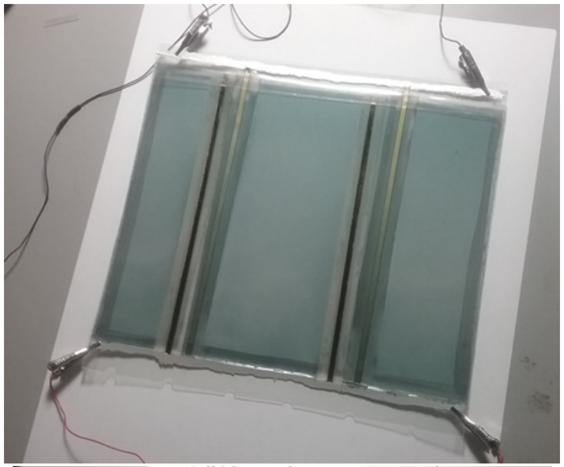
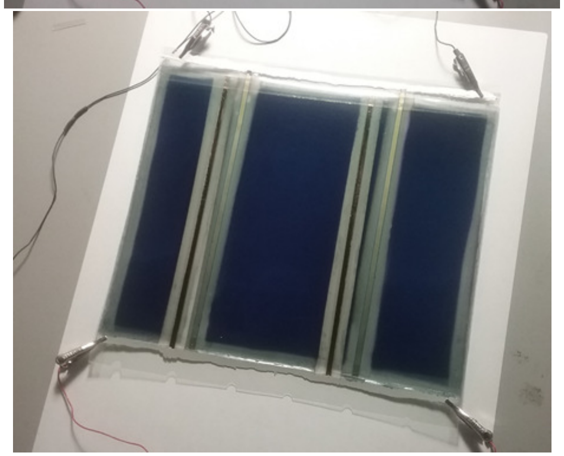
"Electrochromic Auto-Darkening Windows for Buildings for Energy Conservation Based on Unique Conducting Polymers and Already Demonstrated in Sunglasses"

[Retrofit application to existing windows, Est. $3/ft^2 vs. $50 to $300/ft^2 competition]





Ashwin-Ushas Corporation, 2 Timber Lane, Unit 301, Marlboro, NJ 07746 (https://ashwin-ushas.com/)

PI: Prasanna Chandrasekhar, Ph.D. (*Title: President*)

PI Contact Info: 732-739-1122; chandra.p2@ashwin-ushas.com .

Project Summary

Timeline:

Start date: 2018-07-02 (*but Contract awarded 2018-08-27*)

Planned end date: 2019-04-01

Key Milestones

1. Functioning window-dimension electrochromic panels; demonstrated to TM at PI meeting in 12/2018.
2. Drastic reduction in projected cost to the <$12/ft^2 level needed for commercial viability (vs. >$40/ft^2 for competing technologies); functioning panels with this innovation will be demonstrated at BTO presentation, 04/2019.

Budget:

Total Project $ to Date:

- *DOE*: $144,988.00
- *Cost Share*: $144,988.00

Total Project $:

- *DOE*: $149,988.00
- *Cost Share*: $149,988.00

Key Partners: *(No subcontractors or other key partners)*

Project Outcome:

- Objective of project was to demonstrate extension of this firm's patented electrochromic technology [1-2] currently being commercialized in (small area) sunglasses/visors to (larger area) building windows. Key to extension to large areas is need for gridlines.
- Three key innovations *that were not in the original Phase I Proposal* were implemented which demonstrated: **(1)** Functioning window-dimension electrochromic panels (demonstrated to TM at PI meeting in 12/2018); **(2)** Drastic reduction in projected cost to <$4/ft^2, vs. the <$14/ft^2 level needed for commercial viability and the $50 to $140/ft^2 for competing technologies. (Functioning panels with this innovation will be demonstrated with this BTO presentation.)
- All project Objectives met or exceeded.

Team

ASHWIN-USHAS:

- Prasanna Chandrasekhar, Ph.D., P.I. *chandra.p2@ashwin-ushas.com ; highly experienced (>30 years) electrochemist and world authority on Conducting Polymers and electrochromics.*
- Brian Zay, Lead Scientist on project. *zay.b.2@ashwin-ushas.com ; All-round scientist experienced in leading highly multidisciplinary research efforts and "making things work"; expert in electrochromics.*
- Shengyang Huang, Ph.D., Senior Scientist on project. *huang.s.2@ashwin-ushas.com ; highly experienced electrochemist and materials scientist (9 years post-doc prior to joining our firm).*
- Jeremy Willow, Ph.D., Senior Scientist on project. *willow.j.2@ashwin-ushas.com highly experienced electrochemist and materials scientist (8 years post-doc prior to joining our firm).*
- Yanjie Chai, Ph.D., Electrical/Electronics Engineer on project. *doranj.@ashwin-ushas.com ; highly experienced electrical/electronics engineer who has designed and perfected all our electronics.*

OTHER, ACTIVE SUPPORT FROM (vendors we have worked closely with over last 15 years):

- *Zeta Electronic Design, Inc.* (http://www.zetainc.com/), an electronics design firm working actively with us. *Will fabricate our electronic circuits for auto-darkening control of electrochromics, at small as well as large production scale.*
- *Tri-Power, Inc.* (https://www.tripowerdesign.com/), a CAD design, engineering and automation firm working actively with us in current electrochromics, sensors and other projects. *Will aid in design refinement of electrochromic panels.*
- *Eastman Chemical Co. (formerly CP Films, Solutia Inc., https://www.eastman.com/Products/Pages/Product_Selector.aspx). Supplier of inexpensive, bulk ITO/Mylar in 1000ft rolls.*
- *Vaculayer, Inc.* (http://www.vaculayer.com/); *Buellton Advanced Materials* (*BAM*, formerly *Thin Film Technologies,* https://www.lockheedmartin.com/en-us/who-we-are/business-areas/aeronautics/buellton-advanced-materials/buellton-advanced-materials-contacts.html. Vapor deposition vendors we have used for >20 years. For Au (and other noble metals), ITO, etc. *May not be used if screen-printing of gridlines is selected for final manufacture.*
- *Utulla, LLC*, (https://www.utulla.com/) a data processing/software firm working actively with us in current sensor projects. *Will be used for further refinement of existing firmware in Microcontrollers (electronics).*

Challenge

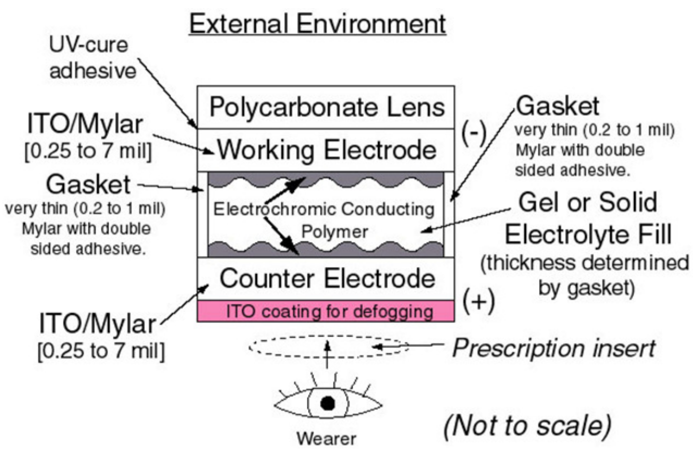
NEED AND EXISTING TECHNOLOGY ("PROBLEM DEFINITION"):

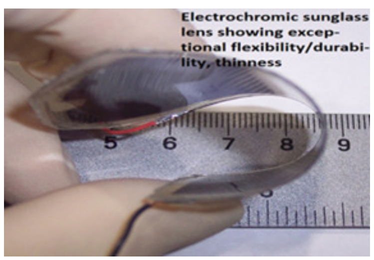
- ***Need in buildings:*** Per DOE and other sources [3], *residential and commercial buildings* account for **>40%** of *total US energy demand* and **>70%** *total US electricity use,* costing **>$430 billion/year** [3]. ***87%*** *of US buildings and homes used AC* in 2009 (vs. 68% in 1993 [3].
- *Approximately* ***35% of this $430B/year consumption can be attributed to losses through the building envelope****,* ***via heat transfer*** *and related means*. Air conditioning accounted for ***18%*** *of annual residential electricity use* in 2017 [3]. For residential use alone, the annual ***CO_2 output*** *is 117m tonnes*. With commercial use factored in, the total is close to ***250m tonnes*** [3].
- *If* ***auto-darkening windows*** *were available for building windows* in warmer US regions, energy for cooling could be greatly reduced ***without effect on visibility through the windows and the need for user-input to darken/lighten, as with window blinds or curtains.***
- ***Savings:*** *Using a very conservative figure*, if just 20% of total building envelope loss is attributable to lack of window auto-darkening, then the ***annual US savings*** is estimated at ***$30.1B/year*** *and* ***50m tonnes CO_2.***
- ***Existing technologies*** include electrochromic windows (mainly metal-oxide (WO_3, MoO_3, other) based, a 50-year-old technology) e.g. by Sage Glass (https://www.sageglass.com/en), View (https://view.com/), have drawbacks including: (1) Price $50 to $140 /ft^2 (*cf.* ***our price ~$2.94/ft²*** ***($32.34/m²), USA production***). (2) OEM windows, i.e. existing windows cannot be retrofit. (3) Poor light/dark contrast. (4) Still have stability issues.
- ***Other technologies,*** , e.g. photochromics (Transitions®), LCD-electrochromics (only extreme light/dark (L/D), On/Off, cf. http://alphamicron.com/technologies/e-tint/), *not applicable to building windows, also many drawbacks*.
- ***Our unique, patented electrochromics technology:*** Patented technology (>15 worldwide patents- see References below) based on unique complimentary dual-polymer Conducting Polymers (CPs). Best L/D contrast, stability (>1M L/D cycles); intermediate states; retrofit model for existing building windows; lowest cost ***(<$3/ft2 ($32.34/m²***, USA production).

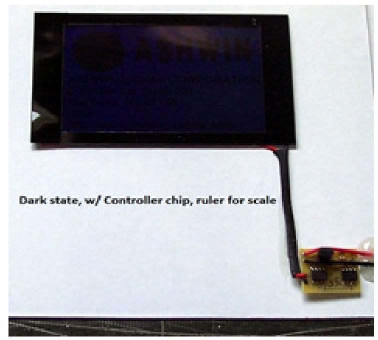
Approach

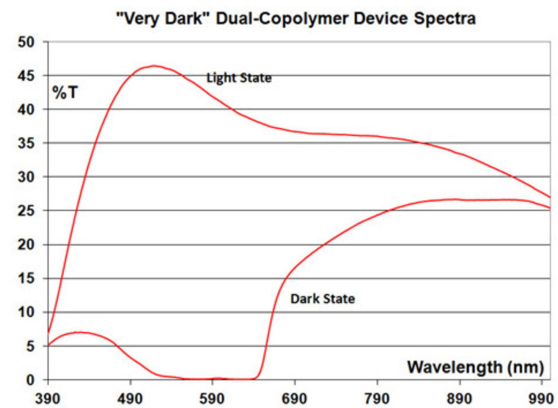
BASIS OF TECHNOLOGY (OUR CURRENT ELECTROCHROMIC SUNGLASSES/VISORS):

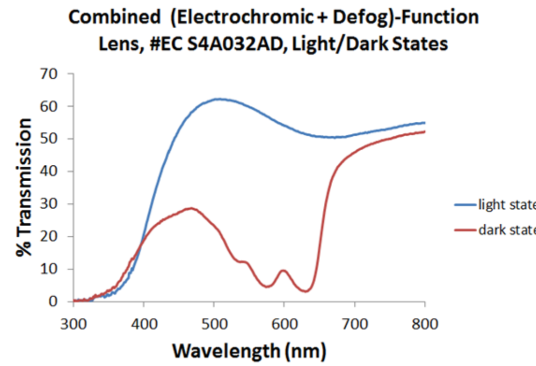
- *Based on* ***unique, patented dual-polymer electrochromics technology*** *(based on unique Conducting Polymers (CPs).* Very thin (<0.4 mm), flexible durable lens construction (base substrates 7 mil ITO/Mylar, which are *naturally UV-blocking*). ***:***











- Desirable color change (transparent to dark-blue-black), high cyclability ***(>1M*** L/D cycles demonstrated w/o observable degradation), shelf life >3 years, high durability. Other colors possible. Excellent optical memory.
- Unique applied-voltage algorithm residing on an inexpensive (<$5) Microcontroller that drastically reduces switching time ***(<2 s L→D, ~instantaneous D→L)*****.**

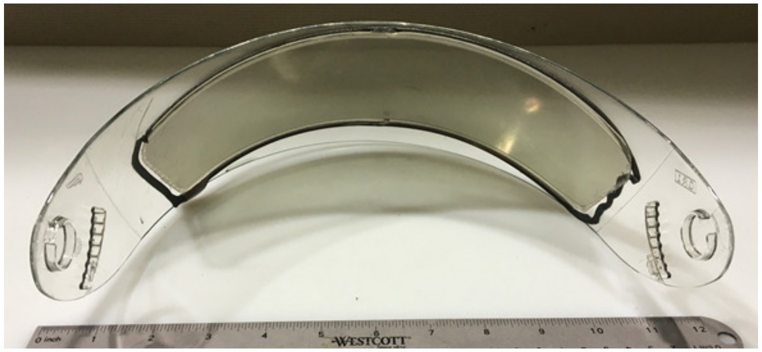
Approach, *cont.*

BASIS OF TECHNOLOGY (OUR CURRENT ELECTROCHROMIC SUNGLASSES/VISORS) (cont.):

- *Based on* ***unique, patented dual-polymer electrochromics technology*** *(based on unique Conducting Polymers (CPs).* Very thin (<0.4 mm), flexible durable lens construction (base substrates 7 mil ITO/Mylar, which are *naturally UV-blocking*). ***:***
- *Fully automated, photosensor-based control* based on ambient light. User sets light level desired at eye; then electrochromic maintains this no matter what the external lighting; Manual override available.
- Very low power consumption,15 µW/cm^2, +/- 3.0 VDC. For sunglasses, rechargeable Li batteries (recharge needed only after 36h continuous operation). For building windows, house-AC power more than adequate. In demo here, we use AA (1.5V) batteries.
- Durability: Demonstrated to conform to *ANSI Z87.1-2010, GL-PD 10-12 and MIL-PRF-32432****;*** not needed for building windows, but show technology's durability.

Sunglasses, schematic

Motorcycle visor insert (RETROFIT application)



Approach, *cont.*

<u>BASIS OF TECHNOLOGY, cont., TRANSITION TO LARGE-AREA (Building) WINDOWS:</u>

- ***ALL*** above features are readily and easily transferred to the building-window application.

- ***However, <u>key for building-windows application is to transition the excellent small-area electrochromic function of the sunglasses to larger areas suitable for building windows</u>*** *This is however not straightforward:*
  - Due to "*resistive drop*" in base conductive substrates used (ITO/Mylar(PET)), *limiting distance between the (+/-) points of electrical contact for effective electrochromic transition is about* ***11cm***. For greater distances, *transition from the points of electrical contact is clearly visible, lightening/darkening is uneven, and switching time is slower.*
  - Only effective method to overcome this is to introduce ***conductive gridlines*** (of Au or other conductor), somewhat like those in a automobile rear-window defroster; to be made as thin and invisible as possible.
  - Such gridlines however present problem with active electrochromics (CPs), since CPs are deposited electrochemically. In a conventional electrochemical deposition ("electroplating"), *CPs would mostly deposit along the gridlines* due to their much greater conductivity; the gridlines would also electrochemically interact with gel electrolyte. *These gridlines thus need to be* ***masked*** *from the "electroplating" solution with an insulator that is compatible with the solvents used in the electrochemical deposition* (including acetonitrile and propylene carbonate).

Approach, *cont.*

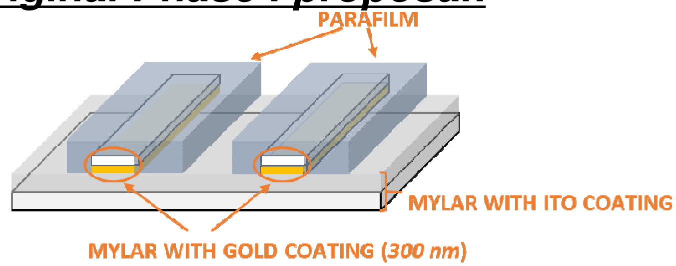
BASIS OF TECHNOLOGY, cont., TRANSITION TO LARGE-AREA WINDOWS:

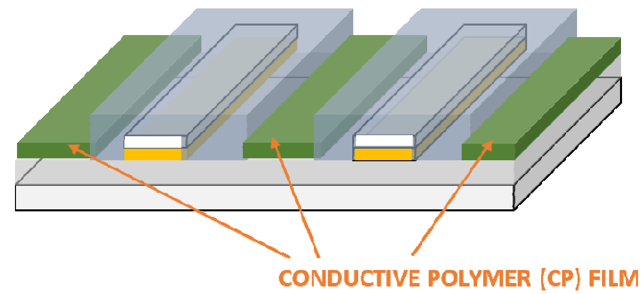
- ***INNOVATIONS TO ACHIEVE OBJECTIVES:***
  - ***In our original Phase I proposal***, we proposed to vapor-deposit Au gridlines through a physical pattern mask onto the ITO/Mylar (procured as inexpensive, bulk 1000 ft rolls). Then, we proposed to study several methods of masking the gridlines.
  - In a ***first innovation NOT in the original Phase I proposal***, we put down the Au gridlines on Mylar *first, then* vapor-deposited the ITO. Thus, the ITO served as its own mask, eliminating the masking step. *This innovation was demonstrated to PM in 12/2018 PI Meeting.*
  - In a ***second, further innovation also NOT in the original Phase I proposal***, we demonstrated laying down of **gridlines using Ag ink** dispensed with a **robot** (Fisnar Corp.) used to imprint conductive perimeters in our electrochromic sunglasses, and the same **robot** to lay done **masking lines consisting of PDMS** on top of the Ag ink gridlines. This brought down the estimated cost of the final product drastically, as it eliminated expensive vapor deposition apparatus. ***This innovation is being shown with this presentation. ***
  - In a ***third, further innovation also NOT in the original Phase I proposal***, we demonstrated laying down of the same **Ag ink gridlines** using **screen printing** (the same, simple process used to print patterns on T-shirts). ***This innovation is also being shown with this presentation. ***
  - *The **first, second and third innovations described above, not in the original Phase I proposal brought down the estimated cost of our electrochromic windows to, respectively, ~$30/ft^2$, $3.25/ft^2$ ($34.97/m^2$) and ~$2.94/ft^2$ ($32.34/m^2$),** for **production in USA. [**** Will open Costing Spreadsheet during presentation here.**]***

Approach, *cont.*

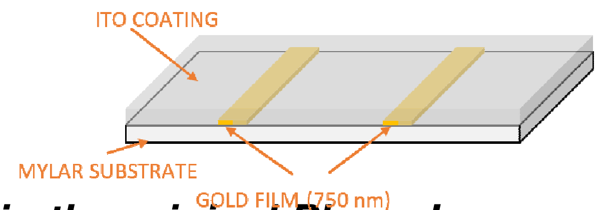
TRANSITION TO LARGE-AREA WINDOWS, INNOVATIONS (PHASE I RESULTS), cont.:

- ***As in our original Phase I proposal:***



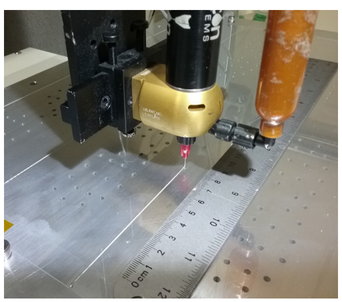


- ***First innovation NOT in the original Phase I proposal:***

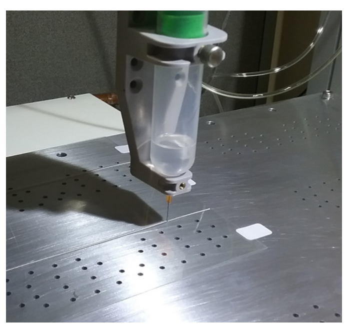


- ***Second, further innovation also NOT in the original Phase I proposal:*** ,

Robot laying Ag ink gridline

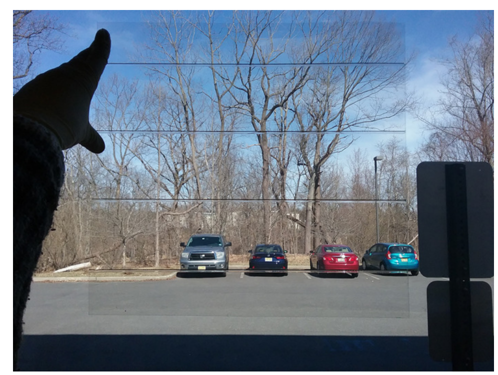


Robot laying PDMS mask on gridline



Finished substrate (masked Ag ink gridlines on ITO/Mylar

Assembled panel in light state, seen through window



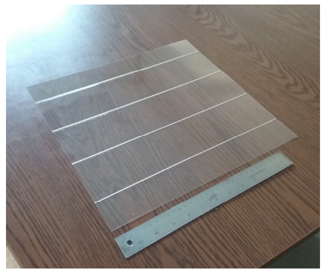
Approach, *cont.*

TRANSITION TO LARGE-AREA WINDOWS, INNOVATIONS (PHASE I RESULTS), cont.:

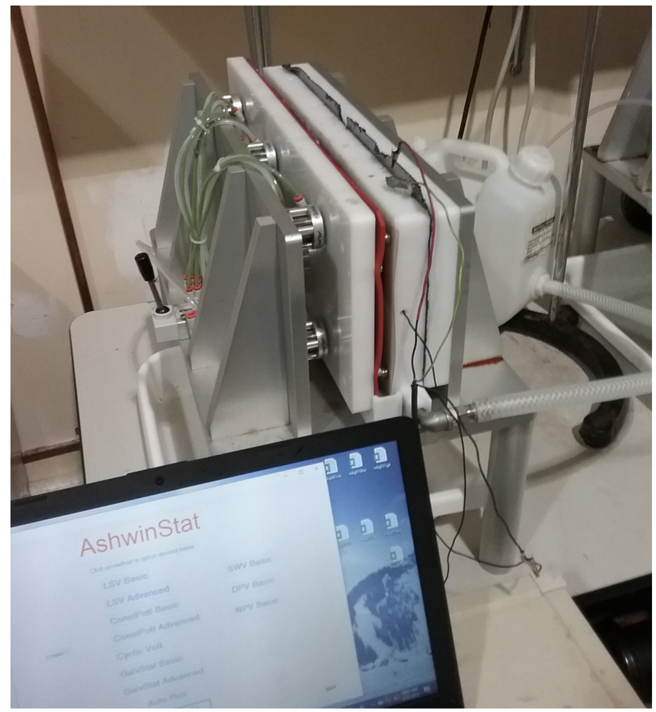
- ***Third, further innovation also NOT in the original Phase I proposal:***

Manual Screen Printing apparatus

Screen Printed masked Ag ink gridlines



Current version of our semi-automated electrochemical deposition tanks



Electrochromic Panel made by Screen Printing mounted in window, LIGHT state

Electrochromic Panel made by Screen Printing mounted in window, DARK state

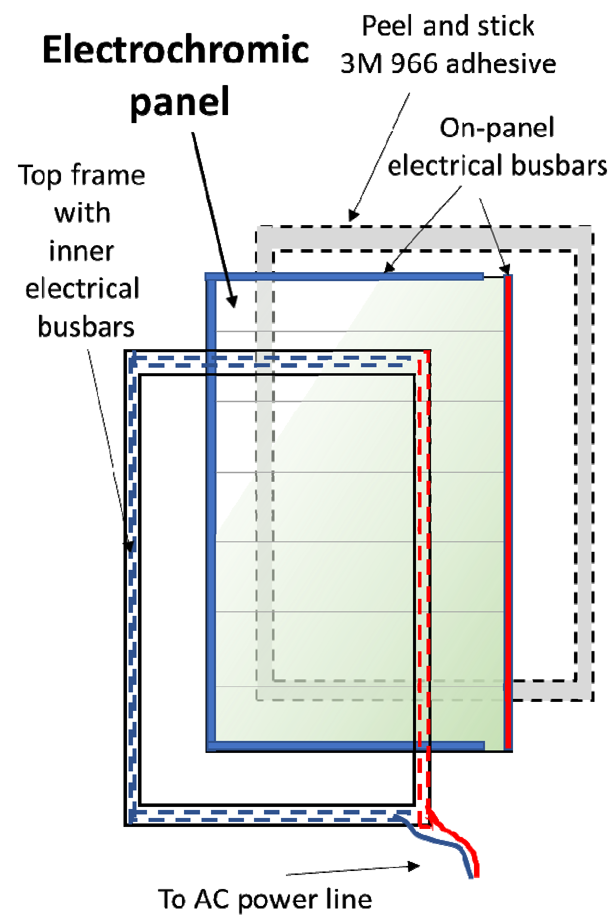
Impact

<u>*HOW OUR TECHNOLOGY COMPARES WITH CURRENT STATE OF THE ART:*</u>

- ***Extant technologies:*** Only other major players in electrochromic building windows field are **Sage Glass** (https://www.sageglass.com/en), **View** (https://view.com/) (photochromics, e.g. Transitions®, and LCD-electrochromics (only extreme light/dark (L/D), On/Off), are *not applicable to building windows).* Sage's and View's technologies have drawbacks, including:
  - **(1)** Price \$50 to \$140 /ft^2 · **(2)** They are OEM windows, i.e. existing windows cannot be retrofit. Customers must replace existing windows. **(3)** Poor light/dark contrast. **(4)** Still have stability issues.
- ***Our technology:***
  - ***Our price ~\$2.94/ft^2 (\$32.34/m^2), USA production***). [***Will open detailed costing spreadsheet here during presentation.***]
  - ***Auto-darkening***, just like our sunglasses, based on ambient light, including all intermediate darkness levels between extreme light and dark. This will eliminate need for curtains/blinds.
  - ***<u>Retrofit model</u>: (***See Figure next slide.) Retrofit model will eliminate a huge "customer apathy" hurdle. So the market expands not just to new construction, but also to existing buildings. Simple "peel-and-stick" retrofit installation with pressure sensitive adhesive perimeter, plus "one-small-box" electrical connection. Perimeter-only bond will allow for additional insulation (with air gap), while having no impact on optical clarity. *(Would still recommend an installation service (can license existing HVAC contractors, though Do-It-Yourself also possible.)* Allows for removal (if customer suddenly changes their mind), and/or upgrade with later, better-performing electrochromic panels.
  - ***Market potential:*** If marketed properly, with even ***10% penetration***, estimate is ***\$5B/year (US only) [3].***
  - ***Other issues: P****rivacy: O*ur electrochromics get dark enough to provide sufficient privacy during night, so curtains not required even for residential buildings (generally not an issue in commercial buildings).

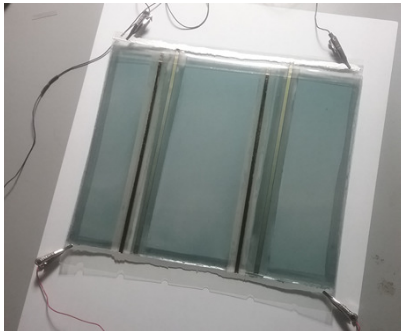
Impact

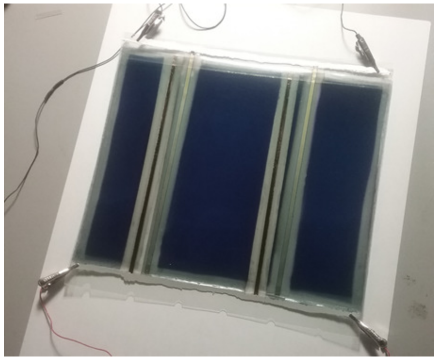
- ❑ ***VALIDATION OF OUR TECHNOLOGY, proposed in potential Phase II:***
  - ➢ Instrumentation and apparatus for fabrication of window-sized (60X90cm), 120X182cm, 300X600cm) electrochromic panels.
  - ➢ Retrofit peripherals, method (Fig. below).
  - ➢ Proof ITO-over-gridlines on large scale.
  - ➢ Design pilot plants for 10m^2/month, 1000m^2/month capacity. Start implementation of 10m^2/month plant. Use these to carry out detailed costing analyses.
  - ➢ Initiate commercial tie-ups, marketing.

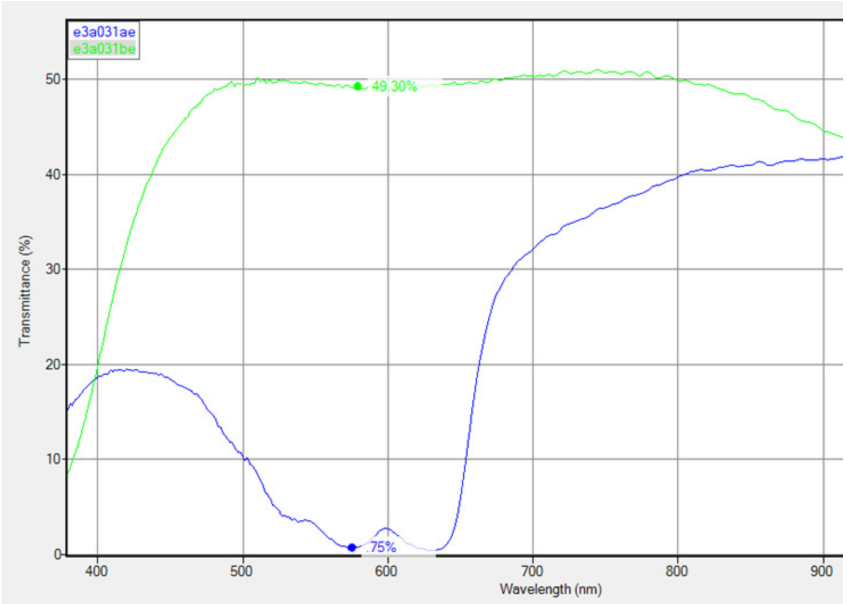


Progress

- ❑ ***Phase I progress and accomplishments*** (also detailed somewhat in Slides 7-10 above):
  - ➢ Phase I project is now in “late” stage, nearly complete. ***<u>All</u> Objectives met or exceeded***, ***having succeeded much more than expected vs. original Phase I work proposed***.
  - ➢ ***Three new innovations not in original Phase I proposal implemented, demonstrated*** (see Slide 7). End result of these was to demonstrate facile, large-scale manufacturing method that brings price of our electrochromics down to ***$32.34/m²*** (~***$2.94/ft²*** ***)***. [*Costing spreadsheet shown earlier in presentation.*].
  - ➢ Switching times for window-sized panels 3s (D→L), 10s(L→D).
  - ➢ ***Functioning window-sized electrochromic panels (60cmX90cm) fabricated, tested***. Includes demonstration of working with AC adapters using house line voltage (120VAC, 50Hz).
  - ➢ ***Peripherals and infrastructure for user-installed retrofit to windows demonstrated***.
  - ➢ ***Tie-ups with commercialization partners*** (window and glass companies) initiated (see further below).







Stakeholder Engagement

- ***Note: This Phase I project is at a "late" stage.***
- ***COLLABORATION AND POTENTIAL CO-PRODUCTION DISCUSSIONS AT ADVANCED STAGE WITH*** :
  - ***APG Glass*** (Belgium-based, worldwide presence, parent *AGP America, S.A.,* https://www.agpglass.com/). They are an auto glass manufacturer (OEM to major auto companies), but are also interested in branching out into commercial building window glass. ***POC:*** Laura Granados, Director, R&D Materials Scouting.
- ***CONTACTS INITIATED WITH AND AT AN EARLY STAGE WITH***:
  - ***Vitro Architectural Glass*** *(formerly PPG Industries,* Pittsburgh-based, worldwide presence, http://www.vitroglazings.com/en-US/About-Us.aspx), North America's largest glass producer, leading provider of building window glass. ***POC:*** Steve Marino, Manager Tech Development, 412-215-1918.
  - ***Trulite Glass & Aluminum Solutions, LLC*** (Minneapolis, MN, https://www.trulite.com/), small manufacturer of window glass. Manufactures, distributes architectural glass products in N. America. It offers ***POC:*** Jeff Haberer, 612-805-2251.
  - ***Andersen Windows*** (Bayport, MN, https://www.andersencorporation.com/), largest manufacturer of OEM residential and commercial windows in N. America. ***POC:*** Kate Graham, "Glass Competency Team Leader", 651-264-7226.
- *It is proposed to initiate lab testing and field trials in collaboration with at least two of the above potential stakeholders during a potential Phase II project.*

Remaining Project Work

- *It is noted that* ***this project has already greatly exceeded the original Phase I goals***. Nevertheless, during the remainder of the project, it is proposed to:
  - Fabricate, characterize and test window-sized panels larger than those currently fabricated (which is 60cmX90cm). Target is 120cmX120cm. For proof-of-concept.
  - Affix these window-sized panels to windows using peripherals shown in Slide 10 but also including photosensor, and demo automated operation (auto-darkening/lightening) over several days with AC voltage.
  - Cost out the ITO-over-gridlines (“Innovation #4”) option.
  - Continue discussions with stakeholders (commercialization partners).

References

[1] ***Our selected publications in Conducting Polymer (CP)-based electrochromics***: **(a)** Chandrasekhar, P.; Zay, B.J.; Cai, C.; Chai, Y.; Lawrence, D., " Matched-dual-polymer electrochromic lenses, using new cathodically coloring conducting polymers, with exceptional performance and incorporated into automated sunglasses", *J. Appl. Polym. Sci*. **2014**, *131* (22), 41043. **DOI**: 10.1002/app.41043. **(b)** Chandrasekhar, P.; Zay, B.J.; Lawrence, D.; Caldwell, E.; Sheth, R.; Shephan, R.; Cornwell, J., "Variable-Emittance Infrared Electrochromic Skins Combining Unique Conducting Polymers, Ionic Liquid Electrolytes, Microporous Polymer Membranes, and Semiconductor/Polymer Coatings, for Spacecraft Thermal Control", *J. Appl. Polym. Sci*. **2014**, *131*, 40850. **DOI**: 10.1002/app.40850. **(c)** Chandrasekhar, P., Zay, B.J.; McQueeney, T.M.; Birur; G.; Sitaram, V.; Menon, R.; Elsenbaumer, R.L. (2005), "Physical, Chemical and Theoretical Aspects of Conducting Polymer Electrochromics in the Visible, IR, and Microwave Regions". *Synth. Met*., **2005,** *155* (3), 623-627. **(d)** Chandrasekhar, P. et al. "Polymers with Large, Dynamic Electrochromism in the Mid- and Far-infrared", *Advanced Functional Materials*, **2002,** *12* (2), 95-10. **(d)** (*Textbook*): Chandrasekhar, P. (sole authorship, non-edited text), *Conducting Polymers: Fundamentals and Applications. A Practical Approach*, with foreword by Lawrence Dalton: A pedagogical textbook; Kluwer Academic Publishers, Dordrecht, Netherlands, Norwell, MA, USA, *ISBN No. 0-7923-8564-0 (August 1999)*. (*New edition, to be published by Springer, is due in mid-2018*.) **(e)** *See also:* https://ashwin-ushas.com/electrochromic-sunglasses-goggles/ , https://www.ashchromics.com/ , https://ashwin-ushas.com/ . *(Accessed March 2019.).*

[2] ***Our selected, relevant PATENTS relating to electrochromics***, *in inverse chronological order (Several other patents, NOT listed for space reasons, can be searched using "Chandrasekhar, Prasanna" on www.freepatentsonline.com*): **(i)** Chandrasekhar, P., "Electrochromic Eyewear", US Design Patent, Notice of Allowance granted **2018-07-11**. **(ii)** Chandrasekhar, P., "Method and Apparatus for Control of Electrochromic Devices", US Patent 9,995,949 B2 (granted) 12 June **2018**). **(iii)** Chandrasekhar, P., "Method and Apparatus for Control of Electrochromic Devices", Taiwan Patent, Notice of Allowance issued on **2018-05-02**. **(iv)** Chandrasekhar, P., "Apparatus and Method for Electrochromic Deposition of Electrochromic Polymers", US Patent 9,945,045 B2, granted **2018-04-17**. **(v)** Chandrasekhar, P., "Complimentary Polymer Electrochromic Device", China Patent, Notice of Intent to Grant (Allowance) issued on **2017-05-09**. **(vi)** Chandrasekhar, P.; Chai, Y.C., "Potentiostat/Galvanostat with Digital Interface", U.S patent 9,632,059 B2 (granted 25 April **2017**). **(vii)** Chandrasekhar, P., "Complimentary Polymer Electrochromic Device". U.S. patent 9,594,284 B2 (granted 14 March 2017). **(viii)** Chandrasekhar, P., "Complimentary Polymer Electrochromic Device". European patent EP 2 780 762 B1. Granted 2016-03-01. **(ix)** Chandrasekhar, P.; Zay, B.J.; Laganis, E.J.; Romanov, V.V.; LaRosa, A.J., "Electrochromic Eyewear", US Patent 9,482,880 B1 (granted 1 Nov **2016**). **(x)** Chandrasekhar, P., "Complimentary Polymer Electrochromic Device". US Patent 9,274,395 B2 ((granted 1 March **2016**). **(xi)** Chandrasekhar, P., "Variable-Emittance Electrochromic Device and Methods of Preparing the Same", US Patent No. 9,207,515 B2 granted 8 December **2015**). **(xii)** Chandrasekhar, P., "Method and Apparatus for Control of Electrochromic Devices", US Patent 8,902,486 B1 ((2 December **2014**).

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References, *cont.*

[3] ***For info on US air conditioning and related energy consumption, see, e.g.:*** **(a)** See description in DOE SBIR FY2018 Phase I Release Topics, , p. 41.**(b)** https://www.eia.gov/todayinenergy/detail.php?id=36692 .
(c) https://www.energy.gov/energysaver/home-cooling-systems/air-conditioning
(d) https://www.utilitydive.com/news/eia-air-conditioners-make-up-18-of-annual-household-electrical-use/443313/
(e) https://grist.org/climate-energy/usa-number-one-in-air-conditioning-use-but-not-for-long/ .

[4] ***For info on size of commercial building windows market in USA only, see, e.g.:*** https://www.globenewswire.com/news-release/2018/07/25/1541719/0/en/Doors-and-Windows-Market-to-cross-260bn-by-2024-Andersen-Corporation-JELD-WEN-Inc-Pella-Corporation-Atis-Group-and-other-players-profiled.html (This notes that the Windows and Doors Market is forecast to reach **USD 260 billion** by 2024; according to a new research report by Global Market Insights, Inc. Residential Windows and Doors Market will contribute more than 60% market share by 2024.

Project Budget

Project Budget: *Original, Total: $149,988.00. Project start date: 2018-07-02 (but Contract awarded 2018-08-27). Project planned end date: 2019-04-01.*
Variances: *None*.
Cost to Date: *$144,988.00*
Additional Funding: *None*.

Budget History					
Start: 2018-07-02 (*but Contract awarded 2018-08-27*). *End:* 2019-04-01. *All FY 2018*		FY 2019 (current) *N/A*		FY 2020 – *N/A* (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$149,988.00		N/A		N/A	

Project Plan and Schedule

Project original initiation date: 2018-07-02 (*but Contract awarded 2018-08-27*)
Project planned completion date: Originally 2019-04-01.

PERFORMANCE SCHEDULE (AS IN ORIGINAL PHASE I PROPOSAL)

(# = decision point). ________= planned; - - - - - = actual.

MONTH → **1 2 3 4 5 6 7 8 9**
TASK ↓

Task 1: Fabricate, Test Large-Area Gridline Substrates ______________#
- - - - - - - - - - - - - - - - - -

Task 2: Echem Deposit CPs ______________#
- - - - - - - - - - - - - - - - - - -

Task 3: Fabricate, Test Large-Area Windows _______________#__________
- -

Task 4: Further Optimize Large-Area Windows ______________
- - - - - - - - - - - - - - -

Task 5: Test Adhesives _____ ______#
- - - - -

Task 6: Optimize, Test Control Electronics _____________#
- - - - - - - - - - - -

Task 7: Demo Semi-Automated Production _________
- - - - - -

Task 8: Commercial Partners, Marketing _______#
- - - - - - - - - - -

Task 9: Design Semi-Automated Pilot Plant _#
- - - - -

Task 10: Final Report _