ADVANCED REFLECTIVE FILMS AND PANELS FOR NEXT GENERATION SOLAR COLLECTORS

PROJECT: Next Generation Solar Collectors for CSP

AWARDEE: 3M Company

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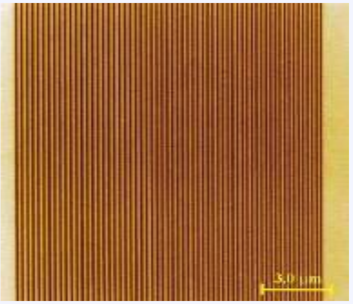
April 22, 2013



cross-section of a multilayer optical film (MOF)

3M Company

Proposed Team: Gossamer Space Frames
Sandia
NREL

Award # DE-EE0005795

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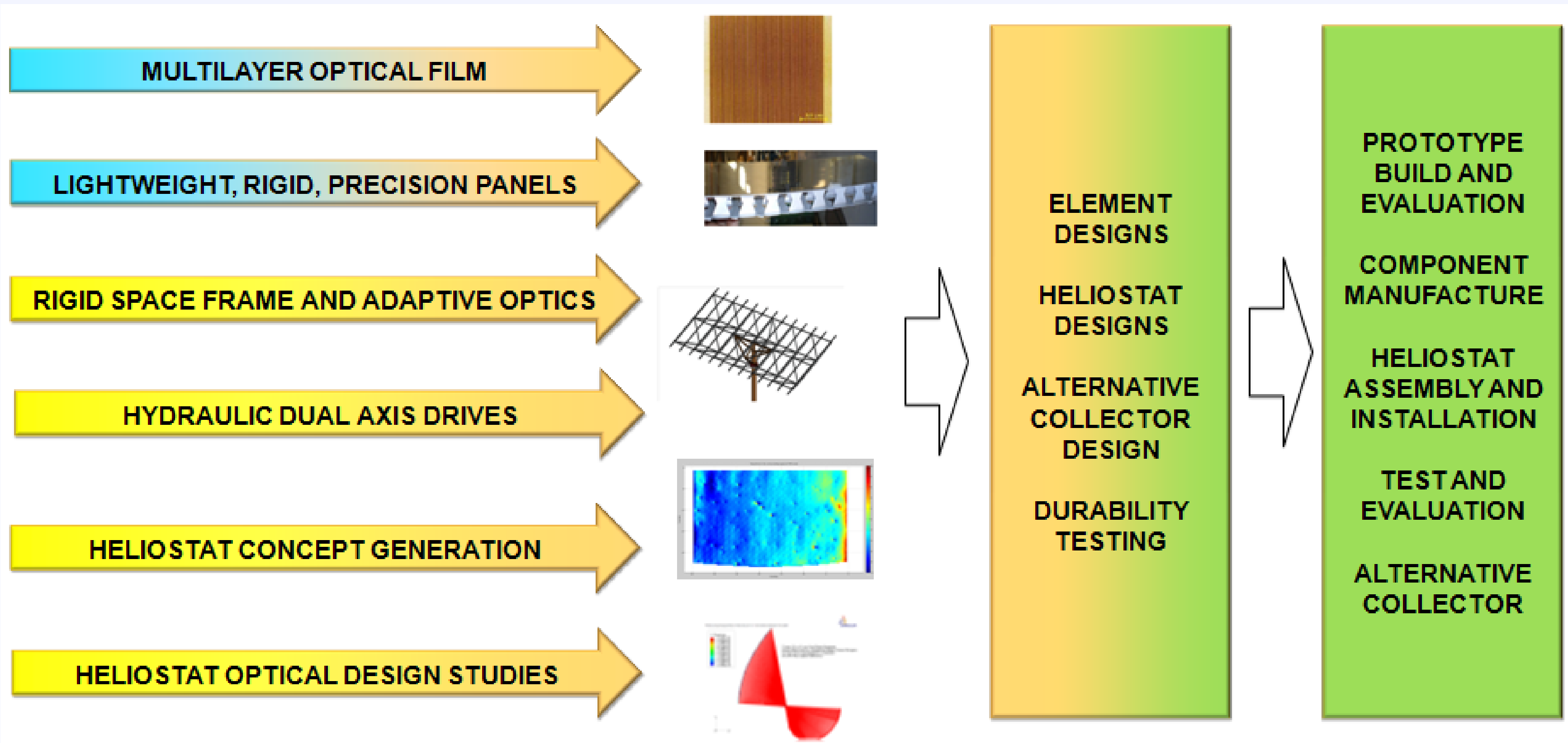
Next Generation Solar Collectors for CSP

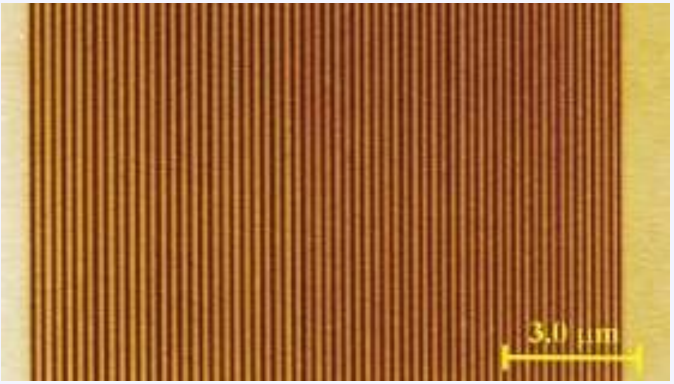
CATEGORY	SPECIFIC TARGETS	PROPOSED SOLUTION
Cost	• <$75/ sqm aperture	• Heliostat designs that reduce number of components and reduce construction costs • Readily manufacturable panel constructions • Reflective film that is scalable at low capital cost
Optical Accuracy	• Total optical error in calm winds ≤ 3.0 mrad • Optical error in windy conditions ≤ 4 mrad	• High fidelity mirror films (98%+ specularity @ 7mrad) • Mirror film based panel –formed at high accuracy (<1.5 mrad RMS slope error) • Adaptive optics (minimizes canting errors) • Space frame based support structure
Operation and survival in wind	• Maximum operational wind speed > 40mph • Maximum survival wind speed > 90mph	• Stiff panel construction • Panel integrated to supporting space frame • Space frame supporting structure • Hydraulic dual-axis drives
Durability	> 30 years	• Aluminum space frames (not subject to corrosion) • Rigid panel and frame bonding • Highly durable polymer based mirror films and hardcoats

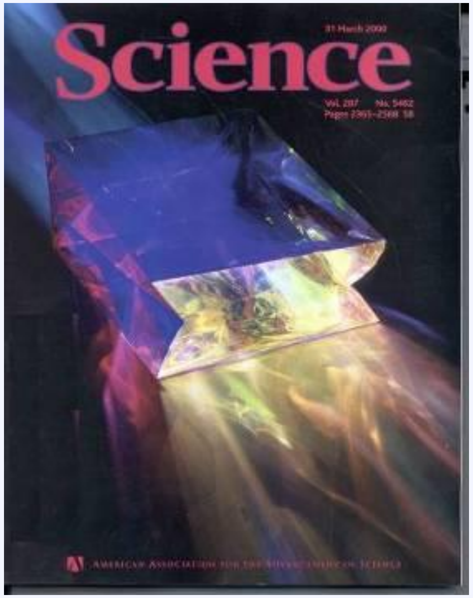
Next Generation Solar Collectors for CSP



ADVANCED REFLECTIVE FILMS: BACKGROUND
Multi-layer Optical Films (MOF)

- Characteristics
  - *100-1000 layers*
  - *15-200 nm thick*
  - *Bi-refringent polymer pairs*
  - *Tunable reflection bands*





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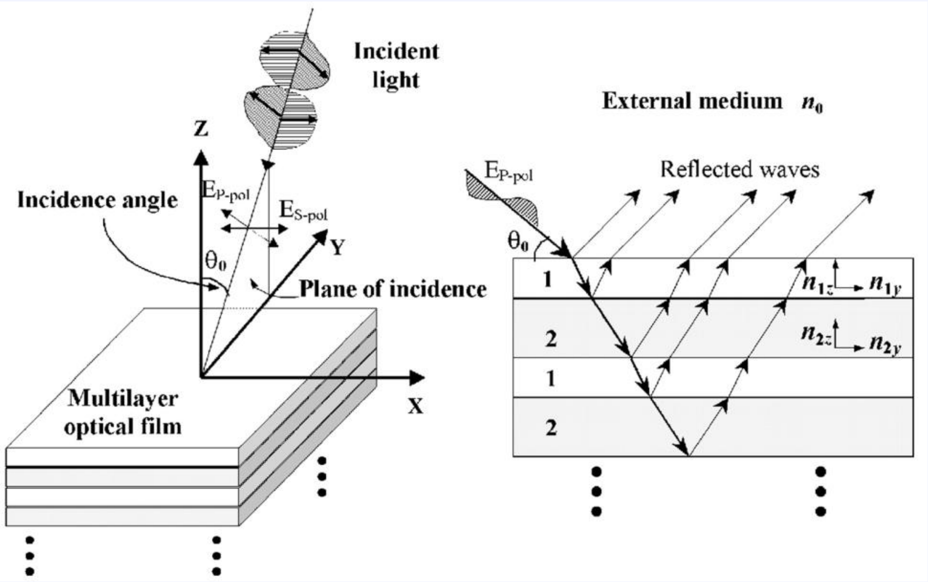
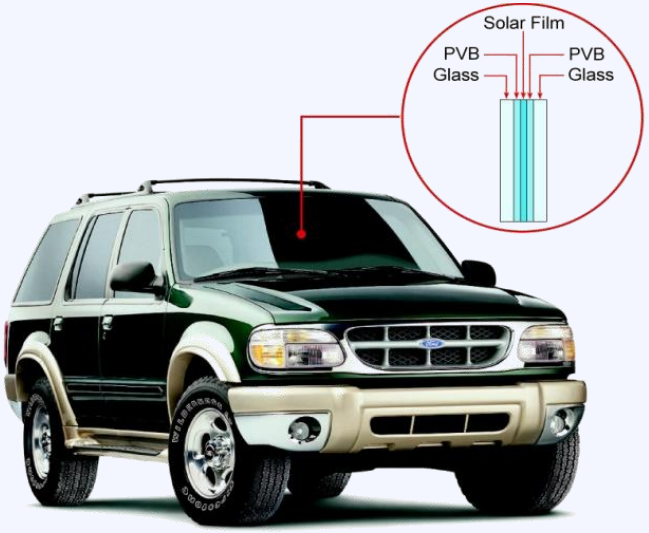


Multilayer Optical Film (MOF): Applications

- Highly reflective mirrors ~98% reflectivity over selected bandwidth
- Tunable reflection bandwidth mirrors
  - UV Mirror (350-400nm)
  - VIS Mirror (400-800nm)
  - Near IR Mirror (800-1600nm)
  - UV/VIS/IR Mirror (350-1600nm)

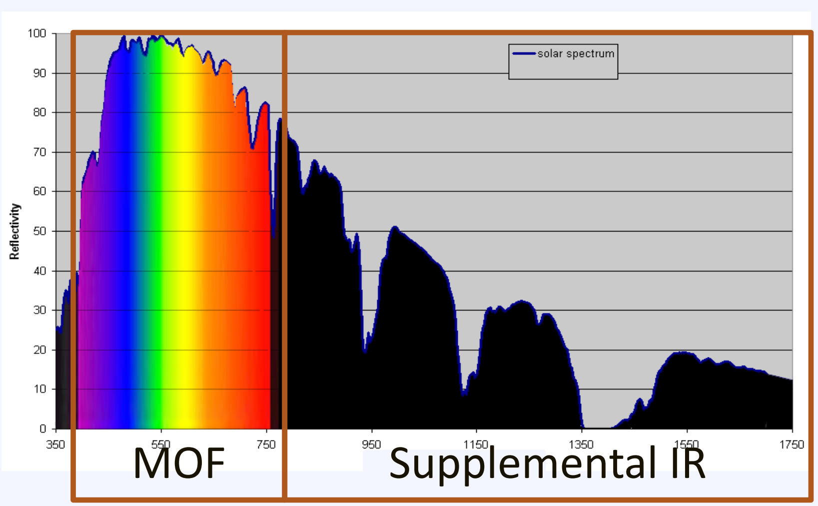


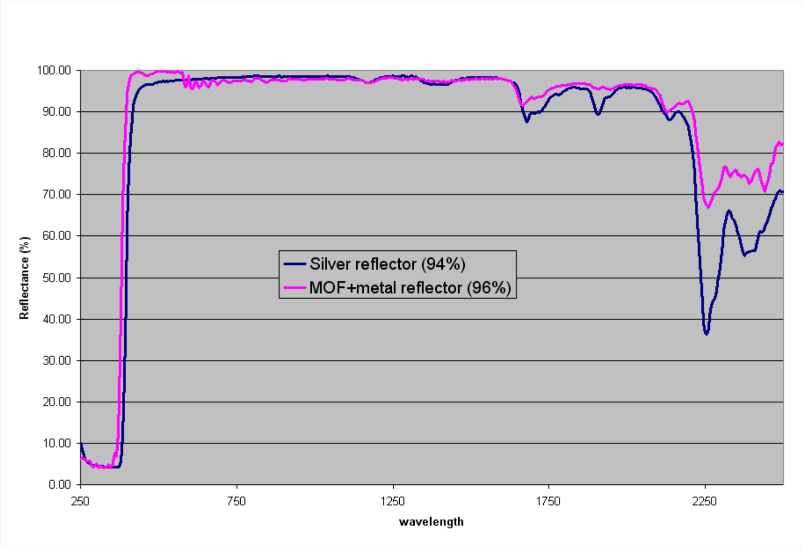
IR blocker for transparent credit cards

ADVANCED REFLECTIVE FILM DEVELOPMENT

APPROACH:

- Use multilayer optical film mirror to reflect over the visible portion of solar spectrum with highest energy
- Supplement IR portion of spectrum with silver
- Resultant mirror has more solar-weighted reflectance than durable silver mirror
- Increase durability through hardcoat and stabilization/protection package

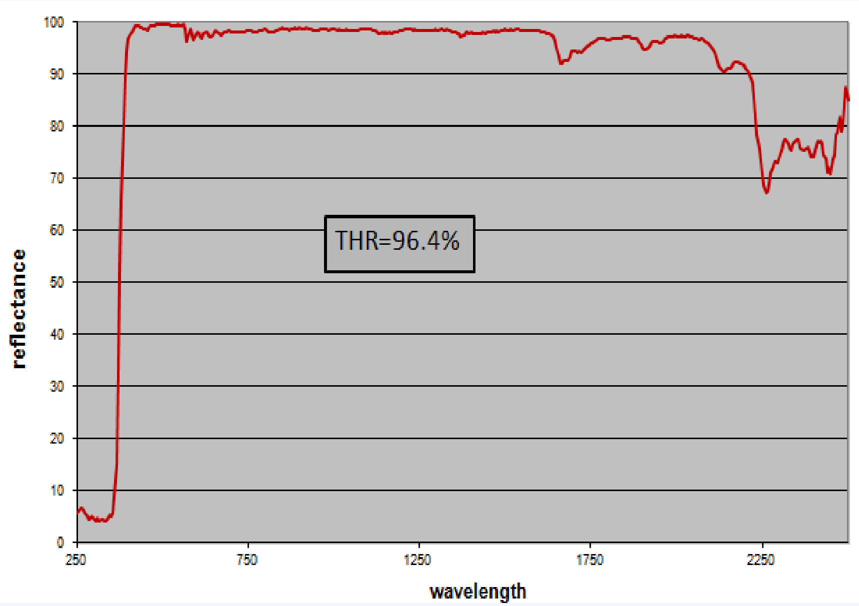


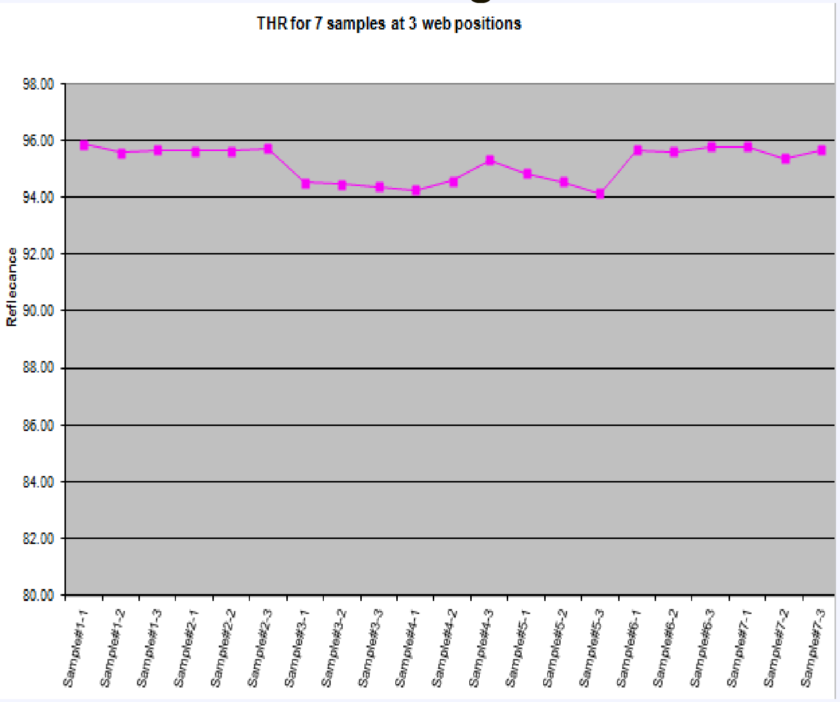


ADVANCED REFLECTIVE FILM DEVELOPMENT

RESULTS (INCREASING REFLECTANCE)

- Lab scale extrusion trial to create samples for durability testing and evaluate material sets
- Metal reflectors have been applied to samples with Total Solar Reflectance 94-96% and specularity routinely 94-96% with some as high as 97-98%

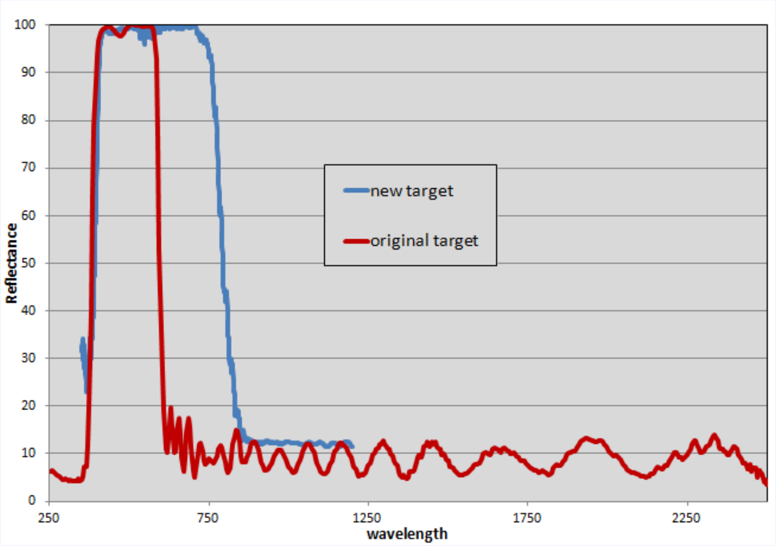




ADVANCED REFLECTIVE FILM DEVELOPMENT

RESULTS (INCREASING REFLECTANCE):

- Lab and pilot scale extrusion trial were run to create samples of MOF mirror with higher reflectance values
- This was achieved through altering process parameters and targets
- A wider bandwidth reflector with high reflectance was produced
- A higher solar weighted hemispherical reflectance is expected when the IR region is supplemented with a metal reflecting layer



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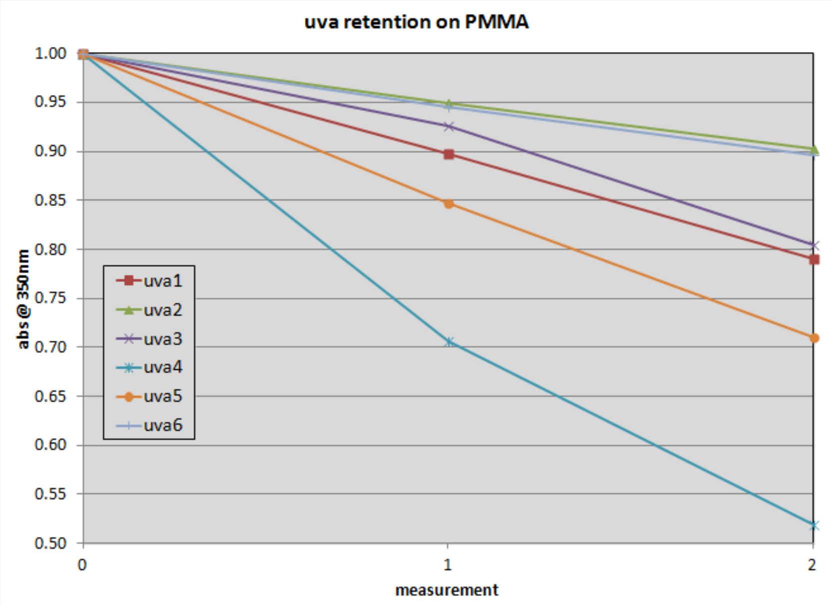
ADVANCED SOLAR REFLECTIVE FILM

RESULTS (DURABILITY)

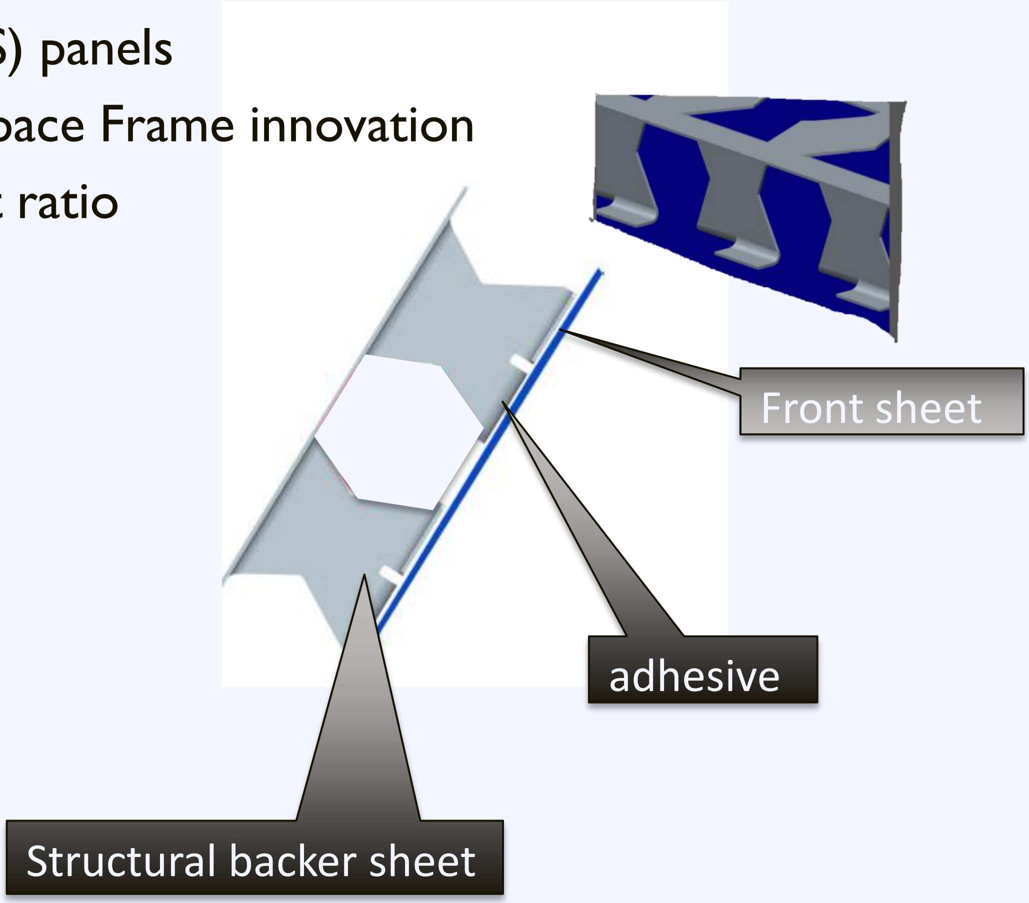
- Lab coating studies have been completed to test different UV protection schemes
- Six UV absorber packages were prepared and coated onto acrylic substrates. These samples are in accelerated weathering chambers to evaluate the retention of optical density of the UV absorber package as it ages
- Additional experiments are planned to combine antioxidant agents with the UV absorber packages for evaluation of retention of optical density



ADVANCED PANEL DEVELOPMENT

APROACH:

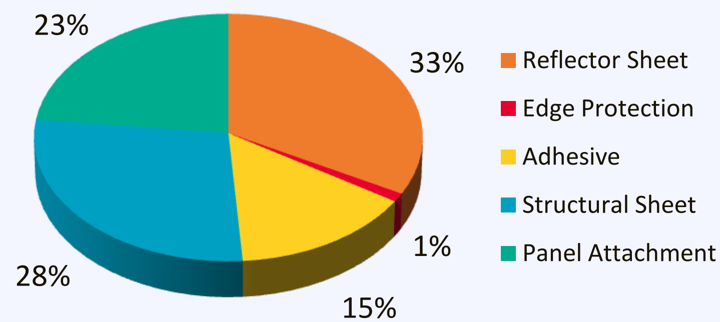
- Mini-truss thin-sheet (MTTS) panels
- The MTTS is a Gossamer Space Frame innovation
- Very high stiffness to weight ratio
- Proven optical accuracy
- Low deflection under load
- Drive cost down :
  - Less/low-cost adhesive
  - Thinner/lower cost metals
- Increase Performance:
  - Increase surface smoothness
  - Minimize distortions



ADVANCED PANELS: COST REDUCTION

Metal Sheet Selection Matrix and Cost Analysis:

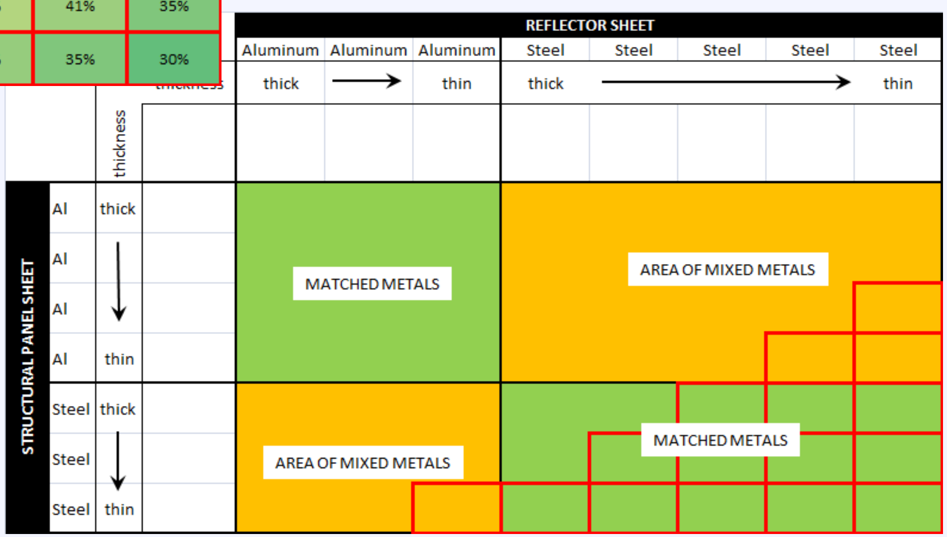
STRUCTURAL PANEL SHEET	thickness	REFLECTOR SHEET: Aluminum	Aluminum	Aluminum	Steel	Steel	Steel	Steel	Steel
		thick	→	thin	thick	→	→	→	thin
Al	thick	100%	89%	81%	81%	77%	75%	70%	65%
Al	↓	89%	78%	70%	70%	66%	64%	60%	54%
Al	↓	81%	70%	63%	63%	59%	56%	52%	46%
Al	thin	78%	67%	59%	59%	55%	53%	49%	43%
Steel	thick	75%	64%	56%	56%	52%	49%	45%	40%
Steel	↓	70%	60%	52%	52%	48%	45%	41%	35%
Steel	thin	65%	54%	46%	46%	42%	40%	35%	30%



Ray Tracing Analysis:

- Mixed Metals Cause Panel Deformation
- Matched Metals Minimize Deformations

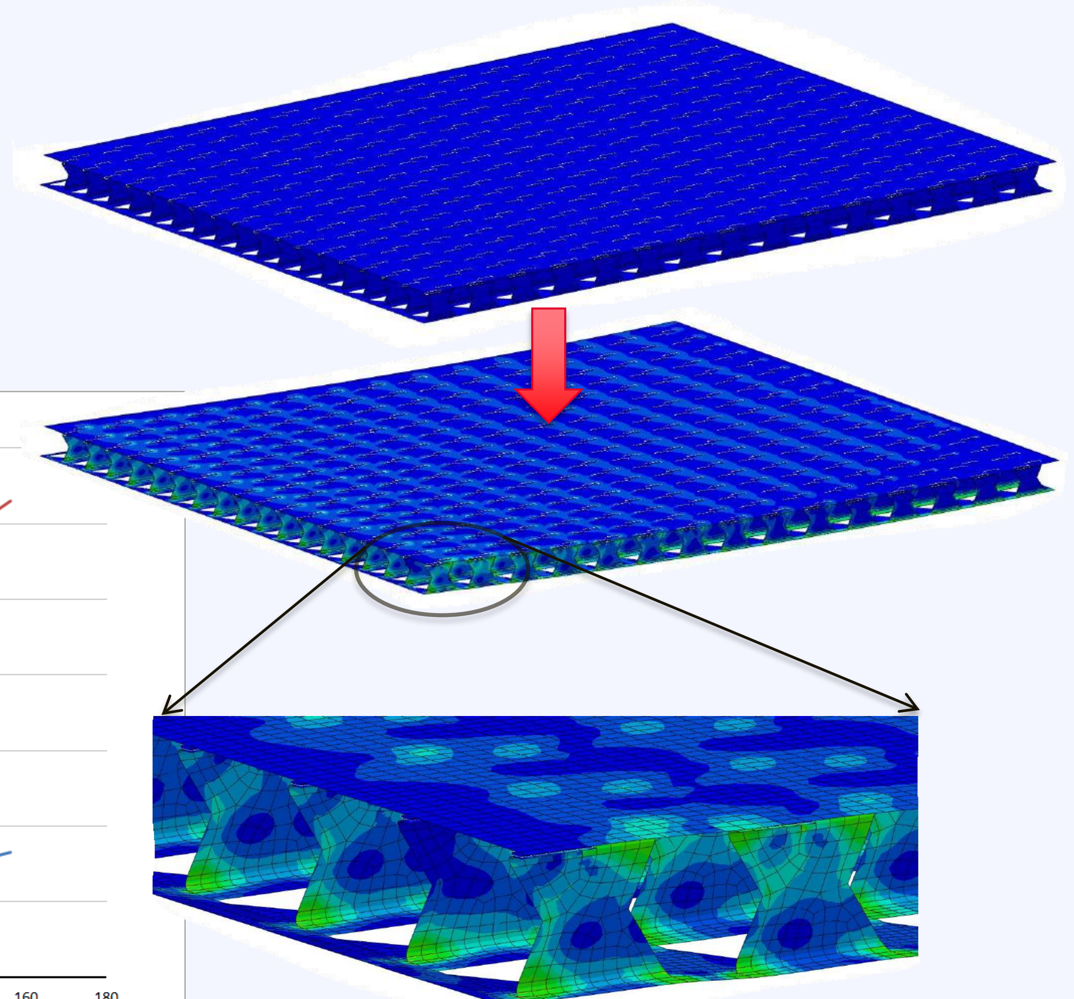
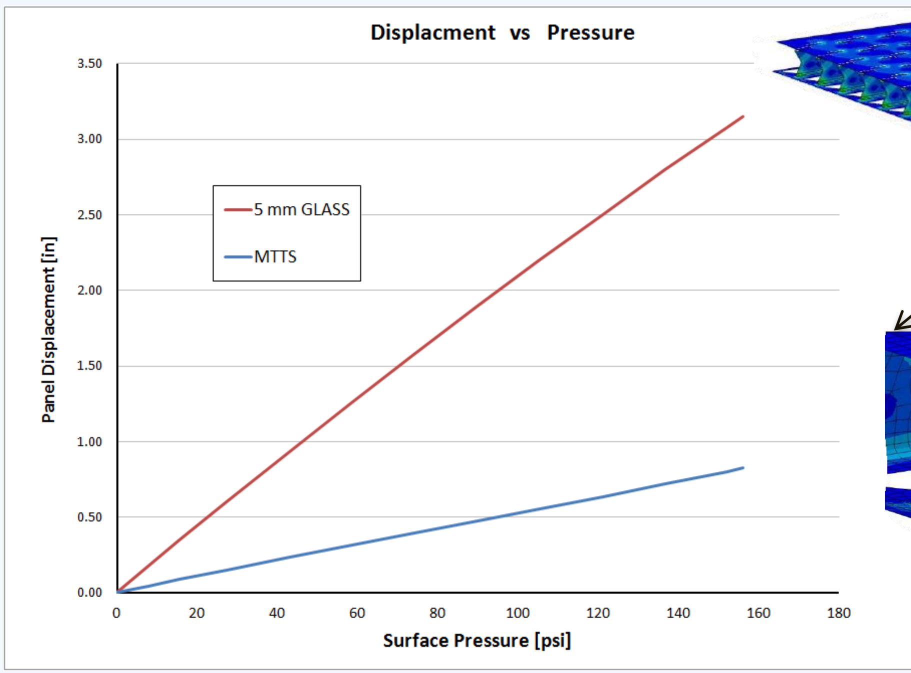
MATCHED METAL SETS ONLY



ADVANCED PANELS: DEFLECTION UNDER LOAD

APROACH:

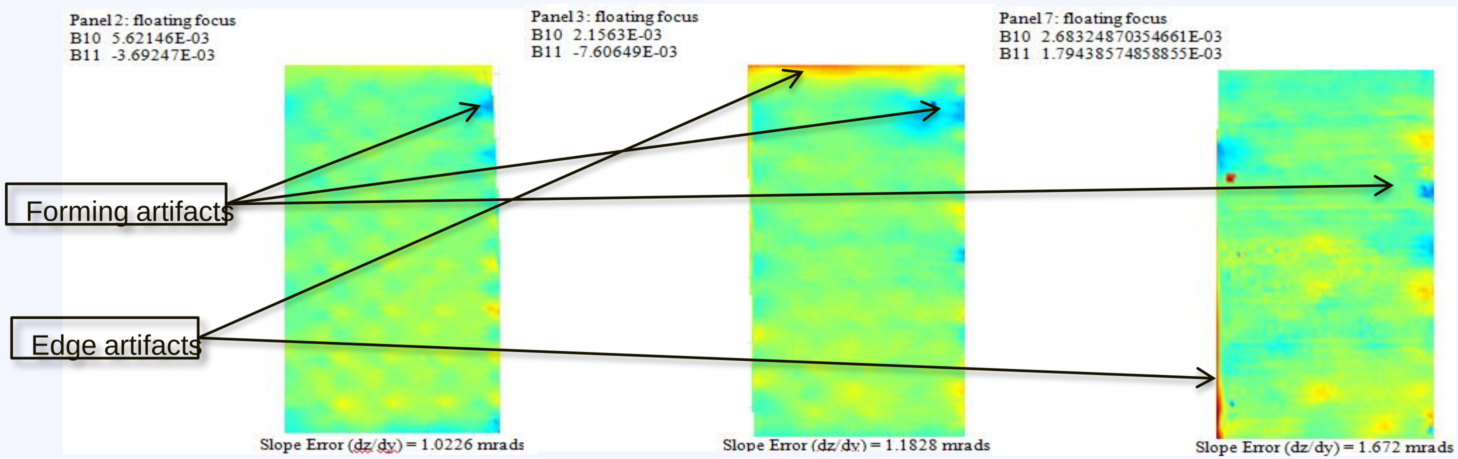
•- CAD modeling
•- Determine sag under weight
•- Vary Support Spacing
•- Determine wind deformation
•- Optimize design

ADVANCED PANELS: SHAPE ACCURACY

- Video Scanning Hartman Optical Tester (VSHOT) at 3M laboratory is being used to test the shape accuracy of formed panels
- Preliminary study indicates adjusting forming variables can produce < 1mrad RMS slope error
- Eliminating edge and forming artifacts can further increase shape accuracy

dz/dy (mrad)	B11 x-alignment	B10 y-alignment	Forming Process	Adhesive ID	Adhesive Application Process
1.06	-1E-02	2E-03	5	A	2
0.95	-4E-03	6E-03	20	A	1
1.13	-8E-03	2E-03	20	A	2
1.43	-2E-02	2E-03	0	A	2
1.26	2E-03	2E-03	0	A	1
1.30	9E-03	-4E-03	5	A	2



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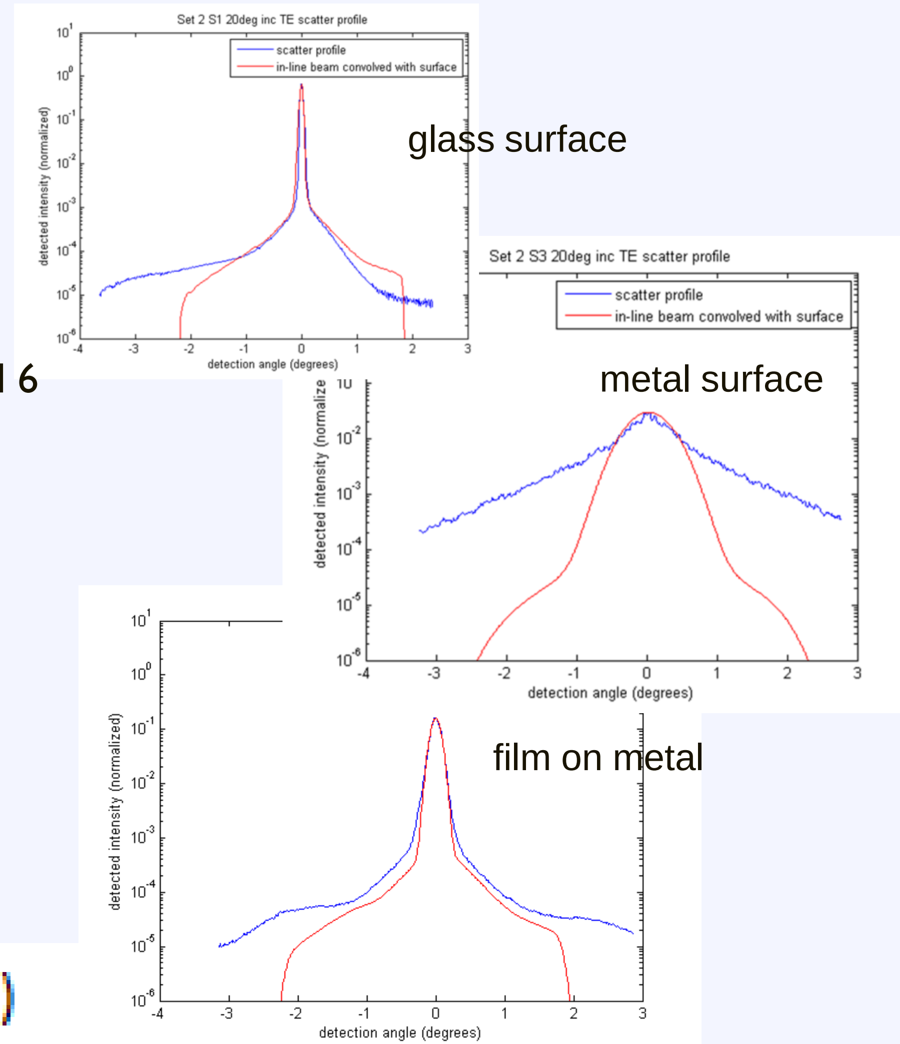
ADVANCED PANELS: SURFACE SMOOTHNESS

- Scatterometry is used to investigate surface roughness effects on beam broadening:
  - Begun characterizing surface roughness and reflected beam broadening through scatterometry
  - Using a 532 nm laser beam of 1 mm and 6 mm diameter
  - Incidence angle of 20 and 40 deg
  - Use vapor deposition to coat surfaces with thin metal layer
  - Beam broadening determined by convolving in-line beam with surface scatter
  - Developing understanding of substrate surface roughness on beam broadening

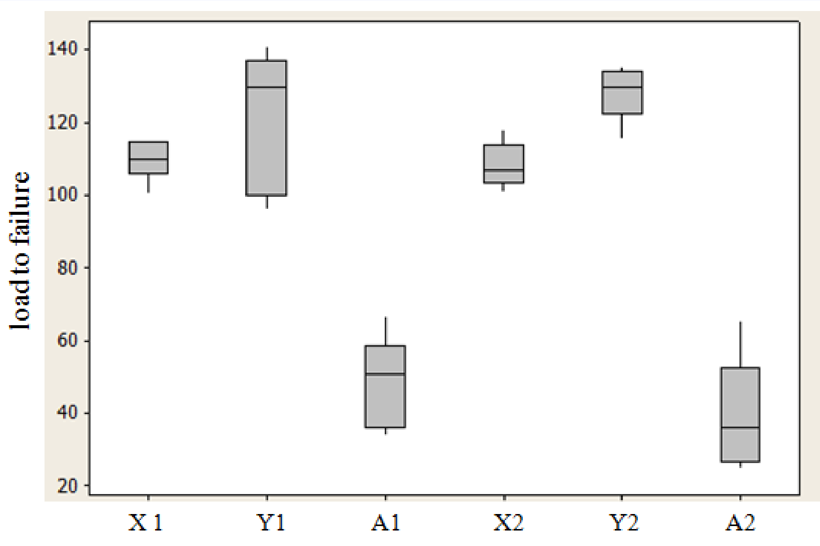


form: exp(-(x^2)/(2*sigma^2))

ADVANCED PANELS: ADHESIVE

APPROACH: COST REDUCTION

- Structural adhesives X & Y under development by 3M
- 30 and 70% cost reduction
- Strength Test Compared to Incumbent Adhesive "A"
- Specific strength test for Panels
- UV exposure (400 hr & continuing)
- Lay-down Profile Study (1 & 2)
- Process Parameters:
  - Mix ratio
  - Set Time
  - Cure Time
  - Viscosity
  - Temperature Increase



- Results so far: all tested properties meet or exceed requirements
- Process parameters are acceptable or better

NEXT STEPS

- Challenges and Barriers:
  - Durability Prediction (Film & Panel)
  - Finding Durable & Smooth Metal coatings for Panels
  - Developing Scalable Panel Assembly Techniques

- Future Work Planned:
  - MOF UV absorber package study
  - Durability Evaluations of MOF
  - Panel Matrix Assembly and Evaluation
  - FEA Computer Modeling of Various Panel Material Sets
  - Optimization of Performance / Cost of Panels