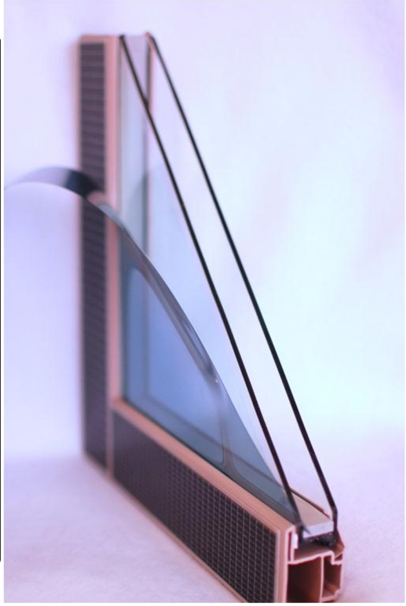
Low-Cost, Highly Transparent Flexible low-e Coating Film to Enable Electrochromic Windows with Increased Energy Savings

2014 Building Technologies Office Peer Review

ITN's Retrofit, Low-e Film Optimized for Compatibility with EC

ITN's Flex EC

- **Low-Cost**
  - Low-Temp, Roll-to-Roll Manufacturing on PET
  - Integrated Process Controls for High Yield
- **Low Power Consumption**
  - No Power to Hold State
    - Leakage Current 100x Lower than Competition
- **New and Retrofit Applications**



ITN's Low-E Film

- **High IR Reflectivity (>90%)**
  - Independent Control of Solar IR and Thermal IR
  - Active or Passive Control of Solar IR to be Guided by Energy Savings Models
- **High Visible Transmission (>90%)**
  - Doesn't Limit Appearance, SHGC Modulation of EC
- **Low-Cost**
  - High Rate PE-CVD at Low Temperatures
    - Energy Optimized PECVD = Dense, Optical Grade Films
    - Engineered Materials as Needed
- **Direct Deposition on FlexEC or Independent Film**
  - Location TBD by Energy Savings Models

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Project Summary

Timeline:

Start date: October 1, 2013

Planned end date: September 30, 2014

Key Milestones

1. Low-e Film: 90% T,vis & R,ir (100 cm^2) (Q2)
2. Low-e Film: 90% T,vis & R,ir (2m long, %T,%R variation < 2% cross web) (Q3)
3. Demonstrate Low-e/EC Film (Q3)

Budget:

Total DOE $ to date: $217,706

Total future DOE $: $531,973

Target Market/Audience:

Window Films, including retrofit markets

Key Partners:

Electric Power Research Institute (EPRI)
Colorado School of Mines (CSM)
Stanford Linear Accelerator (SLAC)
Lawrence Berkeley National Laboratory (LBNL)

Project Goal:

This objective of this award is to develop a retrofitable low-e film with high visible transmission. The novel low-e film will be optimized for compatibility with an electrochromic (EC) film, but could potentially be employed independently, to reduce energy lost through windows.

Purpose and Objectives

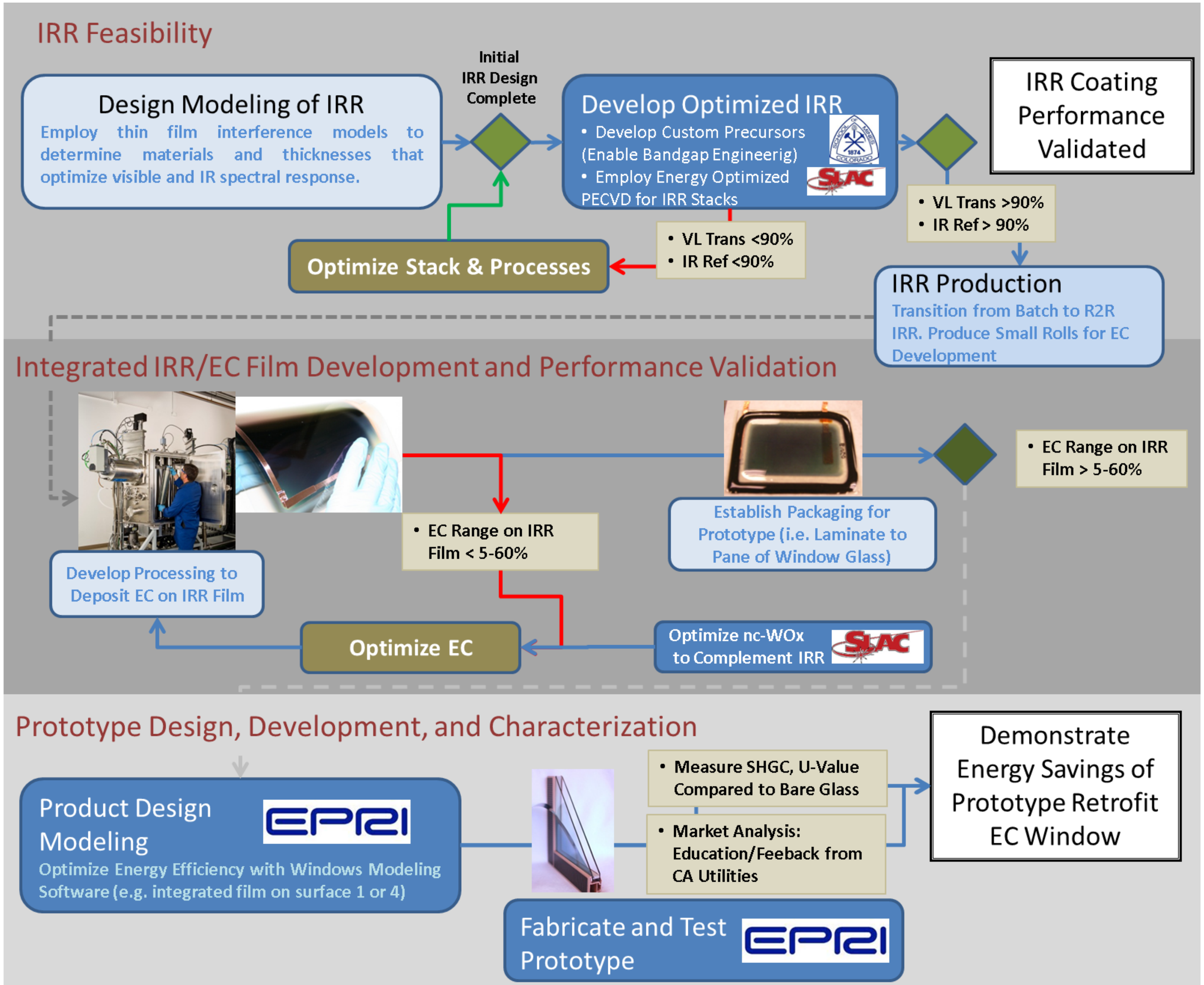
Problem Statement: Windows energy savings are maximized if a low-e coating is used in conjunction with EC. However, available low-e films have a low visible transmission (<70%) that limits compatibility/energy savings for use with EC.

Target Market and Audience: 5 Quads are lost annually through windows in the U.S. This project specifically aims to develop energy savings window films with the potential to address retrofit markets (100,000,000 existing homes)

Impact of Project: EC and Low-e Film Markets are Highly Cost Driven. ITN Strategy for Roll-to-Roll Coatings on PET Enable Low-Cost and Retrofit Markets.

1. Project output: Prototype window films, low-e and integrated low-e/EC will be made and characterized . Energy savings potential will be compared to base case for a variety of building types and climate zones
2. Heat flux through the prototype window films, laminated to glass will be measured at EPRI. Combined with Energy Savings Models.
    a. Near-term: BTO Prioritization Tool Inputs, EPRI Survey of Utilities, etc.
    b. Intermediate and Long-term: EPRI follow up with Utilities, ITN Strategic Partnerships to Accelerate to Market

Approach: Program Flow



Approach: Model Based Design

Key Issues: Work with EPRI/LBNL to Evaluate Best Energy Saving Designs

Visible

Solar IR (Up to 2500 nm)

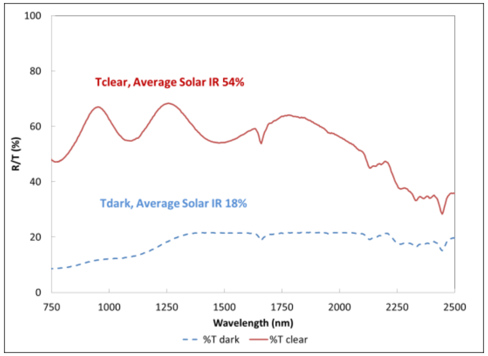
Thermal IR (>2500 nm)

Active Control

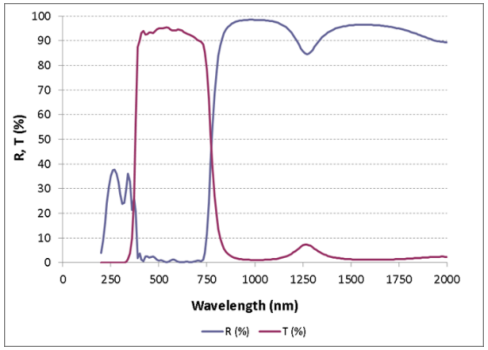
SHGC Modulation with EC Film

Active Control

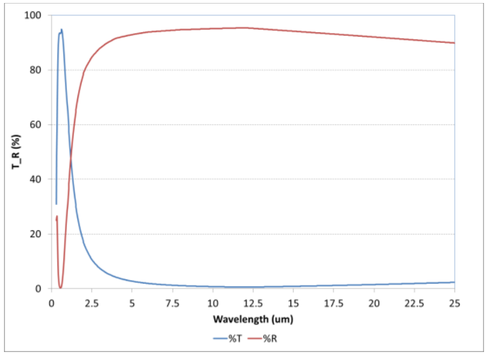
SHGC Modulation with EC Film



Or Passive Low-e



Passive Low-e



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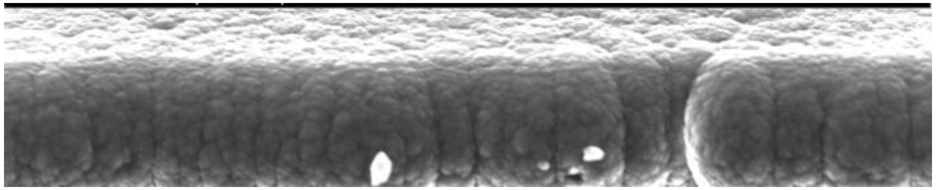
Approach: High Rate PECVD

Distinctive Characteristics: ITN Has a Unique, High Rate PECVD Process that Controls the Plasma Energy to Enable Optical Quality Coatings to be Deposited on Low Temperature Polymeric Substrates (PET).

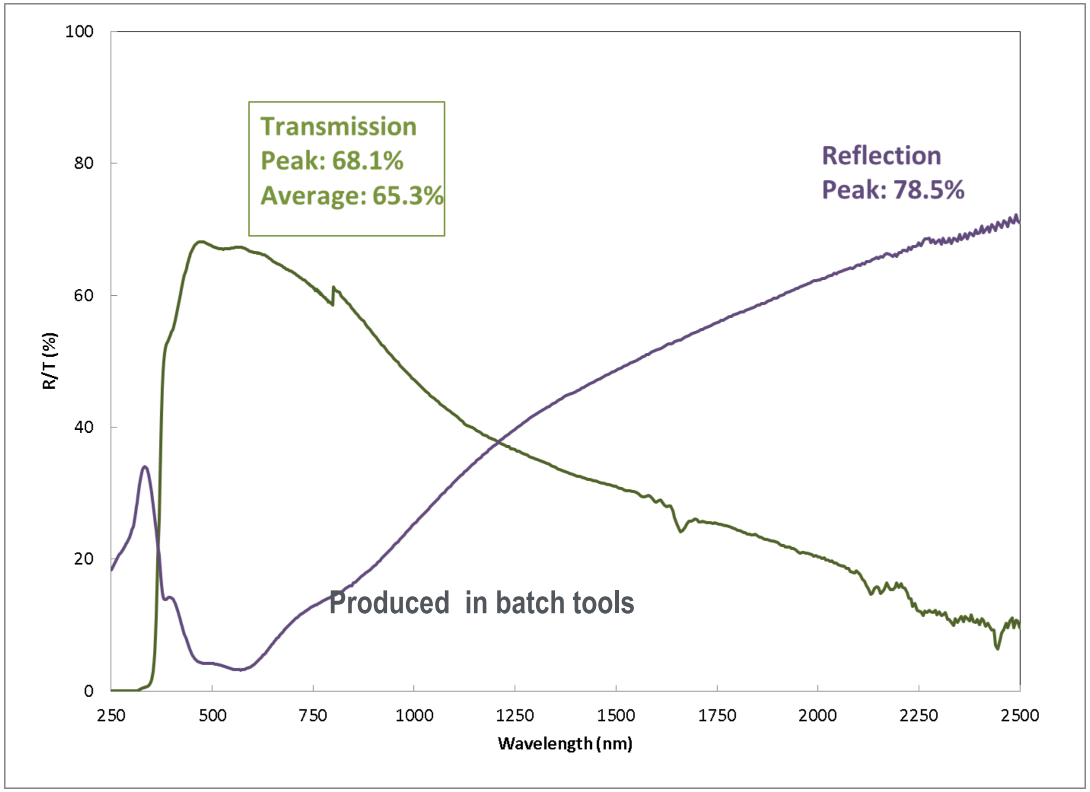
- ❑ Controlled Ion Energy Limits Defect Formation During Film Growth
- ❑ Higher Plasma Density Supports High Growth Rates
- ❑ Plasma Energy Improves Film Quality at Lower Temperature (PET)



Typical PECVD Voided Structure—Poor Optical Quality

ITN PECVD Dense Structure—High Optical Quality

Progress and Accomplishments: Low-e Film #1



Low-e stack #1: Designed for High Visible Transmission, High Thermal IR Reflection

- Low Tvis due to poor interface between 1st and 2nd layer, further optimization possible

Reflection will be higher (~90%) in thermal IR (>2500 nm) due to materials, measurement System in Development for Longer Wavelengths

- Comparable to Existing Commercial Low E Products

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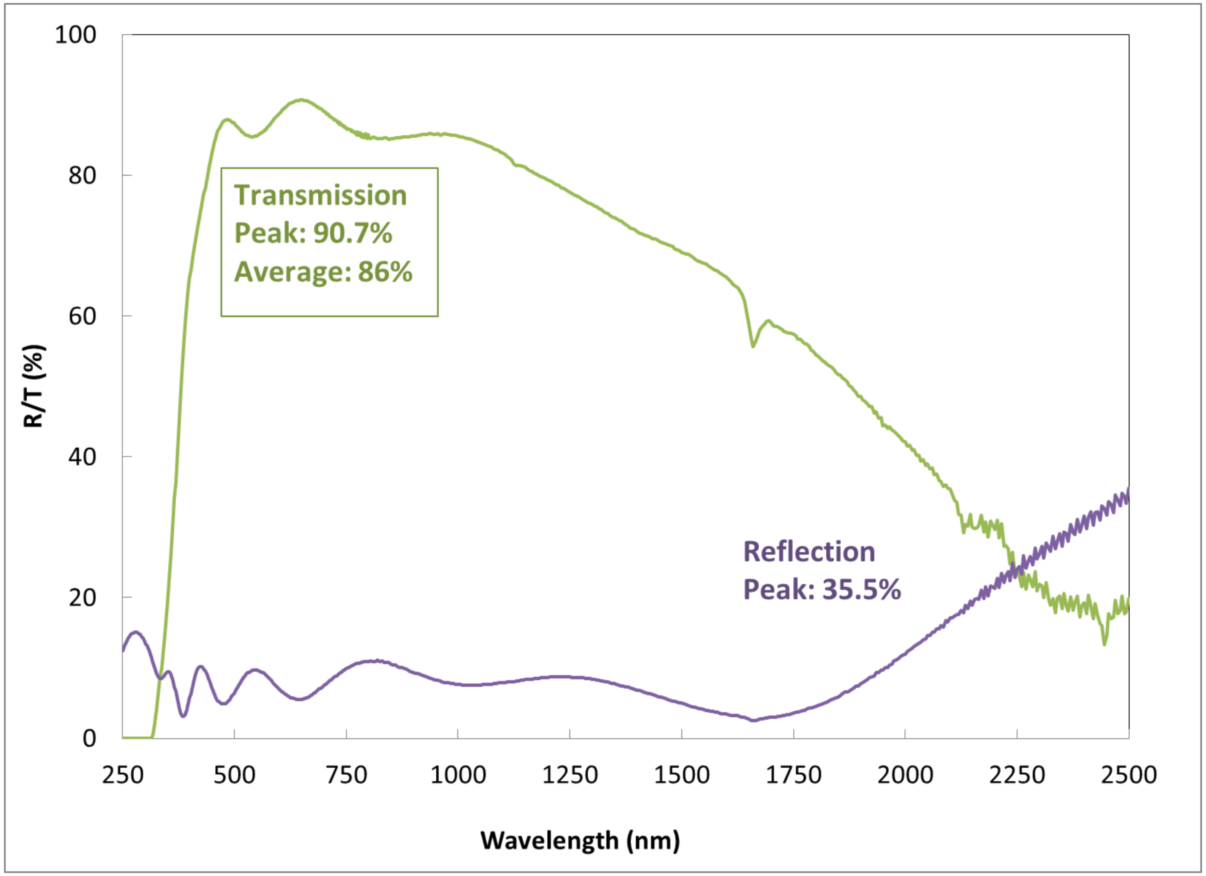
Progress and Accomplishments: Low-e Film#2

Produced R2R, 0.5m wide web



Low-e stack #2: Designed for High Visible Transmission, High Thermal IR Reflection

Reflection will be higher (~80%) in thermal IR (>2500 nm) due to materials, measurement System in Development for Longer Wavelengths

Note: Similar stack with Tvis average = 88.2%, RirPeak 30% (should be higher in long wave IR)

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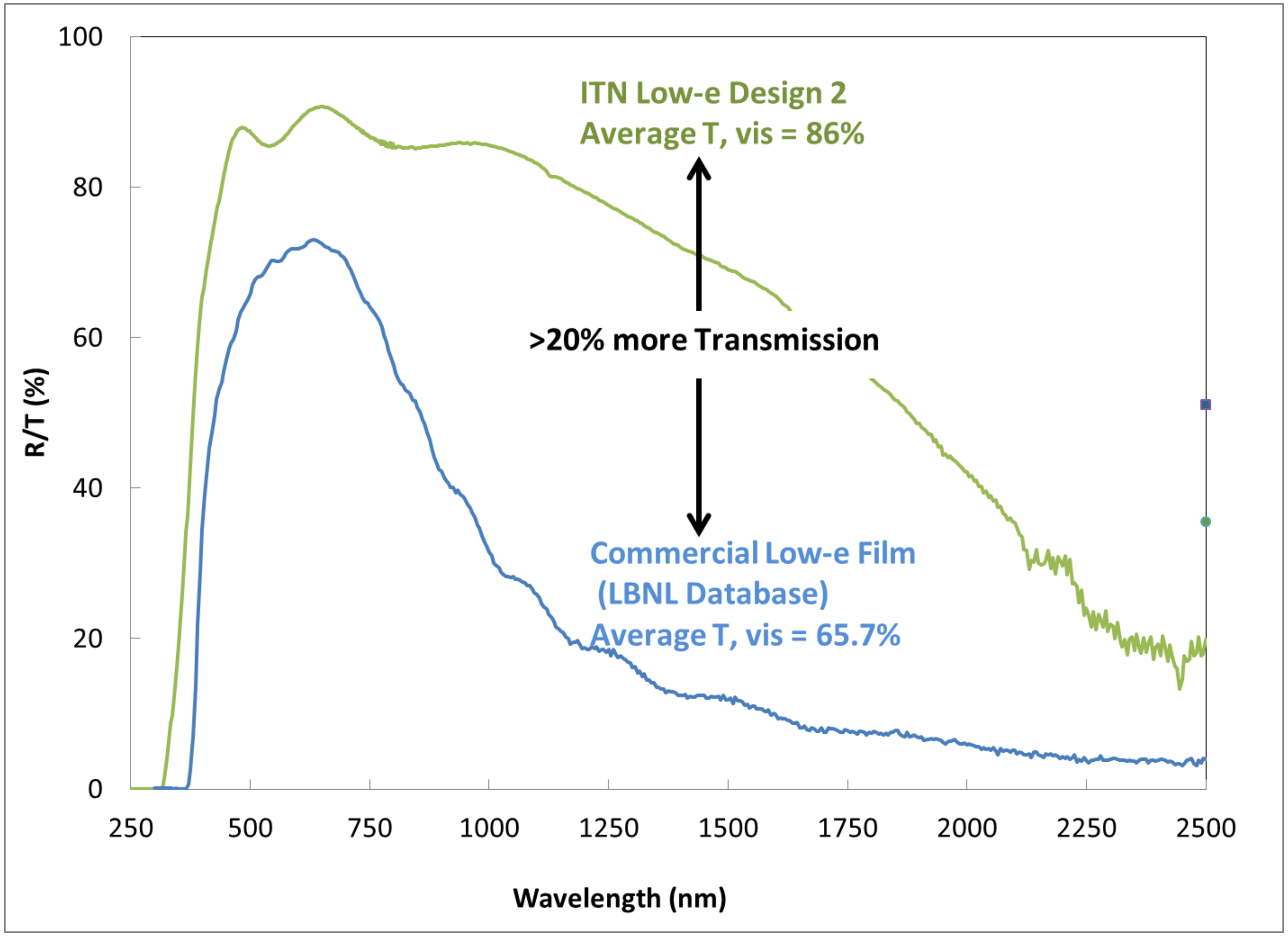
Progress and Accomplishments: Low-e #2 vs Commercial Film



ITN Low-e Design #2 Does Have Lower IR Reflectance at 2,500 nm

- ITN Film Projected to Have Higher Reflection >5 microns
- Modeling Shows High IR Reflection Can be Achieved, Evan at 2500 nm, with Additional Optimization
  - Engineered Materials Development In Progress

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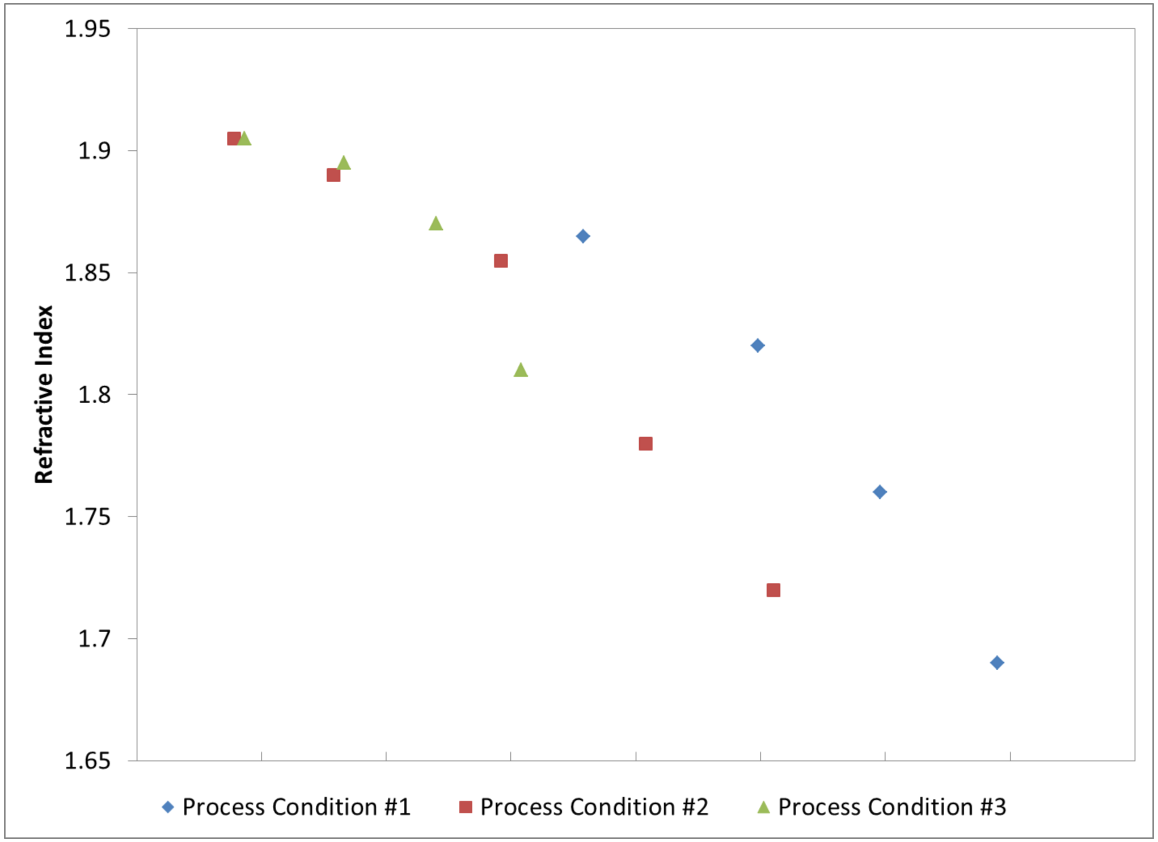
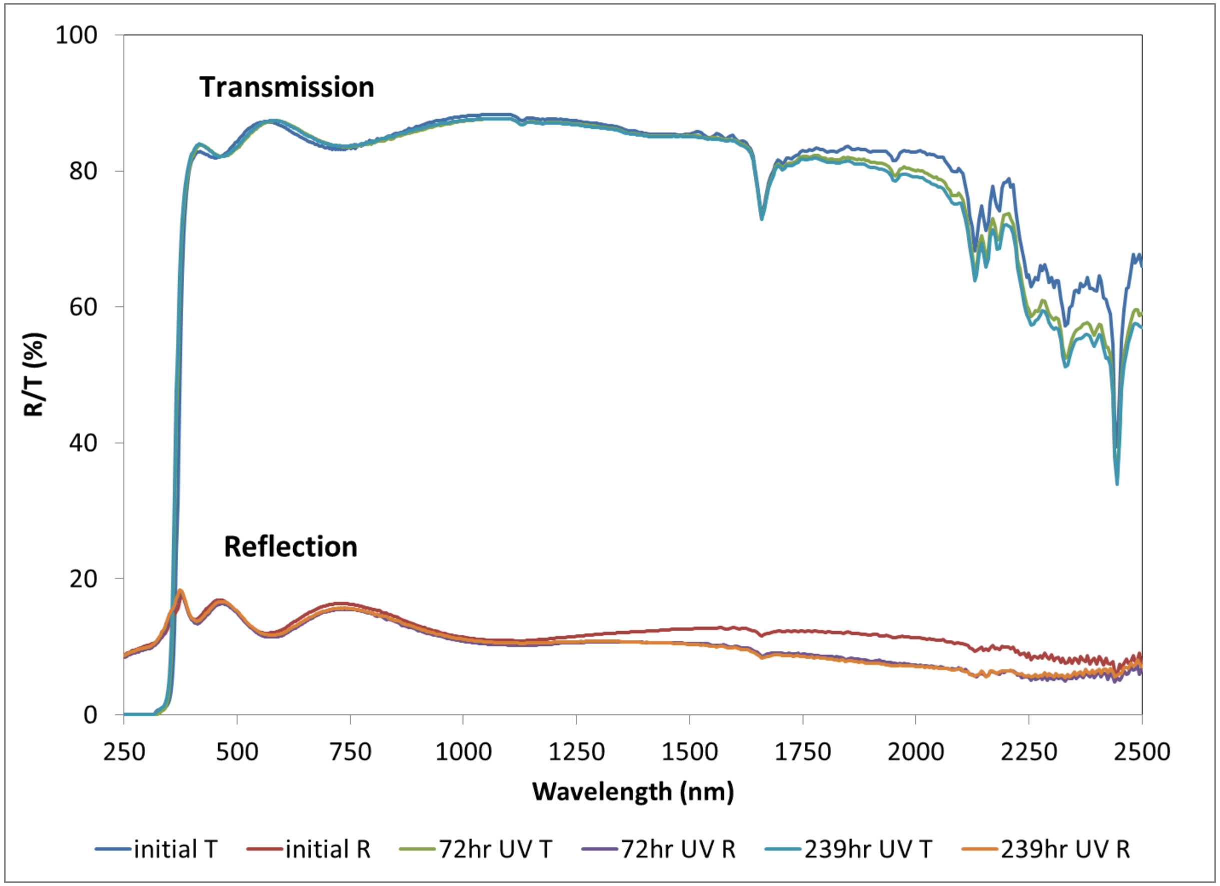
Progress and Accomplishments: Engineered Materials



ITN is working with Colorado School of Mines to Develop Custom Engineered Materials for Greater Flexibility in Low-e Design

ITN's PECVD Energy Higher So More Film Chemistries Possible

Progress and Accomplishments: Low-e Film Durability



Individual PECVD Coating Stable in SunLight

UV Rich, AM1.5 Light Source

Small PET Degradation in IR, UV Stabilized Film Not Used

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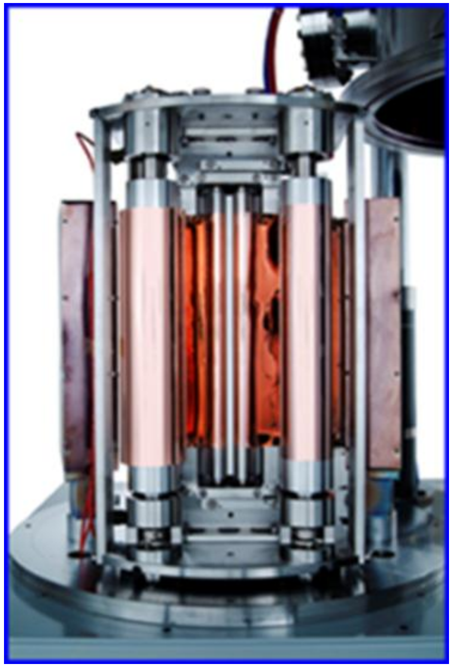
Progress and Accomplishments: Roll-to-Roll, High Rate PECVD



- ❑ Roll-to-Roll High Rate PECVD Tool Commissioned (Q2)
  - ➢ Plasma Ignited, Reflected Power Minimized
- ❑ 12" Web Width Capable
- ❑ Up to 4 Precursor Chemistries (Supports Engineered Materials)
- ❑ Sputtering Sources Also Available

Progress and Accomplishments: Prototypes, X-ray, Modeling

- Initial Low-e and EC Films Laminated to Glass Sent to EPRI
  - Measurement Protocols to be Validated
- Initial EC Layer Samples Sent to SLAC for X-ray Measurements
  - Additional Beam Time Reserved for Q3
  - Initial Focus on Low-e Film Density as this will Impact Durability, Potential Environmental Barrier Performance
- Modeling Strategy Established with EPRI/LBNL
  - Key Questions to be Addressed:
    - Should Solar IR be Actively or Passively Controlled
    - Film Complexity vs film IR reflectance (emissivity) and spectral selectivity to achieve maximum energy savings
    - What is the Relative Performance of the Film on Various Window Surfaces, i.e. 1 vs 4

Project Integration and Collaboration

Team Member	*Roles, Strengths*
ITN Energy Systems (ITN)	• IRR Modeling • Design and Build Energy Optimized PECVD Chamber • Establish Roll-to-Roll IRR Film Process • nc-WOx Development • Fabricate and Test Integrated IRR/EC Films • Prototype Development
Electric Power Research Institute (EPRI), LBNL	• Integrated Window Film Performance Modeling • Prototype Window Testing • Energy Savings Projections • Market Impact Study
SLAC	• IRR Film Density and Porosity Measurements • WOx Film Characterization to Optimize EC Response in IR
Colorado School of Mines (CSM)	• Establish Feasibility of IRR Film in Batch Reactor • Bandgap Engineered Materials Development as Necessary

Next Steps and Future Plans

- Transition Low-E Coatings to High Rate PECVD Chamber
- Further Optimize Low-e Performance
  - Include Engineered Materials As Needed
- Deposit EC Films on Low-E Substrates
  - Introduce Modifications to EC Layer As Needed to Improve IR Modulation Range
  - Guided by SLAC X-Ray Measurements
- Prototype Fabrication and Characterization
  - Heat Conduction Through Glass with SHGC, etc. Measured and Input into Models to Project Energy Savings Across Buildings and Climate Zones

REFERENCE SLIDES

Project Budget

Project Budget: DOE Funds:$749,679 Cost Share (ITN +EPRI): $220,986
Variances: No significant variations. Subcontractor activity ramps in 2nd half of program. ITN will likely contribute extra cost share to add functionality to the PECVD Tool.
Cost to Date: 29% of Federal Funds Expended.
Additional Funding: None.

Budget History					
FY2013 (past)		October 1, 2013- September 30,2014 (current)		FY2015	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
NA	NA	217,706	217,830	NA	NA

Project Plan and Schedule

Project Schedule						
Project Start: October 1, 2013			■ (blue)	Completed Work		
Project End: September 30, 2014			■ (dark)	Active Work		
			◆ (red)	Milestone/Deliverable		
			◆	Milestone Deliverable		
			FY 2014			
#	Type	Description	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-jun)	Q4 (Jul-Sept)
1	T	Establish Feasibility of Novel Low-e Coating on Polymeric Substrates	■	■	■	
1	M	Complete Initial Low-e Design Review that Identifies Materials and Layer Thicknesses for a Coating with ~90% Visible Transmission and IR Reflectance	◆			
1	M	Demonstrate Low-e Film with 90% Visible Transmission and IR Reflectance (~100cm2)		◆		
1	M	Demonstrate Low-e Film Continuously produced in Web Coater with Tvis90/RIR90 Performance (2 meter web length), T/R variation less than 2%			◆	
2	T	Integrated Low-e/Electrochromic Development and Performance Validation	■	■	■	
2	M	Demonstrate Integrated Low-e/EC Film with Vis Trans Switching Range >5-60% (Visible) @ 500 cm2 area, switching time Less than 5 Min, Establish a Pathway to 3-70%			◆	
2	M	Demonstrate Integrated Low-e/EC Film with Vis Transmittance modulation Range >5-60% and IR Reflectance >90%, >5,000 Cycles in High Heat and Humidity for Retrofit				◆
3	T	Prototype Design, Development, and Integration	■	■	■	■
3	M	Measure Energy Savings Performance of Base Glass, Low-E, and Low-E for Retrofit Widow Prototoye and Compare to Base Case. Update integrated low-e/EC Film to BTO prioritization tool based on measurements results and/or updated technology targets				◆
4	T	Technology to Market Strategy	■	■	■	■
4	M	Establish IP Agreements Between Partners	◆			
4	M	Add Integrated Low-e/EC Film to BTO Prioritization Tool Based on Final Project Targets	◆			
4	M	Update value Proposition of Integrated Product with Strategic Partners and Investor Community. Update Cost Model and Strategic Business Plan to Include Integrated Product Commercialization Requirements				◆
5	T	Program Management and Reporting	■	■	■	■