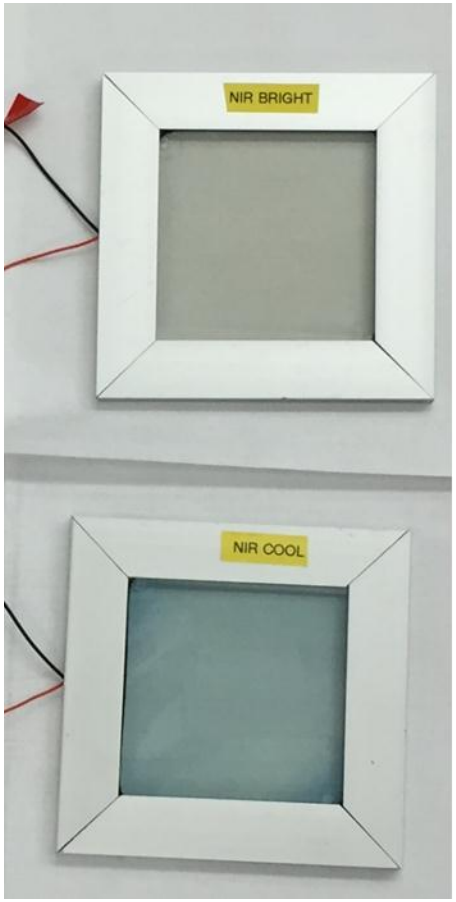
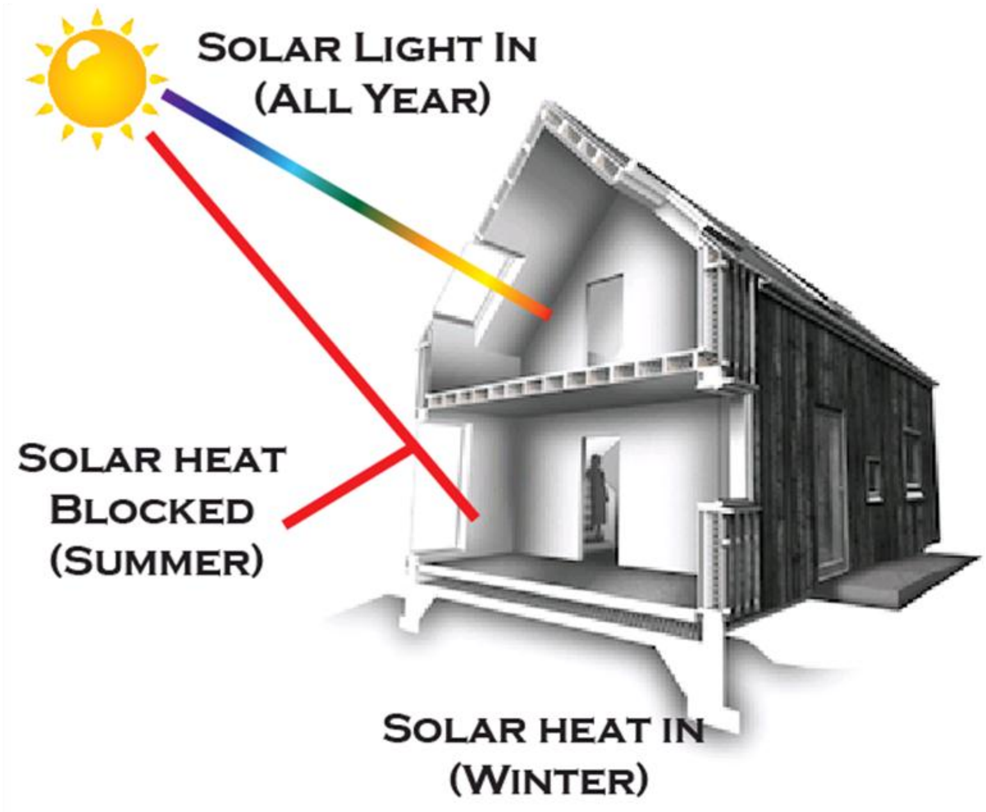
Low Cost Near Infrared Selective Plasmonic Smart Windows

2015 Building Technologies Office Peer Review





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Project Summary

Timeline:

Start date: 5/15/14

Planned end date: 5/15/16

Key Milestones

1. Met device performance milestones by optimizing material composition, **Aug 2014**
2. Established fabrication protocol for transition to commercial scaled samples, **Oct 2014**
3. Validated UV sensitivity, variable temperature operation, and cycle durability for smart pane unit samples, **Dec 2014**

Budget:

Total DOE $ to date: $550k

Total future DOE $: $600k

Target Market/Audience:

Residential and Commercial Skylight and Façade Windows

Key Partners:

BISEM

AGC

THE UNIVERSITY OF TEXAS AT AUSTIN

Project Goal:

- Fabricate 10”x10” NIR selective smart panes using solution processed scaled manufacturing techniques with UT Austin
- Work with AGC Glass to fabricate and model energy performance 8”x8” NIR selective IGUs
- Carry out ASTM standard testing on 8”x8” NIR selective IGUs to validate product durability
- Work with AGC and BISEM USA to investigate the possibility of wireless integration for NIR selective coatings

The Problem For the Built World

- **Buildings have huge energy footprints**
  - 40 Quads/yr = 40% of total US energy consumption[1]
  - 25% HVAC, 25% lighting related[2]
  - Energy is the #1 cost in building operations
- **Window inefficiency is part of the problem**
  - Static performance
  - Solar heat gain → increased HVAC $$
  - Drawn blinds → artificial lighting
- **Owners and occupants want more glass**
  - Higher lease rates and building values
  - Increased comfort and daylighting
  - Trend towards greater window to wall ratios makes problem worse

Sources: [1]US Energy Information Administration, [2]DOE/Navigant 2013
1 Quad = 1 quadrillion BTUs = 10^{15} BTUs

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Industry Solution: Dynamic "Smart" Windows

- **Smart windows have potential to address building energy consumption**
  - Solar heat gain too great – darken the window to block light & heat
  - Glare too great – darken the window
  - Dynamic solution for dynamic conditions
  - Window inefficiency is part of the problem

- **Significant impacts on HVAC OpEx/CapEx[1,2]**
  - >20% energy savings ($60,000/yr, OpEx)
  - >20% peak load reduction ($800k CapEx)

- **Elimination of internal blinds for glare control ($1.3M, CapEx)[1,2]**
- **Improved aesthetics with view preservation**

Electrochromic dynamic window produced by View, installed at W Hotel, San Francisco

Sources: [1]Sage Electrochromics, "Performance Assessment of SageGlass and Electrochromic Coatings and Control Scenarios", 2010; [2]Navigant 2012/2013

The Problem with Current Solutions

- Current market adoption rate is low, less than 0.03% of window market
- Market constrained by either high cost or poor performance
- Currently no inexpensive, high function dynamic window technology

Technology	Price	User control	Dynamic range
Suspended particle devices	$$$	Yes	Med
Thermochromic	$$	No	Low
Electrochromic, Gen I	$$$	Yes	High


Sage Electrochromic window, Chabot College, Hayward, CA

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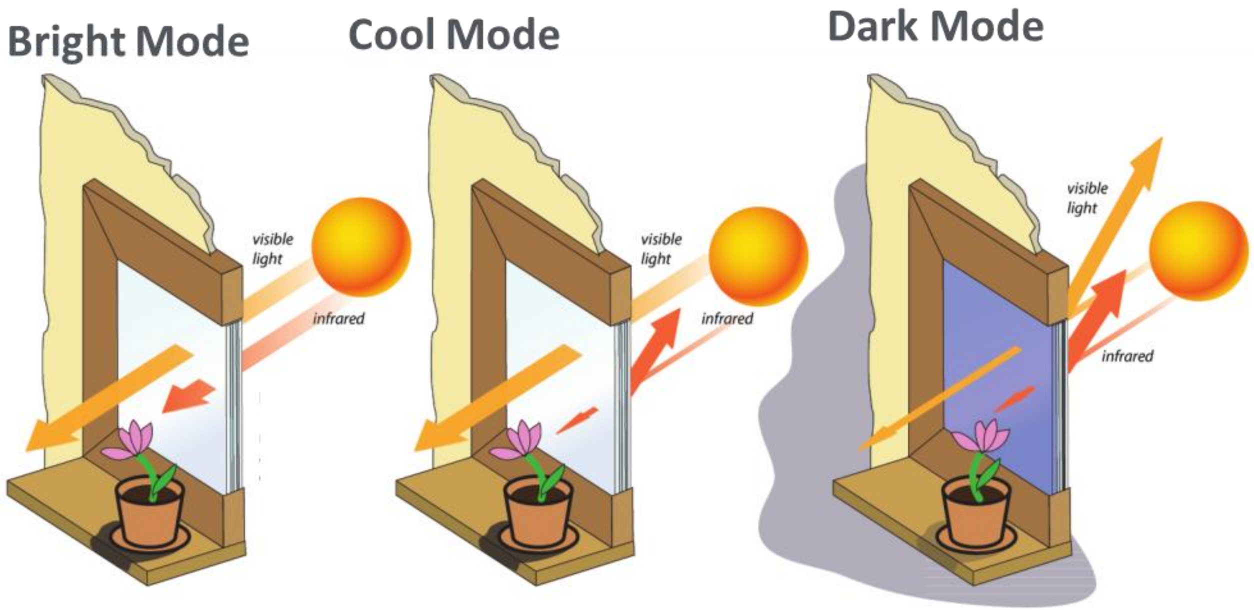
Heliotrope: Generation II Dynamic Windows

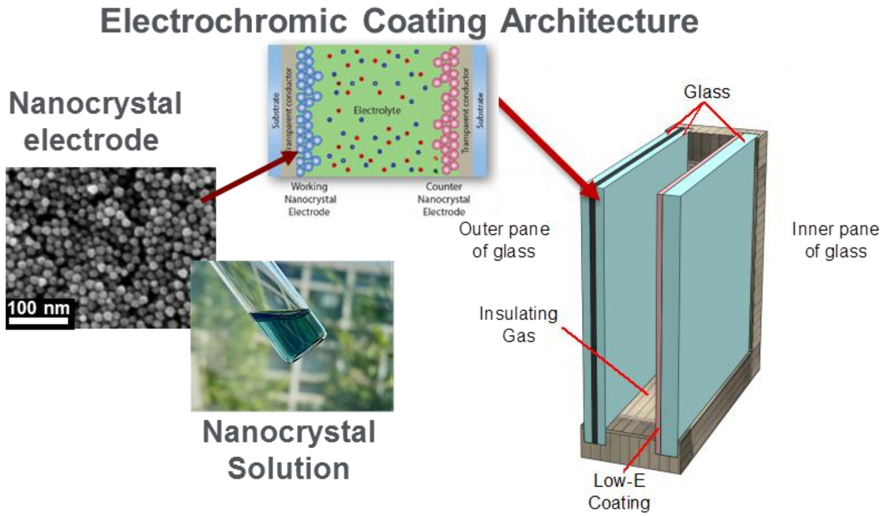
Objective: Develop a low cost dynamic window with improved solar control

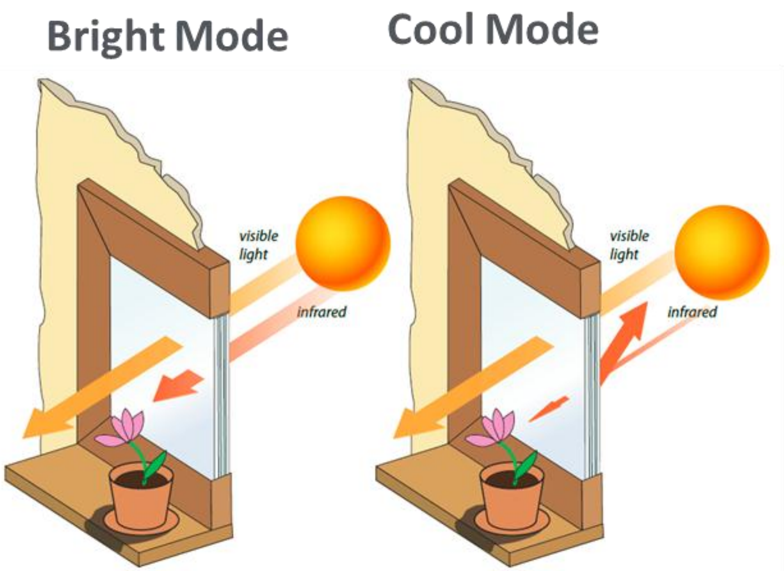
- Heliotrope introduces a new 2nd generation of smart windows
- Control of heat (NIR) and light = HVAC + lighting savings, no tradeoff
- Two novel products
  - **“NIR-only” (Bright/Cool) – development funded by DOE BTO Phase 2 & private funds**
  - “Dual-band” (Bright/Cool/Dark) – development funded by ARPA-E & private funds



Solution Processed NIR Selective Plasmonic Windows

- **Gen I electrochromics intrinsically high CapEx, OpEx**
  - Vacuum, sputter deposition process
  - Similar to “static window” fabrication, but many more steps
- **Heliotrope’s solution process is lower in capital and operating expense**
  - All film precursors can be made into inks
  - Flexibility in choice of deposition method – spray, slot-die and curtain coating





DOE Phase 2 Proposed Workplan Overview

Technology Summary/Approach

- Fabricate 10”x10” NIR selective smart panes using solution processed scaled manufacturing techniques with UT Austin
- Work with AGC Glass to fabricate and model energy performance 8”x8” NIR selective IGUs
- Carry out ASTM standard testing on 8”x8” NIR selective IGUs to validate product durability
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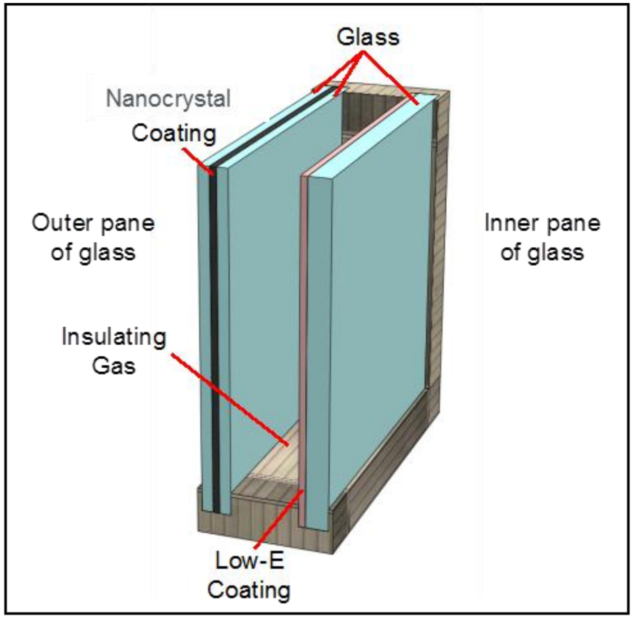

Proposed Performance Targets

Metric	Proposed
NIR Solar Modulation Range	>60%
Visible Solar Modulation Range	<10%
Switching Time	<5 min
Durability (ASTM)	50,000 Cycles

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Phase 2: Year One Workplan

Technical Task

- Fabricate 8”x8” NIR selective smart panes using solution processed scaled manufacturing techniques
- Improve performance by investigating new material composition and controlled porosity with UT Austin
- Work with AGC Glass to fabricate and model energy performance 8”x8” NIR selective IGUs

Partners/ Sub-Awardees

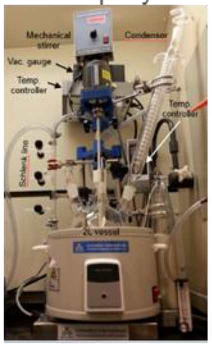
THE UNIVERSITY OF TEXAS AT AUSTIN

Scale Up Equipment

Installed slot-die coater

Installed spray coater

Installed autoclave



Installed Scale Reactor

Scale Up IGU Fabrication

Nanocrystal

Phase 2: Year Two Workplan

Technical Task

•Carry out ASTM standard testing on 8”x8” NIR selective IGUs to validate product durability

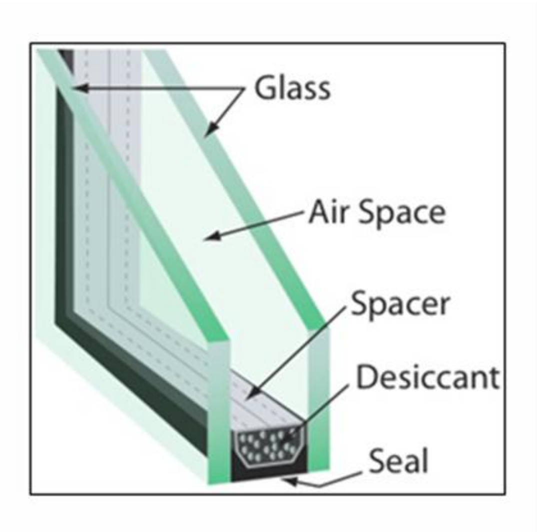
•Work with AGC and BISEM USA to investigate the possibility of wireless integration for NIR selective coatings

Partners/ Sub-Awardees

BISEM

AGC

Durability Testing



Wireless Framing/Integration

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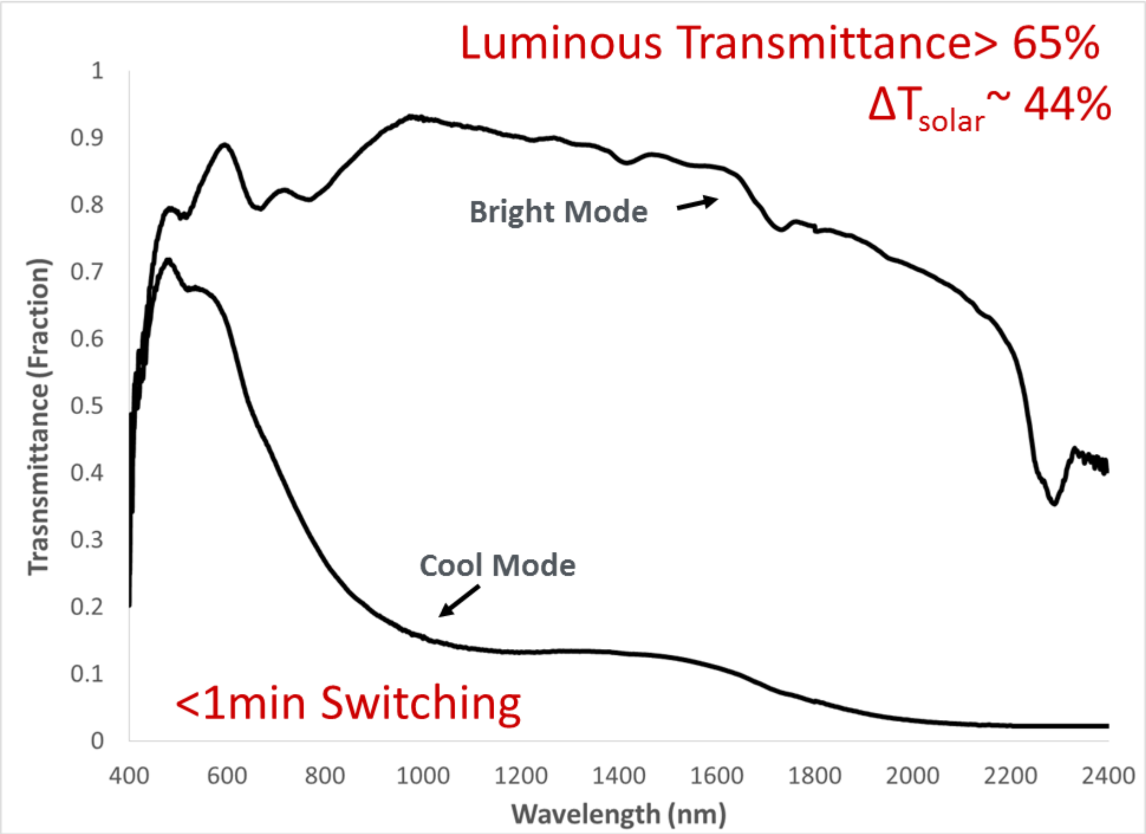
NIR Selective Smart Pane Performance Improvement

Fabricated 4”x4” solid state NIR selective smart panes that meet our Phase 2 goals of >60% NIR modulation, <10% visible modulation, <5min switching time



NOTE: Index matched TCO’s were used to increase bright state transmittance

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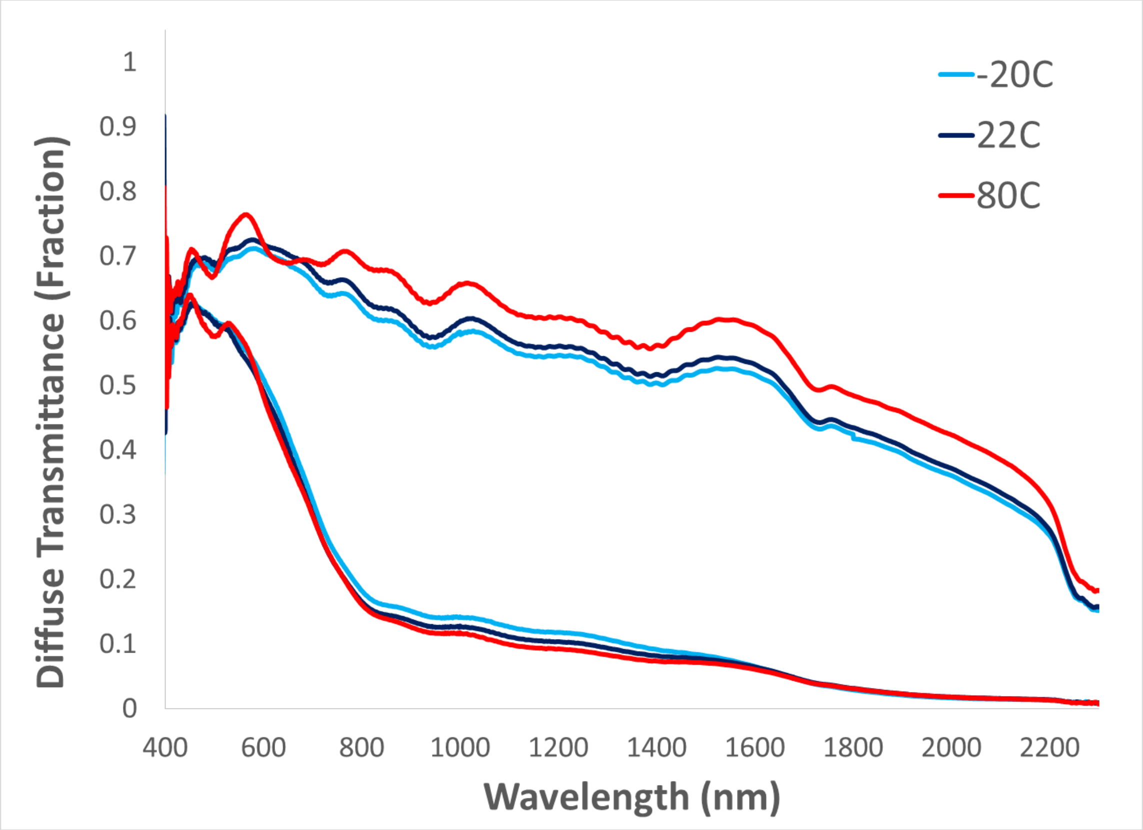
Fabricate Flush NIR Selective Smart Panes With Improved Seals and Busbars for Durability Testing

Developed fabrication protocol that includes scalable device charging approach, electrolyte fill method, perimeter busbar application, improved seal application, and flush design for commercial production

4”x4” Prototype Format

Temperature Modulation Using Flush NIR Selective Smart Panes With Improved Seals and Busbar

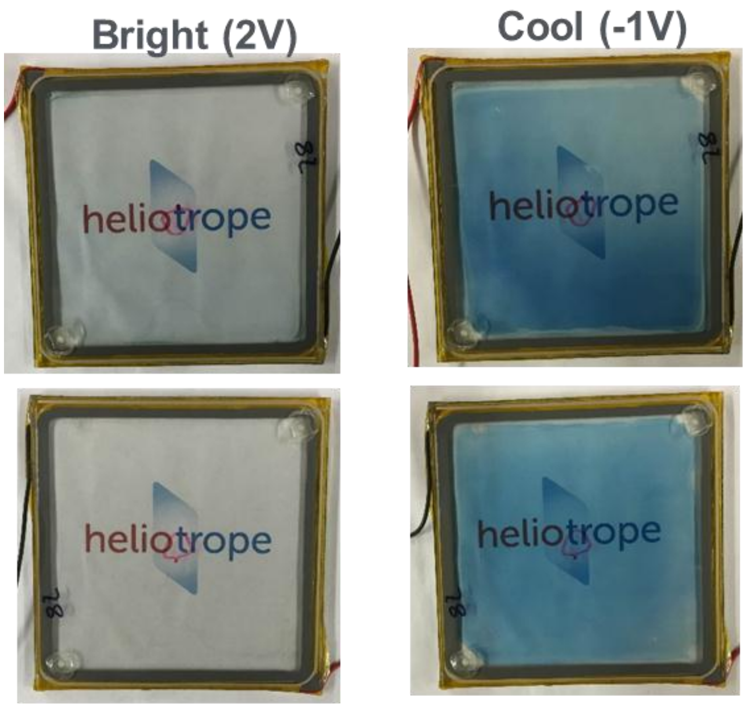
Prototype devices were functional at temperature extremes above ASTM Standards. Samples showed a slight decrease of speed at cold temperatures and slight increase at high temperatures.

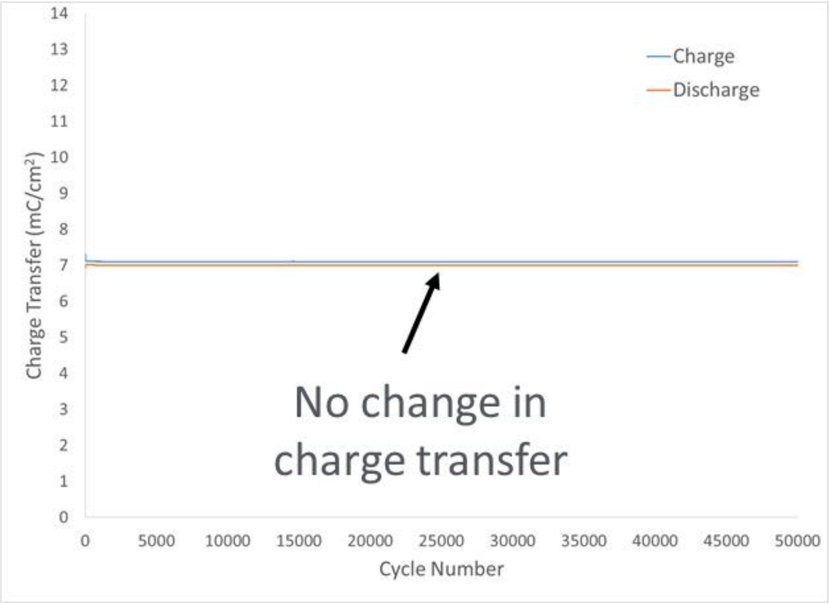


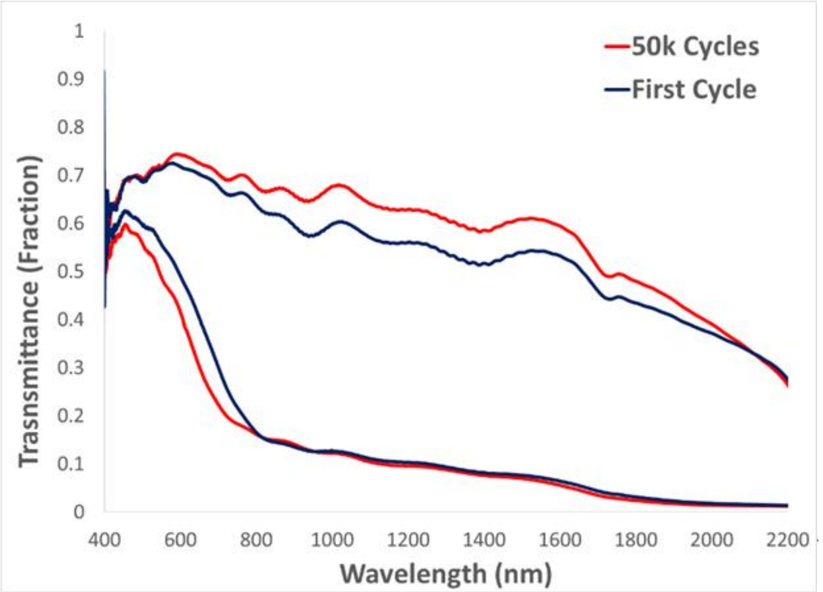
NOTE: Slight reduction in bright state operation due to change in TCO substrate. Index matching will be used in commercial product

ASTM 2141 Room Temperature Durability Cycle Testing Using Flush NIR Selective Smart Panes With Improved Seals and Busbar

Prototype devices show 50,000 stable cycles at room temperature



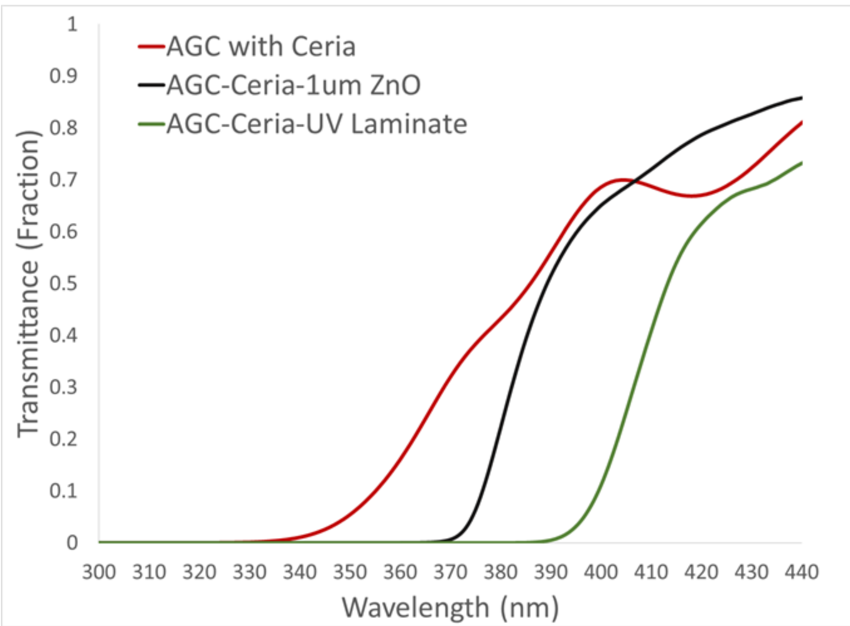




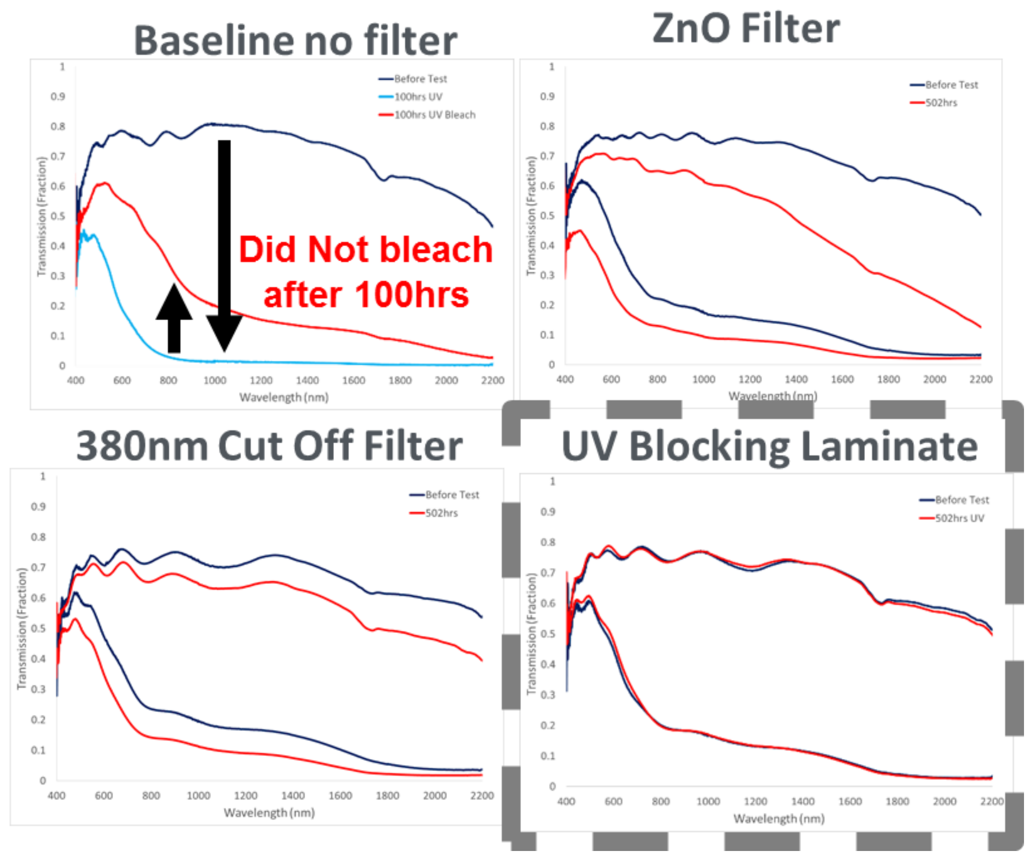
UV Durability Assessment on NIR Selective Smart Panes

Determined UV light sensitivity of NIR selective smart panes by illuminating samples at 3 sun intensity with a range of UV filters

UV Light Filters



Modulation Before and After 500 Light Illuminating Hours



- Baseline No Filter (AGC-Ceria Only)
- ZnO Filter (1um)
- 380nm Cut off Filter (**Not Shown**)
- UV Blocking Exterior Laminate

Only UV laminate Passed Test. Sensitivity up to 390nm

Heliotrope Company and Partner Updates

Heliotrope Company Updates

- Added Scott Thompsen, former president of Guardian Global Flat Glass Unit, as chairman of our board of directors
- Have closed three rounds of financing and currently closing our A round for initial pilot line development
- Have filed new provisional patents for UV durability and device charging under this Phase 2 SBIR grant

Partner Updates

- AGC and Bisem have both confirmed their interest in participating in IGU development and wireless control under this project
- Hold monthly meetings to coordinate progress with all partners

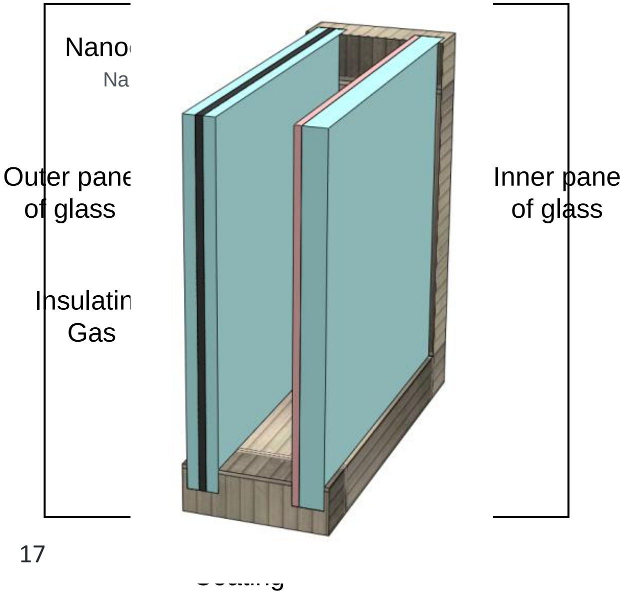
Prototype Scale Up to 8”x8” in Preparation for IGU Fabrication and ASTM Durability Testing

Scale Up Equipment

Installed slot-die coater

Installed blade coater

Scale Up IGU Fabrication



- Will transition into 8”x8” protoyptes using a slot and blade coater respectively for ASTM testing this quarter
- Will fabricate first IGU configurations with our smart panes based on WINDOWS modeling results this quarter. Initial candidates include Cardinal x89 low-E panes
- Will implement UV-blocking layers into IGU configuration and begin durability testing final quarter
- Will initiate ASTM durability testing using scaled 8”x8” prototype devices final quarter

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REFERENCE SLIDES

Project Budget

Project Budget: $1.15M (including $150k Phase 1 project)
Variances: Allocated travel budget for this year to labor hours.
Cost to Date: $550k
Additional Funding: $2.8M in private equity funding

Budget History					
5/15/14– FY2014 (past)		FY2015 (current)		FY2016 – Insert End Date (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$288k	$0	$72k	$0	$640k	$0

Project Plan and Schedule

As seen on the table, these are the milestones we have hit and expect to hit through the extent of the project. We have been on schedule and plan to continue on schedule to achieve all milestones in the chart below.

Project Schedule													
Project Start: 5/14/15		Completed Work											
Projected End: 5/14/16		Active Task (in progress work)											
		Milestone/Deliverable (Originally Planned) use for missed milestones											
		Milestone/Deliverable (Actual) use when met on time											
	FY2014-2015				FY2015-2106				FY2016-2017				
Task	Q1 (May-July)	Q2 (Aug-Oct)	Q3 (Nov-Jan)	Q4 (Feb-April)	Q1 (May-July)	Q2 (Aug-Oct)	Q3 (Nov-Jan)	Q4 (Feb-April)	Q1 (May-July)	Q2 (Aug-Oct)	Q3 (Nov-Jan)	Q4 (Feb-April)	
Past Work													
Improve NIR SPU Performance													
Scale Up Material Synthesis													
Finalize SPU Fabrication Protocol													
Validate UV, Thermal, and Cycling Sensitivity													
Make 8"x8" Larger Scale Prototype													
Current/Future Work													
Create 8"x8" IGU Window													
Initiate 8"x8" Durability testing													
Demonstrate 8"x8" Wireless Window Operation													