Dynamic Windows Program

2014 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: October, 2009

Planned end date: September, 2014

Key Milestones

1. Transfer next generation materials to Sage Electrochromics (09/2013)
2. Formation of a laminated electrochromic device employing a PVB based gel electrolyte layer and initial testing under inert condition.(09/2013)
3. Demonstrate new reflective dynamic technology on flexible substrates. (12/2014)

Budget:

Total DOE $ to date: $4.8M

Total future DOE $: N/A

Target Market: Commercial and residential fenestration; new and existing construction.

Audience: Dynamic window developers and manufacturers; Glass and window manufacturers.

Key Partners:

- **Sage Electrochromics, Inc.**
- **e-Chromic Technologies, Inc.**
- **Stanford Linear Accelerator Laboratory**
- **Colorado School of Mines**
- **University of Denver**

Project Goal:

This work focuses on addressing key market barriers to the adoption of dynamic windows including improving performance and functionality of existing products, development of lower cost manufacturing paths and introducing next generation products.

Purpose and Objectives

Problem Statement: Multiple barriers are currently limiting the market adoption of dynamic window technologies. This project addresses these issues through improving performance of existing materials, demonstrating a candidate low-cost manufacturing process as well as development of a new technology suitable for retrofit.

Target Market and Audience: Dynamic window technologies target both commercial and residential fenestration markets including new construction and retrofit. EERE estimates the potential market for energy savings across all of these applications at ~4.75 quads. This work is focused toward dynamic window developers as well as glass and window manufactures in order to address key market barriers.

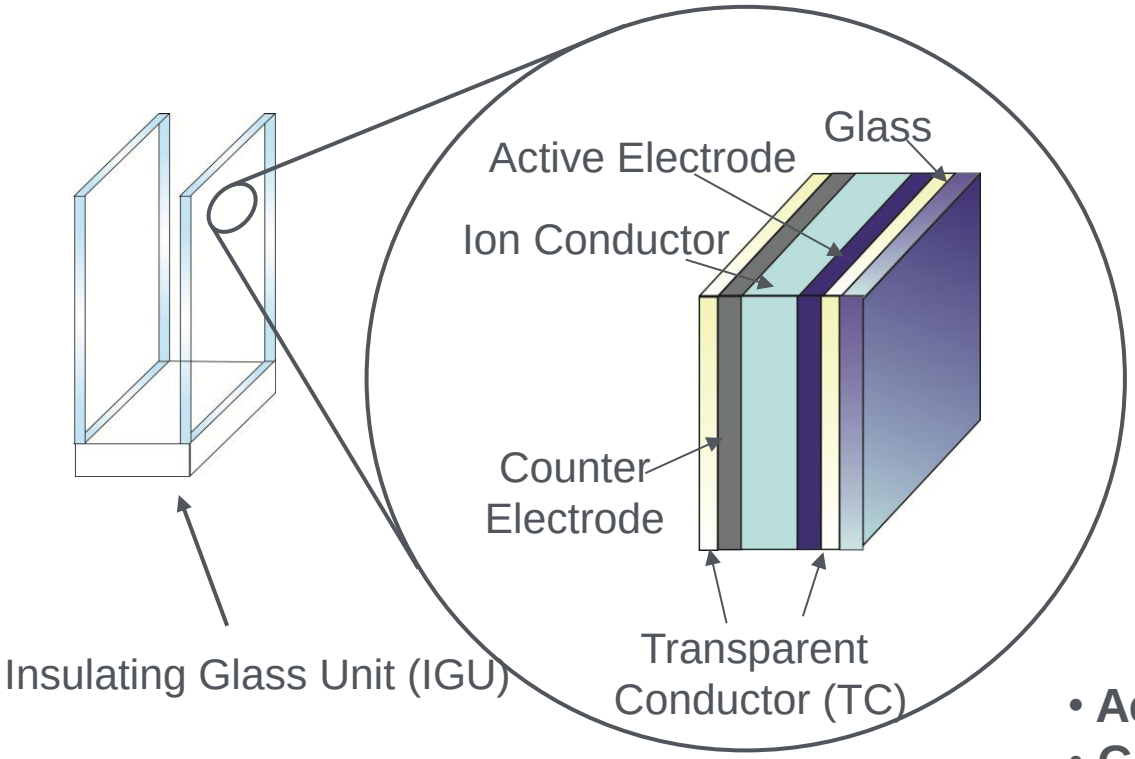
Impact of Project: This work has produced a new class of materials to improve performance of existing dynamic window materials, demonstrated a low-cost manufacturing process and developed a next generation dynamic window device. The success of this work has been measured by generation of patents and publications as well as licensing and technology transfer to commercial development partners. The results of this work includes technology transfer to industry leaders, formation of an emerging company based on a new class of dynamic window device as well as in depth knowledge of dynamic window performance and potential for low cost manufacturing. Longer term results are anticipated to include increased market adoption of existing technologies based on improved performance, opening of new markets based on window retrofit and the creation of alternate manufacturing methods to reduce cost and increase market adoption.

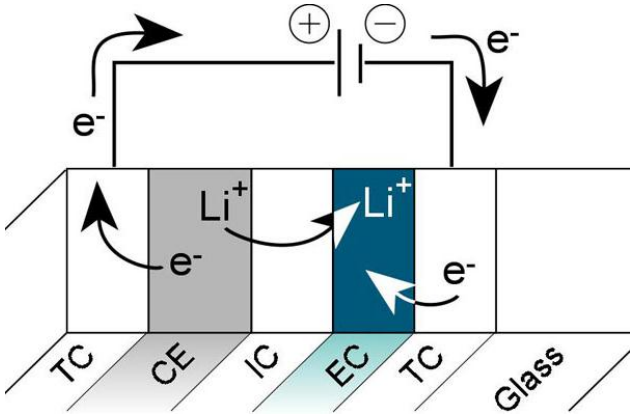
Purpose and Objectives

Key Issues Limiting Electrochromic Windows

- Expense
  - Current market price of $50-$100/ft^2
  - Projections indicate under $20/ft^2 needed
- Aesthetics
  - Adopter preference for neutral tone
  - Switching speeds and uniformity
- Durability
  - New technologies must meet expected product lifetime of already existing systems
  - Valid and unbiased durability testing methods must be developed

Background: Electrochromic Dynamic Windows Materials





- **Active Electrode Material: WO_3**
- **Counter Electrode Material: NiO**

Electrochromic windows act similarly to lithium ion batteries, but change color when charged and discharged.

Approach: Improved Performance Electrochromic Materials (CRADA)

Our research strategy seeks to improve the relatively poor performance of the counter electrode

Goals:

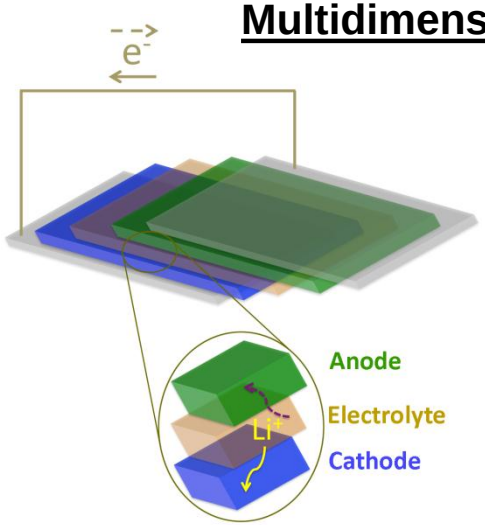
- Improve visual appearance
- Increase switching kinetics
- Increase device efficiency and durability to simultaneously improve energy and cost savings

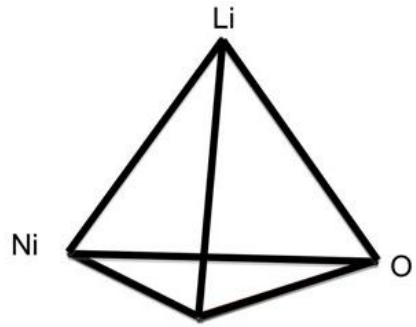
Partners:

SageGlass®

SLAC NATIONAL ACCELERATOR LABORATORY

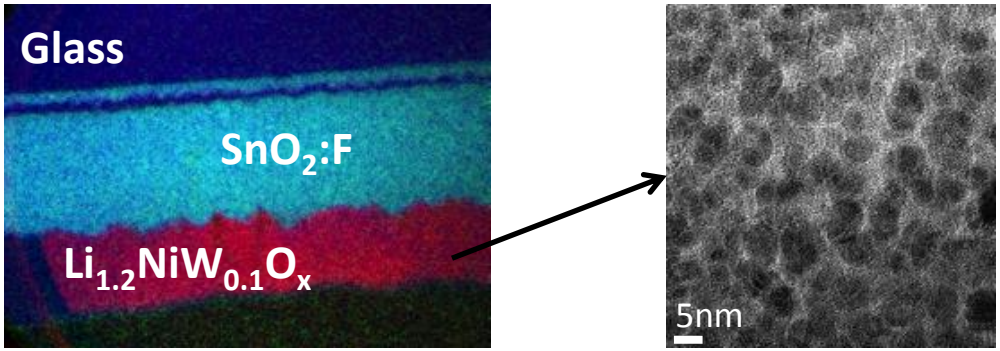
Multidimensional Process Space





Metal and/or Dopant
(e.g., Mg, Al, Si, Zr, Nb, Ta, W, N, ozone)

Nanocomposite Counter Electrodes



Gillaspie, D.; et al. *J. Electrochem. Soc.* **157**, *3*, H328-H331 (2010).

Impact

Licensing negotiations in process for multiple patents

Four peer reviewed publications

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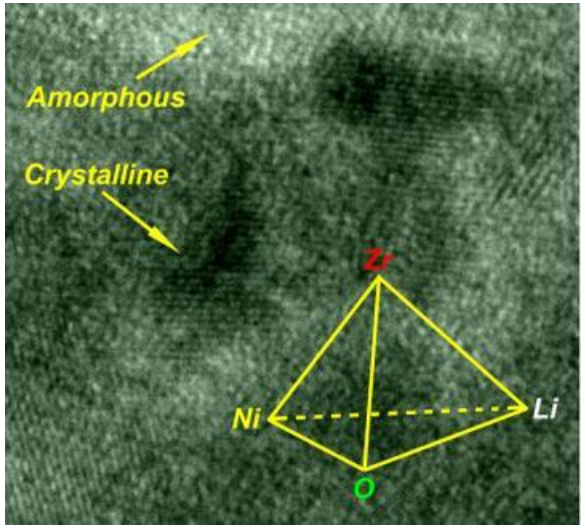
Accomplishments: Transfer of Improved Materials to Sage

SageGlass®

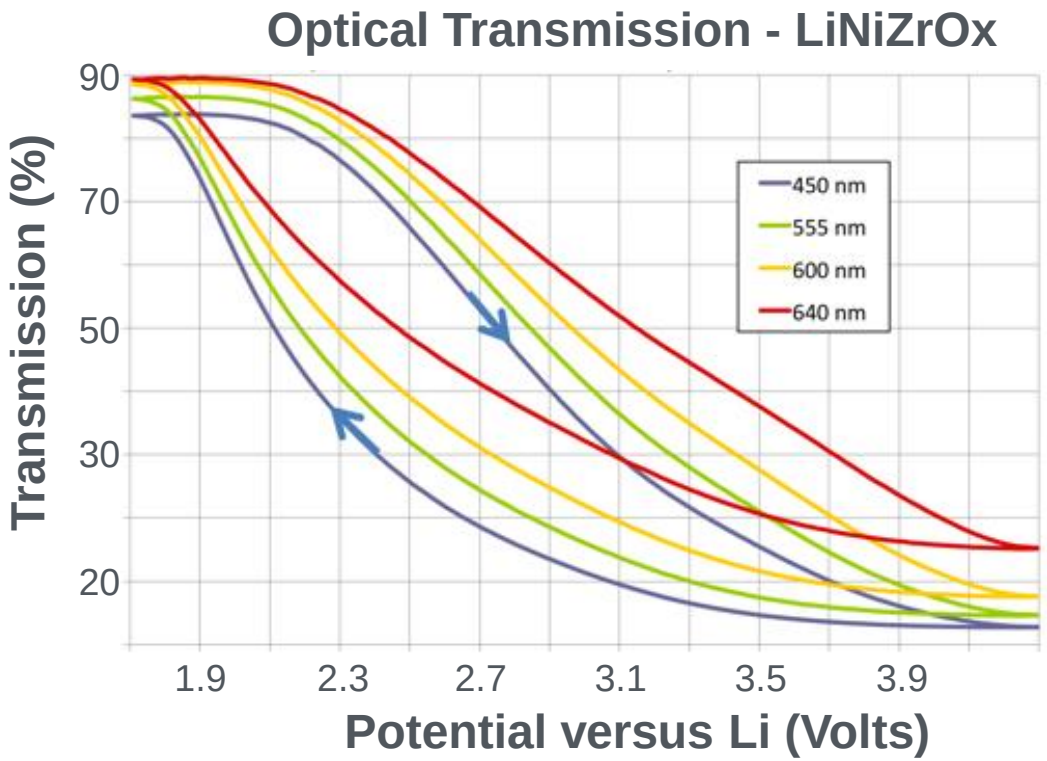
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Superior electrochromic performance (bleached state transparency, optical modulation, durability, switching speed) developed by NREL successfully verified by Sage Electrochromics

$Li_{2.34}NiZr_{0.28}O_x$



Improved NREL film deposited on Sage Glass (ITO)



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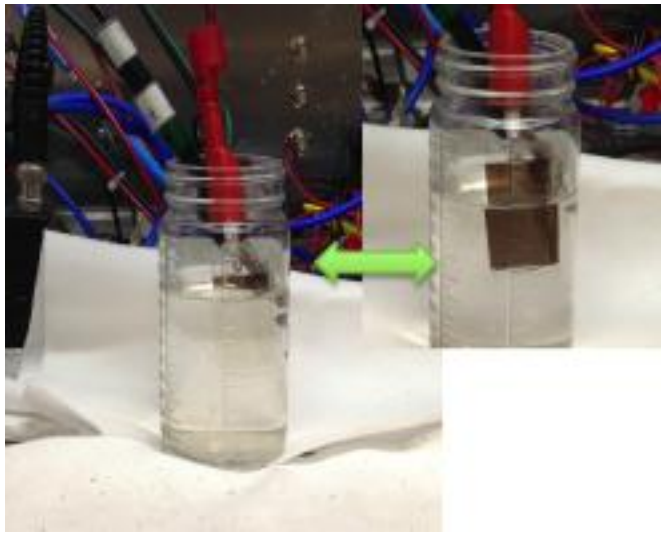
Accomplishment: Compatibility with Manufacturing Demonstrated

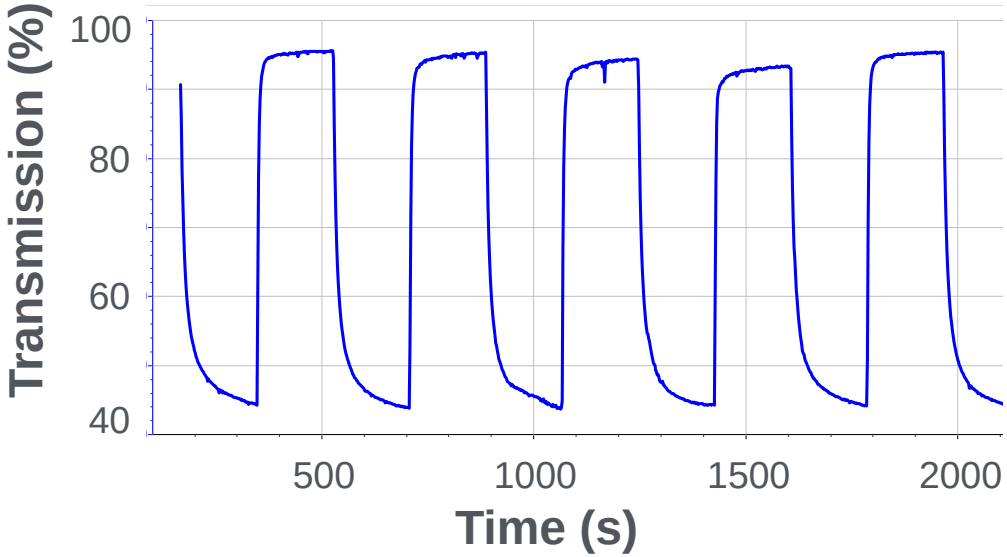


NREL has worked closely with Sage to transfer our improved counter electrode materials into their manufacturing processes

Key processing steps were identified that led to improvement in clarity and switching speed

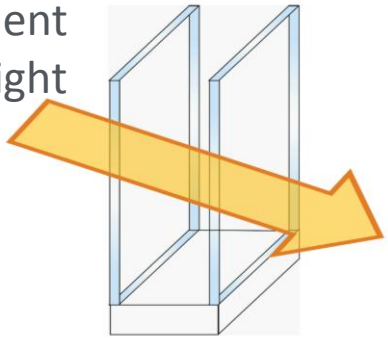
Licensing negotiations with Sage to transfer intellectual property are on-going

Sage has provided funding to continue this collaboration

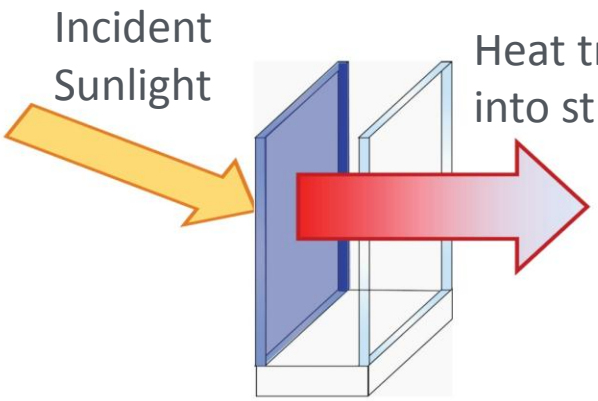


Approach: Next Generation Reflective Dynamic Windows

Transparent State

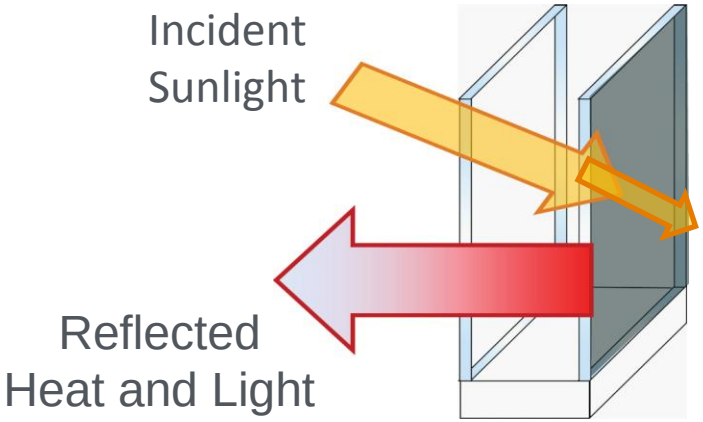


Absorptive Device



http://www.echromic.com/

Reflective Device



Heating mitigation may make retrofit more practical

Accomplishments: Prototype Development to Date

Initial reflectance formation demonstration

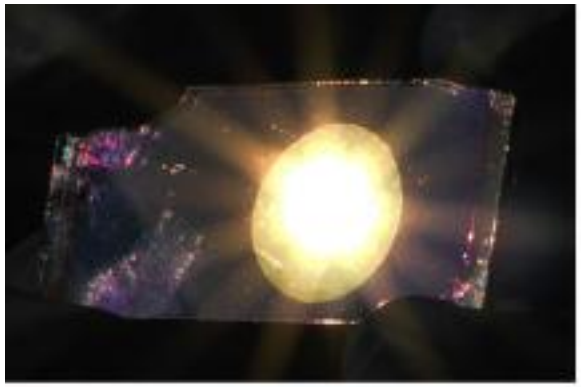
New transparent conductor development

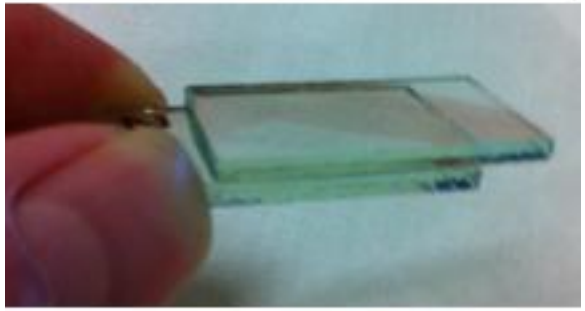
Early stage prototype demonstration with liquid testing cell and glass substrates

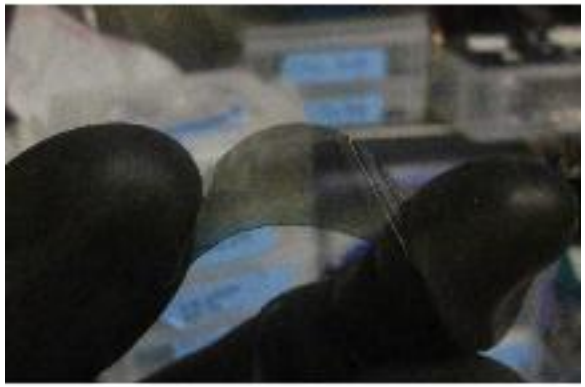
Prototype refinement with lamination process development

Transfer of technology to flexible device format

Initial work funded through company as well as NREL internal investment, new to FY14 AOP







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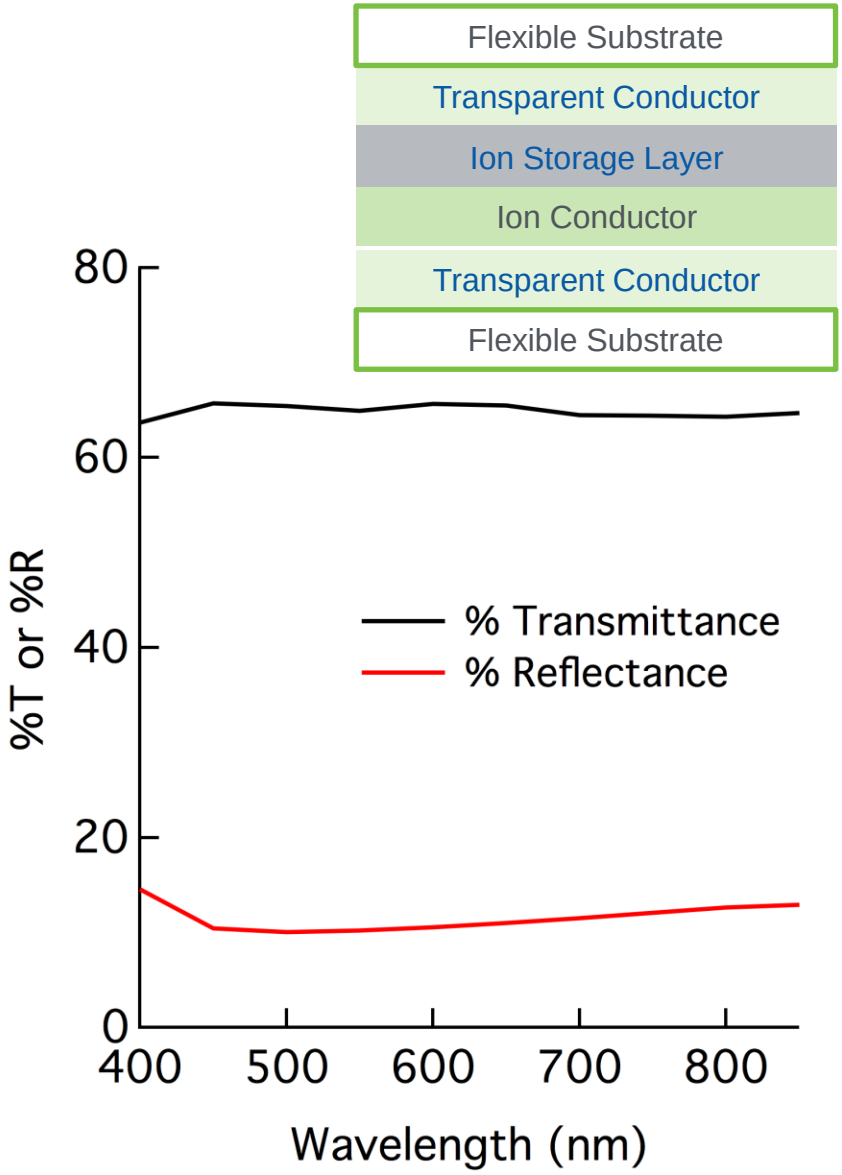
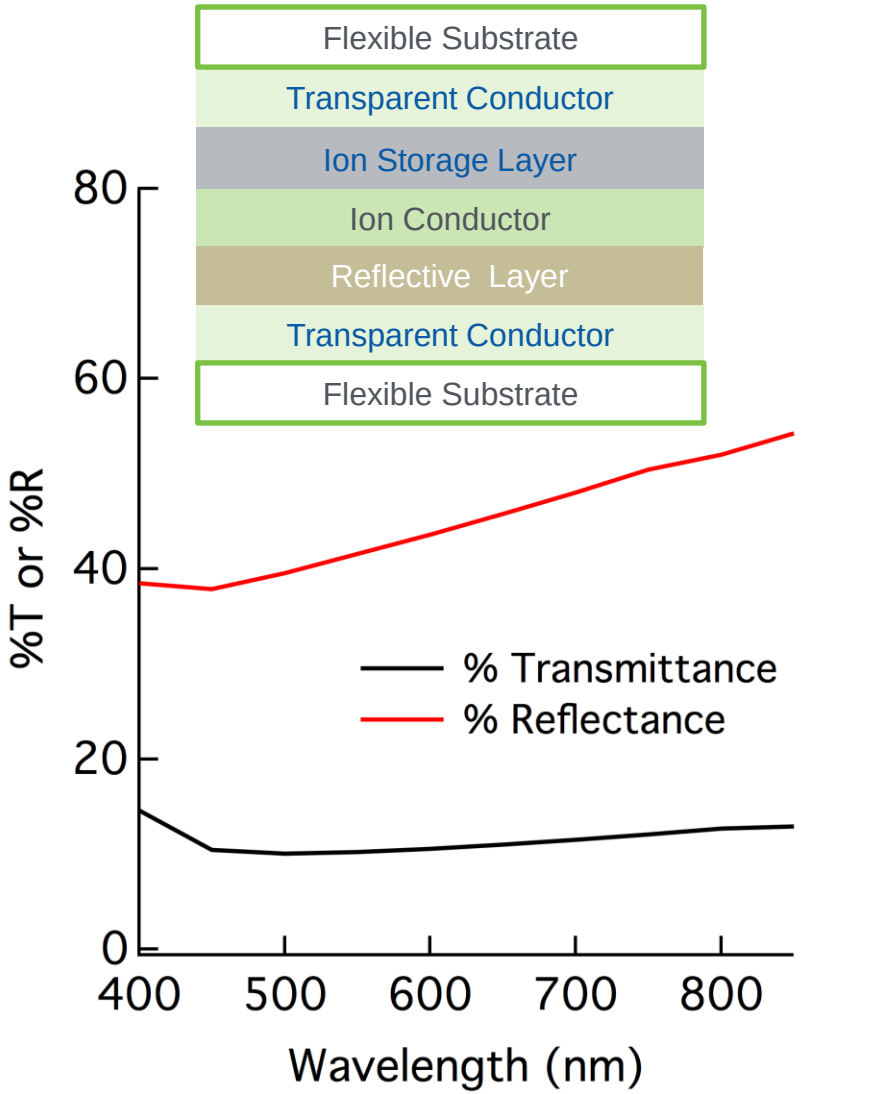
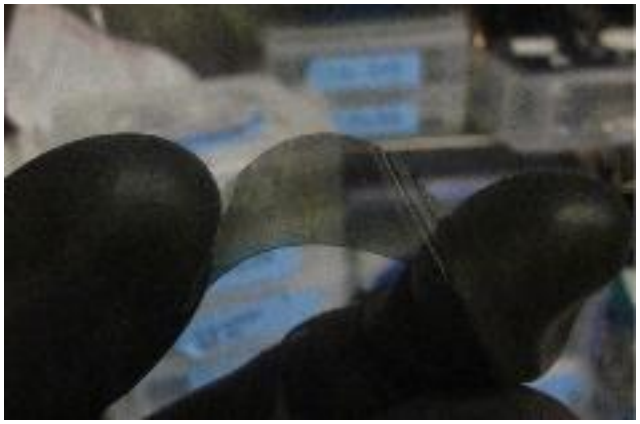
Accomplishment: Initial Device Functionality Confirmed





FY14 Accomplishments: Transfer to Flexible Substrates



- Uniform deposition on 3” by 3” flexible samples demonstrated.
- Reflectance forming and counter electrode layers demonstrated on flexible substrates.
- Full device integration on flexible substrates currently in progress.

Impact

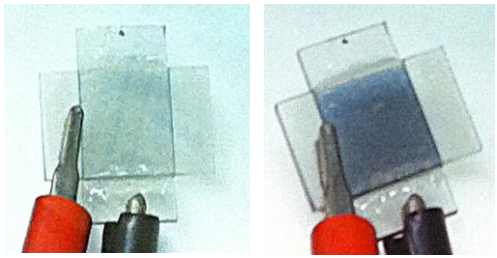
Licensing agreement including multiple existing and new patents to carry technology to commercial production.

Results to date enable e-Chromic Technologies to raise $600K private seed venture investment for further development and commercialization.

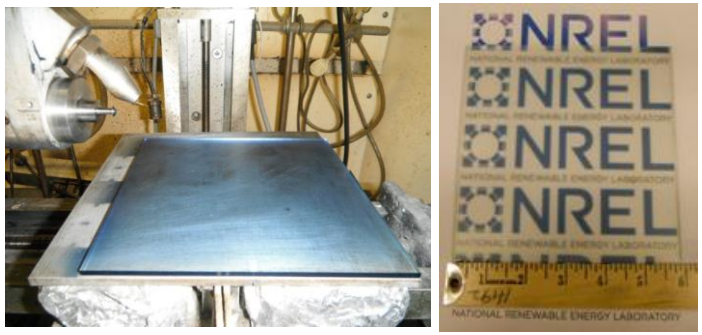
http://www.windowfilmmag.com/index.php/archives/5273
http://www.newenergyworldnetwork.com/investor-news/renewable-energy-news/by-technology/energy-efficiency/e-chromic-technologies-closes-600000-seed-financing.html

Approach: Low Cost EC Processing

Complete Device Fabrication



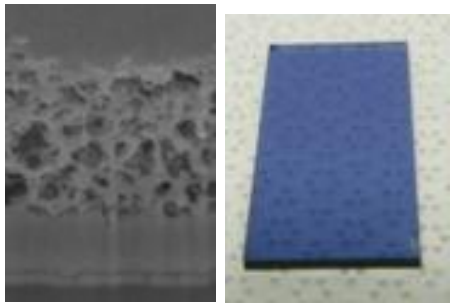
Ultrasonic Spray Deposition



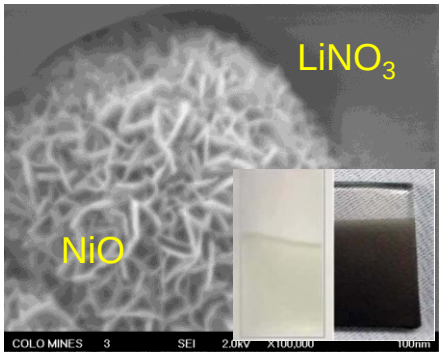
EC Lamination Process

- TCO-Coated Glass
- $NiO/LiNO_3$ Counter Electrode
- PVB Based Polymer Ion Conductor Layer
- Tungsten Oxide Active Electrode
- TCO-Coated Glass

Tungsten Oxide Active Electrode



Nickel Oxide Counter Electrode



Progress and Accomplishments: Low Cost Processing

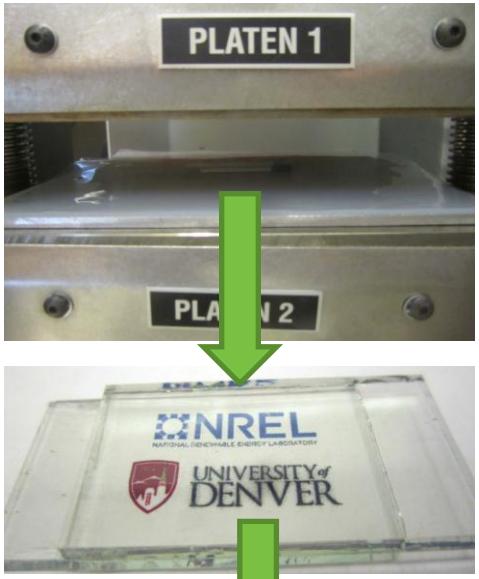
University collaborations enable low cost dynamic window prototype demonstration

Impact

Two PhD students graduated

Two patent applications filed

Two peer reviewed publications



COLORADOSCHOOLOFMINES
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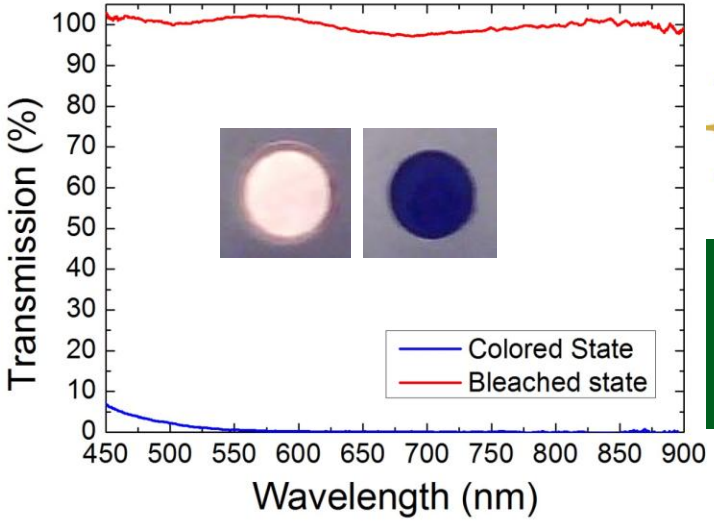
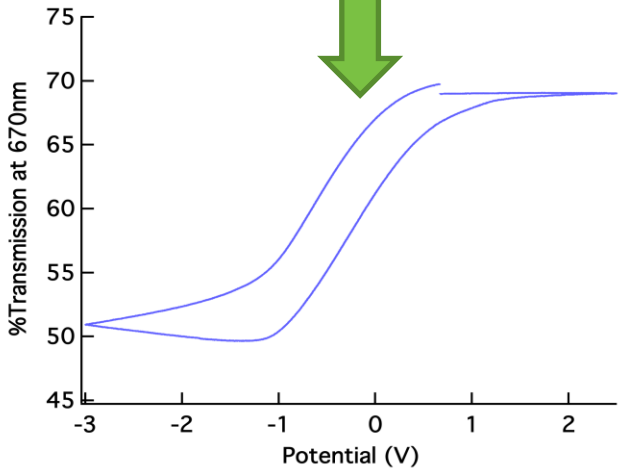


NSF

Renewable Energy Materials Research Science and Engineering Center
REMRSEC



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Progress and Accomplishments

Lessons Learned: Discussions with coated glass and window manufacturers indicate a preference for gas phase coating methods for high volume production. NREL is currently in discussions with high volume coated glass producers interested in new methods of depositing electrochromic device layers.

Accomplishments: Multiple technologies demonstrated and transferred through licensing agreements to industry partners for commercial development. NREL continues to work with these partners to drive further success. Six peer reviewed publications and four patent applications generated.

Market Impact: Technologies transferred to external partners are expected to increase market penetration for dynamic windows through improved performance of exiting technologies as well as opening new avenues to retrofit of dynamic functionality. Quantitative impact depends on success of further collaborations with partner companies.

Awards/Recognition: 2013 NREL Outstanding Business Collaboration

Project Integration and Collaboration

Project Integration:

- University and industry collaborators work on-site and side by side with NREL scientist.
- NREL staff hold research appointments with partner universities.

Partners, Subcontractors, and Collaborators:
Neil Sbar, Jean-Christophe Giron, Doug Weir, Sage Electrochromics
Loren Burnett, Judith McFadden, Nader Mahvan, e-Chromic Technologies
Rob Moore, Dennis Nordlund, Tsu-Chien Weng, SLAC
Chi-Ping Li, Colin Wolden; Colorado School of Mines
David Alie, Mohammad Matin, University of Denver

Communications: Six peer reviewed articles in various journals; Invited presentations and articles: Materials Research Society, Journal of Materials Chemistry; Multiple student presentations

Next Steps and Future Plans

Next Steps and Future Plans:

After project completion date, NREL hopes to continue assisting our development partners if additional funding can be identified.

On-going discussions with major glass manufacturer to assess viability of additional electrochromic materials production methods.

REFERENCE SLIDES

Project Budget

Project Budget:
DOE - $300,000 (carryover only, no new BA)
Variances: None
Cost to Date: $122,340
Additional Funding: External Funding: Sage Electrochromics ($150K); e-Chromic Technologies ($100K); NSF funded post-doc through CSM working at NREL ($60K)

Budget History					
FY2010 – FY2013 (past)		FY2014 (current)		FY2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$4.8M	$600K	$300K (carryover)	$310K	TBD	TBD

Project Plan and Schedule

Project initiation date: October, 2009
Planned completion date: September, 2014
Milestones: Slipped milestone in FY13-Q3 due to apparent chemical incompatibility with device layers; passivation strategy allowed complete device fabrication in Q4. All other milestones complete and on schedule.

Project Schedule													
Project Start: October, 2009		Completed Work											
Projected End: September, 2014		Active Task (in progress work)											
		Milestone/Deliverable (Originally Planned) use for missed milestones											
		Milestone/Deliverable (Actual) use when met on time											
	FY2013				FY2014				FY2015				
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	
Past Work													
FY13-Q4 Milestone: Demonstrate successful transfer of state-of-the-art thin film counter electrode to Sage's solid-state electrochromic device structure													
FY13-Q3 Milestone: Formation of a laminated electrochromic device employing a PVB based gel electrolyte layer and initial testing under inert conditions													
FY13-Q4 Milestone: Technical support to US e-Chromic staff													
Current/Future Work													
FY14-Q1 Milestone: Reflectance forming device layer structure demonstrated on a 3" by 3" flexible substrate.													
FY14-Q2 Milestone: Counter electrode device layers demonstrated on a 3" by 3" flexible substrate.													
FY14-Q3 Milestone: Integration of reflectance forming and counter electrode layers with electrolyte layer to form fully laminateed 3" by 3" device													