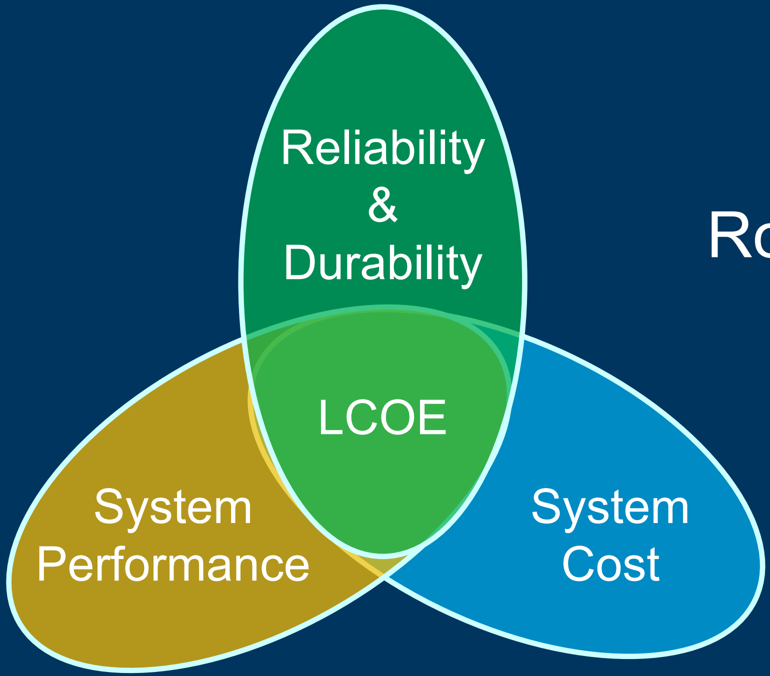
Low Concentration Photovoltaics: Reliability and Durability Issues



Roger H. French
Materials Science
Case School of Engineering
Case Western Reserve University
Cleveland OH 44106

roger.french@case.edu
http://dmseg5.case.edu/people/faculty.php?id=rxf131

Introduction

Require cost effective materials, components & design

- Design simplicity
- Typically conventional silicon cells

Can utilize conventional materials & construction

- High concentration challenges not essential
- Reliability and durability derive from conventional approaches
- e. g. c-Si cells, encapsulation

Challenge is cost-competitive, reliable LCPV technology

Calls for integrated optimization for reliability & lifetime

- Yielding lower cost and LCOE

Many LCPV efforts

Reflective efforts

- Abengoa Solar NT
  - 1.5 and 2.2X tracked
- JX Crystals
  - 3X
- Megawatt Solar
  - 20X
- Replex
  - MAPV, fixed or tracked
  - LC2PV, tracked
- Skyline High Gain Solar
  - ~10X tracked
- SunPower
  - 7X tracked
- tenKsolar
  - !2X, fixed, UV/IR shielding
- Zytech Solar,

Refractive efforts

- Solaria
  - ~2X tracked

Need: Lifetime & Degradation Science for PV Modules

Qualification testing of systems not sufficient for reliability & lifetime

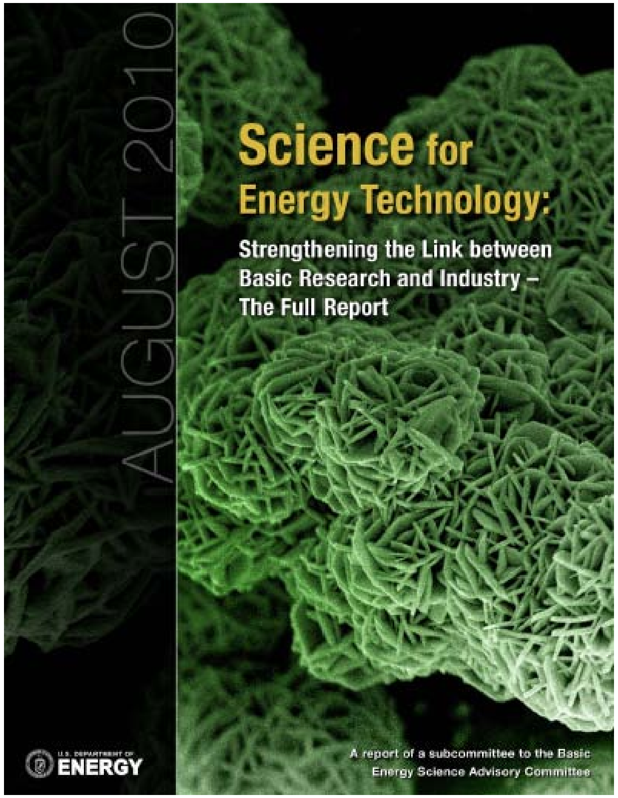
- To avoid excessively high degradation rates
- Dramatically reduced service lifetimes

Must determine degradation mechanisms and rates

- Scientific underpinning of reliability and qualification standards

Quantitative degradation rate modeling

- Connects materials, components, system
- To overall degradation rate, linearity, reciprocity
- And system lifetime performance



Science For Energy Technology Workshop

- Convened by U. S. DOE, Basic Energy Sciences

Science challenges across 9 areas of energy

PV prioritized research directions

- ***Photovoltaic module lifetime and degradation science***
- *Fundamental properties of photovoltaic interfaces*
- *Advanced photovoltaic analysis and computational modeling for scale-up*

http://www.er.doe.gov/bes/reports/files/SETF_rpt.pdf

Outline

2 characteristic LCPV systems:

- Replex's MAPV & LC2PV
  - => LC2PV Poster

LCPV elements, stressors and design characteristics

- Primary optics, secondary optics, cell encapsulation, heat sinking

LCPV solar and environmental durability

- Materials examples: acrylics, outdoors, 4 Suns and 50 Suns
- Elements examples: Al/Ag mirrors, back & front surface mirrors, UV blocking mirrors

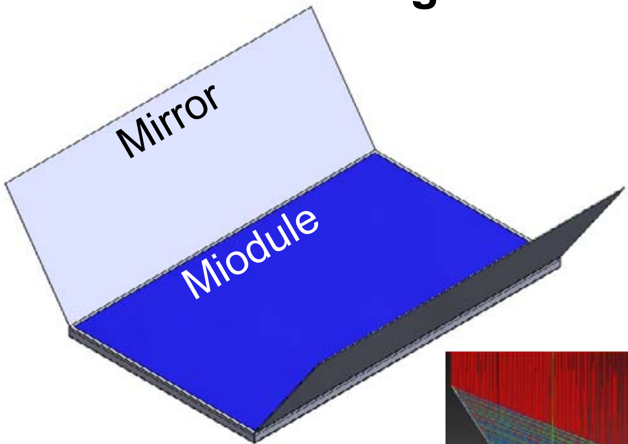
Cell encapsulation and thermal management

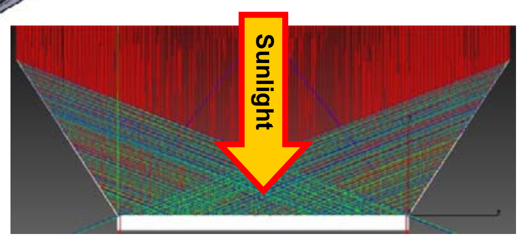
LCPV challenges

Conclusions

Two Replex LCPV Systems

MAPV: Mirror augmented PV

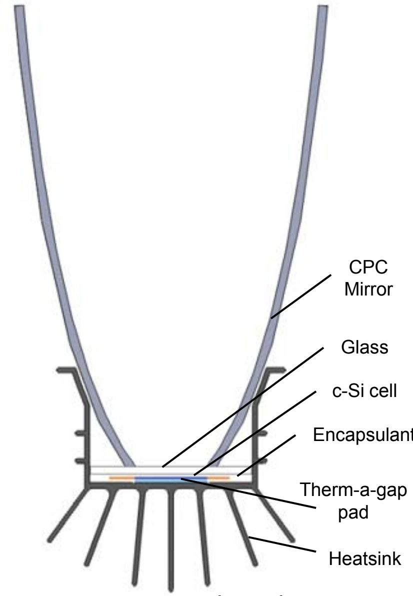




Flat mirrors & c-Si modules

- 1.15X (fixed)
- 1.5 to 2.2X (tracked)

LC2PV: Low cost, low conc. PV



Compound parabolic concentrator

10X geometrical concentration

Validation of LCPV degradation rates and lifetime needed

- Carrizo Plains / Arco Solar: R_d = 10%/yr degradation

Requires a materials/components/systems optimization approach

- Based on lifetime and degradation science
- Not just qualification testing results

LCPV Elements, Stressors and Design Characteristics,

LCPV elements

- 1 Sun optics
- Multi-sun optics
- Cell level encapsulation
- Silicon cells
- Dielectric isolation / thermal conduction
- Thermal management

Stressors

- Irradiance
- Temperature
  - Thermal degradation
  - Thermal expansion mismatches
- Humidity
  - Florida
  - Arizona
- Cycling
- Electrical
  - Current, voltage
  - Corrosion

Geometrical concentration

- MAPV - 1.5 to 2 Suns
- LC2PV - 5 to 10 Suns

Solar Mirror based optics

- Acrylic substrate
- Silver or aluminum mirrors
- First or second surface acrylic

Silicon cells

- Encapsulation
- Stringing and tabbing
- Heat sinking

LCPV cost constraints

- Performance & LCOE
- Manufacturability
- Durability
- Reliability
- Lifetime

LCPV Solar and Environmental Durability Issues

Acrylic solar durability

- PMMA: Arizona & Florida weathering
- PMMA: A new solar radiation durability metric: Induced absorbance to dose

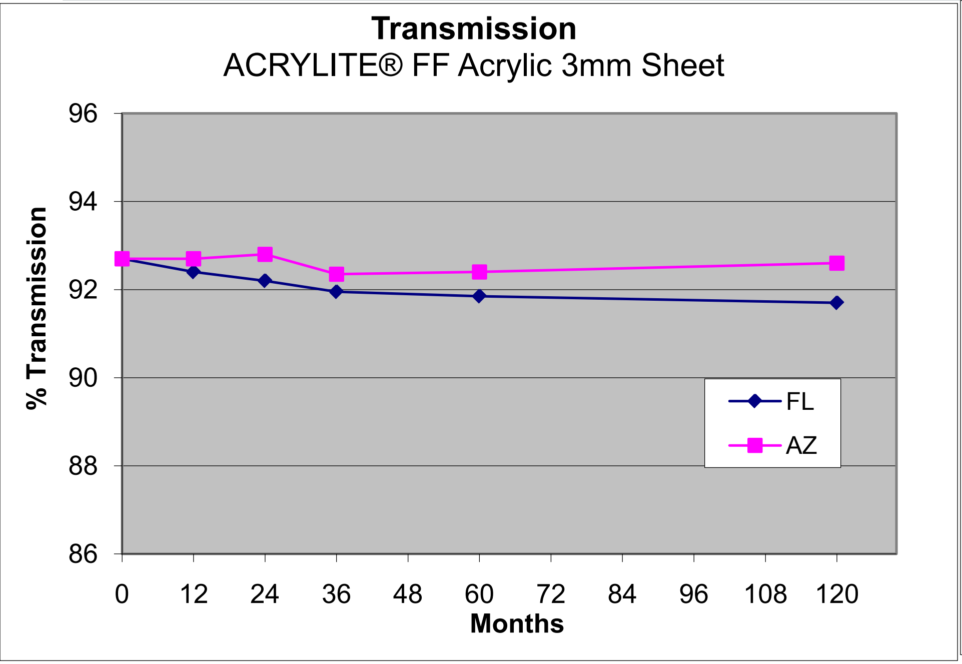
Solar mirror durability

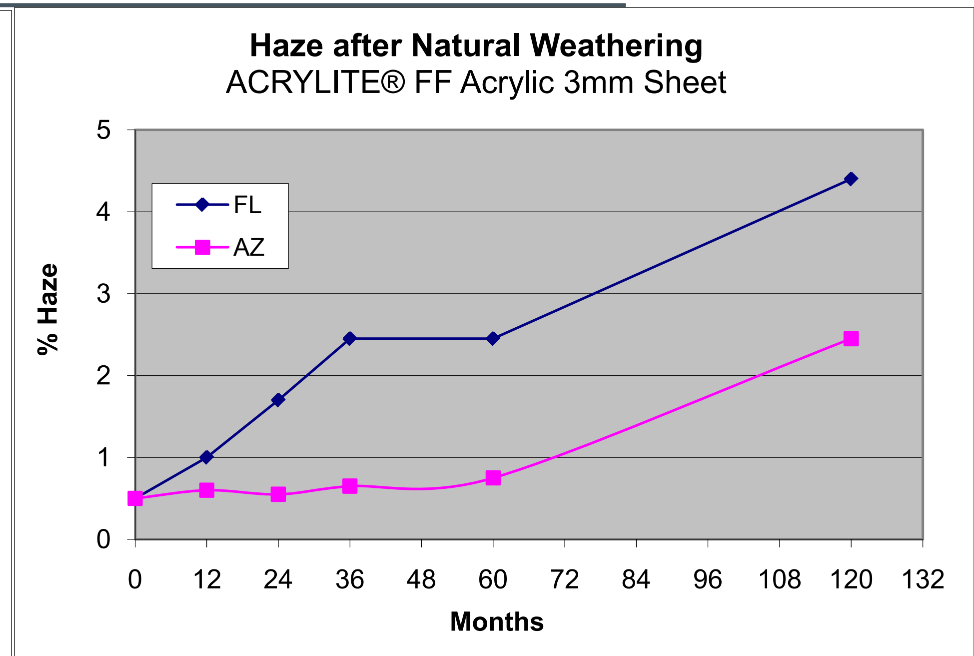
- Aluminum & silver mirrors: Arizona & Florida weathering
- Accelerated QUV testing of Al & Ag mirrors

Solar durability of back surface Al mirrors in a CPC

Cell encapsulation and thermal management

Natural Weathering of Acrylic Sheet: Arizona & Florida





Not much change in transmission

- Over 10 years exposure

Humidity in Florida increases

- Transmission drop
- Compared to AZ (dry)

Haze also affected by humidity

- Rate of change higher in FL

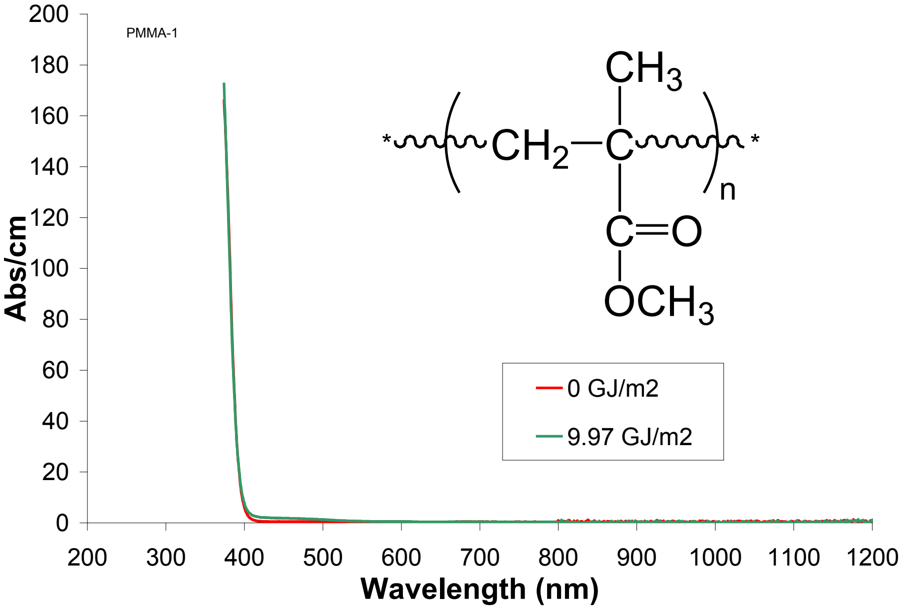
What are quantitative requirements?

- On material for this LCPV application?

Varies with system/element design

- Yes/No answer not germane

Induced Absorbance to Dose: PMMA-1 @ 3.8 kW/m2 Irradiance



75 mm film with UV stabilizers

- Shows strong absorption edge at 400 nm

Annual 1Sun Dose = 9.3 GJ/m2

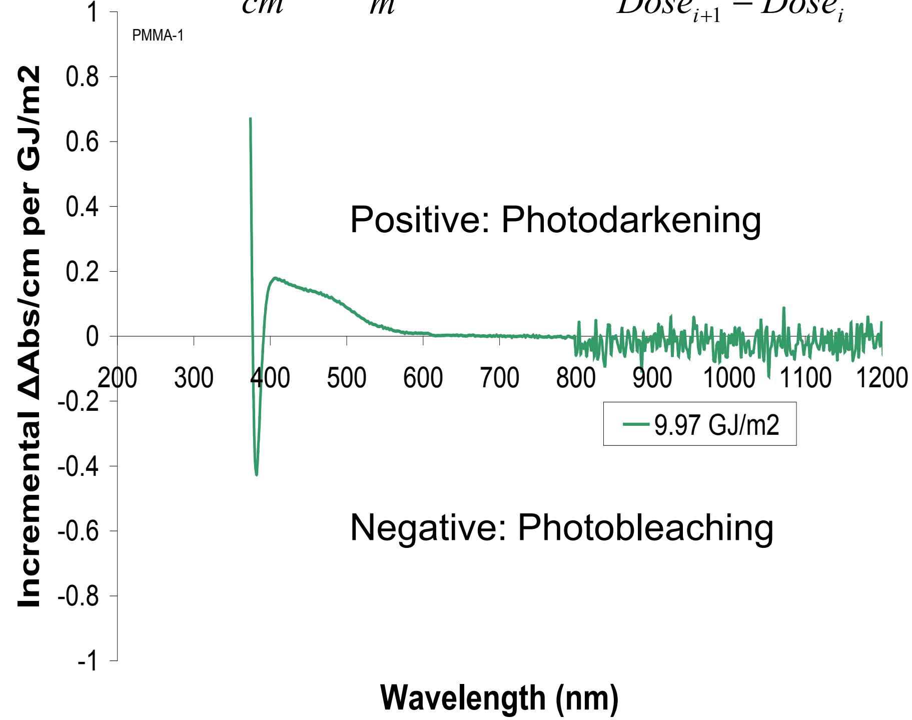
Photodarkening at 400-600 nm

Some photobleaching below 400 nm

Quantitative degradation rates R_d

Induced Absorbance To Dose

$$Incremental\ \frac{Abs}{cm}\ per\ \frac{GJ}{m^2}\ Dose \equiv \frac{Abs_{i+1}(\lambda)/cm - Abs_i(\lambda)/cm}{Dose_{i+1} - Dose_i}$$



Not all acrylics are alike

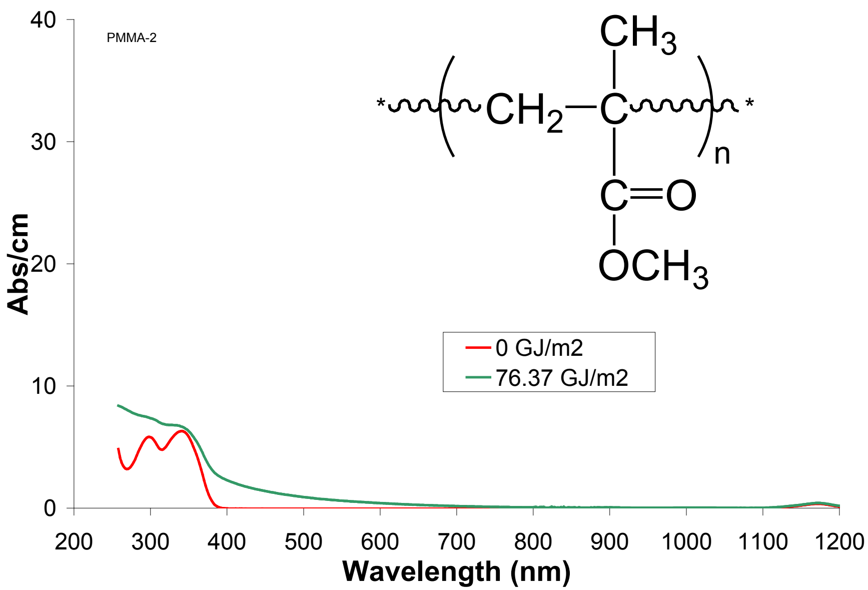
Need sufficient durability

- Without excessive cost of ownership

Optimize material to application

Induced Absorbance to Dose: PMMA-2 @ 48 kW/m2 Irradiance

Optical Absorbance/cm



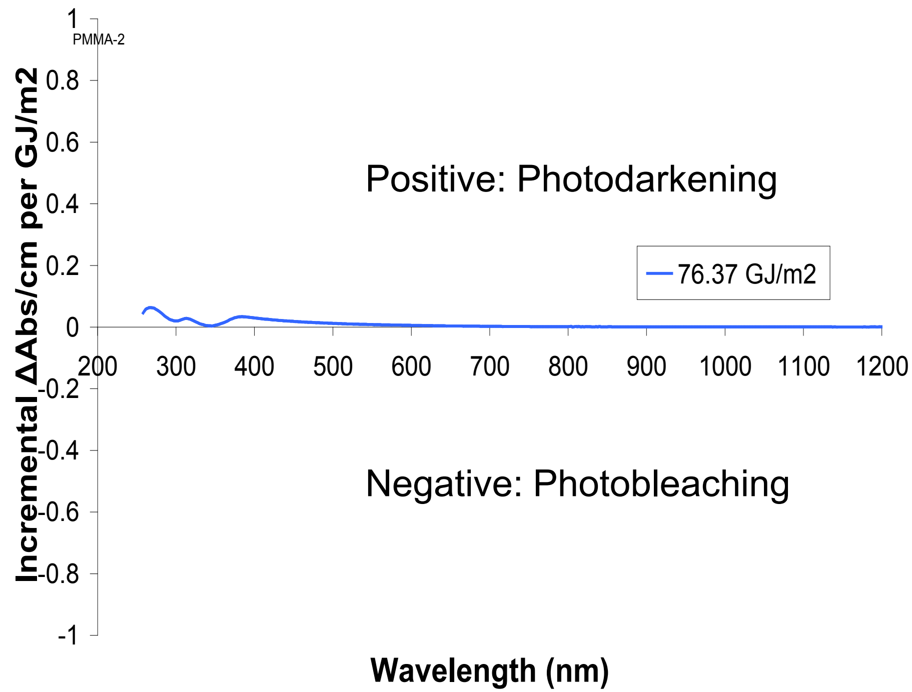
1.6 mm thick sheet with UV stabilizers

- Shows strong absorption edge at 400 nm

After ~76 GJ/m2 exposure

- Photodarkening at 250-600 nm
- No photobleaching observed

Induced Absorbance To Dose



Much lower degradation rates

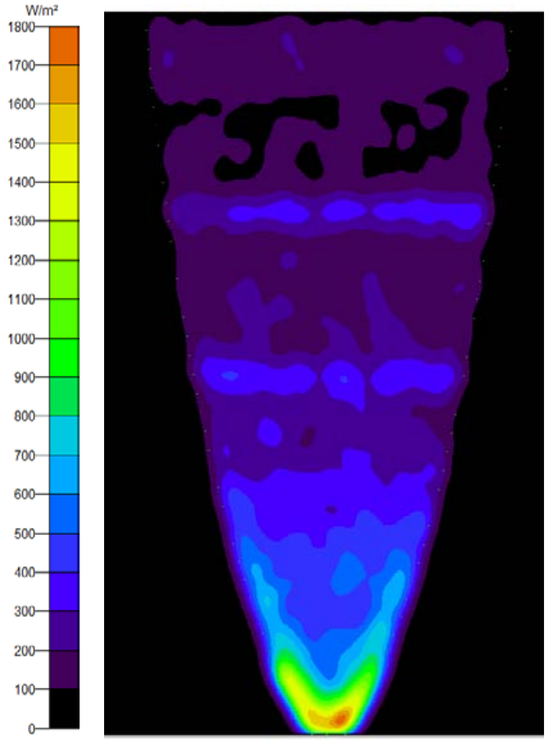
- Than highly stabilized PMMA-1

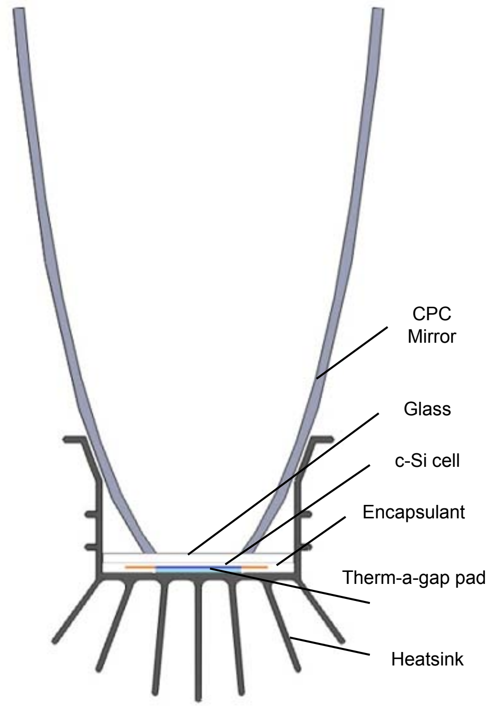
Check linearity & reciprocity

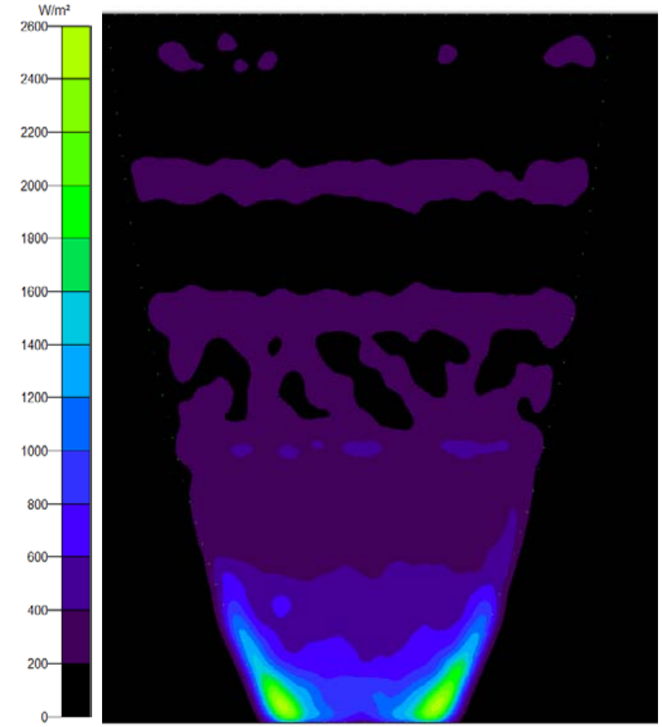
Then Use for accelerated testing

- Or real time 50 Sun testing

Expected Irradiance on LC2PV CPC Reflector







Non-tracking N/S direction

Max irradiance = 1.8 kW/m^2

Tracking E/W direction

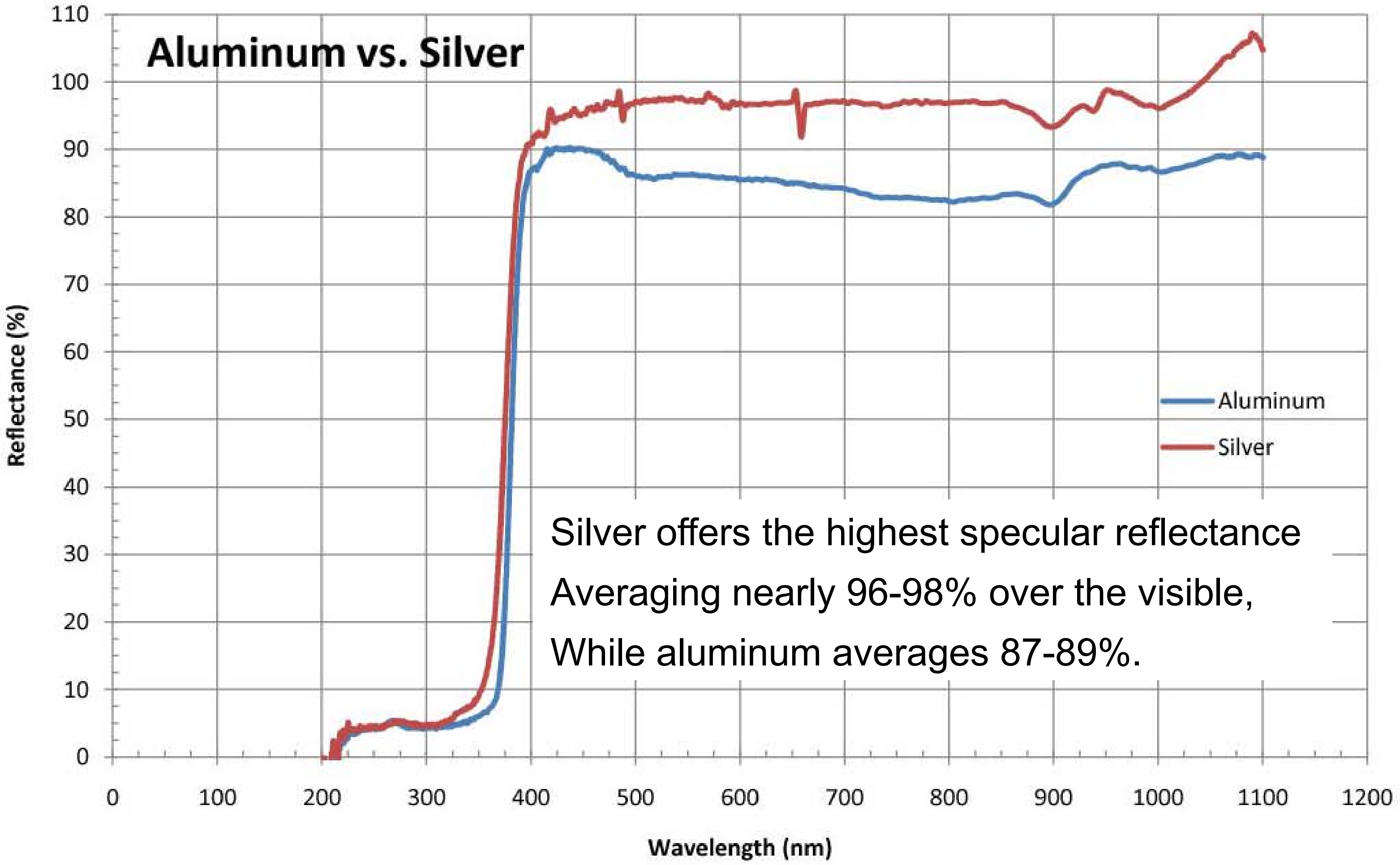
Max irradiance = 2.8 kW/m^2

What are critical material requirements? Not just qual. testing requirements

- MAPV PO: 1 Sun Irradiance. LC2PV: 2.8 Sun Irradiance in some areas

Must optimize materials, componets and system for durability & lifetime

Optical Efficiency: Al vs. Ag Back Surface (BS) Mirrors

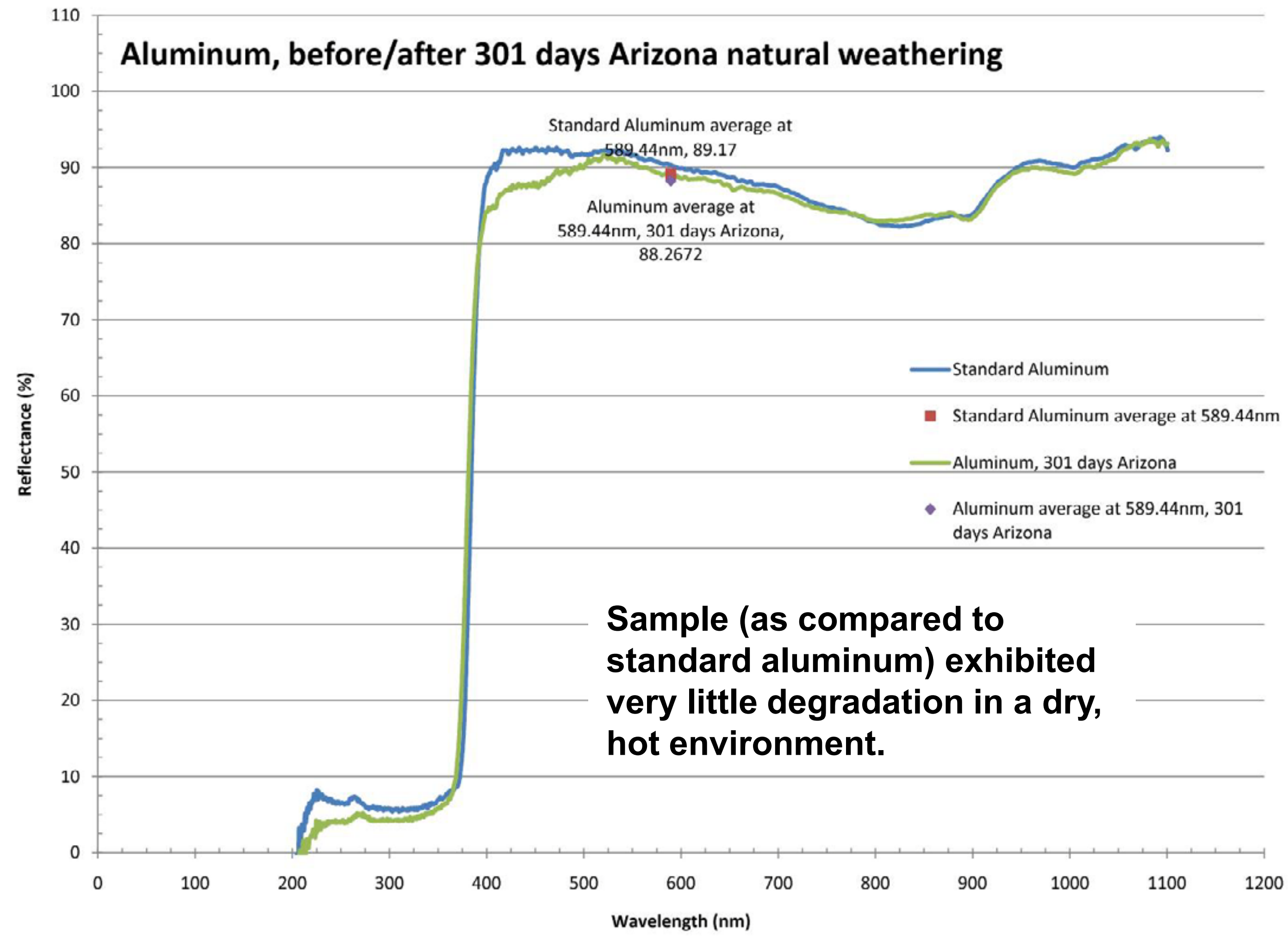


High reflectivity of silver, improves optical efficiency and performance

- But increases costs, and reduces durability and lifetime

Must carefully avoid increasing cost of ownership

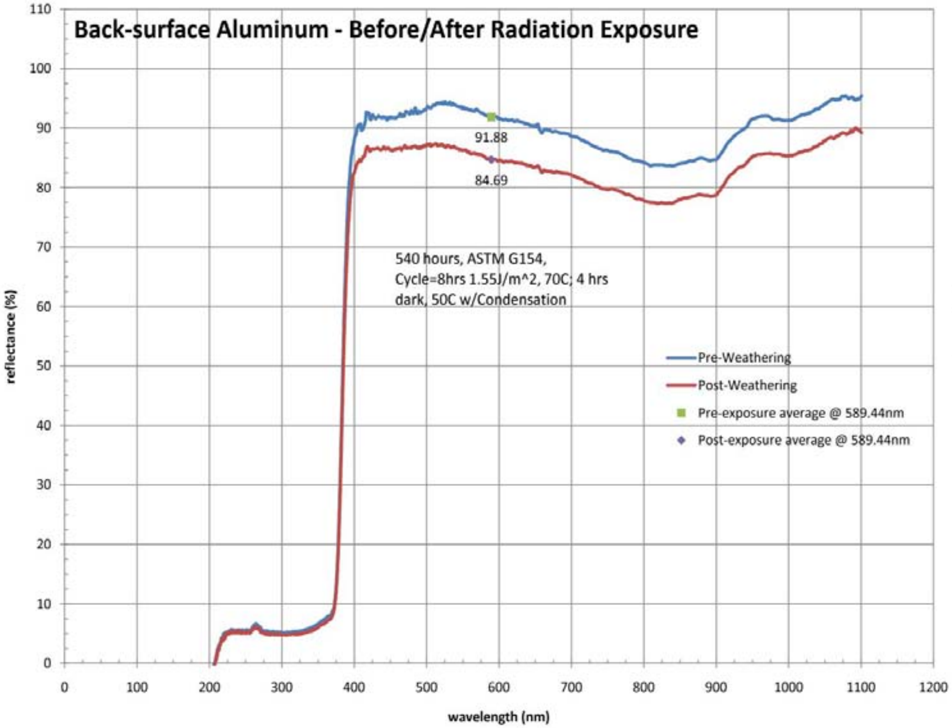
Al/Back Surface Mirror Durability: Arizona Outdoors

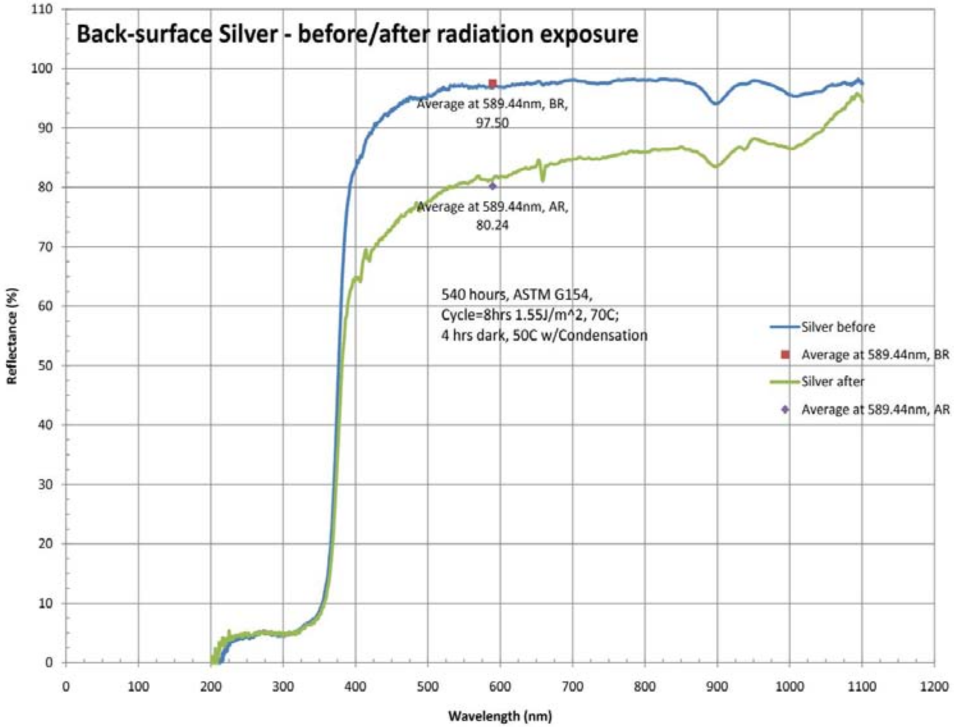


Sample (as compared to standard aluminum) exhibited very little degradation in a dry, hot environment.

Aluminum back surface mirrors show good durability

Al/Back Surface Mirror Durability: Accelerated Testing





QUV exposures with condensing humidity and heat during dark periods

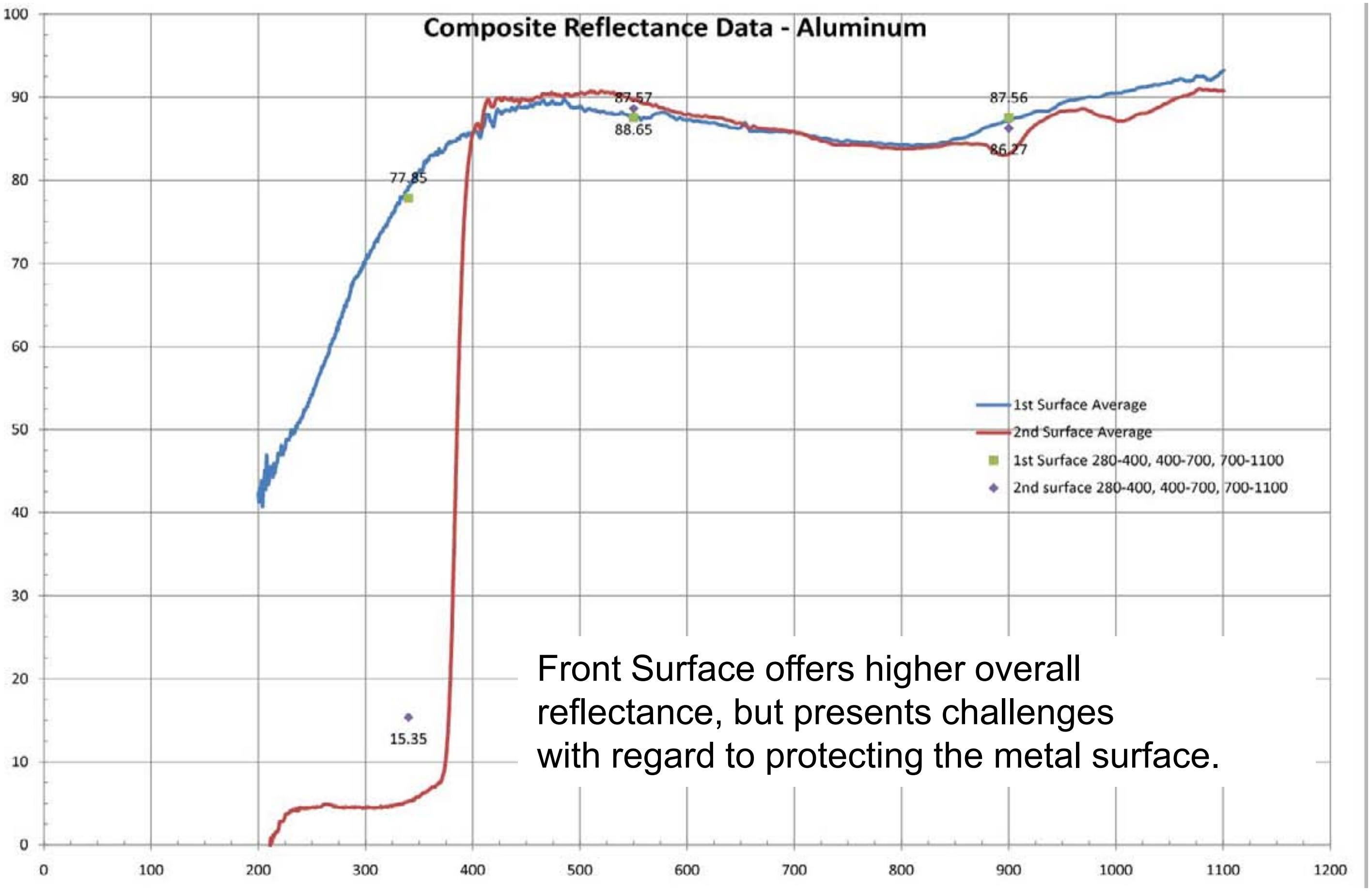
- Compare to Florida natural weathering

Aluminum/BS mirror: average 7% reduction in specular reflectance

Silver/BS mirror: average 17% reduction in specular reflectance

Aluminum/BS mirrors more durable in humid conditions

Al Back vs. Front Surface Mirrors: Optical Efficiency

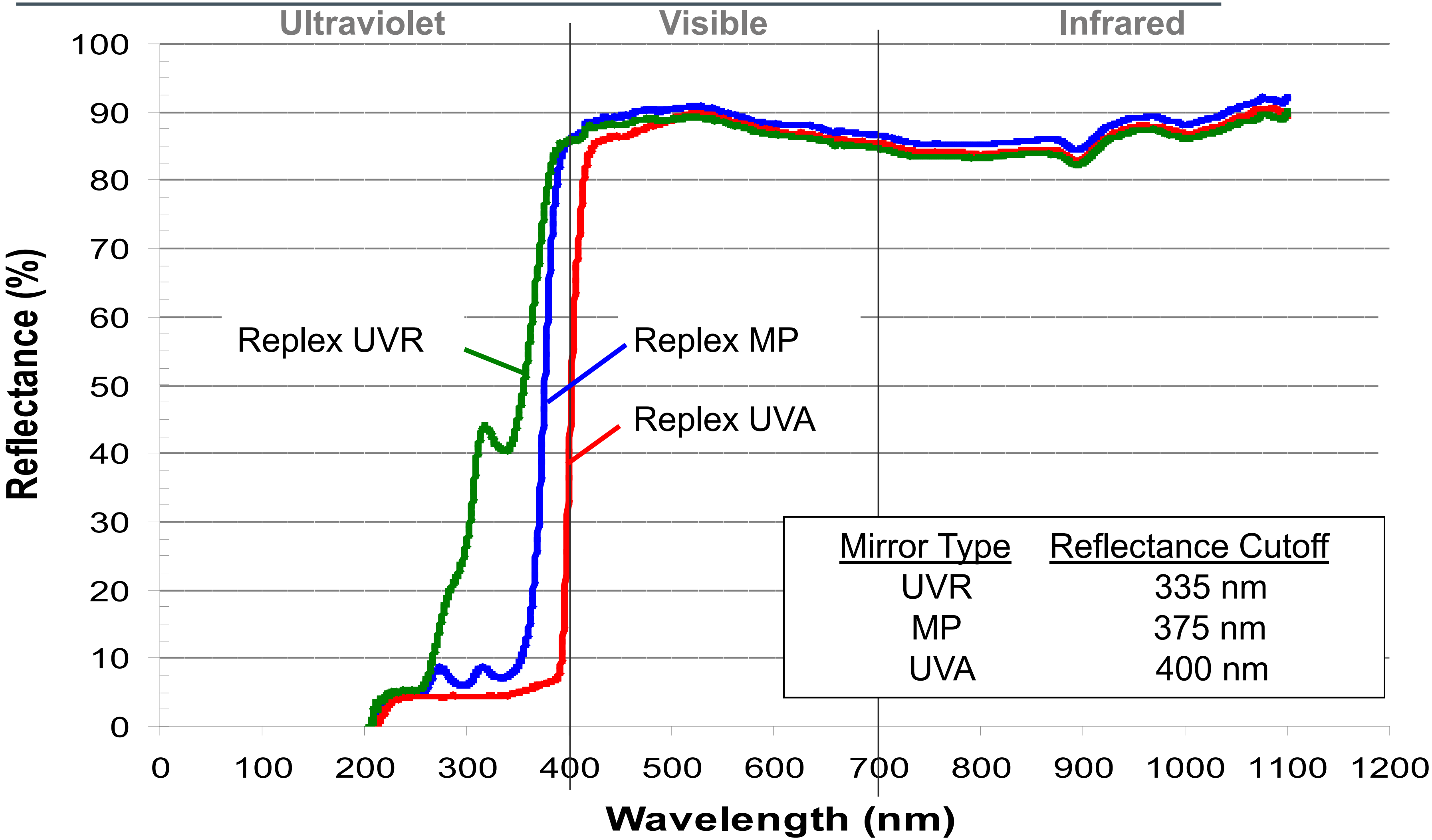


Front surface mirrors reflect UV and have similar visible reflectance

Back surface mirrors don't reflect UV, reduce UV exposure of cell encapsulation

- With similar optical efficiency when used with c-Si cells

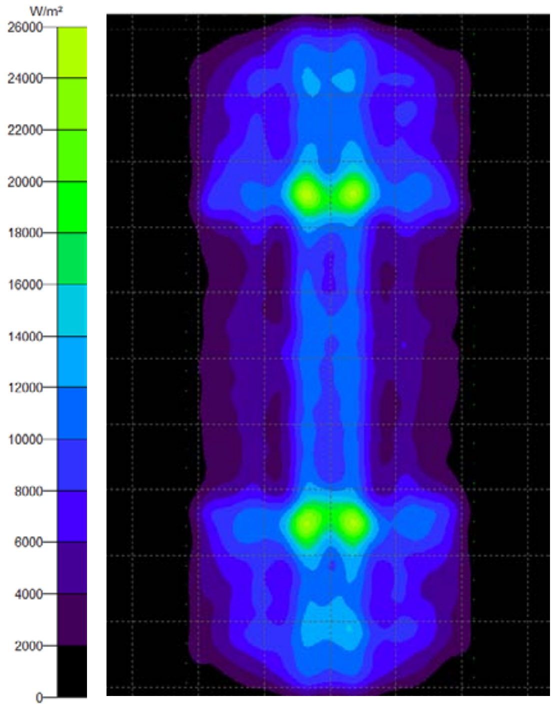
Replex UV Selective Al/Back Surface Mirrors

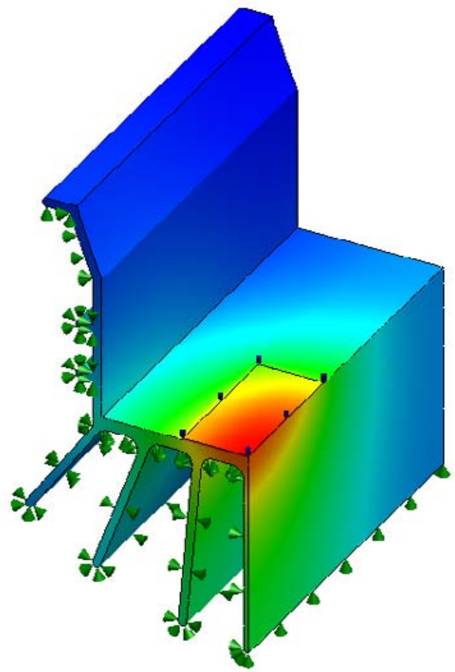


And back surface mirrors allow tuning of UV absorption edge

- Creating wavelength selective mirrors

Cell Level Irradiance and Thermal Management





10X CPC geometrical concentration

- Average cell irradiance = 6.9 kW/m^2

Hot spot, max conc. on cell = 26X

Encapsulation durability concern

Some decrease in performance

- But doesn't justify cost of secondary optic

Thermal management of cell

- Using aluminum heat sink,

7X area ratio: cell to heat sink

- Also aligns optics

Heat sinking a cost challenge

- not a technical challenge

LCPV Challenges

Using standard materials and components

- Under “accelerated” conditions

Maximizing optical efficiency

Sufficient, but cost effective, materials & component durability

- Acrylic
- Mirrors

Resistive losses due to more current out of standard cells

Cost of Manufacture

- Complexity
- Manufacturing throughput
- Cost model for design decisions

Conclusions

Interactive optimization essential

- Of materials, components (mirror, cell etc.) and system
- Not just materials and vendor choices by qual. testing and price

LCPV allows conventional materials and components

- And requires close attention to cost-effective technology choices

PV performance focus, can obscure important durability and lifetime choices

- High initial performance with high degradation rate

Essential efforts for reliable, durable, long-lived systems

- Quantitative degradation mechanisms and rates
- Detailed knowledge of system characteristics
- Detailed knowledge of environmental conditions and variability

i.e. a clear understanding of materials, components, and system

CASE SCHOOL
OF ENGINEERING

CASE WESTERN RESERVE
UNIVERSITY

System Designs:

- MAPV - 1.5 to 2 Suns
- LC2PV - 5 to 10 Suns

Solar Mirror based

- Acrylic Substrate
- First or Second Surface Acrylic
- Silver or Aluminum Reflectors

Silicon Cells

- Encapsulation
- Stringing and Tabbing
- Heat Sinking

LCPV Cost Constraints

- Manufacturability
- Durability
- Reliability
- Lifetime