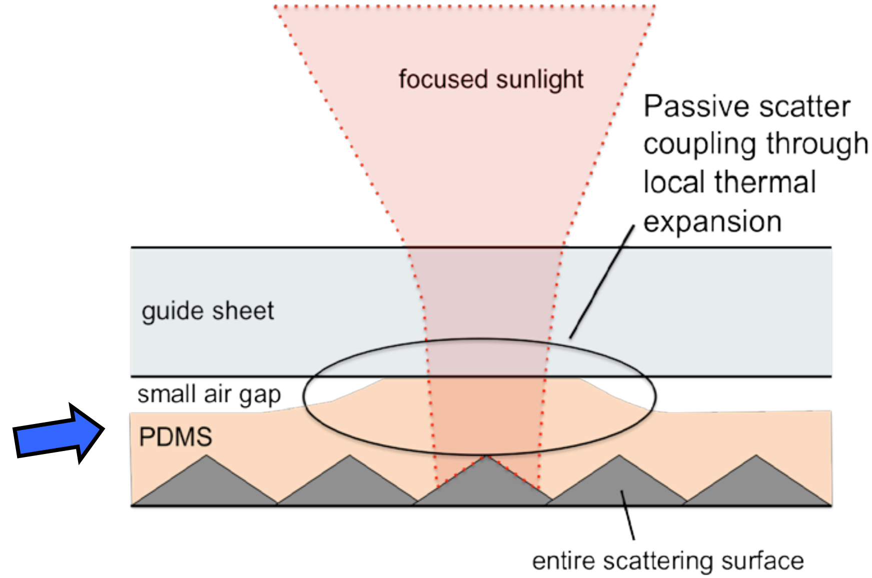


>100x increase in photocurrent for incidence beyond 50°

Self-adaptive response

the ultimate goal…

- focal intensity → drives local change in waveguide coupling
  - essentially a giant nonlinearity
- example:
  - local coupling triggered by thermal expansion

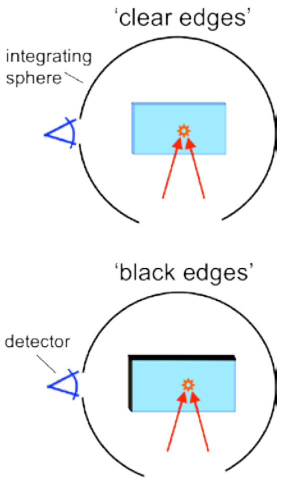


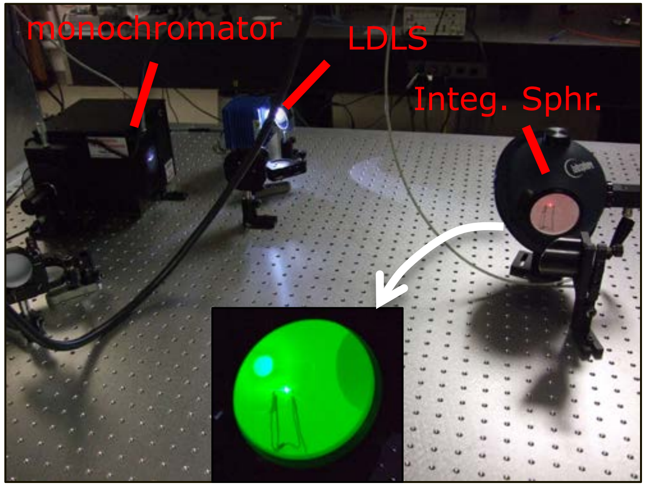
- flurry of recent work in this area:
  - ‘Reactive solar concentrators…’ K.A. Baker et. al. *Appl. Opt.* (2012)
  - ‘Thermal phase change for self-tracking…’ E.J. Tremblay et. al. *Opt. Exp.* (2012)
  - ‘Light induced fluidic waveguide coupling’ V. Zagolla et. al. *Opt. Exp.* (2012)

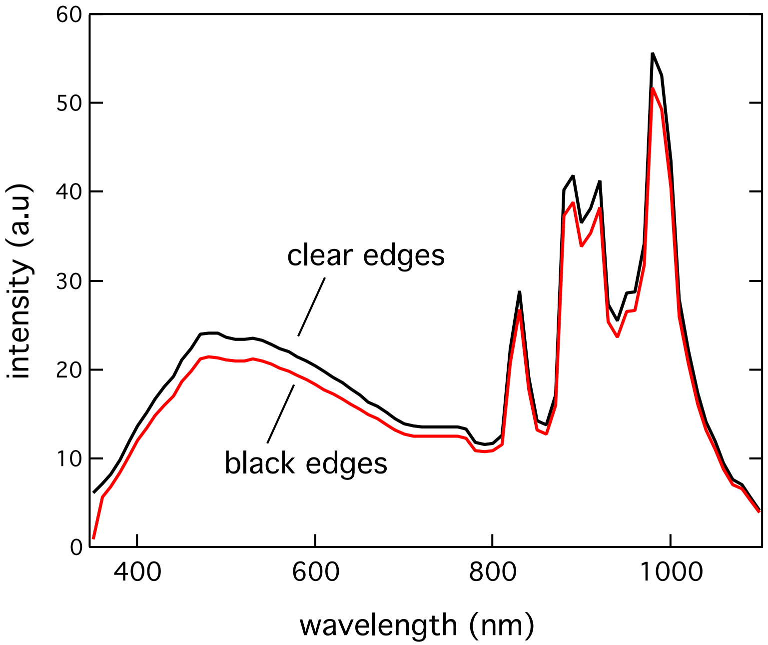
Can we do this efficiently & reliably?

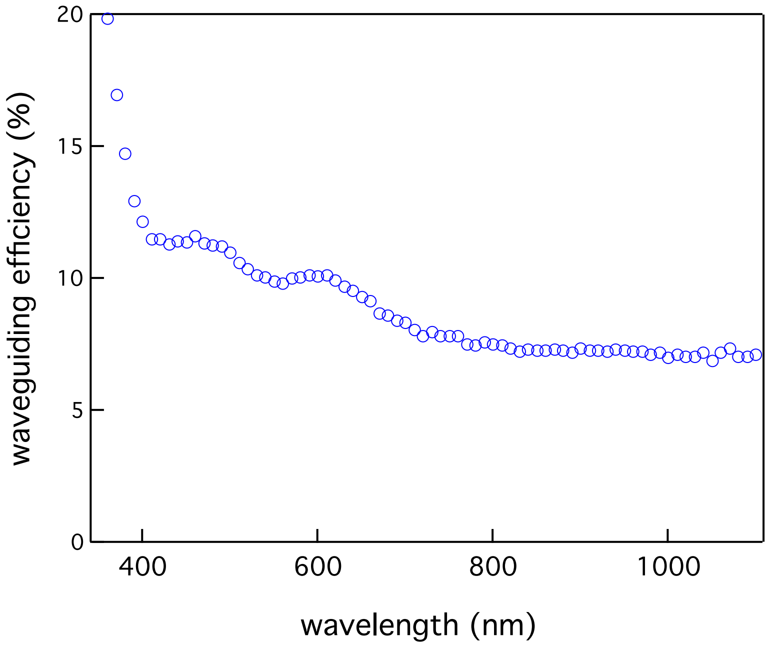
Thermally-induced Wrinkling

- thermally-induced buckling in PDMS
  - elasticity + thermal expansion coeff. mismatch
    - → µm-scale wrinkles form
- investigated wrinkle scattering efficiency into waveguide



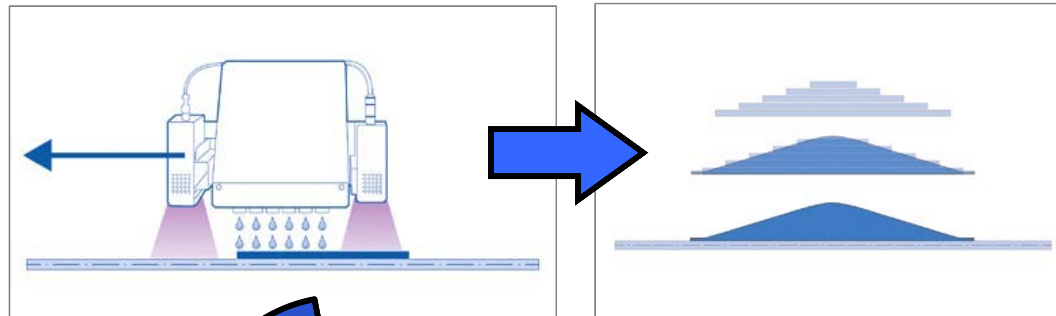




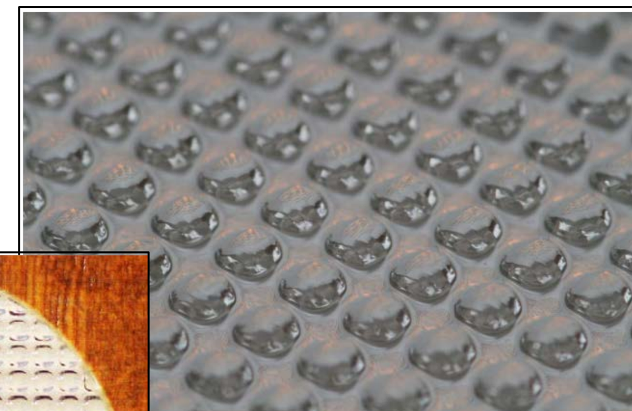


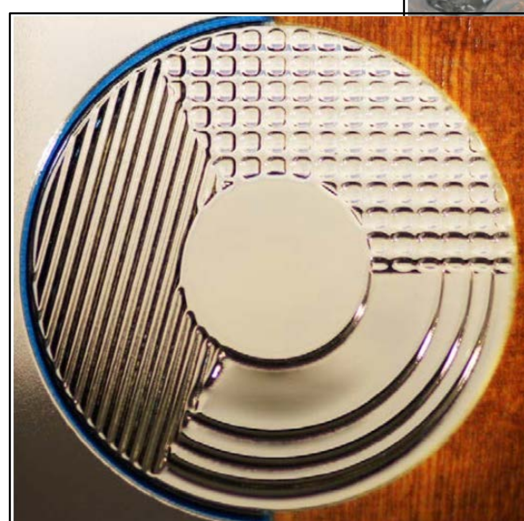
Moving forward & scaling up

- partnering with LUXeXcel B.V.
  - ‘printoptical’ technology
    - inkjet printing optics
    - large area, volume capable



- collection optic assessment
  - microcell array collaboration with UIUC
    - CPV demonstration





- concentrator global optimization
  - toward 75% efficiency at G>80x
- scattering feature fabrication & testing

Conclusions

- **microtracking:**
  - minimal tracking motion: <2cm lateral movement
  - avoids wind loading error
  - compatible with stationary heat transfer elements
- **folded optic design:**
  - efficient collection 8 hrs/day
  - simple, compact & potentially inexpensive
    - **CSP**: simulated G=112x, η_{opt} >60% 8hrs/day
    - **microcell CPV**: simulated G=225x, η_{opt} >72% 8hrs/day
  - self-adaptive concentration: difficult to do well but high payoff
    - worth pursuing

promising development for concentrating solar power

Acknowledgements

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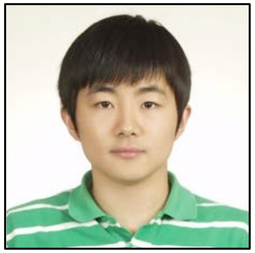
  - 1st year EE PhD student

- **Taehwan Kim**
  - 1st year EE PhD student



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