

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

AMBILIGHT INC
Petitioner,

v.

LANNRAY OPTOELECTRONICS (ZHENJIANG) CO. LTD
Patent Owner.

Case IPR2026-00367
U.S. Patent No. 10,539,851

DECLARATION OF COLIN A. WOLDEN, PH.D.
IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW
OF U.S. PATENT NO. 10,539,851

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I, Colin Wolden, hereby declare as follows:

I. INTRODUCTION

1. I am over the age of 18 and am competent to submit this declaration. The statements and opinions herein are based on my personal knowledge and upon my background, education, research, training, and experience relating to the subject matter discussed.

2. I have been retained by Dickinson Wright PLLC on behalf Petitioner Ambilight Inc (“Ambilight” or “Petitioner”) in this matter to offer technical opinions relating to U.S. Patent No. 10,539,851 (“the ’851 Patent”) and to submit this declaration in connection with the *Inter Partes* Review of Claims 1-20 of the ’851 Patent. If called upon to do so, I am prepared to testify as an expert witness in this regard.

II. BACKGROUND AND QUALIFICATIONS

3. I received a B.S. in Chemical Engineering from the University of Minnesota in 1990, an M.S. in Chemical Engineering Practice from the Massachusetts Institute of Technology (“MIT”) in 1992, and a Ph.D. in Chemical Engineering from MIT in 1995.

4. From 1995-1997, I was a National Research Council/Army Research Office Postdoctoral Fellow and conducted my research at North Carolina State University, Department of Materials Science.

5. From 1997-2002, I was an assistant professor in the Department of Chemical Engineering at the Colorado School of Mines in Golden, Colorado. In 2002, I was promoted to Associate Professor with Tenure, and in 2008, I was promoted to Full Professor.

6. In 2010, I was appointed the Weaver Distinguished Professor in the Department of Chemical and Biological Engineering at the Colorado School of Mines. Since August 2024, I have served as the William K. Coors Distinguished Chair and Professor in the same Department of Chemical and Biological Engineering at the Colorado School of Mines. I have also held a joint appointment with the National Laboratory of the Rockies (formerly NREL) since 2017. Since 2022, I have also served as Co-founder and Chief Scientific Officer of Blaze Energy Technologies.

7. My areas of expertise and research interests include the development of thin film deposition techniques for the molecular engineering of nanostructured thin film structures, with specific applications in renewable energy, solid state ionics, membranes, and microelectronics. My current research interests more specifically include (1) catalytic membrane reformers; (2) nanostructured membranes; (3) chalcogenide-based photovoltaics and solid state battery materials; (4) fusion fuel processing; (5) macroscopic modeling of plasma and thermal CVD reactors; and (6)

understanding the fundamental process-structure-property-performance relationships in these systems.

8. I have authored or co-authored over 150 peer-reviewed academic publications in the field of chemical engineering, including thin film deposition and electrochromic films. My publications include work specifically directed to electrochromic tungsten oxide films, electrochromic performance, nanocomposite electrochromics, and smart windows. I have also delivered invited presentations relating to electrochromic films, smart windows, and related thin film technologies.

9. In addition, I have been an associate editor for the Journal of Vacuum Science and Technology (2010-2020) and a reviewer for numerous chemical engineering journals, including *Applied Physics Letters*, *Journal of Materials Science*, *Materials Letters*, *Journal of the Electrochemical Society*, *Chemical Engineering Education*, *Vacuum*, *Diamond and Related Materials*, *Thin Solid Films*, *Journal of Electronic Materials*, *Langmuir*, *Journal of Crystal Growth*, *Macromolecules*, *Surface and Coatings Technology*, *Optical Materials*, *Solar Energy Materials and Solar Cells*, *Applied Surface Science*, *Plasma Chemistry and Plasma Processing*, and *Journal of Materials Chemistry*.

10. For my contributions to thin film deposition technology, I was elected a Fellow of the American Vacuum Society (AVS) in 2014, a recognition given to AVS members who have made sustained and outstanding technical contributions in

areas of interest to the AVS. The membership percentage of Fellows cannot exceed 0.5% of AVS members in any calendar year.

11. I have extensive experience in the deposition of thin films, including the deposition of transparent conducting oxides, such as indium tin oxide (ITO). I also have extensive experience in electrochromics, both in my laboratory at the Colorado School of Mines and through collaborative work with the National Renewable Energy Laboratory (NREL) in Golden, Colorado. I have expertise in several thin film deposition techniques include sputtering, evaporation, plasma-enhanced chemical vapor deposition, chemical bath deposition, and ultrasonic spray deposition. Further, I have extensive experience on the interpretation and use of thin film characterization techniques such as X-ray diffraction (XRD), selected area diffraction (SAD), and transmission electron microscopy (TEM) for the determination of crystal size and structure. I also have extensive expertise in optoelectronic characterization of both thin films and complete devices using techniques such as four point probe, UV-Vis-NIR spectrophotometry, current-voltage, capacitance-voltage, cyclic voltammetry, and electrochemical impedance spectroscopy.

12. I am a named inventor on multiple United States patents and patent applications. These include, among others, patent filings relating to electrochromic

tungsten oxide for optical modulation, as well as additional patents and applications in thin films, photovoltaics, membranes, and related materials technologies.

13. In recognition of my technical contributions, I was awarded the E. T. S. Walton Fellowship by Science Foundation Ireland in 2010. I have also received numerous professional honors and awards during my career, including an NSF CAREER Award and other distinctions listed in my curriculum vitae.

14. A copy of my latest curriculum vitae (CV) is attached as **Appendix A**.

15. I have been retained as an expert in other *Inter Partes* Review (“IPR”) matters regarding electrochromic systems. This includes, for example, IPR2015-00245 involving U.S. Patent No. 7,193,763 titled “Electrochemical/electrocontrollable device electrode.”

16. In addition to my general knowledge from education and experience in this field, I have reviewed and considered, among other things: the ’851 Patent, the prosecution history of the ’851 Patent, the prior art of record, and the prior art described in this Declaration. I have also researched and reviewed other prior art references that are relevant to the ’851 Patent.

III. SCOPE OF ASSIGNMENT AND MATERIALS REVIEWED

17. I have been retained as an expert on behalf of Ambilight to provide information and opinions to the Patent Trial and Appeal Board (“the Board”) to

assist in its analysis of the patentability of the '851 Patent in the above-captioned *Inter Partes* Review.

18. I am being compensated at the rate of \$300 an hour. My compensation does not depend on the substance of my opinions nor on the outcome of this proceeding.

19. In formulating my opinions herein, I have relied upon my training, knowledge, and experience that are relevant to the '851 Patent. Furthermore, I have specifically considered the following documents listed below in addition to any other documents cited in this declaration. I understand that the references are true and accurate copies of what they appear to be:

Exhibit No.	Description
EX1001	U.S. Patent No. 10,539,851 (“the '851 Patent”)
EX1002	File History of the '851 Patent
EX1003	Declaration of Dr. Colin Wolden
EX1004	Engfeldt (WO 2017/123138)
EX1005	Pradhan (WO 2017/189307)
EX1006	Duarte (U.S. Patent No. 11,227,522)
EX1007	Carl M. Lampert, “Durability of Electrochromic Switching Devices for Glazings,” Lawrence Berkeley Laboratory Report No. LBL-24103 Rev., presented at The International Congress on Optical Science and Engineering, The Hague, The Netherlands, Mar. 12-15, 1990, and published in <i>Optical Materials Technology for Energy Efficiency and Solar Energy Conversion IX</i> , Proc. SPIE Vol. 1272, 1990.
EX1008	Hulya Demiryont & Kenneth Shannon III, “Solid-State Monolithic Electrochromic Switchable Visors and Spectacles,” in <i>Head- and Helmet-Mounted Displays XIV: Design and Applications</i> , Proc. of SPIE Vol. 7326, 73260K, 2009.

EX1009	R. Vergaz, J.M. Sánchez-Pena & D. Barrios, “Microcontrolled Electrooptic System for Online Light Transmission Control of Novel Electrochromic Devices,” <i>Microwave and Optical Technology Letters</i> , Vol. 48, No. 8, pp. 1572-1574, Aug. 2006.
EX1010	Gunnar A. Niklasson & Claes G. Granqvist, “Electrochromics for Smart Windows: Thin Films of Tungsten Oxide and Nickel Oxide, and Devices Based on These,” <i>Journal of Materials Chemistry</i> , Vol. 17, pp. 127-156, 2007.
EX1011	C.G. Granqvist, E. Avendaño & A. Azens, “Novel Electrochromic Materials and Devices,” <i>46th Annual Technical Conference Proceedings</i> , Society of Vacuum Coaters, p. 75 et seq., 2003, ISSN 0737-5921.
EX1012	U.S. Patent No. 5,610,756
EX1013	U.S. Patent No. 4,519,930
EX1014	WO 03/011688
EX1015	U.S. Patent No. 4,712,879
EX1016	D. Papathanasopoulos, G. Leftheriotis & E. Mitronikas, “Design, Fabrication, and Testing of an Electronic Device for the Automatic Control of Electrochromic Windows,” <i>Journal of Building Engineering</i> , Vol. 12, pp. 248-258, 2017.

IV. LEGAL STANDARDS AND UNDERSTANDINGS APPLIED

20. I am not an attorney. In connection with the opinions that I am offering herein, I am relying upon the legal standards and understandings that Petitioner’s attorneys have provided and/or explained to me, which I summarize below.

21. I understand that in an IPR proceeding, the Petitioner has the burden to prove that the challenged claims are unpatentable by a preponderance of the evidence. I understand that a “preponderance of the evidence” means that a fact is more likely than not to be true.

22. I understand that the first step in analyzing the patentability of a claim over the prior art is to determine the claim's meaning and scope from the perspective of a person having ordinary skill in the art ("POSA"), *i.e.* what I understand is called claim construction. Next, I understand that the claim as construed is compared to the prior art, as described in more detail below.

23. I understand that each claim must be analyzed from the perspective of a POSA at the time of invention. Petitioner's counsel has asked me to consider the state of the art from the perspective of a POSA during the time period shortly before March 6, 2018, which is the earliest claimed priority date listed on the face of the '851 Patent.

24. I understand that several factors should be considered in determining the ordinary level of skill in the art including (1) the types of problems encountered in the art; (2) the prior art solutions to those problems; (3) the rapidity with which innovations are made; (4) the sophistication of the technology; and (5) the educational level of active workers in the field of the patent.

25. I have been informed by Petitioner's counsel that in this proceeding, the Board interprets the claims of a patent in an IPR under the same standards used in a United States District Court. I understand that this standard requires interpreting the claims through the lens of a POSA in view of the entire patent and the prosecution history. I understand that, unless an express claim construction is

adopted by the Board for any term, the terms of the claims should be given their plain and ordinary meaning to a POSA at the time of the invention, in the light of the specification and prosecution history. Accordingly, in formulating my opinions, I have reviewed the claims of the '851 Patent as I perceive a POSA would have understood them at the time of the earliest claimed priority date (March 6, 2018) of the '851 Patent, after reading the entire '851 Patent specification and the prosecution history.

26. I understand that, for a patent to be “anticipated” by the prior art, every limitation of the claim must be found expressly, implicitly or inherently, to be disclosed and arranged as required by the claim, in a single prior art reference which describes the claimed invention in sufficient detail to enable a person of ordinary skill in the art to carry out the claimed invention. I understand that if one limitation of a claim is missing from that prior art, then the claim is not anticipated by the prior art.

27. I understand that a limitation of a claim may be expressly disclosed in the prior art even if the prior art does not use identical terminology. Rather, I understand that the focus is whether the substance of the limitation is disclosed. I understand that a limitation that is not expressly disclosed may be considered to be implicitly disclosed based on the inferences that a POSA would be expected to draw from the express disclosures based on the POSA’s knowledge and experience.

Moreover, I understand that where an item is not expressly or implicitly disclosed in an item of prior art, the prior art may be considered to disclose that limitation inherently if the limitation would be necessarily present in the prior art, such as when a characteristic necessarily flows from the teachings of the applied prior art.

28. I understand that even if a claimed invention is not anticipated, the claimed invention is still unpatentable as obvious if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a POSA.

29. I understand that there must have existed an apparent reason, as of the effective filing date, for a POSA to have combined the prior art references in the manner claimed. I understand that reasons that can support conclusion of obviousness include:

- Combining prior art elements according to known methods to yield predictable results;
- Simple substitution of one known element for another to obtain predictable results;
- Use of known technique to improve similar devices (methods, or products) in the same way;
- Applying a known technique to a known device (method, or product) ready for improvement to yield predictable results;
- “Obvious to try” – choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;

- Known work in one field of endeavor may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations are predictable to one of ordinary skill in the art;
- Some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

V. LEVEL OF ORDINARY SKILL IN THE ART

30. Based on my experience, and applying my above-explained understanding of the relevant legal principles, it is my opinion that a POSA of the '851 Patent, at the time of its claimed earliest filing date, would have had at least a bachelor's degree in electrical engineering, materials science, chemical engineering, physics, or a similar discipline, and at least 2-3 years of experience working with electrochromic devices, thin-film optical devices, smart-window systems, electrochemical devices, or control systems for such devices. Additional education, such as a master's degree or Ph.D. in one of these fields, could substitute for some practical experience.

VI. CLAIM CONSTRUCTION

31. Based on my experience, and applying my above-explained understanding of the relevant legal principles, it is my opinion that no express construction of any claim term of the '851 Patent is needed to resolve any of the issues of patentability I opine about here. Except as otherwise noted below, I have applied the plain and ordinary meaning of the terms of the patent to a POSA as of

the purported earliest filing date in light of the specification and the prosecution history.

32. I understand that claim construction is ultimately a question of law, and that the Board may choose to provide a construction of certain terms should any dispute arise between the parties over how a term should be construed. I reserve the right to review and potentially modify any of my opinions discussed below in view of any such claim construction which is adopted by the Board or any other tribunal.

VII. BACKGROUND OF THE TECHNOLOGY

33. Electrochromic technology was already a well-developed field well before the earliest effective filing date of the '851 Patent. Electrochromic devices were understood as devices that could reversibly change visible appearance and optical performance in response to an applied electrical input, including by changing transmittance, reflectance, absorptance, tint, or optical density. (EX1010, 127-128; EX1011, 75-76.) In practical terms, these devices were already being used or proposed for products such as smart windows, rear-view mirrors, display devices, visors, spectacles, goggles, and aircraft transparencies. (EX1008, Abstract; EX1008, 73260K-1; EX1010, 127-128; EX1011, 75-76; EX1012, Abstract; EX1014, Abstract.) For example, EX1008 describes solid-state monolithic electrochromic switchable visors and spectacles for use in helmets and eyewear, while EX1009 describes a microcontrolled electro-optic system for online light-transmission

control of electrochromic devices. (EX1008, Abstract, 73260K-1; EX1009, 1572-1573.) By the time of the alleged invention, a person of ordinary skill in the art would have viewed electrochromic devices as a familiar class of electrically driven light-control systems. (EX1004, 1:10-21; EX1010, 127-128.)

34. The development of electrochromic device technology has spanned decades. By the early 1980s, electrochromic display devices using electrodes and electrolytes were already known and were operated by applying voltage to produce coloration and bleaching. (EX1013, Abstract.) By the late 1980s and 1990s, electrochromic mirrors had been developed in layered solid-state form, with variable darkening and lightening controlled through electrical input, and with drive circuitry used to establish a desired reflectance level. (EX1015, claim 1; EX1012, Abstract; EX1012, claims 1, 15, 18, 20.) By the early 2000s, electrochromic technology had expanded beyond displays and mirrors to architectural windows, automotive windows, visors, and aircraft transparency windows with variable luminous transmittance. (EX1008, Abstract; EX1011, 75-76; EX1014, Abstract.) Around that same period, the literature also described controller-based electrochromic systems for continuously adjusting light transmission in real time, further reflecting that electrochromic technology had matured into a practical electronic control technology. (EX1009, 1572-1573.)

35. The basic architecture and operation of electrochromic devices were also understood well before 2018. Typical devices included transparent conductive layers, an electrochromic layer, an ion-conducting layer or electrolyte, and often a complementary counter or ion-storage layer on glass or flexible polymer substrates. (EX1011, 75-76; EX1010, 127-128.) Applying voltage across those conductive layers changed the optical properties of the device, and changing the electrical drive could move the device back toward a prior state or to a different state. (EX1010, 128; EX1011, 75-76.) It was also well understood that electrochromic devices were not limited to simple on/off operation, but could be driven to intermediate optical states and could maintain a selected condition through open-circuit memory with little or no continued power. (EX1010, 128; EX1011, 75-76.) Electrochromic devices could continuously change transmission, and optical density could be continuously changed by varying voltage (EX1008, 73260K-3), and online light-transmission control was already known to use a microcontrolled system that monitors electrical behavior during switching. (EX1009, 1572-1573.)

36. In practical terms, it was well known before March of 2018 for a user or controller to select a target tint, reflectance, or transmittance level, drive the device to that level electrically, and then maintain it there. (EX1008, 73260K-3; EX1009, 1572-1573; EX1010, 128; EX1011, 75-76.) Such was basic control operation of electrochromic devices.

37. Moreover, it has been known for decades that electrochromic devices could be described and controlled in both voltage-based and current-based terms. Wikipedia defines electrochromism as a “phenomenon in which a material displays changes in color or opacity in response to an electrical stimulus.” A person of ordinary skill in the art would have understood that as a basic feature of electrochromic operation, because electrochromic switching fundamentally involves electrically driven movement of charge into or out of the electrochromic material, and practitioners in the field commonly characterized and controlled that process using either an applied voltage condition, an applied current condition, or charge derived from current over time, depending on the device architecture and the particular control or testing objective. Stated differently, a person of ordinary skill in the art would have understood voltage-controlled operation and current-controlled operation as established electrical control approaches for driving an electrochromic transition. That understanding is consistent with the contemporaneous literature explaining that, “[i]n general, a d.c. voltage is used to drive actual devices,” but also that “since electrochromism is actually a current controlled phenomenon, fixed voltage sources with controlled current have also been used for testing.” (EX1007, “Durability of Electrochromic Switching Devices for Glazings,” at 5.) It is also consistent with older patent literature such as U.S. Patent No. 4,519,930, which describes electrochromic operation in both current-drive and voltage-drive terms,

including that a display film was “colored by a coloring charge . . . injected . . . with constant current,” and that the coloring charge was then moved between electrochromic films “by the external voltage.” (EX1013, U.S. Patent No. 4,519,930, at 7:35-41.) That same understanding is reflected in more modern electrochromic-window control systems, such as the reference explaining that its microcontroller-based apparatus for “transmittance control of electrochromic windows” allows the user to select among different operating modes and that “either voltage or current control can be performed.” (EX1016, “Design, Fabrication, and Testing of an Electronic Device for the Automatic Control of Electrochromic Windows,” Abstract.) A person of ordinary skill in the art would have understood, as rudimentary knowledge, that both voltage-based and current-based electrochromic control were well-known and conventional.

VIII. OVERVIEW OF THE '851 PATENT

A. Specification and Claims

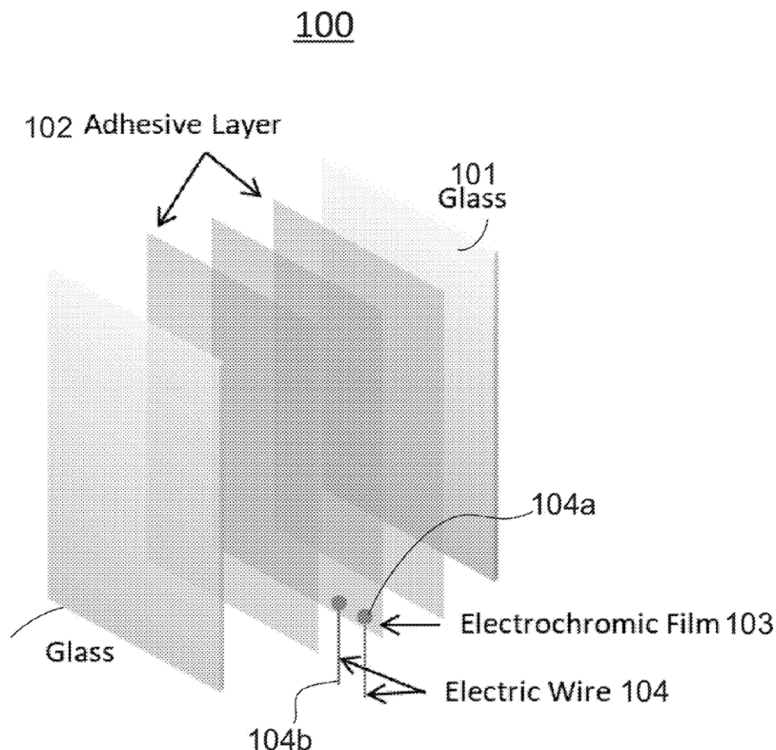
38. The '851 Patent relates generally to methods of changing the optical state of an electrochromic film with a plurality of optical states. (EX1001, Abstract.) As described in the specification, the electrochromic film may be used in glass windows, smart windows, or other devices in which optical properties such as lightness, transparency, color, or reflectance are changed. (EX1001, 1:15-28.) The patent is directed broadly to electronically controlling the optical state of an

electrochromic film by injecting charge into the film or extracting charge from the film until a selected optical state is reached. (EX1001, Abstract; 1:19-30.)

39. The specification explains that the optical state of an electrochromic film depends on the amount of charge injected into or extracted from the film. (EX1001, 1:19-23.) Specifically, “[t]he optical state of an electrochromic material depends on the amount of charge injected or extracted,” and “[t]he electrochromic film’s optical state could be set at any state by controlling the amount of charges.” (*Id.*, 1:18-24.) To accomplish the desired tinting, the patent describes selecting a desired optical state, determining a corresponding amount of charge or driving force, applying electrical drive to the electrochromic film, monitoring the amount of charge moved into or out of the film, and then stopping when a preset amount corresponding to the desired state has been reached. (EX1001, Abstract; 7:21-39.) The specification also explains that electric controllers may be used to control electrochromic films integrated with glass windows, including smart windows. (EX1001, 1:24-28.) Thus, the patent presents the claimed methods as controller-based approaches for moving an electrochromic film to a selected optical state by managing electrical input to the film. (EX1001, 1:24-30.)

40. Figure 1 depicts a simplified electrochromic device 100, such as a smart window, including outer glass layers 101, an electrochromic film 103 sandwiched

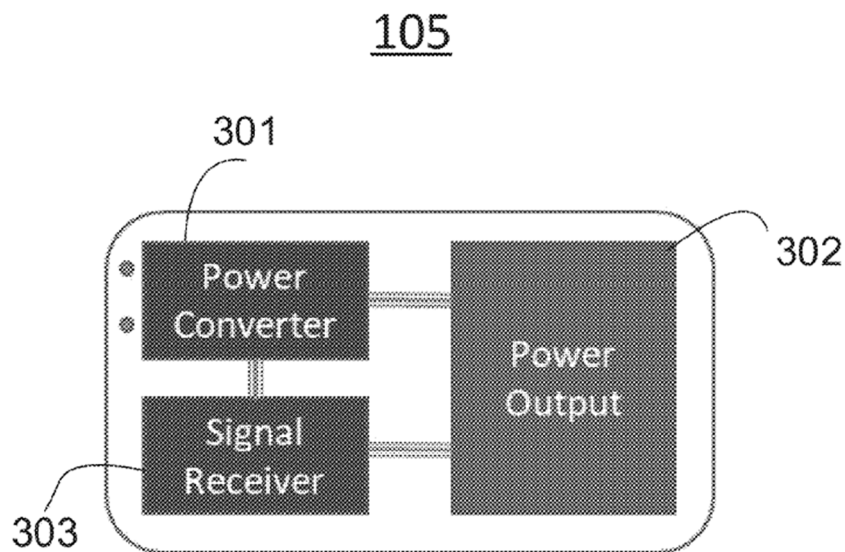
between the glass layers, and adhesive layers 102 attaching the electrochromic film 103 to the glass layers 101. (*Id.*, 3:23-34.)



EX1001, Figure 1

41. Structurally, Figure 3 depicts a controller 105 that is “configured to control the state of the electrochromic device 100 by controlling the states of the electrochromic film 103.” (EX1001, 3:41-43.) The controller 105 includes “a power converter 301, a power output control 302, and a signal receiver 303.” *Id.*, 7:36-38. “The power converter 301 may convert input power from a power source to the power required by the signal receiver 303 and the power output control 302.” (*Id.*, 7:38-46.) The power output control 302 is “configured to supply power to the electrochromic film 103.” (*Id.*) “Since the state of the electrochromic film 103 is

driven by electric charges, the power output control 302 can inject into or extract a certain amount of electric charges from the electrochromic film 103 based on the signals the signal receiver 303 receives, in order to change the state of the electrochromic film 103.” (*Id.*, 7:49-54.)



EX1001, Figure 3

42. The specification discloses a wide variety of ways to inject charge into or extract charge from the electrochromic film. The patent states that both voltage driving and current driving may be employed to inject or extract electric charges, and that a combination of voltage driving and current driving may also be employed. (EX1001, 7:60-8:2.) The specification further states that voltage driving and current driving may be operated using either direct current (“DC”) or alternating current (“AC”). (EX1001, 8:1-2.) It also explains that combinations of voltage driving and current driving, pulsed voltage driving and current driving, and combinations of

pulsed and DC driving may be used to change electrochromic materials to a desired optical state. (EX1001, 10:29-32.) The specification appears to be intentionally broad in this respect and describes numerous alternative electrical techniques for supplying or removing charge, rather than focusing on a single specific implementation.

43. The claims reflect that same broad approach. The patent includes three independent claims—claims 1, 8, and 15—each directed to a method of changing an optical state of an electrochromic film. (EX1001, claims 1, 8, 15.) Independent claim 1 is directed to injecting electric charges into the electrochromic film by a driving force that includes voltage driving, current driving, and/or a combination of voltage driving and current driving, while monitoring the injected charge and stopping when the charge reaches a preset amount corresponding to the desired state. (EX1001, claim 1.) Independent claim 8 is similar, but directed to extracting electric charges from the electrochromic film by a driving force that likewise includes voltage driving, current driving, and/or a combination of voltage driving and current driving, while monitoring the extracted charge and stopping when the charge reaches a preset amount corresponding to the desired state. (EX1001, claim 8.) Independent claim 15 recites setting a plurality of predetermined optical states, determining an amount of electric charges corresponding to each of those states, selecting a desired state, determining a driving force, and adjusting the amount of electric charges within the

electrochromic film to the amount corresponding to the selected desired state. (EX1001, claim 15.) This is all old technology, as I will explain below in further detail. The claim re-iterate standard practices for controlling the optical properties of electrochromic devices that have been done for years and years before the '851 Patent.

44. The dependent claims further confirm that the patent seeks to cover a broad range of electrical driving techniques. For example, Claims 2 and 9 recite applying an external DC *voltage*. (EX1001, claims 2, 9.) Claims 3 and 10 recite applying an external DC *current*. (EX1001, claims 3, 10.) Claims 4 and 11 recite applying an external *pulsed voltage*. (EX1001, claims 4, 11.) Claims 5 and 12 recite applying an external *pulsed current*. (EX1001, claims 5, 12.) Other claims recite combinations of the same. This is a broad attempt to capture scope in the field that has been known and used for literally decades. Below I go into more detail about this opinion.

IX. GROUND 1: CLAIMS 1-2, 4, 7-9, 11, 14-16 AND 20 ARE INVALID UNDER §103 IN VIEW OF ENGFELDT

45. I have reviewed claims 1-2, 4, 7-9, 11, 14-16 and 20. A POSA would have found these claims to be obvious over the teachings of EX1004 (“Engfeldt”).

A. Overview of Engfeldt

46. Engfeldt is directed to the same general field as the '851 Patent: electronically controlling the optical state of an electrochromic device based on the

device's measured electrical properties. Engfeldt explains that electrochromic devices had already been used in many applications, including "vehicle mirrors, construction windows, spectacles or different kinds of imaging devices." (EX1004, 1:10-14.) Engfeldt further explains that "[t]he transmittance is typically controlled by charging or discharging the electrochromic device," and that, by changing the electric potential across the device, "ions or electrons are caused to pass the electrolyte layer" and "the result is a changing or a discharging of the electrochromic layered structure, resulting in a colouring or bleaching of the electrochromic layer and/or counter electrode layer." (EX1004, 1:13-21.) Thus, Engfeldt is plainly concerned with controlling the optical state or transmittance of an electrochromic device by controlling how charge is applied to or removed from the device. This includes obtaining a target coloring level, measuring the existing coloring level, and then charging or discharging the device to achieve the desired optical state. (EX1004, Abstract.)

47. Engfeldt also addresses the practical problem of how to change the transmittance of an electrochromic device quickly without overdriving or damaging the device. Engfeldt explains that, when a change in transmittance is requested, "[t]he change is typically requested to be performed as rapidly as possible, which is favoured by applying a high voltage across the electrochromic device." (EX1004, 1:23-26.) But Engfeldt immediately notes that "electrochromic devices may be

damaged, or at least the life time of an electrochromic device may be significantly reduced [if] too high voltages are applied.” (EX1004, 1:26-29.) Engfeldt therefore explains that “it is necessary to find a suitable compromise between transition time and applied voltages.” (EX1004, 1:28-29.) In my opinion, that discussion is important because it shows that Engfeldt is focused on selecting and controlling electrical drive conditions to move the device to a desired optical state efficiently, while accounting for practical concerns such as temperature, device age, configuration, and device lifetime. (EX1004, 2:1-8; 3:21-30.)

48. Engfeldt’s proposed solution is to control the electrochromic device using electrical measurements taken from the device itself, rather than relying on external transmittance or temperature sensors. Engfeldt states that its technology is “primarily based on the insight that it would be of benefit not to have to rely on any external sensors at all and instead only rely on the electric behaviour of the electrochromic film and the power supply arrangement.” (EX1004, 6:10-13.) Engfeldt further explains that “[m]easurements of electrical quantities are relatively easy to implement in a robust manner,” and that, “[b]y monitoring only a charge density of the electrochromic film (which e.g. can be computed from integration of measurements of charging current) and the open circuit voltage, there is a possibility to control the charge operations in a favourable manner independent on ageing or temperature changes.” (EX1004, 6:13-19.) In my opinion, this is a central teaching

of Engfeldt: the device's optical transition is controlled using charge-related electrical behavior, including charging current, integrated charge, and open-circuit voltage.

49. The Engfeldt patent is much more advanced than the '851 patent. The '851 simply relates the optical state to the amount of charge. Engfeldt not only does that, but also describes control algorithms that are used to derive the best way to deliver the desired amount of charge when balancing practical concerns such as minimizing the switching time while constraining electrical parameters (voltage/current density) within acceptable ranges so as to not damage the device or its lifetime.

50. Engfeldt describes several embodiments for accomplishing that objective. At a high level, those embodiments begin by obtaining a target coloring level and information about the electrochromic device's then-current condition, and then using electrical control stages to move the device to the desired optical state. As Engfeldt explains:

is changed into a charging state. This charging state can in turn comprise a number of sub- states ... In a first substate, a calibration state, relatively gentle charging is performed while monitoring the responses on charge and open circuit voltage to different charging voltages. From this monitoring, suitable conditions for the main charging operation are deduced. (*Id.*, 7:24-31.)

51. Figure 1 and its associated description provide a useful illustration of how Engfeldt's control method works. In step 210, Engfeldt obtains "a target colouring level and a measure of an initial colouring level." (EX1004, 8:15-21.) Engfeldt explains that "[t]he target colouring level is a representation of the requested colouring level," and that it may be represented as a percentage value where "100% corresponds to a fully charged condition and 0% corresponds to a fully discharged condition." (EX1004, 8:20-21; 8:27-9:8.) In step 220, Engfeldt obtains "a measure of an initial open circuit voltage between electrodes of the electrochromic device." (EX1004, 9:16-19.) The device then enters the charging state, and initially the calibration substate 239 (shown in **yellow** below). (EX1004, 9:21-24.)

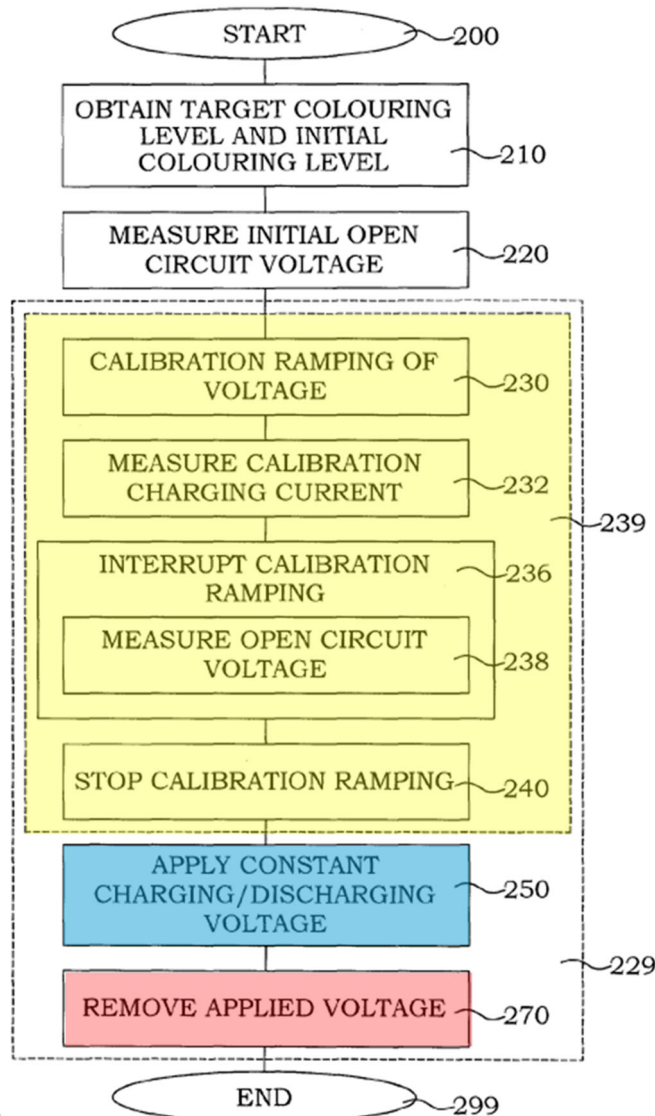


Fig. 1

EX1004, Figure 1

52. During that calibration substate, Engfeldt explains that “a calibration ramping is performed, ramping a voltage applied between electrodes of the electrochromic device.” (EX1004, 9:24-27.) Engfeldt further explains that, in step 232, “a calibration charging current is measured,” and that “[t]he charging current corresponds to a change of the charge of the electrochromic device.” (EX1004,

10:24-28.) The calibration ramping is “interrupted, intermittently and temporarily,” and, during those interruptions, “a calibration open circuit voltage between the electrodes of the electrochromic device is measured.” (EX1004, 10:30-34.) Engfeldt then explains the importance of those measurements: “[t]he evolution of the charging current, or therefrom deducible quantities, such as the charge of the electrochromic device, and of the open circuit voltage, reveals details of the charging conditions of the electrochromic device.” (EX1004, 11:1-3.)

53. When a calibration condition is satisfied, Engfeldt stops the calibration ramping and transitions to a main charging or discharging stage. Specifically, Engfeldt explains that, in step 240, “the calibration ramping of the voltage is stopped when a calibration condition based on the calibration charging current and/or the calibration open circuit voltage is met.” (EX1004, 11:16-21.) Engfeldt then states that, in step 250 (shown in **blue** above), “a constant main charging/discharging voltage is applied between the electrodes of the electrochromic device,” and that “[t]he main charging/discharging voltage is thereby selected in dependence of the ramped voltage when stopped.” (EX1004, 11:21-25.) Engfeldt further explains that, “[d]ue to the information obtained during the calibration ramping, the now selected main charging/discharging voltage can now be set to compensate for variations in configuration, temperature, age, etc.” (EX1004, 11:25-29.) Engfeldt therefore determines an appropriate electrical driving condition based on the device’s

measured electrical behavior during calibration, and then applies that selected voltage to move the electrochromic device toward the target optical state.

54. Engfeldt also explains that the applied voltage is removed when the target coloring level is reached. In the embodiment of Figure 1, Engfeldt states that, in step 270 (shown in **red** above), “when the target colouring level is reached, any application of a voltage between the electrodes of the electrochromic device is removed.” (EX1004, 11:29-33.) That same general control concept appears throughout Engfeldt’s disclosure: a desired optical condition is identified, the device is driven electrically toward that condition, and the applied voltage is stopped when the target condition is reached.

55. Engfeldt further teaches that “there are many possible procedures to use for arriving to the intended transmittance level.” (EX1004, 15:25-27.) Figure 3 illustrates another embodiment in which, after calibration substate 239 (yellow), the device proceeds to a static state 259 that continues monitoring electrical behavior while the device is driven toward the requested final condition. (EX1004, 15:25-30.) In that embodiment, Engfeldt measures “a main charging current” in step 252 (blue) while the constant main charging/discharging voltage is applied. (EX1004, 15:30-16:3.) Engfeldt further teaches in step 254 that the measured main charging current may be integrated “into a main charge change” and used to update “the present device charge.” (EX1004, 16:9-12.) Engfeldt also explains that the application of the

constant main charging/discharging voltage may be “interrupted, intermittently and temporarily,” and that, during the interruption, “a main open circuit voltage” is measured (steps 256/258). (EX1004, 16:1-4.) The main voltage application is then stopped at step 270 (red) when “a main stop condition based on the main charging current and/or the main open circuit voltage is met.” (EX1004, 16:4-7.)

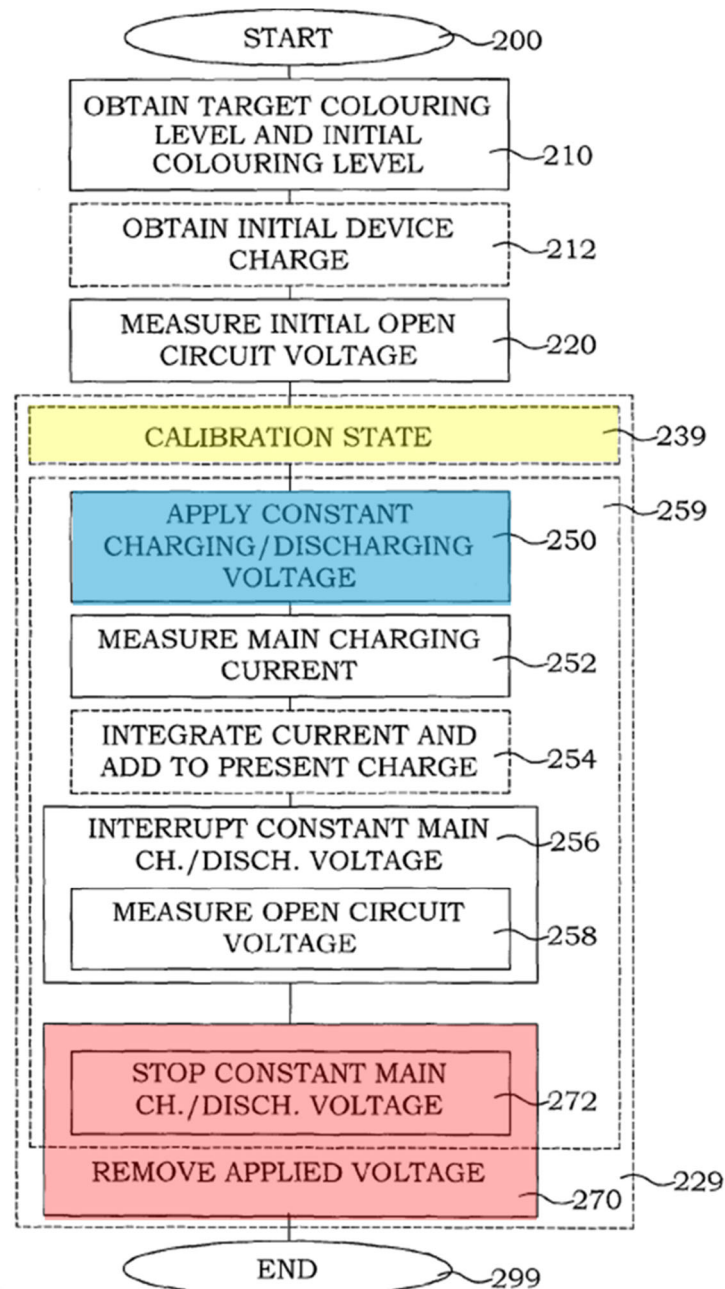
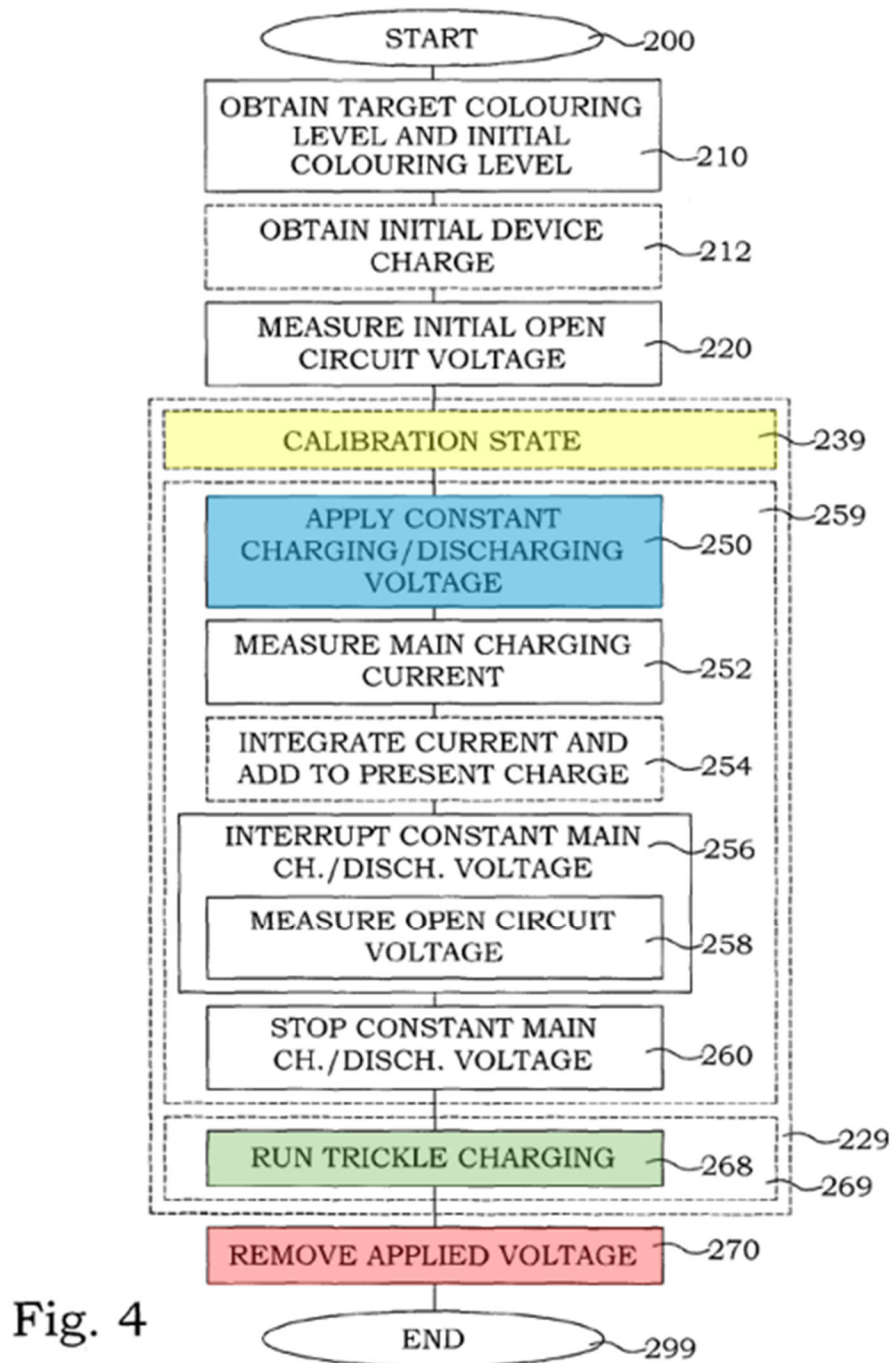


Fig. 3

EX1004, Fig. 3

56. Figure 4 discloses yet another embodiment, which again includes calibration substate 239 and application of a constant main charging/discharging voltage, but then adds a trickle charging stage to approach the final transmittance

state more gradually. Specifically, Engfeldt explains that, when coming closer to the intended final transmittance condition, the static-state operation “might be experienced as a somewhat coarse charging method.” (EX1004, 17:15-17.) Engfeldt therefore introduces “an additional trickle substate 269” in which “the stopping of the constant main charging/discharging voltage is here instead followed by the trickle substate.” (EX1004, 17:17-24.) In step 268 (green), “a trickle charging is run when the applying of the constant main charging/discharging voltage is stopped,” and “[t]he trickle charging continues until the target colouring level is reached.” (EX1004, 17:24-27.) Engfeldt explains that, in the trickle state, “the charge of the electrochromic device is increased, if a charging is requested, or decreased, if a discharging is requested, in small amounts, to slowly approach the final transmittance.” (EX1004, 17:29-18:2.) Engfeldt also states that “[m]easurements of the charge, leading to a present device charge as well as of the open circuit voltage may continue also during this substate.” (EX1004, 18:2-5.) Figure 4 reinforces that Engfeldt discloses not just a single rigid charging routine, but a flexible control approach in which electrical drive conditions are adjusted as the device approaches its desired optical state.



EX1004, Fig. 4

57. Engfelt defines “trickle” as having the general meaning of allowing “small portions something to pass. In the trickle state, the charge of the electrochromic device is increased . . . or decreased . . . in small amounts, to slowly

approach the final transmittance (EX1004, 17:29-32). Moreover, Engfelt clearly states that trickle charging is run when the application of the “constant main charging/discharging voltage is stopped” (EX1004, 30: 29-30). From the explicit cessation of constant voltage and the description of changing the number of charges in discrete amounts, a person of ordinary skill in the art would conclude that this trickle charging is accomplished by pulsing the voltage.

58. Finally, Engfeldt makes clear that its control techniques are intended for broad use in electrochromic applications. As noted above, Engfeldt identifies “vehicle mirrors, construction windows, spectacles or different kinds of imaging devices” as example applications. (EX1004, 1:10-14.) Engfeldt also states that “[t]he present technology is applicable on most prior art electrochromic films, where the electrochromic film presents a transmittance that is dependent on a charge of the electrochromic film.” (EX1004, 6:29-31.) In my opinion, a person of ordinary skill in the art would have understood Engfeldt as disclosing a broadly applicable method for electronically controlling an electrochromic device by obtaining a desired optical condition, monitoring the open circuit voltage and amount of charge injected/removed from the film, selecting an appropriate charging or discharging voltage, adjusting the applied voltage as it approaches the desired state, and removing the voltage and stopping the injection/extraction of charge when the target condition is reached.

B. Claims 1-2, 4, 7, 8-9, 11, 14-16 and 20 are Invalid Under §103 in View of Engfeldt

1. Claim 1

- a) [1.pre] A method of changing an optical state of an electrochromic film, wherein the electrochromic film has a plurality of optical states, comprising:**

59. Engfeldt discloses a method of changing an optical state of an electrochromic film, wherein the electrochromic film has a plurality of optical states.

60. A person of ordinary skill in the art would have understood Engfeldt to disclose a method for changing the optical state of an electrochromic film because Engfeldt is expressly directed to controlling the transmittance, or transparency, of an electrochromic device by electrically charging or discharging it. Engfeldt explains that electrochromic devices had already been used in applications including “vehicle mirrors, construction windows, spectacles or different kinds of imaging devices,” and that “[t]he transmittance is typically controlled by charging or discharging the electrochromic device.” (EX1004, 1:10-15.) Engfeldt further explains that, when the electric potential across the device is changed, “ions or electrons are caused to pass the electrolyte layer” and “[t]he result is a charging or a discharging of the electrochromic layered structure, resulting in a colouring or bleaching of the electrochromic layer and/or counter electrode layer.” (EX1004, 1:15-21.) A person of ordinary skill in the art would have understood this disclosure to describe changing the optical state of an electrochromic film.

61. Engfeldt also discloses that the electrochromic film has a plurality of optical states. Engfeldt explains that “the present technology is applicable on most prior art electrochromic films, where the electrochromic film presents a transmittance that is dependent on a charge of the electrochromic film.” (EX1004, 6:29-32.) Engfeldt does not describe only two fixed end states. Instead, it explains that a controller obtains “a target colouring level” that represents the requested optical condition, and that the target coloring level may be expressed as a percentage value, where “100% corresponds to a fully charged condition and 0% corresponds to a fully discharged condition.” (EX1004, 8:15-21; 8:27-9:8.) In my opinion, a person of ordinary skill in the art would have understood those disclosures to mean that Engfeldt’s electrochromic film can be driven to multiple different optical states between those endpoints, rather than merely toggled between a single clear state and a single dark state.

62. Engfeldt further discloses a method of changing among those different optical states. Engfeldt states that “when a change of transparency is requested, the electrochromic device is changed into a charging state,” and that, through its charging substates, the device is driven toward the requested condition. (EX1004, 7:24-8:6.) Engfeldt likewise explains that, in one embodiment, “when the target colouring level is reached, any application of a voltage between the electrodes of the electrochromic device is removed,” confirming that the device is electrically driven

until the selected optical condition is achieved. (EX1004, 11:29-33.) Engfeldt also states that “there are many possible procedures to use for arriving to the intended transmittance level,” again reflecting that its disclosed methods are directed to moving an electrochromic film from one optical state to another selected optical state. (EX1004, 15:25-27.)

63. For these reasons, a POSA would therefore have understood Engfeldt to disclose the limitations of [1.pre], namely, “a method of changing an optical state of an electrochromic film, wherein the electrochromic film has a plurality of optical states.”

b) [1.1] selecting a desired state of the plurality of optical states;

64. Engfeldt discloses selecting a desired state of the plurality of optical states.

65. A person of ordinary skill in the art would have understood Engfeldt to disclose selecting a desired optical state because Engfeldt expressly begins its control method by obtaining a requested target optical condition for the electrochromic device. Engfeldt explains that, in step 210 of Figure 1, “a target colouring level and a measure of an initial colouring level is obtained.” (EX1004, 8:15-21.) Engfeldt further explains that “[t]he target colouring level is a representation of the requested colouring level.” (EX1004, 8:20-21.)

66. Engfeldt also makes clear that the “target colouring level” corresponds to a selected optical state from among multiple possible optical states of the electrochromic device. Engfeldt explains that the target coloring level “is represented by a percentage value, where 100% corresponds to a fully charged condition and 0% corresponds to a fully discharged condition, which in turn typically corresponds to a maximum colouring and a fully bleaching, respectively, of the electrochromic device.” (*Id.*, 8:27-9:8.) A person of ordinary skill in the art would have understood this disclosure to mean that a user or controller can select different desired optical conditions along a range of possible states, rather than being limited to only two fixed endpoints. In other words, selecting a “target colouring level” in Engfeldt is selecting a desired one of the plurality of optical states of the electrochromic film.

67. This is consistent with Engfeldt’s overall objective, which is to move the electrochromic device to an “intended transmittance level” or requested transparency condition. Engfeldt explains that “there are many possible procedures to use for arriving to the intended transmittance level.” (EX1004, 15:25-27.) Engfeldt also states that, “when the target colouring level is reached, any application of a voltage between the electrodes of the electrochromic device is removed.” (EX1004, 11:29-33.) A person of ordinary skill in the art would have understood

from these disclosures that Engfeldt first identifies the desired optical condition to be achieved and then controls the device so that it reaches that selected condition.

68. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt to disclose the limitations of [1.1], *i.e.*, “selecting a desired state of the plurality of optical states.”

c) **[1.2] injecting electric charges into the electrochromic film by a driving force, wherein the driving force includes voltage driving, current driving, and/or a combination of voltage driving and current driving;**

69. Engfeldt discloses “injecting electric charges into the electrochromic film by a driving force, wherein the driving force includes voltage driving, current driving, and/or a combination of voltage driving and current driving.”

70. A person of ordinary skill in the art would have understood Engfeldt to disclose injecting electric charges into the electrochromic film by a driving force, and that driving force includes voltage. First, Engfeldt states that, during the calibration substate, “a calibration ramping is performed, ramping a voltage applied between electrodes of the electrochromic device.” (EX1004, 9:24-27.) Engfeldt further states that, after calibration, “a *constant main charging/discharging voltage* is applied between the electrodes of the electrochromic device. The main charging/discharging voltage is thereby selected in dependence of the ramped voltage when stopped. Due to the information obtained during the calibration ramping, the now selected main charging/discharging voltage can now be set to

compensate for variations in configuration, temperature, age., etc.” (EX1004, 11:21-29.)

71. A person of skill in the art would have also understood Engfeldt to teach injecting electric charges into the electrochromic film by voltage driving *during any trickle charging*. Engfeldt explains that, in this trickle substate, “the charge of the electrochromic device is increased, if a charging is requested, or decreased, if a discharging is requested, in small amounts, to slowly approach the final transmittance.” (EX1004, 17:29-18:2.) In my opinion, a person of ordinary skill in the art would have understood this trickle charging stage to still use voltage as the driving force for charging, even though Engfeldt states that the earlier “constant main charging/discharging voltage” is stopped. That is because Engfeldt is still describing an electrical charging operation in which the device’s charge is deliberately increased in controlled increments until the target coloring level is reached. (EX1004, 17:24-18:2.) This is further evidenced in the Fig. 4 embodiment by the subsequent removal of that voltage in step 270 “when such a target colouring level is reached”. Earlier in the reference, Engfeldt explains that electrochromic transmittance is controlled by charging or discharging the device through application of electric potential across the device, and that changing the electric potential causes the electrochromic structure to color or bleach. (EX1004, 1:13-21.) A person of ordinary skill in the art therefore would have understood the trickle substate as

continuing that same voltage-driven charging process, but with smaller, more gradual or perhaps discrete electrical inputs (i.e. pulses) as the device approaches the final transmittance. This understanding is also consistent with Engfeldt's statement that, during the trickle substate, measurements of charge and open-circuit voltage may continue, confirming that the device remains under electrical control as it is brought to the target optical state. (EX1004, 1817:29-18:5.)

72. And, as eluded to earlier, Engfeldt also teaches injecting electric charges into the electrochromic film *during the calibration stage*. For example, Engfeldt explains that, when a change of transparency is requested, the device enters a charging state and, “[i]n a first substate, a calibration state, relatively gentle charging is performed while monitoring the responses on charge and open circuit voltage to different charging voltages.” (EX1004, 7:28-30.) In the FIGS. 2-4 embodiments, during this calibration substate, “a calibration ramping is performed, ***ramping a voltage applied between electrodes of the electrochromic device***,” and “a calibration charging current is measured.” (*Id.*, 9:24-10:28, emphasis added.) Engfeldt further explains that the measured calibration charging current is added to the initial device charge, which gives the present device charge. (*Id.*, 11:32, 12:1.)

73. In my opinion, a person of ordinary skill in the art would have understood these disclosures to teach using voltage as the driving force for injecting electric charges into the electrochromic film.

74. Engfeldt’s discussion of charging current confirms that the applied voltage is used to drive charge into the electrochromic device. Engfeldt explains that, during calibration, “a calibration charging current is measured,” and that “[t]he charging current corresponds to a change of the charge of the electrochromic device.” (EX1004, 10:24-28.) Engfeldt also explains in its Figure 3 embodiment that “a main charging current” is measured while the constant main charging/discharging voltage is applied, and that this current may be integrated “into a main charge change” and used to update “the present device charge.” (EX1004, 15:30-16:3; EX1004, 16:9-12.) Potentiostatic charging means holding the voltage constant and allowing the current density to fluctuate. Galvanostatic charging means controlling the voltage so that the applied current density is constant. A person of ordinary skill in the art would have understood that charging through an applied voltage or an applied current are two variations of the same electrical charging operation, and that Engfeldt’s disclosed voltage driving causes current flow and corresponding charge injection into the electrochromic film

75. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt to disclose or at least render obvious the limitations of [1.2], *i.e.*, “injecting electric charges into the electrochromic film by a driving force, wherein the driving force includes voltage driving, current driving, and/or a combination of voltage driving and current driving.”

d) [1.3] determining the driving force based on the desired state of the plurality of optical states;

76. Engfeldt discloses determining the driving force based on the desired state of the plurality of optical states.

77. A person of ordinary skill in the art would have understood Engfeldt to disclose determining the driving force based on the desired state because Engfeldt first obtains the requested optical condition to which the electrochromic device is to be driven. As discussed above regarding Claim [1.2], Engfeldt explains that, in step 210, “a target colouring level and a measure of an initial colouring level is obtained.” (EX1004, 8:15-21.) Engfeldt further explains that “[t]he target colouring level is a representation of the requested colouring level,” and that the target coloring level may be represented as a percentage value, where “100% corresponds to a fully charged condition and 0% corresponds to a fully discharged condition.” (EX1004, 8:20-21; 8:27-9:8.) A person of ordinary skill in the art would have understood this “target colouring level” to be the desired state of the plurality of optical states.

78. Engfeldt then determines suitable charging conditions after obtaining that desired optical state. Engfeldt explains that, when a change of transparency is requested, the electrochromic device enters a charging state and, “[i]n a first substate, a calibration state, relatively gentle charging is performed while monitoring the responses on charge and open circuit voltage to different charging voltages.” (EX1004, 7:24-30.) Engfeldt then states: “From this monitoring, suitable conditions

for the main charging operation are deduced.” (EX1004, 7:30-31.) In the Figure 1 embodiment, Engfeldt further explains that “a calibration ramping is performed, ramping a voltage applied between electrodes of the electrochromic device,” that “a calibration charging current is measured,” and that calibration open-circuit voltage is measured during intermittent interruptions of the ramping. (EX1004, 9:24-10:34.) The steps in calibration stage 239 of FIGS. 1 and 2 are incorporated into the calibration stage 239 in the embodiments of FIGS. 3 and 4. “Due to the information obtained during the calibration ramping, the now selected main charging/discharging voltage can now be set.” (*Id.*, 11:26-29, *see also* 15:19-22.)

79. Engfeldt also explains that “the calibration ramping is selected to be started from the initial open circuit voltage or from a predetermined voltage in dependence of a relation between the target colouring level and the initial colouring level.” (*Id.*, 10:9-12.) “In other words, the starting value is adapted to the particular situation. If a small change in transmittance is requested, the initial open circuit voltage operates well as a start value. If a large change in transmittance is requested, standard starting values may instead be a better choice.” *Id.*, 10:12-16. Based on at least the language above, a person of ordinary skill in the art would have understood Engfeldt’s calibration process as the step in which Engfeldt determines the electrical driving force to be applied in order to move the electrochromic device toward the requested target coloring level.

80. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt to disclose the limitations of [1.3], *i.e.*, “determining the driving force based on the desired state of the plurality of optical states.”

e) [1.4] monitoring an amount of the electric charges injected into the electrochromic film; and

81. Engfeldt discloses monitoring an amount of the electric charges injected into the electrochromic film.

82. First, Engfeldt discloses monitoring an amount of electric charges injected into the electrochromic film during the main or static charging stage. Engfeldt explains that, after calibration, “When the calibration substate has been ended, there is a preferred static voltage, with which the main charging is intended to be performed.” (EX1004, 15:24-29.) Engfeldt also explains that the static state “utilizes, in a similar manner as in the embodiment of FIG. 1, measures of charging currents and open circuit voltages in order to reach a requested final condition.” (EX1004, 15:24-29.) More specifically, Engfeldt teaches that “a main charging current is measured,” while the constant main charging/discharging voltage is applied. (EX1004, 16:2-3.) Engfeldt then explains that “the main charging current is integrated into a main charge change,” and that this information is used “for updating a present device charge.” (EX1004, 16:9-12.) In my opinion, a person of ordinary skill in the art would have understood this to disclose monitoring the amount of

injected charge by measuring charging current and determining updated device charge from that measured current.

83. Engfeldt further explains that “[t]he application of the constant main charging/discharging voltage is interrupted, intermittently and temporarily,” and that, during the interruption, “a main open circuit voltage between the electrodes of the electrochromic device is measured.” (EX1004, 16:1-4.) Engfeldt then states that the main charging/discharging voltage is stopped when “a main stop condition based on the main charging current and/or the main open circuit voltage is met.” (EX1004, 16:4-7.) A person of ordinary skill in the art would have understood these disclosures to mean that, during main charging, Engfeldt actively monitors the charge being injected into the electrochromic device, including through the measured charging current and updated device charge, while also using open-circuit voltage as part of the control process.

84. Engfeldt also discloses monitoring an amount of electric charges injected into the electrochromic film during calibration. Engfeldt teaches that, during calibration, “a calibration charging current is measured,” that “[t]he current charges the electrochromic device,” and that “[t]he charging current corresponds to a change of the charge of the electrochromic device.” (EX1004, 10:24-28.) Engfeldt further explains that “the evolution of the charging current, or therefrom deducible quantities, such as the charge of the electrochromic device,” is used during

calibration. (EX1004, 11:1-6.) Engfeldt additionally teaches using the measured calibration current to determine updated device charge. As Engfeldt explains, the charging current is integrated into a calibration charge change, and the resulting calibration charge is added to the initial device charge to update the present device charge. (EX1004, 12:32-13:2.) A person of ordinary skill in the art would have understood this to disclose monitoring the amount of injected charge during calibration by measuring current and determining charge from that current.

85. Additionally, during trickle charging, Engfeldt teaches that “measurements of the charge, leading to a present device charge ... may continue.” (*Id.* 17:32-18:1.) A POSA would understand this to correspond to monitoring the device’s accumulated charge (i.e., the charge injected into the electrochromic film) during the trickle charging stage.

86. Accordingly, in my opinion, a person of ordinary skill in the art would have understood Engfeldt to teach monitoring injected charge during both main charging and calibration, as well as during the trickle charging state. Because Engfeldt measures charging current, derives charge-related quantities from that current, and updates present device charge during those stages, Engfeldt discloses monitoring an amount of the electric charges injected into the electrochromic film. (EX1004, 10:24-28; 11:1-6; 12:32-13:2; 15:24-16:12.)

87. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt to disclose the limitations of [1.4], *i.e.*, “monitoring an amount of the electric charges injected into the electrochromic film.”

f) [1.5] stopping injecting the electric charges when the electric charges reaches a pre-set amount corresponding to the desired state.

88. Engfeldt discloses stopping injecting the electric charges when the electric charges reaches a pre-set amount corresponding to the desired state.

89. A person of ordinary skill in the art would have understood Engfeldt to disclose stopping charge injection when the electrochromic device reaches the selected desired state. In the Figure 1 embodiment, Engfeldt explains that a “target colouring level” is first obtained as a representation of the requested colouring level. (EX1004, 8:15-21.) Engfeldt then states that, in step 270, “when the target colouring level is reached, *any application of a voltage* between the electrodes of the electrochromic device *is removed*.” (EX1004, 11:29-33, emphasis added.) A person of ordinary skill in the art would have understood this to mean that Engfeldt stops the electrical charging operation when the device reaches the selected target optical condition.

90. A person of ordinary skill in the art also would have understood that, in Engfeldt, reaching the “target colouring level” corresponds to reaching a pre-set amount of injected charge corresponding to the desired state. Engfeldt explains that

“the target colouring level is a representation of the requested colouring level,” and that it may be represented by a percentage value where “100% corresponds to a fully charged condition and 0% corresponds to a fully discharged condition.” (EX1004, 8:20-21; 8:27-9:8.) Engfeldt also explains that “the electrochromic film presents a transmittance that is dependent on a charge of the electrochromic film.” (EX1004, 6:29-31.) A person of ordinary skill in the art would therefore have understood that, when Engfeldt stops charging at the point the target coloring level is reached, the device has reached the amount of injected charge corresponding to that selected optical state.

91. Engfeldt’s Figure 3 embodiment confirms the same point. Engfeldt explains that, during the static state, “a constant main charging/discharging voltage is applied between the electrodes of the electrochromic device,” and “a main charging current is measured.” (EX1004, 15:30-16:3.) Engfeldt further explains that “the main charging current is integrated into a main charge change” and used “for updating a present device charge.” (EX1004, 16:9-12.) Then, at “step 272, ***the application of the constant main charging/discharging voltage is stopped*** when a main stop condition based on the main charging current and/or the main open circuit voltage is met.” (*Id.*, 16:4-8, emphasis added.) A person of ordinary skill in the art would have understood this disclosure to mean that Engfeldt stops charge injection

based on monitored electrical quantities associated with the injected charge, again when the device reaches a pre-set amount corresponding to the desired state.

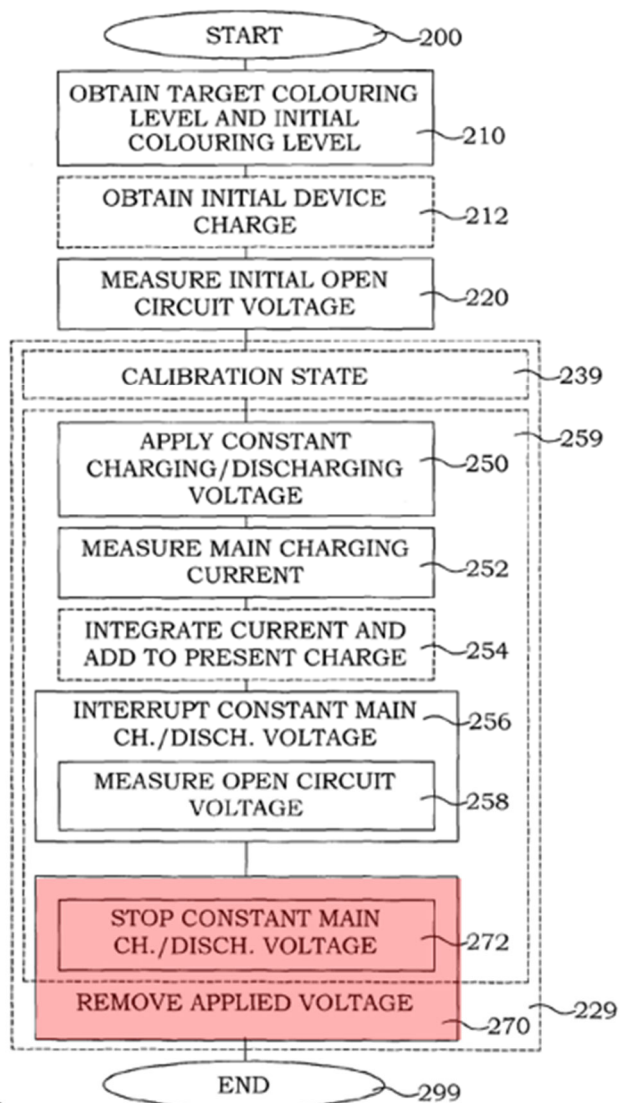
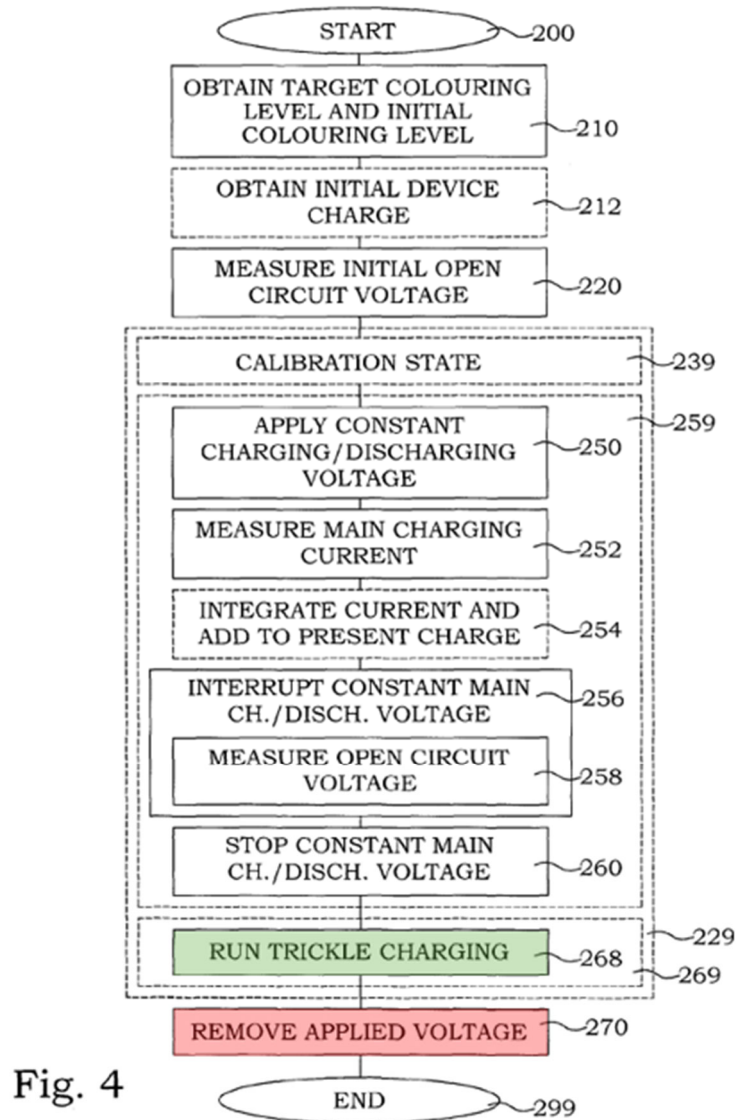


Fig. 3

EX1004, Figure 3

92. Engfeldt’s Figure 4 embodiment likewise teaches stopping charge injection at the desired endpoint. Engfeldt explains that, after the constant main charging/discharging voltage is stopped, “a trickle charging is run,” and that “[t]he

trickle charging continues until the target colouring level is reached.” (EX1004, 17:24-27.) Engfeldt further explains that, in this trickle substate, “the charge of the electrochromic device is increased, if a charging is requested, or decreased, if a discharging is requested, in small amounts, to slowly approach the final transmittance.” (EX1004, 17:29-18:2.) In my opinion, a person of ordinary skill in the art would have understood this to be another disclosure that charge injection is stopped when the device reaches the selected target optical state, i.e., when the device has reached the corresponding charge amount.



EX1004, Figure 4

93. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt to disclose the limitations of [1.5], *i.e.* “stopping injecting the electric charges when the electric charges reaches a pre-set amount corresponding to the desired state.”

2. Claim 2: The method of claim 1, wherein the voltage driving comprises applying an external DC voltage to the electrochromic film.

94. Engfeldt teaches that the voltage driving “comprises applying an external DC voltage to the electrochromic film.”

95. Engfeldt teaches the driving force includes voltage driving, *e.g.*, during main charging/discharging, the trickle charging, and the calibration stage. *See* [1.2] above.

96. Engfeldt repeatedly teaches applying voltage between the electrodes of the electrochromic device from the device’s control circuitry or power supply arrangement. For example, Engfeldt explains that, during calibration, “a calibration ramping is performed, ramping a voltage applied between electrodes of the electrochromic device.” (EX1004, 9:24-27.) After calibration, “a constant main charging/discharging voltage is applied between the electrodes of the electrochromic device.” (EX1004, 11:21-23.) And, Engfeldt states that the electrochromic film “is coloured/bleached by applying an *external voltage* pulse between the electron conducting layers . . . by electrodes . . . on the two sides of the stack,” thereby charging the electrochromic film. (*Id.*, 20:30-32, emphasis added.) A person of ordinary skill in the art would have therefore understood that a voltage applied between the electrodes of the electrochromic device is an *external* voltage applied to the device.

97. A person of skill in the art would have also understood that Engfeldt's applied voltage is DC voltage. Engfeldt describes applying a constant voltage between the electrodes to drive charging or discharging in a selected direction. Engfeldt explains that, during calibration, for charging "the voltages are successively increased," while for discharging "the voltages are successively decreased." (EX1004, 9:24-33.) Engfeldt further explains that the charging or discharging may occur "in a positive or negative direction." (EX1004, 9:24-33.) As shown in Figures 1-4, Engfeldt then teaches that, after calibration, "a constant main charging/discharging voltage" is applied between the electrodes. (EX1004, 4:9-10; 11:21-23.)

98. A person of ordinary skill in the art would have understood this disclosure of a constant charging/discharging voltage to describe a non-alternating voltage of selected polarity applied across the electrochromic film, that is, a DC voltage, rather than an AC waveform that periodically reverses polarity. Engfeldt's disclosure of voltages that are increased or decreased during calibration, followed by application of a constant main charging/discharging voltage to continue charging or discharging in the selected direction, is fully consistent with applying an external DC voltage. (EX1004, 9:24-33; 11:21-23.)

3. Claim 4: The method of claim 1, wherein the voltage driving comprises applying an external pulsed voltage to the electrochromic film.

99. Engfeldt teaches that the voltage driving comprises “applying an external pulsed voltage to the electrochromic film.”

100. Engfeldt teaches voltage driving, *e.g.*, during main charging/discharging. *See* [1.2] above. Engfeldt also explains that the applied voltage is applied to the electrochromic film, and is external. (*See* claim 2 above, ¶¶94-98).

101. A person of skill in the art would have also recognized that Engfeldt teaches that the applied external voltage can be pulsed. First, Engfeldt specifies that the “electrochromic film 10 is coloured/bleached by applying an *external voltage pulse* between the electron conducting layers 24, 34 by electrodes 20, 30 on the two sides of the stack.” (EX1004, 24:30-25:1, emphasis added.)

102. Second, Engfeldt specifies that in the embodiments shown in Figs. 3 and 4, the step of applying constant charging/discharging voltage 250 is interrupted 256 to measure the open circuit voltage. (EX1004, Figs. 3 and 4.) Engfeldt explains, “[i]n step 256, the application of the constant main voltage charging/discharging is interrupted, intermittently and temporarily” in order to measure “the main open circuit voltage between the electrodes of the electrochromic device.” (*Id.*, 15:33-16:4.) And for calibration, Engfeldt teaches that the charging may be interrupted

“e.g., once every second, for a very short time” as the open circuit voltage is measured. (*Id.*, 13:9-14.) Thus, Engfeldt discloses a pattern of charging/discharging with voltage, with interruptions in the charging/discharging for short times to measure the open circuit voltage. These constant interruptions would be akin to voltage pulses. In short, a person of ordinary skill in the art would have understood that an applied voltage that is repeatedly interrupted intermittently and temporarily (e.g., once every second) is delivered in pulses.

103. Third, in Engfeldt’s “trickle charge 268” state, the charge of the electrochromic device is increased or decreased in small amounts to slowly approach the final transmittance. (*Id.*, 17:21-32.) In particular, “the charge of the electrochromic device is increased, if a charging is requested, or decreased, if a discharging is requested, in small amounts, to slowly approach the final transmittance.” (EX1004, 17:24-18:2.) Like for the constant main charging/discharging step, Engfeldt teaches taking measurements of the charge and open circuit voltage during the trickle step. (*Id.*, 17:32-18:3.) A POSA would understand that taking measurements of the charge and open circuit voltage would necessarily require interrupting (“e.g., once every second”) the trickle voltage applied to the electrochromic film, similar to how the main charge/discharge is measured as explained above.

104. In view of all the reasons above, it would have been obvious to a person of ordinary skill in the art, based on Engfeldt's disclosure, to use a driving voltage that comprises an external pulsed voltage. Not only does Engfeldt teach applying an "*external voltage pulse*," but its "intermittent and temporary" interruption to the main charging/discharging and trickle charging would yield a voltage profile that pulses.

105. *Even if* the intermittent interruptions to Engfeldt's constant main charging/discharging voltage were not expressly disclosed as a "pulsed voltage," a person of ordinary skill in the art would still have understood Engfeldt to render this limitation obvious. Engfeldt describes a voltage-driving approach in which voltage is applied to the electrochromic device, temporarily removed, and then applied again as charging continues. (EX1004, 15:30-16:4.) In my opinion, a person of ordinary skill in the art would have understood that type of repeated application and interruption of voltage to be substantially similar in form to pulsed-voltage driving, because in both cases the electrochromic film is not driven by one uninterrupted electrical input, but instead by separated intervals of applied voltage over time. A person of ordinary skill in the art also would have understood that Engfeldt's approach results in the same practical delivery of voltage in discrete increments or pulse-like intervals, rather than as a purely uninterrupted waveform. And from a control perspective, both Engfeldt's intermittently interrupted voltage application

and an expressly pulsed voltage allow the controller to regulate when voltage is applied, for how long it is applied, and how much charging progresses between interruptions, thereby providing similar control over the amount and timing of charge delivered to the electrochromic film as it approaches a desired optical state. Engfeldt also explains that “there are many possible procedures to use for arriving to the intended transmittance level.” (EX1004, 15:25-27.) In my opinion, a person of ordinary skill in the art would therefore have understood that using an external pulsed voltage as part of Engfeldt’s voltage-driving scheme would have been an obvious variation of Engfeldt’s disclosed control methods.

106. Engfeldt therefore discloses, or at least renders obvious, the limitations of claim 4, *i.e.*, “wherein the voltage driving comprises applying an external pulsed voltage to the electrochromic film.”

4. Claim 7: The method of claim 1, wherein injecting electric charges into the electrochromic film comprises applying a combination of a constant power source and a pulsed power source to the electrochromic film.

107. Engfeldt discloses injecting electric charges into the electrochromic film by applying a combination of a constant power source and a pulsed power source to the electrochromic film.

108. First, Engfeldt generally teaches injecting charge into the electrochromic film using *constant power*. For example, as explained above, Engfeldt further teaches that “a ***constant*** main charging/discharging voltage is

applied between the electrodes of the electrochromic device.” (EX1004, 15:24-33; 11:21-23.)

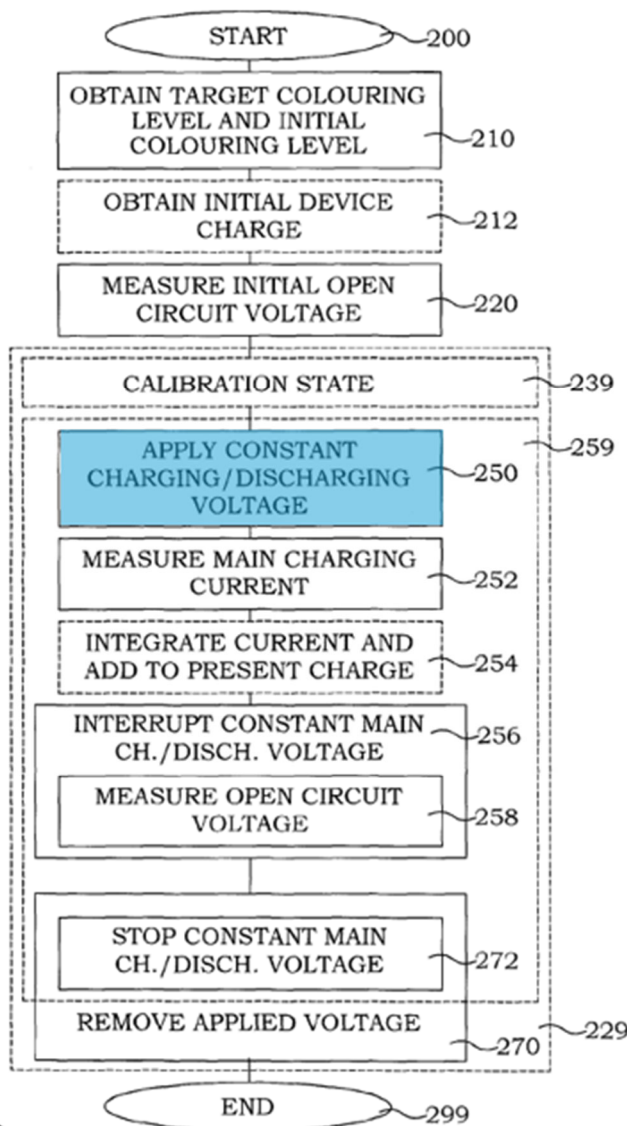


Fig. 3

EX1004, Fig. 3

109. A person of ordinary skill in the art would have understood this constant main charging/discharging voltage to be a constant power source applied to charge the electrochromic film because a constant voltage applied between the electrodes

of the electrochromic device must be supplied by an electrical source that provides that voltage during the charging or discharging operation. (EX1004, 11:21-23; 15:30-16:1.) In other words, Engfeldt's disclosed constant-voltage drive is not self-generated by the electrochromic film itself, but is provided from an external electrical source that supplies the energy used to charge or discharge the device.

110. A person of ordinary skill in the art also would have understood Engfeldt to disclose applying a *pulsed* power source to the electrochromic film. As described with reference to Claim 4 above, Engfeldt teaches that, during the static state, "[t]he application of the constant main charging/discharging voltage is interrupted, intermittently and temporarily," in order to measure "a main open circuit voltage between the electrodes of the electrochromic device." (EX1004, 16:1-4.) Engfeldt further explains elsewhere that such interruption may occur "e.g. once every second, for a short time." (EX1004, 13:12-14.) A person of ordinary skill in the art would have understood this repeated, time-separated application of the charging voltage to constitute pulsed or pulse-like power delivery to the electrochromic film, as explained with reference to Claim 4.

111. A person of ordinary skill in the art would therefore have understood Engfeldt's disclosed charging approach to comprise a combination of a constant power source and a pulsed power source. Engfeldt's main charging stage uses a constant main charging/discharging voltage as the baseline charging input, while the

intermittent and temporary interruptions to that applied voltage create repeated pulse-like intervals in the delivery of power to the electrochromic device. (EX1004, 15:24-16:4.)

112. Engfeldt therefore discloses, or at least renders obvious, the limitations of claim 7, i.e., “wherein injecting electric charges into the electrochromic film comprises applying a combination of a constant power source and a pulsed power source to the electrochromic film.”

5. Claim 8

- a) **[8.pre] A method of changing an optical state of an electrochromic film, wherein the electrochromic film has a plurality of optical states, comprising:**

113. *See* [1.pre].

- b) **[8.1] selecting a desired state of the plurality of optical states;**

114. *See* [1.1].

- c) **[8.2] extracting electric charges from the electrochromic film by a driving force, wherein the driving force includes voltage driving, current driving, and/or a combination of voltage driving and current driving;**

115. *See* [1.2]. [8.2] differs from [1.2] in that it requires “*extracting* electric charges from” (rather than “*injecting* electric charges into”) the electrochromic film. Engfeldt expressly states that its disclosed control methodology applies to both “charging and discharging,” and further explains that “charging” should be

understood as “charging/discharging” in a positive or negative direction. (EX1004, 8:8-13.) Further, “[f]or a charging action, the voltages are successively increased, causing an increasing charge of the electrochromic device. For a discharging, the voltages are successively decreased, causing a decreasing charge of the electrochromic device.” (EX1004, 9:29-33.) A person of ordinary skill in the art would have understood that disclosure to mean that Engfeldt’s voltage-driving teachings apply not only to driving charge into the electrochromic film, but also to driving charge out of the film during discharging. Engfeldt does not describe charging and discharging as different control frameworks. Rather, it explains that the same voltage-based control methodology is used in either direction, with the distinction being whether the applied voltage is selected and adjusted to increase device charge or to decrease device charge. (EX1004, 8:8-13; 9:29-33.) In my opinion, a person of ordinary skill in the art would therefore have understood Engfeldt’s disclosure of “discharging” an electrochromic device, including applying voltages that cause a “decreasing charge of the electrochromic device,” to mean extracting electric charges from the electrochromic film. That is because, in technical terms, reducing the charge state of the electrochromic film by electrical driving necessarily involves removing charge from the film rather than adding charge to it. Accordingly, a person of ordinary skill in the art would have understood

Engfeldt's discharging disclosure to satisfy the "extracting electric charges from the electrochromic film" requirement.

- d) **[8.3] determining the driving force based on the desired state of the plurality of optical states;**

116. *See* [1.3].

- e) **[8.4] monitoring an amount of the electric charges extracted from the electrochromic film; and**

117. *See* [1.4]. *See also* [8.2] regarding Engfeldt's teachings applying to both extracting and injecting.

- f) **[8.5] stopping extracting the electric charges when the electric charges reaches a pre-set amount corresponding to the desired state.**

118. *See* [1.5]. *See also* [8.2] regarding Engfeldt's teachings applying to both extracting and injecting.

- 6. **Claim 9: The method of claim 8, wherein the voltage driving comprises applying an external DC voltage to the electrochromic film.**

119. *See* claim 2 above.

- 7. **Claim 11: The method of claim 8, wherein the voltage driving comprises applying an external pulsed voltage to the electrochromic film.**

120. *See* claim 4 above.

8. **Claim 14: The method of claim 8, wherein extracting charges into the electrochromic film comprises applying a combination of a constant power source and a pulsed power source to the electrochromic film.**

121. *See* claim 7 above. *See also* [8.2] regarding Engfeldt's teachings applying to both extracting and injecting.

9. **Claim 15**

- a) **[15.pre] A method of changing an optical state of an electrochromic film, comprising:**

122. *See* [1.pre].

- b) **[15.1] setting a plurality of pre-determined optical states of the electrochromic film;**

123. *See* [1.pre] and [1.1]. Engfeldt states that the target coloring level (which can be represented as a percentage value anywhere between 0% and 100%) can be “obtained,” “requested,” or “entered,” which a POSA would understand to mean “setting” the target coloring level. (EX1004, 8:19-9:8.)

- c) **[15.2] determining an amount of electric charges corresponding to each of the plurality of pre-determined optical states;**

124. *See* [1.3]. Furthermore, Engfeldt teaches determining an amount of electric charges corresponding to each of the pre-determined optical states of the electrochromic film. Specifically, Engfeldt explains that the electrochromic device, and its electrochromic film, present a transmittance that depends on charge.

(EX1004, 3:26-30, 4:17-19.) Thus, Engfeldt teaches that optical state, expressed as transmittance, corresponds to charge state.

125. Engfeldt further teaches determining specific charge amounts for particular pre-determined optical states. For example, Engfeldt explains that the device is brought into “well-defined conditions, typically fully discharged,” after which “a measure[] of a total charge of the electrochromic film is then set to a predefined value, typically zero.” (EX1004, 7:18-8:6.) Accordingly, Engfeldt teaches determining charge amounts corresponding to pre-determined optical states of the electrochromic film. In my opinion, a person of ordinary skill in the art would have understood Engfeldt to teach the claimed correspondence between pre-determined optical states and respective amounts of electric charge because Engfeldt expressly ties the device’s optical condition, namely its transmittance, to the charge state of the electrochromic film. (EX1004, 3:26-30; 4:17-19.) Engfeldt then goes further and identifies specific charge values associated with defined optical endpoints, including a predefined value, typically zero, for the fully discharged condition and a measured device charge q_{100} when the minimum-transmission condition is reached. (EX1004, 7:18-8:6; 11:3-6; 20:21-26.) A person of ordinary skill in the art would have understood those disclosures to define charge amounts corresponding to pre-determined optical states at opposite ends of the device’s

optical range, e.g., a fully discharged or clear optical state, and a fully charged or dark optical state.

126. A person of ordinary skill in the art also would have understood that, once Engfeldt teaches that transmittance depends on charge and identifies charge values for defined optical endpoint states, the same charge-state relationship necessarily extends across the intermediate optical states between those endpoints. In other words, if the electrochromic film can occupy a range of optical states, and if those optical states are charge-dependent, then each selected or pre-determined optical state within that range corresponds to a respective amount of charge in the film. That understanding is consistent with Engfeldt's broader disclosure of obtaining a "target colouring level" as a representation of a requested optical condition and controlling the device based on measured charge-related behavior to reach that condition. (EX1004, 8:15-21; 8:27-9:8; 11:1-6.) A person of ordinary skill in the art therefore would have understood Engfeldt to teach determining an amount of electric charges corresponding to each of the plurality of pre-determined optical states.

127. Accordingly, Engfeldt teaches determining charge amounts corresponding to pre-determined optical states of the electrochromic film. And because Engfeldt teaches that transmittance depends on charge, while identifying charge values for opposite ends of the optical range, a person of skill in the art would

have understood Engfeldt to teach the claimed correspondence between the plurality of pre-determined optical states and their respective amounts of electric charge. (*See also* [1.pre].

- d) **[15.3] selecting a desired state of the plurality of pre-determined optical states; and**

128. *See* [1.1].

- e) **[15.4] determining a driving force, wherein the driving force includes voltage driving, current driving, and/or a combination of voltage driving and current driving;**

129. Regarding “determining a driving force,” *see* [1.3]. Regarding the driving force including “voltage driving, current driving, and/or a combination of voltage driving and current driving,” *see* [1.2].

- f) **[15.5] adjusting an amount of electric charges within the electrochromic film to the determined amount of electric charges corresponding to the selected desired state.**

130. Engfeldt teaches adjusting the amount of electric charge within the electrochromic film to the amount corresponding to the selected desired state. As discussed in [15.2], Engfeldt explains that the film’s transmittance depends on its charge, such that reaching the selected target coloring level corresponds to reaching the associated charge condition. (EX1004, 3:26-30, 4:17-19.) Engfeldt further teaches applying a “constant main charging/discharging voltage” between the electrodes, where that voltage is selected based on the preceding calibration. (EX1004, 4:9-13; 11:21-25.) Engfeldt also teaches monitoring and updating the

device charge during that operation: the charging current is measured and integrated into a charge change, and the “present device charge is updated” accordingly. (*Id.*, 13:7-12; 16:9-17.) A person of ordinary skill in the art would have understood this to disclose adjusting the amount of charge in the electrochromic film toward the amount associated with the selected optical state. Engfeldt teaches a controlled electrical process in which the amount of charge within the electrochromic film is progressively adjusted based on measured charge-related behavior until the device reaches the selected target coloring level. Because Engfeldt ties transmittance to charge state and updates the present device charge during the charging operation, a person of ordinary skill in the art would have understood Engfeldt to disclose adjusting the amount of charge in the electrochromic film toward the determined amount of charge associated with the selected desired optical state.

131. Engfeldt’s Figure 4 embodiment that includes trickle charging makes that adjustment even more explicit. Engfeldt explains that, as the device comes closer to the intended final transmittance, the static-state operation may be “a somewhat coarse charging method,” so the constant main charging/discharging voltage is stopped at step 260 and followed by a trickle substate. (EX1004, 17:15-27.) In step 268, “a trickle charging is run” until “the target colouring level is reached.” (*Id.*) Engfeldt further explains that, in this trickle state, “the charge of the electrochromic device is increased, if a charging is requested, or decreased, if a

discharging is requested, in small amounts, to slowly approach the final transmittance,” and that charge measurements may continue during this substate. (*Id.*, 17:29-18:1.) A person of ordinary skill in the art would have understood this embodiment to be a particularly clear example of adjusting charge to the determined amount corresponding to the selected desired state. Engfeldt is not merely driving the device generally in the right direction; it is refining the device’s charge in small measured increments as the film approaches the final target coloring level. A person of ordinary skill in the art therefore would have understood this trickle-charging disclosure to teach final adjustment of the amount of electric charge within the electrochromic film to the amount corresponding to the selected desired optical state.

10. Claim 16: The method of claim 15, wherein adjusting the amount of electric charges within the electrochromic film comprises applying the voltage driving, the voltage driving including an external DC voltage, an external pulsed voltage, or combination thereof to the electrochromic film.

132. *See* claims 2 and 4 above.

11. Claim 20: The method of claim 15, wherein the plurality of pre-determined optical states include a clear state and a dark state of the electrochromic film.

133. Engfeldt teaches that the plurality of pre-determined optical states include a clear state and a dark state of the electrochromic film. Engfeldt states that the target coloring level may be represented as a percentage value, where “100% corresponds to a fully charged condition and 0% corresponds to a fully discharged

condition, which in turn typically corresponds to a maximum colouring and a fully bleaching, respectively, of the electrochromic device.” (EX1004, 8:32-9:9.) A person of skill in the art would have understood Engfeldt’s “maximum colouring” state to correspond to a dark state, and Engfeldt’s “fully bleaching” state to correspond to a clear state.

X. GROUND 2: CLAIMS 3, 6, 10, 13, AND 17-18 ARE OBVIOUS OVER ENGFELDT IN VIEW OF PRADHAN

A. Overview of Pradhan

134. Pradhan is directed to methods for controlling an optical transition and the ending state of an optically switchable device. (EX1005, Abstract.) Pradhan teaches controller-based techniques for electrically driving an electrochromic device from one optical state to another and for using measured electrical feedback to control that transition. More specifically, Pradhan discloses “improved methods for driving optical transitions in electrochromic devices,” in which the device is driven using controlled electrical conditions and its electrical response during the transition is used as feedback to assess progress toward, and control the device’s movement to, a desired optical state. (EX1005, [0004]-[0006].)

135. Pradhan explains that its embodiments “relate to methods for transitioning an optically switchable device using feedback obtained during the transition to control the ongoing transition,” and that the device “can be probed by applying certain electrical conditions (e.g., voltage pulses and/or current pulses)”

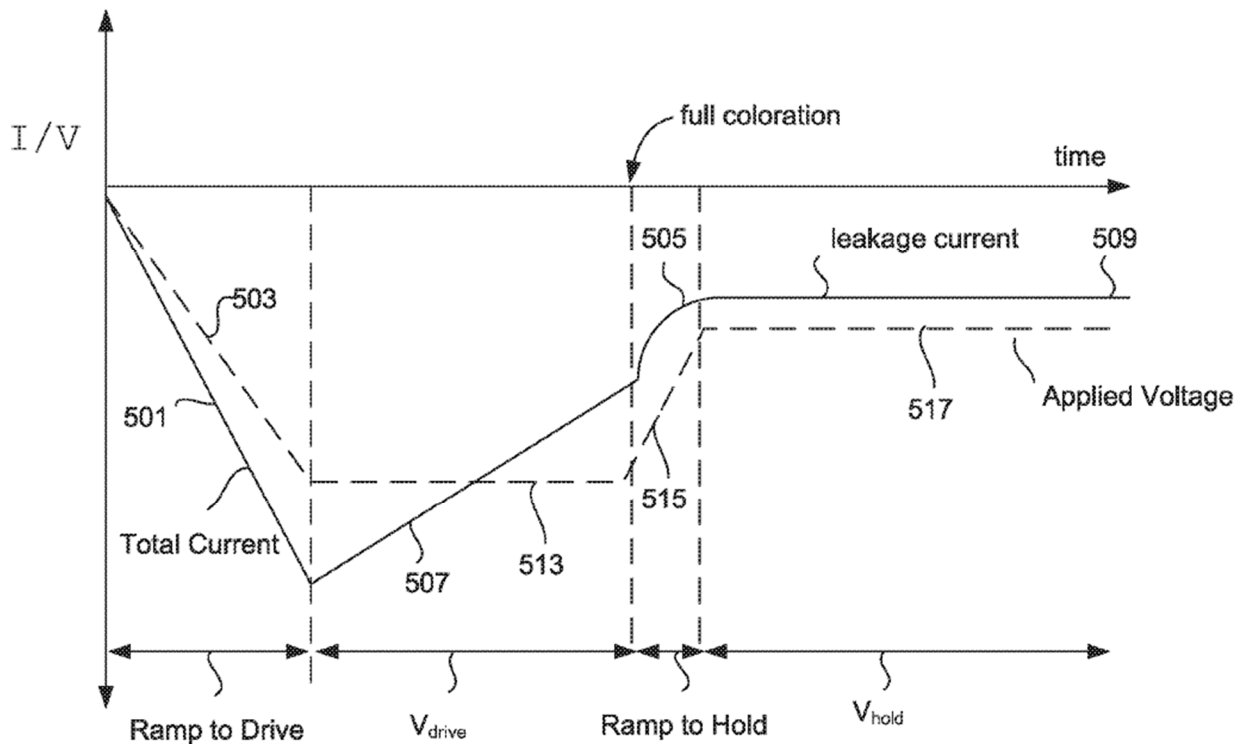
such that “[a]n electrical response to the probing can be used as feedback to control the ongoing transition.” (EX1005, [0005].) Pradhan further teaches “a method of controlling an optical transition of an optically switchable device from a starting optical state to an ending optical state,” including “applying a voltage or current for driving the optically switchable device,” “determining an electrical characteristic of the optically switchable device,” and “using the determined electrical characteristic as feedback to adjust the applied voltage or current to further control the optically switchable device transition.” (EX1005, [0006].) Pradhan therefore describes a controller-driven electrochromic transition framework in which electrical drive conditions and measured electrical feedback are used together to move the device to a selected ending optical state.

136. Pradhan also contemplates different forms of voltage driving. Pradhan explains that the applied voltages supplied by the external power source may be DC voltages or AC voltage signals. (EX1005, [0259].) Pradhan further teaches that the supplied voltage signals may be converted to pulse-width modulated voltage signals and that, although the supplied signals may take different forms, the voltages actually applied to the bus bars are effectively DC voltages. (*Id.*) Pradhan also teaches that an oscillating drive voltage may have an appropriate wave profile taking into account frequency, duty cycle, mean voltage, amplitude, and other factors. (EX1005, [0260].) Pradhan explains that this level of control permits transitioning

“to any state over the full range of optical states between the two end states,” including providing “a continuous range of transmissivity (% T) which can be tuned to any value between end states.” (*Id.*) In my opinion, a person of ordinary skill in the art would have understood Pradhan to disclose a flexible voltage-driving framework capable of driving an electrochromic device not only to endpoint states, but also to intermediate optical states across a continuous range.

137. Pradhan likewise contemplates using both voltage and current to drive the optical transition from a first optical state to a second optical state. Pradhan explains that, when it is determined that the transition is not progressing sufficiently fast, “the transition switches to a mode where it is driven by an applied current.” (EX1005, [0172].) Pradhan further explains that the applied current is selected so that it is “sufficiently great to increase the speed of the transition but is not so great that it degrades or damages the electrochromic device.” (*Id.*) During that current-controlled drive step, the applied voltage is allowed to float, and the controller may still periodically probe by, for example, dropping to the hold voltage and checking for completeness of transition in the same way as when using a constant drive voltage. (*Id.*) Pradhan therefore teaches that voltage driving and current driving were both recognized options for controlling electrochromic transitions, including switching from one to the other when useful to improve transition speed while still protecting the device.

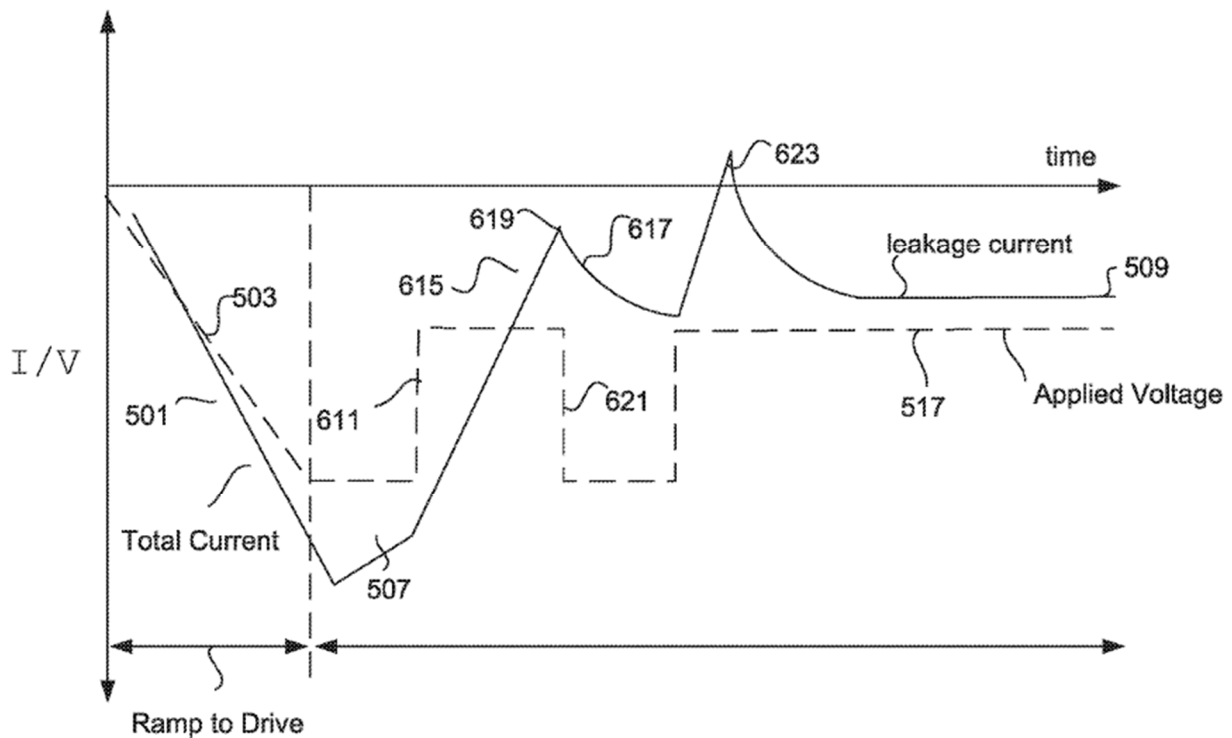
138. Pradhan also describes specific voltage-driving techniques for carrying out optical transitions. In one technique shown in Figure 5, a “voltage control profile” is used “to drive the transition from a clear state to a tinted state,” in which the “applied voltage profile is shown by the dashed line” and the “current density in the device is shown by the solid line.” (EX1005, [0108]-[0109].) Figure 5 illustrates a control sequence in which the applied voltage is first ramped to a drive voltage to initiate the transition, held at that drive voltage to continue driving the transition, then ramped to a hold voltage that maintains the device at the desired ending optical state. (EX1005, [0109]-[0110], [0125].) More specifically, the applied voltage profile “includes four components: a ramp to drive component 503, which initiates the transition, a V_{drive} component 513, which continues to drive the transition, a ramp to hold component 515, and a V_{hold} component 517.” (EX1005, [0109].) Pradhan explains that the “hold voltage” is the applied voltage necessary to indefinitely maintain the device in an ending optical state, while the “drive voltage” is used during at least a portion of the optical transition and is applied “to speed the transition to a point where applying the hold voltage will result in a time invariant desired optical state.” (EX1005, [0052]-[0053], [0125].) Pradhan therefore teaches a structured voltage-control technique in which different applied voltages are used for different phases of the optical transition.



EX1005, Figure 5

139. Pradhan also discloses a pulsed or alternating voltage technique in connection with Figure 6B. There, Pradhan shows an initial ramping of voltage to the main drive voltage V_{drive} to increase current flow and transition the device from one optical state to another. (EX1005, [0124].) Because the optical transition is not yet complete, the system then drops the applied voltage from V_{drive} to V_{hold} , monitors the resulting current response, and, if the current response indicates that the transition has not yet proceeded far enough, returns the applied voltage to V_{drive} for a further period before again dropping to V_{hold} . (*Id.*) Pradhan explains that, when the resulting current establishes that the optical transition has proceeded far enough, the applied voltage remains at V_{hold} for the duration of the ending optical state. (*Id.*)

Pradhan further explains that the ending optical state may be a maximum, minimum, or intermediate optical state. (*Id.*) Figure 6B therefore discloses using repeated changes in applied voltage, including pulsed transitions between V_{drive} and V_{hold} , together with measured electrical response, to determine when the device has reached a sufficiently advanced point in the transition.



EX1005, Figure 6B

140. Pradhan also discloses using both constant voltage and pulsed voltage to reach a desired intermediate optical state. Pradhan explains that, to drive the device to an intermediate state using oscillatory driving voltage, a controller may first apply a high-voltage pulse suitable for full transition and then back off to the voltage of the oscillating intermediate state. (EX1005, [0261].) Stated another way,

Pradhan teaches that “an initial low-frequency single pulse” of selected magnitude and duration may be used to speed the transition, after which “a higher frequency voltage oscillation” can be used to sustain the intermediate state for as long as desired. (*Id.*) This is a further example of Pradhan’s flexible use of different voltage-drive modes, including constant, pulsed, and oscillatory voltage techniques, to efficiently reach and maintain selected optical states.

141. Pradhan further emphasizes that electrical feedback may be used to determine whether the optical transition has progressed sufficiently and to adjust the applied electrical conditions in real time. Pradhan states that “feedback is used to determine when an optical transition is complete or nearly complete.” (EX1005, [0093].) Pradhan further explains that “electrical probing and monitoring” may be used “to determine when an optical transition between a first optical state and a second optical state of an optically switchable device has proceeded to a sufficient extent that the application of a drive voltage can be terminated.” (EX1005, [0094].) One example probing technique “involves pulsing the applied drive voltage by dropping it to the level of the hold voltage . . . and monitoring the current response,” where “the device control system determines that it is now time to transition from the drive voltage to the hold voltage” when the measured response reaches a threshold. (EX1005, [0122].) Pradhan also teaches using open-circuit-voltage-based feedback and, in some embodiments, determining “the total delivered charge

density” by integrating current over time to assess whether the optical transition is nearly complete. (EX1005, [0150], [0157], [0159].) These disclosures teach that Pradhan monitors multiple electrical characteristics, including current, voltage, open-circuit voltage, and delivered charge, as feedback for controlling the transition and determining when to terminate the drive condition or change to a hold condition.

142. Pradhan therefore presents a controller-based framework in which either voltage or current, or both, drives an electrochromic transition, while measured electrical characteristics are used to monitor progress, refine control, and determine when the desired ending optical state has been reached. (EX1005, [0005]-[0006], [0093]-[0094], [0109], [0122], [0157].) Pradhan’s control methods may be used in various optically switchable devices, including electrochromic windows. (EX1005, [0007].) A person of ordinary skill in the art would have understood Pradhan as disclosing a broadly applicable set of control techniques for electrically driving electrochromic devices between optical states using voltage drive, current drive, pulsed or oscillatory electrical conditions, and electrical feedback to improve transition speed, endpoint control, and device safety.

B. Motivation to Combine Engfeldt with Pradhan

143. After reviewing both Engfeldt and Pradhan, it is very clear to me that a person of ordinary skill in the art would have been motivated to combine the methods of charging and discharging electrochromic films disclosed in Engfeldt with the

similar methods of charging and discharging electrochromic films disclosed in Pradhan for multiple reasons. First, both references are directed to controller-based techniques for electrically driving electrochromic devices from one optical state to another desired optical state. Both references also recognize that optical-state transitions should be performed efficiently and accurately, while avoiding damage to the electrochromic device. A person of ordinary skill in the art would have understood Pradhan to provide specific control techniques that could be incorporated into, or used to modify, Engfeldt's existing charging framework to better control charging and discharging as the electrochromic device transitions between optical states. Those modifications would have yielded predictable benefits, including improved switching speed, improved endpoint control, and safer operation during charging and discharging.

144. Second, a person of ordinary skill in the art would have been motivated to combine Engfeldt with Pradhan to incorporate Pradhan's techniques of using current, or a combination of voltage and current, to improve Engfeldt's switching speed between optical states when voltage-based charging alone is insufficient. Engfeldt expressly recognizes a speed-voltage tradeoff, explaining that "it is of benefit if the intended charging voltage for a static state is relatively large, since this typically increases the charging speed. However, the charging voltage for a static state cannot be too high without damaging the device." (EX1004, 14:6-11.) Thus,

Engfeldt itself acknowledges both the desirability of faster switching and the practical limitation that simply increasing voltage is not always an acceptable solution.

145. A person of ordinary skill in the art would have recognized that Pradhan provides a direct solution to that same problem. Pradhan teaches that, during voltage drive, “when it is determined that the transition is not progressing sufficiently fast, the transition switches to a mode where it is driven by an applied current,” and that the current is selected so that it is “sufficiently great to increase the speed of the transition but is not so great that it degrades or damages the electrochromic device.” (EX1005, [0172].) A person of ordinary skill in the art would have understood this teaching to improve Engfeldt’s charging and discharging method in a predictable way. Rather than relying only on increased voltage to accelerate charging or discharging, a person of ordinary skill in the art would have understood that Engfeldt could be modified to switch to current driving, or to use both voltage and current as appropriate, when faster transition is needed while still controlling the process via charge feedback to avoid undesirable or damaging operating conditions.

146. That modification would have been technically straightforward and would have yielded a predictable benefit. Engfeldt already teaches controller-based management of transitions between optical states using measured electrical behavior, and Pradhan confirms that voltage control and current control were known

implementation options for accomplishing that same type of transition control. Pradhan explains that the controller may increase or decrease current rather than voltage and that “[w]hether voltage or current is controlled by the hardware (potentiostatic or galvanostatic control), the algorithm attains the desired result.” (EX1005, [0083].) In my opinion, a person of ordinary skill in the art therefore would have been motivated to incorporate Pradhan’s use of voltage driving and current driving into Engfeldt’s charging and discharging method as a predictable way to accelerate the transition without depending solely on higher applied voltage.

147. Third, a person of ordinary skill in the art would have been motivated to incorporate Pradhan’s probing-based feedback techniques into Engfeldt’s final-stage optical-transition control to improve endpoint control as the optical transition approaches its desired state. Engfeldt explains that “[w]hen coming closer to the intended final transmittance condition, the static state operation might be experienced as a somewhat coarse charging method.” (EX1004, 17:15-17.) Engfeldt thus recognizes that final-stage control of charging and discharging can be difficult. As one solution, Engfeldt introduces a trickle substate in which “the charge of the electrochromic device is increased, if a charging is requested, or decreased, if a discharging is requested, in small amounts, to slowly approach the final transmittance.” (EX1004, 17:29-18:2.) In my opinion, a person of ordinary skill in the art would have understood this disclosure to reflect Engfeldt’s recognition that

more refined transition control is desirable as the device nears the endpoint of the optical transition.

148. Pradhan identifies the same practical endpoint-control problem and provides a known technique for addressing it. Pradhan explains that “it can be difficult to predict how long the applied drive voltage should be applied before transitioning to the hold voltage” because device size, fabrication differences, and environmental conditions can affect transition behavior. (EX1005, [0117].) Pradhan further explains that pre-determining different drive times for many different devices can be “tedious, expensive, and time-consuming,” and teaches that “[a]n improved approach . . . is to determine on-the-fly the length of time that the drive voltage should be applied.” (EX1005, [0118].) To do so, Pradhan discloses a probing technique that “involves pulsing the current or voltage applied to drive the transition and then monitoring the current or voltage response to detect an overdrive condition,” including “pulsing the applied drive voltage by dropping it to the level of the hold voltage . . . and monitoring the current response.” (EX1005, [0121]-[0122].) When the response reaches a threshold, “the device control system determines that it is now time to transition from the drive voltage to the hold voltage.” (EX1005, [0122].) A person of ordinary skill in the art would have been motivated to apply these techniques to Engfeldt’s endpoint charging and discharging control. Rather than relying only on Engfeldt’s comparatively “coarse” final-stage

logic and trickle-charge adjustments, a person of ordinary skill in the art would have understood that Pradhan's pulsing-and-monitoring technique could be used to assess, in real time, whether the transition had progressed far enough to shift from stronger driving conditions to more refined charging or discharging as the device approached its desired optical state. The combination would take advantage of Pradhan's improved measured electrical-response feedback to refine the point at which Engfeldt changes charging behavior near the endpoint, thereby improving final-state control in a predictable and technically sensible manner.

149. Fourth, a person of ordinary skill in the art would have been motivated to incorporate Pradhan's current-feedback safety logic into Engfeldt's existing charging controller so that Engfeldt's measured charging current could be used to limit damaging operating conditions during electrochromic transitions. Engfeldt expressly warns that, although higher charging voltage can increase switching speed, "the charging voltage for a static state cannot be too high without damaging the device." (EX1004, 14:6-13.) Engfeldt also discloses hardware for measuring current during operation, including a "current meter 42" configured to "measure a charging current." (EX1004, 22:6-15.) Thus, Engfeldt already recognizes the risk of damage during charging and already includes current-sensing capability within its control architecture.

150. Pradhan provides a direct way to address that same concern. Pradhan teaches that “[i]f the current or voltage supplied to a device is too great, it can cause damage to the device,” and that “electrical feedback is used to ensure that the optically switchable device is maintained within a safe window of operating conditions.” (EX1005, [0061].) Pradhan further explains that, where “the measured current is above I_{safe} ,” the controller should “decrease voltage (or rate of increase in the voltage) in order to bring the current below I_{safe} ,” and that the controller may “actively monitor current and voltage” and “quickly adjust the applied voltage to ensure that the current remains below I_{safe} during the entire controlled current phase of the transition.” (EX1005, [0081]-[0082].) A person of ordinary skill in the art would have understood this to provide a specific enhancement to Engfeldt’s charging process: using the charging current already measured by Engfeldt’s current meter as feedback to adjust the applied voltage, or the rate at which voltage is increased, when the current indicates that the device is entering an unsafe operating region. In my opinion, a person of ordinary skill in the art would have understood Pradhan’s safety-feedback teaching to fit naturally within Engfeldt’s existing controller architecture because Engfeldt already measures charging current and uses electrical measurements to control the transition of the electrochromic device. A person of ordinary skill in the art therefore would have recognized that Pradhan’s disclosed logic for reducing voltage, or reducing the rate of voltage increase, when

measured current exceeds a safe threshold could be implemented in Engfeldt as a straightforward control refinement using Engfeldt's already-available current information. That modification would have been straightforward because Engfeldt already measures charging current and already seeks to avoid damage from excessive voltage, so incorporating Pradhan's current-feedback safety limits would have predictably improved Engfeldt's ability to charge or discharge the device quickly while still keeping operation within a safe range.

151. Fifth, a person of ordinary skill in the art would have been motivated to combine Engfeldt with Pradhan to use both constant and pulsed power sources to drive charging and discharging to improve transition speed, refine control, and reduce the risk of damage. Engfeldt already teaches the basic framework for such a combination. Engfeldt teaches applying an "external voltage pulse" to color or bleach the electrochromic film, interrupting the constant main charging and discharging voltage "intermittently and temporarily" to measure open-circuit voltage, and using a voltage-driven trickle state to increase or decrease charge "in small amounts" as the device approaches the final transmittance. (EX1004, 24:30-25:1; 15:34-16:4; 17:29-18:3.) These disclosures show that Engfeldt already uses a control framework that combines generally continuous drive with temporary interruptions and smaller incremental adjustments to better monitor and control the transition.

152. Pradhan provides a more explicit and advantageous implementation of that same general approach. Pradhan teaches “pulsing the current or voltage applied to drive the transition and then monitoring the current or voltage response,” including “pulsing the applied drive voltage by dropping it to the level of the hold voltage” to determine when the drive condition should be changed. (EX1005, [0121]-[0122].) Pradhan also explains that the probing protocol may vary in timing, duration, magnitude, and frequency, and further teaches switching to a current-drive mode when the transition is “not progressing sufficiently fast,” with the current selected to increase speed without degrading or damaging the device. (EX1005, [0130]; [0172].) A person of ordinary skill in the art therefore would have been motivated to incorporate Pradhan’s use of a combination of constant and pulsed power – voltage, current or both – into Engfeldt’s controller so that Engfeldt could use constant power for part of the optical transition, use current-drive mode for faster switching, and then use pulsed power to drive portions of the optical transition for finer adjustment, better endpoint control, and safer operation.

153. Sixth, a person of ordinary skill in the art would have understood that there were a small and finite number of predictable ways to drive charging or discharging of an electrochromic film by inserting or removing electric charge: voltage-based drive, current-based drive, or both. A person of skill in the art would have likewise understood that there are a limited, finite, and predictable number of

ways to apply and control voltage or current to the system: constant/continuous, or pulsed. Selecting among these well-known and limited driving and control options depends on the characteristics and operating requirements of the electrochromic device, including desired transition speed, endpoint precision, and avoidance of damage. In that context, Pradhan's teachings regarding voltage driving, current driving, combining voltage driving and current driving, using pulsed power, and feedback-based safety control would have presented a known, limited and predictable set of implementation options for improving Engfeldt's existing controller-based charging framework. In my opinion, a person of ordinary skill in the art therefore would have been motivated to incorporate those teachings into Engfeldt as routine selection and adaptation of known electrochromic control techniques to achieve a desired balance of switching speed, control refinement, and safe operation.

C. Reasonable Expectation of Success

154. In my opinion, a person of ordinary skill in the art would have had a reasonable expectation of success in combining Engfeldt's well-known voltage-driven electrochromic film charging/discharging methods with Pradhan's well-known feedback-based transition-control techniques that employ voltage, current, combinations of voltage and current, as well as different types of constant and pulsed power sources to charge/discharge electrochromic films. Both references are

directed to controlling charging and discharging using measured electrical characteristics during electrochromic film transitions, and both rely on the same general types of electrical inputs, sensing, and controller-directed adjustment of charging behavior. Engfeldt teaches controller-based charging and discharging using measured charging current and open-circuit voltage to control the electrochromic device as it moves toward a target coloring level. (EX1004, 10:24-34; 11:1-29; 15:24-16:12.) Pradhan likewise teaches using voltage or current to drive an optical transition and using measured electrical feedback during the transition to determine how the drive conditions should be adjusted and when the desired ending optical state has been sufficiently reached. (EX1005, [0005]-[0006], [0093]-[0094], [0122], [0157], [0172].) In my opinion, a person of ordinary skill in the art therefore would have understood the two references to be technologically compatible and directed to closely related control problems using similar electrochromic control tools.

155. Pradhan's teachings therefore would have been applied as targeted enhancements to Engfeldt's existing controller, including, for example, current driving when voltage driving to charge or discharge the electrochromic film is too slow or imprecise, using probing-based feedback to refine endpoint control, and using measured current to keep the device within safe operating conditions. Pradhan expressly teaches switching to current drive when the transition is "not progressing sufficiently fast," using pulsing and monitoring techniques to determine when a

drive condition should be changed, and using measured current and voltage feedback to maintain operation within a safe range. (EX1005, [0061], [0081]-[0082], [0117]-[0122], [0172].) In my opinion, a person of ordinary skill in the art would have understood those teachings not as changing Engfeldt's basic mode of operation, but as improving Engfeldt's already-existing controller-based charging and discharging framework. That is because Engfeldt already seeks to balance transition speed, endpoint control, and device safety, and already uses electrical measurements and controller logic to govern charging behavior. (EX1004, 14:6-13, 17:15-18:5, 22:6-15.)

156. Because those modifications are structurally and functionally consistent with Engfeldt's existing control architecture, implementing them would have required only routine adaptation of controller logic and ordinary programming or configuration work, as well-known to a person of ordinary skill in the art, to achieve predictable results, rather than any significant modification of Engfeldt's system. In my opinion, a person of ordinary skill in the art would have understood that adding Pradhan's current-driving option, probing-based feedback refinements, or current-based safety logic to Engfeldt would involve adjusting how Engfeldt's controller selects, times, and modifies electrical drive conditions in response to measured electrical behavior, not redesigning the electrochromic film or replacing Engfeldt's basic hardware framework. A person of ordinary skill in the art therefore

would have reasonably expected success that the combination would operate predictably and improve transition control to achieve the common objectives shared by Engfeldt and Pradhan described above. (EX1004, 14:6-13, 17:15-18:5, 22:6-15; EX1005, [0061], [0081]-[0082], [0117]-[0122], [0172].)

D. Claim Element Analysis

1. Claim 3: The method of claim 1, wherein the current driving comprises applying an external DC current to the electrochromic film.

157. The combination of Engfeldt in view of Pradhan renders obvious the limitations of claim 3, *i.e.*, “wherein the current driving comprises applying an external DC current to the electrochromic film.”

158. A person of ordinary skill in the art would have understood Pradhan to teach driving an optical transition by applying an external DC current to the electrochromic film. Pradhan teaches that, when feedback indicates that a voltage-driven transition “is not progressing sufficiently fast,” the controller may switch to “a mode where it is driven by an applied current,” with the current chosen to be “sufficiently great to increase the speed of the transition but . . . not so great that it degrades or damages the electrochromic device.” (EX1005, [0172].) Pradhan therefore expressly teaches using applied current as the electrical driver for the transition itself, rather than merely as something that is incidentally present during voltage driving. A person of ordinary skill in the art would have understood that,

when Pradhan switches the transition into a current-driven mode, that applied current is what drives insertion or extraction of electric charge in the electrochromic film so as to accelerate the optical transition while still avoiding damaging operating conditions.

159. Further, a person of ordinary skill in the art also would have understood Pradhan's applied current to be external DC current. Pradhan discloses that the electrochromic device is connected to an "external DC power source," and describes supplying electrical drive to the device from that external source. (EX1005, [0257]-[0258].) Read together with Pradhan's express teaching that the transition may be "driven by an applied current," a person of ordinary skill in the art would have understood that the applied current used in that current-drive mode is current supplied from the external DC power source, i.e., external DC current. (EX1005, [0172], [0257]-[0258].) A person of ordinary skill in the art would not have understood Pradhan's current-drive disclosure as referring to some internally generated or alternating current source. Rather, in the context of Pradhan's controller-driven electrochromic system, the disclosed applied current would have been understood as externally supplied direct current used to drive the optical transition in a selected direction.

160. As explained above in ¶¶143-156, a person of ordinary skill in the art would have been motivated to incorporate Pradhan's use of current driving into

Engfeldt's voltage-driven control framework to address Engfeldt's recognized speed-versus-damage tradeoff—*i.e.*, Engfeldt's recognition that higher charging voltage increases charging speed, but can run the risk of damaging the device. (EX1004, 14:6-11; EX1005, [0172].) A person of ordinary skill in the art would have understood Pradhan's current-drive teaching to provide a direct and useful refinement to Engfeldt's system because Pradhan teaches exactly how to improve transition speed without simply increasing voltage to potentially harmful levels. Thus, where Engfeldt already seeks faster charging and discharging but recognizes limits on how high the charging voltage can safely be, a person of ordinary skill in the art would have understood Pradhan to provide an additional known control option—namely, switching to current drive when needed to speed the transition while still protecting the electrochromic device.

161. In addition to voltage, a person of ordinary skill in the art therefore would have known to use the external DC charging current taught by Pradhan as part of Engfeldt's electrochromic control framework to help charge or discharge the electrochromic film and achieve the shared Engfeldt/Pradhan objective of increased optical-transition speed and increased control without damaging the electrochromic device. In my opinion, this would have been a straightforward application of a known electrochromic control technique to Engfeldt's existing controller-based system, using the same type of externally supplied electrical drive and feedback-

based control already employed by both references. Because both references are directed to controlling electrochromic transitions using measured electrical behavior, a person of ordinary skill in the art would have expected Pradhan's external DC current-driving technique to operate predictably if incorporated into Engfeldt. *See* ¶¶143-156.

162. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt in view of Pradhan to disclose the limitations of claim 3, i.e., “wherein the current driving comprises applying an external DC current to the electrochromic film.” (EX1001, claim 3.)

2. Claim 6: The method of claim 1, wherein injecting electric charges into the electrochromic film comprises applying a combination of an external voltage and an external current to the electrochromic film.

163. Engfeldt in view of Pradhan renders obvious claim 6, which depends from claim 1 and further recites “wherein injecting electric charges into the electrochromic film comprises applying a combination of an external voltage and an external current to the electrochromic film.”

164. While Engfeldt teaches using voltage as the driving force to charge the electrochromic film, as explained above relative to claim 3, Pradhan teaches using voltage driving, current driving, or both to charge or discharge the electrochromic film. Pradhan teaches “a method of controlling an optical transition” that includes “applying a voltage or current for driving the optically switchable device,” and

further teaches controller-based use of those electrical driving modes during the transition. (EX1005, [0006].) Pradhan also teaches that, when feedback indicates a voltage-driven transition “is not progressing sufficiently fast,” the controller may switch to “a mode where it is driven by an applied current.” (EX1005, [0172].) A person of ordinary skill in the art would have understood these disclosures to show that Pradhan does not treat voltage driving and current driving as mutually exclusive, unrelated concepts, but instead as complementary control options within the same electrochromic transition-control framework. When voltage-driving is not sufficient, the control can switch to current-driving. Pradhan further teaches selecting the applied current so that “the current is sufficiently great to increase the speed of the transition but it is not so great that it degrades or damages the electrochromic device.” (*Id.*) A person of ordinary skill in the art would have understood this disclosure to teach coordinated use of both externally applied voltage and externally applied current during an electrochromic transition, with voltage used as one drive mechanism and current used as another drive mechanism when needed to improve speed or control while avoiding damage.

165. Pradhan also teaches using probing techniques in which the controller pulses the current or voltage applied to drive the transition and monitors the electrical response to determine transition progress and when to alter drive conditions. (EX1005, [0121]-[0122], [0142].) A person of ordinary skill in the art would have

understood this disclosure to reinforce that Pradhan's controller is capable of operating with either type of applied electrical input, and of adjusting between them as part of a unified control methodology for driving the optical transition. In my opinion, because Pradhan teaches both applying voltage to drive the transition and applying current to drive the transition, while also teaching controller-based adjustment of those drive conditions in response to feedback, a person of ordinary skill in the art would have understood Pradhan to teach injecting electric charges into the electrochromic film using a combination of both external applied voltage and external applied current. And because Pradhan discloses that the electrochromic device is connected to an external DC power source and receives applied electrical drive from that source, a person of ordinary skill in the art would have understood both the applied voltage and the applied current to be external. (EX1005, [0257]-[0259].)

166. As explained above in ¶¶143-156, a person of ordinary skill in the art would have been motivated to incorporate Pradhan's combination of voltage driving and current driving into Engfeldt's existing voltage-driven charging framework to improve transition speed when voltage-based charging alone is insufficient and to refine control of the transition as the device approaches its desired optical state. In my opinion, a person of ordinary skill in the art would have understood that Engfeldt's controller could continue to apply external voltage during charging, while

also using Pradhan's applied-current driving mode during portions of the optical transition to increase the speed of the transition and/or refine control of the optical transition so as to avoid degrading or damaging the electrochromic device. That is, a person of ordinary skill in the art would have understood the proposed combination not as replacing Engfeldt's voltage-driving approach, but as supplementing it with Pradhan's current-driving capability when useful to achieve the shared objectives of faster switching, improved control, and safe device operation.

167. The resulting combination therefore would have involved injecting electric charges into the electrochromic film using a combination of an external voltage and an external current, as recited by claim 6. In my opinion, a person of ordinary skill in the art would have understood this combined mode of operation to be a straightforward and predictable implementation of Pradhan's known current-drive refinements within Engfeldt's existing voltage-driven electrochromic control framework.

168. For these reasons, a person of ordinary skill in the art would therefore have understood Engfeldt in view of Pradhan to disclose the limitations of claim 6, i.e., "wherein injecting electric charges into the electrochromic film comprises applying a combination of an external voltage and an external current to the electrochromic film." (EX1001, claim 6.)

3. **Claim 10: The method of claim 8, wherein the current driving comprises applying an external DC current to the electrochromic film.**

169. *See* Ground 2, Claim 3 above. (¶¶157-162.)

4. **Claim 13: The method of claim 8, wherein extracting electric charges from the electrochromic film comprises applying a combination of an external voltage and an external current to the electrochromic film.**

170. *See* Ground 2, Claim 6 above. (¶¶163-168.) . *See also* [8.2] (¶115)

regarding Engfeldt's teachings applying to both extracting and injecting.

5. **Claim 17: The method of claim 15, wherein adjusting the amount of electric charges within the electrochromic film comprises applying the current driving, the current driving including an external DC current, an external pulsed current, or a combination thereof to the electrochromic film.**

171. The combination of Engfeldt and Padhan teaches adjusting the amount of electric charges within the electrochromic film by applying the current driving, the current driving including an external DC current. *See* Ground 2, Claims 3 and 6 above.

6. **Claim 18: The method of claim 15, wherein adjusting the amount of electric charges within the electrochromic film comprises applying a combination of an external voltage and an external current to the electrochromic film.**

172. *See* Ground 2, Claim 6 above.

XI. GROUND 3: GROUND 3: CLAIMS 3-5, 7, 10-12, 14, AND 16-17 ARE OBVIOUS OVER ENGFELDT IN VIEW OF DUARTE

A. Overview of Duarte

173. Duarte is directed to “controlling electrochromic panels, which lighten and darken in response to applied electric current and/or voltage.” (EX1006, 1:6-10; Abstract.) In my opinion, Duarte is similar to Engfeldt and Pradhan in that it addresses controller-based techniques for electrically driving an electrochromic device between optical states. Specifically, Duarte discloses techniques for controlling the optical transmittance of an electrochromic panel by using a controller to cause a power supply to apply voltage and/or current to the panel according to a “predetermined pattern.” (EX1006, Abstract.) The ‘851 patent broadly claims to consider the use of pulsed current or voltage to change the optical state but provides no examples nor any specifics regarding how this might be accomplished. Duarte goes far beyond that, explicitly quantifying the details of appropriate pulse sequences including limits on voltage, current, pulse duration, and the length of the interval between pulses. A person of ordinary skill in the art would have understood Duarte’s “predetermined pattern” disclosure to describe controlling not merely whether electrical power is applied, but also the timing, duration, magnitude, polarity, and sequencing of the applied electrical drive used to darken or lighten the electrochromic panel.

174. Duarte teaches that these predetermined patterns of voltage and/or current can include repeated electrical pulses, which Duarte refers to as “micro-pulses.” (EX1006, 4:42-44.) Duarte explains that, by utilizing these micro-pulses, “the energy in an electrochromic system is increased with faster color change (both during darkening and lightening) without damaging the electrochromic materials contained in the panels.” (EX1006, 4:42-47.) Duarte further teaches that, because micro-pulses are short in duration, pulses of greater magnitude may be used in certain situations that otherwise could damage system components if applied for longer periods. (EX1006, 4:54-58.) In my opinion, a person of ordinary skill in the art would have understood Duarte to teach that pulsed electrical drive can be used to increase the rate of electrochromic transition while reducing the risk of damage that could result from applying larger electrical drive levels continuously.

175. Duarte also contemplates applying voltage, current, or both, either continuously or as a repeating series of pulses. (EX1006, 7:56-8:10; 13:61-14:10.) For example, Duarte explains that micro-pulses “can be interspersed” between longer-duration pulses or “between periods in which a voltage is applied substantially continuously.” (EX1006, 9:35-51.) Duarte’s controller causes an external power supply to deliver continuous or pulsed voltage and/or current to darken or lighten an electrochromic panel. (EX1006, 9:35-51; see also EX1006, 12:11-31.) In my opinion, a person of ordinary skill in the art would have understood

Duarte to disclose a flexible controller-based drive scheme in which the controller may select among continuous drive, pulsed drive, or combinations of continuous and pulsed drive, depending on the desired transition behavior.

176. Duarte's Figure 3 provides an example of such a control technique. Duarte explains that voltage is first applied continuously, as shown at portion 312, and then applied as a series of micro-pulses, as shown at portion 314, to achieve a darkened state. (EX1006, 10:10-25.) Duarte then transitions the electrochromic panel to a lightened state by applying a series of negative voltage pulses, as shown at portion 316. (*Id.*) A person of ordinary skill in the art would have understood this example to teach using both substantially continuous electrical drive and pulsed electrical drive during different portions of the same electrochromic control process. In particular, Duarte uses continuous voltage to help drive the panel toward the desired darkened state and then uses micro-pulses to further control the panel's optical state, while later using negative voltage pulses to transition the panel back toward a lightened state.

177. Duarte therefore teaches that electrochromic panels may be driven using continuous or pulsed voltage and/or current, including combinations of continuous drive and micro-pulsing. A person of ordinary skill in the art would have understood that the combination of continuous or constant voltage and/or current with micro-pulsing provides complementary benefits: continuous charging or

discharging can help drive the panel efficiently toward the desired optical state, while micro-pulses can be interspersed with continuous power delivery to better control charge delivery and reduce the risk of damaging the electrochromic materials. (EX1006, 4:42-47; 9:35-51.) In that way, Duarte provides controller-based techniques for improving electrochromic transition speed and control while protecting the electrochromic panel from damage during faster darkening and lightening operations.

B. Motivation to Combine Duarte with Engfeldt

178. A person of ordinary skill in the art would have been motivated to combine Engfeldt's methods of charging and discharging electrochromic films with Duarte's similar controller-based techniques for charging and discharging electrochromic films for multiple reasons. The reasons are similar to those for combining Engfeldt and Pradhan. In particular, a person of ordinary skill in the art would have understood Duarte to provide specific pulse-based control techniques that could be incorporated into and/or used to modify Engfeldt's existing charging framework to better control charging and discharging from one optical state to another desired optical state. For example, a person of ordinary skill in the art would have been motivated to use Duarte's continuous-and-pulsed drive techniques to improve transition speed, refine control of charge delivery during the optical transition, and reduce the likelihood of damaging the electrochromic device during

faster switching. Incorporating Duarte's teachings into Engfeldt would have achieved the predictable result of improved charging and discharging control and performance because both references address the same general problem: electrically controlling an electrochromic device as it transitions between optical states.

179. First, a person of ordinary skill in the art would have been motivated to combine Engfeldt with Duarte to improve Engfeldt's switching or transition speed between optical states without relying solely on higher continuously applied voltage. Engfeldt expressly recognizes a speed-voltage tradeoff, explaining that "it is of benefit if the intended charging voltage for a static state is relatively large, since this typically increases the charging speed. However, the charging voltage for a static state cannot be too high without damaging the device." (EX1004, 14:6-11.) Thus, Engfeldt acknowledges the desire for faster switching between optical states, while also recognizing that simply increasing voltage is not always an acceptable solution. A person of ordinary skill in the art would have understood this disclosure to identify a common design problem in electrochromic control: stronger electrical drive can speed a transition, but if applied in an uncontrolled manner or for too long, it can risk damaging the electrochromic device.

180. A person of ordinary skill in the art would have recognized that Duarte provides a solution to that same problem. Duarte teaches that micro-pulses may be used such that "the energy in an electrochromic system is increased with faster color

change (both during darkening and lightening) without damaging the electrochromic materials contained in the panels.” (EX1006, 4:42-47.) Duarte further teaches that pulses of greater magnitude may be used that otherwise could damage system components if applied for longer durations. (*Id.*, 4:54-58.) In my opinion, a person of ordinary skill in the art would have understood Duarte’s micro-pulse teachings to improve Engfeldt’s method of charging and discharging electrochromic films by allowing higher or more effective electrical drive to be delivered in short, controlled intervals. This would have yielded the predictable result of faster or more efficient charging and discharging without relying solely on increasing the amplitude of a continuously applied voltage.

181. Second, a person of ordinary skill in the art would have been motivated to incorporate Duarte’s techniques for pulsing power into Engfeldt’s transition-control framework to refine charging and discharging control as the electrochromic film moves toward its desired optical state. Engfeldt explains that, “[w]hen coming closer to the intended final transmittance condition, the static state operation might be experienced as a somewhat coarse charging method,” and introduces a “trickle” substate to adjust the film’s charge “in small amounts” as the device approaches the final transmittance. (EX1004, 17:1-18:5.) Engfeldt thus recognizes that a single, static charging mode may not always provide the desired degree of control throughout the transition. A person of ordinary skill in the art would have understood

Engfeldt's trickle-charging disclosure to reflect the desirability of more granular control over charge delivery, particularly near the endpoint of an optical transition.

182. Duarte expands on that same general approach. Duarte teaches that the controller may apply voltage and/or current according to a “predetermined pattern” comprising “pulses, micro-pulses, and/or periods of continuous voltage and/or current,” and that micro-pulses may be interspersed between periods in which voltage is applied substantially continuously. (EX1006, Abstract, 9:35-51.) A person of ordinary skill in the art would have understood these teachings to allow the controller to deliver charge in smaller, spaced increments, rather than only through a continuous application of power, thereby giving the controller more flexibility to shape how the transition progresses. In my opinion, that added flexibility would have been useful in Engfeldt's system because Engfeldt already controls charging and discharging based on target optical state and measured electrical behavior. Duarte would have supplied a specific enhancement to Engfeldt's existing control logic by enabling more granular modulation of the applied voltage and/or current driving force during the transition.

183. Finally, a person of ordinary skill in the art would have understood that there are a limited and predictable number of ways to deliver external electrical drive to an electrochromic film during a transition, including substantially continuous drive, pulsed drive, or combinations of the two. A person of ordinary skill in the art

likewise would have understood that selecting among those known control options depends on the operating requirements of the electrochromic device, including desired transition speed, control refinement, and avoidance of damage. In that context, Duarte's teachings regarding predetermined pulse patterns, interspersed micro-pulses, and continuous-and-pulsed drive would have presented a known and predictable set of implementation options for improving Engfeldt's existing controller-based charging framework. A person of ordinary skill in the art therefore would have been motivated to incorporate those teachings into Engfeldt as routine selection and adaptation of known electrochromic control techniques to achieve a predictable balance of switching speed, control refinement, and safe operation.

C. Reasonable Expectation of Success

184. A person of ordinary skill in the art would have had a reasonable expectation of success in combining Engfeldt with Duarte in the manner discussed above. Engfeldt already includes the electrical-control infrastructure needed to implement such a modification. Engfeldt teaches a charge control arrangement that applies the main charging/discharging voltage, measures charging current, and measures open-circuit voltage for use in controlling transitions between optical states and approaching a target coloring level. (EX1004, 15:29-16:4, 22:6-15.) Duarte teaches that the same type of controller-based electrochromic system may apply electrical drive according to predetermined patterns including pulses, micro-

pulses, and periods of substantially continuous voltage and/or current, including micro-pulses interspersed between periods of continuous application. (EX1006, 4:42-47, 9:35-51.) A person of ordinary skill in the art therefore would have understood that Duarte's teachings were compatible with Engfeldt's existing controller-based architecture because both references use externally applied electrical drive under controller direction to transition an electrochromic device between optical states.

185. Implementing Duarte's teachings in Engfeldt would have involved only routine adaptation of controller logic and ordinary programming or configuration of Engfeldt's existing control electronics to vary the timing and profile of the applied drive during a transition, rather than any unpredictable redesign of the underlying electrochromic device. Engfeldt already applies electrical drive, measures electrical response, and uses those measurements to control the charging or discharging process. Duarte's micro-pulse and predetermined-pattern teachings would have simply provided additional known ways for the controller to shape that applied drive over time, including by interspersing shorter pulses with periods of substantially continuous application. A person of ordinary skill in the art would have understood that changing the drive waveform, timing, pulse duration, or sequencing of applied voltage and/or current was a predictable controller-implementation issue, not a change to the fundamental electrochromic film structure or operating principle.

186. A person of ordinary skill in the art also would have reasonably expected that modification to succeed because Duarte expressly teaches that its use of pulsed power to charge or discharge electrochromic films provides performance benefits in the same technological context. Duarte teaches that using micro-pulses allows “the energy in an electrochromic system” to be increased with “faster color change (both during darkening and lightening) without damaging the electrochromic materials contained in the panels.” (EX1006, 4:42-47.) Duarte further teaches that, because micro-pulses are short in duration, pulses of greater magnitude may be used in some circumstances that otherwise could damage system components if applied for longer periods. (EX1006, 4:54-58.) A person of ordinary skill in the art would have understood these teachings to provide a clear basis for expecting that Duarte’s pulsed-power techniques would improve Engfeldt in the same way: by permitting more effective charge delivery during electrochromic transitions while reducing the risk of damage associated with stronger continuously applied drive.

187. Given Engfeldt’s existing controller-based charging architecture and Duarte’s express teaching that pulsed power can improve optical transition in electrochromic films, a person of ordinary skill in the art would have expected Duarte’s method of applying pulsed power to operate predictably when implemented in Engfeldt’s system and to provide the same type of benefits taught by Duarte. Both references address the same type of device and the same control problem—how to

electrically drive an electrochromic device from one optical state to another while balancing transition speed, control, and device protection. Because Duarte's contribution would have been implemented through ordinary controller programming and drive-profile selection within Engfeldt's already-existing electrical-control framework, a person of ordinary skill in the art would have had a reasonable expectation of success in making the combination.

D. Claim Element Analysis

1. Claim 3: The method of claim 1, wherein the current driving comprises applying an external DC current to the electrochromic film.

188. As explained above for Ground 1, Engfeldt teaches a method of charging and discharging an electrochromic film by driving electric charge into and out of the film during both main charging/discharging and calibration. Although Engfeldt primarily describes voltage-driven embodiments, a person of ordinary skill in the art would have understood Engfeldt's voltage-driven charging/discharging framework to be compatible with a current-driven charging/discharging framework because transitioning an electrochromic film between optical states fundamentally involves moving electric charge into and out of the electrochromic material. A person of ordinary skill in the art would have understood that this charge movement could be driven and controlled by selecting an applied voltage, by controlling an applied current, or by using both, depending on the particular device architecture

and control objectives. Thus, a person of ordinary skill in the art would have understood voltage control and current control to be established and conventional alternatives for driving electrochromic transitions, including through the application of external DC current.

189. Duarte reinforces this point. Duarte is directed to “controlling electrochromic panels, which lighten and darken in response to applied electric current and/or voltage,” and repeatedly explains that its “electronic circuitry may be configured to adjust a voltage and/or current applied to an electrochromic panel.” (EX1006, 8:56-63; see also EX1006, Abstract, 1:6-10, 1:32-36, 1:42-47, 1:51-54, 1:56-64, 2:1-17, 2:47-50, 4:12-14, 4:32-35, 5:1-4, 8:11-19, 8:56-63, 9:40-10:2, 10:24-25, 10:40-43, 11:55-60, 12:1-10, 14:6-10.) Duarte therefore repeatedly teaches that electrochromic transitions may be driven using voltage, current, or both. In particular, Duarte explains that its electrochromic panel transitions between darkened and lightened states by applying voltage and/or current according to a predetermined pattern, and that applying current and/or voltage in one polarity causes darkening while applying current and/or voltage in the opposite polarity causes lightening. (EX1006, 8:11-19.) A person of ordinary skill in the art would have understood this disclosure to describe current as an applied driving force for moving charge in the electrochromic panel, not merely as a passive measurement.

190. Duarte further confirms, in its discussion of darkening control and drive waveforms, that current-based driving is a recognized implementation option. Duarte explains that, while “positive and/or negative voltage can be applied to the panel” using various waveforms, “[s]uch waveforms could also be applied as a controlled current to the system and/or panel.” (EX1006, 13:61-67.) In my opinion, a person of ordinary skill in the art would have understood that disclosure to teach that the same type of electrochromic transition control described in voltage terms may be implemented using controlled applied current. A person of ordinary skill in the art also would have understood the applied current to be external because Duarte’s system uses a power supply and electronic circuitry or a controller to cause voltage and/or current to be applied to the electrodes of the electrochromic panel. (EX1006, Abstract, 8:56-63, 9:35-51.) And because Duarte describes current and/or voltage applied in selected polarities to darken or lighten the panel, and elsewhere refers to “direct current” being applied in an electrochromic-window control context, a person of ordinary skill in the art would have understood Duarte’s current-control teachings to include external DC current. (EX1006, 8:11-19, 13:61-67, 14:20-25.)

191. A person of ordinary skill in the art would have found it obvious to modify Engfeldt’s electrochromic film charging/discharging framework to use current driving in view of Duarte. Both references concern controller-based electrochromic systems in which external power drives charging or discharging of

the electrochromic film to transition the device between optical states. Engfeldt already measures charging current and uses electrical feedback to control the transition, while Duarte expressly teaches driving electrochromic transitions between optical states by applying current as well as voltage. (EX1004, 15:29-33, 22:6-15; EX1006, 1:6-10, Abstract, 13:61-67.) A person of ordinary skill in the art would have viewed Duarte's current-control teachings as technically compatible with Engfeldt's controller-based charging framework because both systems use applied electrical drive to control charge movement in an electrochromic device. Incorporating Duarte's current driving into Engfeldt would not have required changing the basic electrochromic film or the overall purpose of Engfeldt's controller; rather, it would have involved using a known current-controlled drive mode as an alternative or supplement to Engfeldt's voltage-controlled drive mode.

192. Further, voltage-controlled operation and current-controlled operation were established and conventional electrochromic control approaches known in the art for decades, and a person of ordinary skill in the art would have regarded selection between them as a routine implementation choice based on device architecture and control objectives. In my opinion, because electrochromic switching is driven by charge movement, a person of ordinary skill in the art would have understood that controlling the applied current is a direct way to control the rate and amount of charge delivered to or removed from the electrochromic film. A

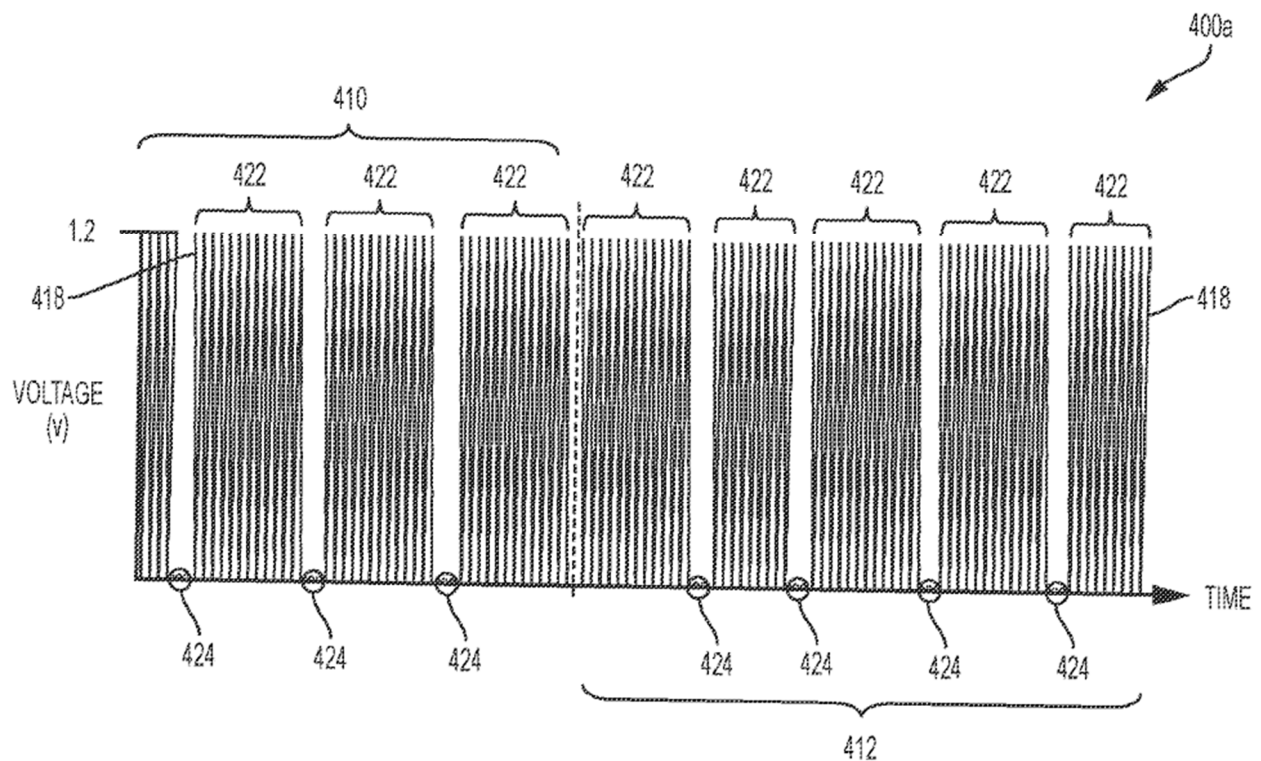
person of ordinary skill in the art therefore would have understood current control, including application of external DC current, to be a technically compatible and predictable alternative implementation of Engfeldt's voltage-driven charging/discharging framework. The resulting combination therefore would have rendered claim 3 obvious.

2. Claim 4: The method of claim 1, wherein the voltage driving comprises applying an external pulsed voltage to the electrochromic film.

193. Duarte discloses using pulsed voltage to drive the electrochromic transition. In particular, Duarte teaches that a controller causes an external power supply to apply voltage and/or current to an electrochromic panel according to a “predetermined pattern,” and that such patterns can include repeated electrical pulses, which Duarte refers to as “micro-pulses.” (EX1006, Abstract, 4:42-44.) A person of ordinary skill in the art would have understood these disclosures to teach applying external pulsed voltage to the electrochromic film to drive the optical transition. The voltage is external because Duarte's controller causes a power supply to apply the electrical drive to the electrochromic panel, and the voltage is pulsed because Duarte expressly describes repeated micro-pulses as part of the predetermined drive pattern. A person of ordinary skill in the art therefore would have understood Duarte's micro-pulse teachings to disclose a voltage-driving

technique in which electrical energy is delivered to the electrochromic film in discrete pulses rather than only as uninterrupted continuous voltage.

194. Duarte's Figure 4 (below) illustrates an example of using pulsed voltage to drive optical transition of an electrochromic film. Duarte explains that voltage profile 400a includes "a first portion 410 including an applied voltage in the positive polarity, which causes darkening of the panel 10." (EX1006, 10:54-60.) Duarte further explains that the first portion 410 "includes groups 422 of positive voltage micro-pulses 418." (EX1006, 10:60-64.) A person of ordinary skill in the art would have understood this disclosure to teach using externally applied pulsed voltage to drive charging or discharging of an electrochromic film to transition between optical states. Duarte is not merely describing a theoretical waveform; it describes an applied voltage profile used to cause darkening of the electrochromic panel. Because darkening and lightening in an electrochromic panel are caused by electrically driven charge movement within the electrochromic structure, a person of ordinary skill in the art would have understood Duarte's positive voltage micro-pulses to be pulsed voltage drive applied to the electrochromic film to affect the optical transition.



EX1006, Figure 4A

195. It would have been obvious to a person of ordinary skill in the art to incorporate Duarte’s pulsed-voltage driving technique into Engfeldt’s controller-based charging framework because Engfeldt recognizes that increasing applied voltage can increase charging speed, but that the voltage cannot be too high without damaging the device. (EX1004, 14:6-11.) Duarte teaches a specific solution to that same problem, explaining that use of micro-pulses increases the rate of charging or discharging the electrochromic film “with faster color change” “without damaging the electrochromic materials contained in the panels,” and further that pulses of greater magnitude may be used that otherwise could damage system components if

applied for longer durations. (EX1006, 4:42-58.) A person of ordinary skill in the art would have understood Duarte's pulsed-voltage technique as a predictable way to deliver a more effective electrical drive in short, controlled intervals, thereby improving transition speed while reducing the risk associated with continuously applying a higher voltage. A person of ordinary skill in the art therefore would have been motivated to modify Engfeldt to incorporate Duarte's pulsed-voltage driving technique to achieve faster electrochromic transition while reducing the risk of damage, as discussed in XI.B above ("Motivation to Combine Duarte with Engfeldt). The resulting combination therefore would have rendered claim 4 obvious.

3. Claim 5: The method of claim 1, wherein the current driving comprises applying an external pulsed current to the electrochromic film.

196. As explained above with respect to claim 3, it would have been obvious to modify Engfeldt's electrochromic charging and discharging framework to use external current driving in view of Duarte. Claim 5 adds only that the current driving comprises applying an external pulsed current to the electrochromic film. Duarte expressly teaches that its controller may cause a power supply to apply a "predetermined pattern" of "voltage and/or current" to the electrochromic panel, and Duarte further teaches that such predetermined patterns may include "pulses" or "micro-pulses." (EX1006, Abstract, 9:40-55, 4:42-44, 5:10-14, 9:25-32.) A person of ordinary skill in the art would have understood these disclosures to teach that the

electrical drive applied to the electrochromic panel may be current-based and may be delivered in pulsed form. Because Duarte's controller causes an external power supply to apply that current to the electrochromic panel, a person of ordinary skill in the art would have understood Duarte's pulsed-current implementation to involve applying an external pulsed current to drive the electrochromic transition.

197. A person of ordinary skill in the art therefore would have understood the combination of Engfeldt and Duarte to teach driving charging and discharging of an electrochromic film with current by applying an external pulsed current to the electrochromic film. This is a natural extension of Duarte's broader teaching that electrochromic panels may be controlled using voltage, current, or both, and that the applied electrical drive may be structured as pulses, micro-pulses, continuous application, or combinations of those drive forms. Duarte does not limit its pulsed drive teachings to voltage alone. Rather, Duarte repeatedly describes applying voltage and/or current according to predetermined pulse patterns, which a person of ordinary skill in the art would have understood to include pulsed current as an available current-driving implementation. (EX1006, Abstract, 4:42-44, 9:25-55.)

198. For the same reasons discussed above for claim 3, a person of ordinary skill in the art would have found it obvious to incorporate Duarte's pulsed-current implementation into Engfeldt's controller-based electrochromic charging framework. Doing so would have been a technically compatible and predictable

modification of the same current-driving approach already discussed for claim 3, with the further benefit taught by Duarte that pulsed drive can improve transition performance without damaging the electrochromic materials. (EX1006, 4:42-47.) In particular, a person of ordinary skill in the art would have understood pulsed current as a known way to deliver charge in controlled increments, thereby allowing the controller to influence the timing and amount of charge delivered to or removed from the electrochromic film during the transition. That implementation would have predictably improved control over the electrochromic transition while remaining compatible with Engfeldt's existing controller-based charging and discharging framework.

199. The resulting combination therefore would have rendered claim 5 obvious.

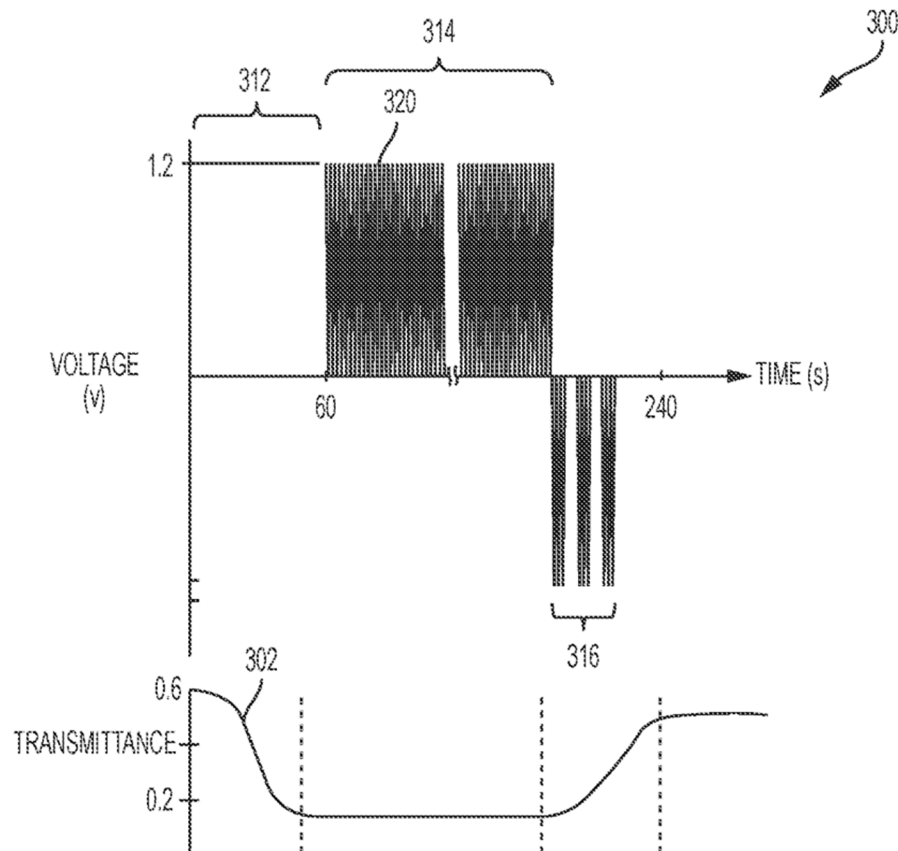
4. Claim 7: The method of claim 1, wherein injecting electric charges into the electrochromic film comprises applying a combination of a constant power source and a pulsed power source to the electrochromic film.

200. As explained in Ground 1, this claim would have been obvious in view of Engfeldt alone. (¶¶107-112.) Claim 7 is also obvious over Engfeldt in view of Duarte. Duarte teaches that its controller can cause a power supply to apply voltage and/or current to the electrochromic panel according to a “predetermined pattern” that can include both “repeated electrical pulses,” which Duarte refers to as “micro-pulses,” and periods in which voltage and/or current are applied substantially

continuously. (EX1006, Abstract, 4:42-61, 9:25-55, 10:10-14, 10:21-24.) Specifically, Duarte explains that “micro-pulses can be interspersed between periods of longer duration pulses or periods in which a voltage is applied substantially continuously.” (EX1006, 9:35-39.) In my opinion, a person of ordinary skill in the art would have understood Duarte to disclose applying a combination of constant power and pulsed power to the electrochromic film because Duarte’s controller causes externally supplied electrical drive to be applied both continuously and in discrete pulse form during electrochromic darkening or lightening.

201. Duarte’s Figure 3 (below) provides an example of this combined continuous-and-pulsed drive technique. Duarte explains that “a voltage profile 300 includes a first portion 312 for causing the panel to darken (e.g., to transition from a lightened or bleached state to a darkened state).” (EX1006, 10:3-5.) The voltage applied during this first portion is “a continuous positive voltage.” (EX1006, 10:6-13.) Duarte then teaches that voltage is applied as a series of micro-pulses, shown at portion 314, to achieve a darkened state. (EX1006, 10:10-25.) Additionally, since Duarte teaches “interspersing” the micro-pulses between the continuous voltage, a person of skill in the art would have understood that the “continuous positive voltage” applied during the first portion 312 can include interspersed micro-pulses. Duarte confirms this: “As shown in FIG. 3, a continuous positive voltage of 1 minute in duration is applied in the first portion 312; however, *micro-pulses or longer*

duration pulses could also be applied.” (Id., 10:6-13) (emphasis added). A person of ordinary skill in the art would have understood those disclosures to teach that Duarte’s substantially continuous voltage drive and its micro-pulse drive may be used together as part of the same predetermined drive pattern.



EX1006, Figure 3

202. A person of ordinary skill in the art would also have understood Duarte’s combined continuous-and-pulsed voltage application to correspond to injecting or removing electric charges into or from the electrochromic film. Duarte describes using positive voltage to cause darkening and negative voltage pulses to

cause lightening, and it explains that electrochromic panels lighten and darken in response to applied electric current and/or voltage. (EX1006, 1:6-10, 10:3-25.) A person of ordinary skill in the art would have understood that applying voltage or current to darken or lighten an electrochromic panel necessarily drives the movement of charge into or out of the electrochromic material. Accordingly, Duarte's continuous positive voltage and micro-pulses would have been understood as electrical drive conditions used to inject or remove charge from the electrochromic film to change its optical state.

203. As explained in Section XI.B ("Motivation to Combine"), a person of ordinary skill in the art would have been motivated to implement Duarte's teachings of combined constant and pulsed voltage in Engfeldt's method of applying voltage during the main charging/discharging operation. Engfeldt already applies voltage to charge or discharge the electrochromic film and recognizes the need to balance faster switching with avoiding damage. Duarte teaches that micro-pulses can increase the energy delivered to an electrochromic system for faster color change "without damaging the electrochromic materials contained in the panels." (EX1006, 4:42-47.) In my opinion, a person of ordinary skill in the art would have understood Duarte's combined continuous-and-pulsed drive approach as a predictable enhancement to Engfeldt's voltage-driven charging and discharging method because it would allow Engfeldt's controller to use substantially continuous drive for efficient transition

while using pulses or micro-pulses to better control charge delivery, increase transition speed, and reduce the potential for damage during optical transitions.

204. For these reasons, Engfeldt in view of Duarte renders obvious claim 7.

5. Claim 10: The method of claim 8, wherein the current driving comprises applying an external DC current to the electrochromic film.

205. See claim 3 above. (Section XI.D.1.)

6. Claim 11: The method of claim 8, wherein the voltage driving comprises applying an external pulsed voltage to the electrochromic film.

206. See claim 4 above. (Section XI.D.2.)

7. Claim 12: The method of claim 8, wherein the current driving comprises applying an external pulsed current to the electrochromic film.

207. See claim 5 above. (Section XI.D.3.)

8. Claim 14: The method of claim 8, wherein extracting charges into the electrochromic film comprises applying a combination of a constant power source and a pulsed power source to the electrochromic film.

208. See claim 7 above. (Section XI.D.4.) See also element [8.2] of Ground 1 regarding Engfeldt's teachings applying to both extracting charge from and injecting charge into an electrochromic film. (Section IX.B.5.c.)

209. The same is true for Duarte: applying a positive voltage and/or current darkens the panel, and applying a negative voltage and/or current lightens the panel. (EX1006, 8:11-27.) As I have explained above in this Declaration, a person of skill

in the art would understand that applying a positive voltage/current “injects” charge into the electrochromic film, while applying a negative voltage/current “extracts” charge from the electrochromic film.

9. **Claim 16:** The method of claim 15, wherein adjusting the amount of electric charges within the electrochromic film comprises applying the voltage driving, the voltage driving including an external DC voltage, an external pulsed voltage, or combination thereof to the electrochromic film.

210. Duarte teaches adjusting the amount of electric charges in the electrochromic film by applying a external pulsed voltage. *See* claim 4 (Section XI.D.2.)

10. **Claim 17:** The method of claim 15, wherein adjusting the amount of electric charges within the electrochromic film comprises applying the current driving, the current driving including an external DC current, an external pulsed current, or a combination thereof to the electrochromic film.

211. Regarding “wherein adjusting the amount of electric charges within the electrochromic film comprises applying the current driving, the current driving including an external DC current,” *see* claim 3. (Section XI.D.1.) Regarding “the current driving including... an external pulsed current,” *see* claim 4. (Section XI.D.2.)

XII. GROUND 4: CLAIM 19 IS OBVIOUS OVER ENGFELDT IN VIEW OF PRADHAN AND DUARTE

A. Claim 19: The method of claim 18, wherein the external voltage includes DC voltage and pulsed voltage, and the external current includes DC current and pulsed current.

212. As explained above for claim 18, Engfeldt and Pradhan teach adjusting the amount of electric charges within the electrochromic film by applying a combination of external voltage and external current. (EX1004, 15:29-33.) (EX1005, [0083], [0172].) Claim 19 specifies that the external voltage includes DC voltage and pulsed voltage, and the external current includes DC current and pulsed current. Duarte teaches that additional limitation.

213. Duarte teaches a controller-based electrochromic system in which a power supply applies “voltage and/or current” according to a predetermined pattern comprising “pulses, micro-pulses, and/or periods of continuous voltage and/or current.” (EX1006, Abstract.) Duarte further teaches that micro-pulses may be interspersed between periods in which voltage is applied substantially continuously. (EX1006, 9:35-39, 9:49-51.) Duarte also explains, in connection with Figure 3, that a continuous positive voltage may be applied during one portion of the transition and that the positive voltage may be applied “continuously or periodically,” for example, “as a series [of] micro-pulses.” (EX1006, 9:58-10:21.) In my opinion, a person of ordinary skill in the art would have understood these disclosures to teach both DC or substantially continuous voltage drive and pulsed voltage drive. The continuous

positive applied voltage is a DC-type voltage drive because it is applied in a fixed polarity to drive the electrochromic panel in a selected transition direction, while the micro-pulses are pulsed voltage because the applied electrical drive is delivered in discrete pulses rather than continuously.

214. Duarte further applies these same continuous and pulsed power teachings to driving optical transitions with current. Duarte explains that “[a]s will be appreciated by those skilled in the art,” various pulsed waveforms “can be applied as a controlled current to the system and/or panel” and that “different waveforms can be combined together to generate unique voltage and/or current patterns or profiles.” (EX1006, 13:61-14:10.) In my opinion, a person of ordinary skill in the art would have understood this disclosure to teach that Duarte’s pulsed waveform techniques are not limited to voltage control, but also apply to current control. Thus, Duarte teaches using current as a controlled driving force and delivering that current according to pulsed waveforms, *i.e.*, pulsed current. Duarte’s repeated disclosure of applying voltage and/or current in selected polarities to darken or lighten the electrochromic panel also would have conveyed to a person of ordinary skill in the art that the applied current includes DC current, because the current is supplied externally in a selected direction to drive charge into or out of the electrochromic structure during the optical transition.

215. Duarte teaches that these pulsed-control techniques provide “faster color change” “without damaging the electrochromic materials.” (EX1006, 4:42-47.) A person of ordinary skill in the art would have understood these teachings to disclose that electrochromic transition control may use both continuous DC driving force and pulsed driving force. A person of ordinary skill in the art also would have understood that Duarte’s control architecture contemplates voltage-controlled driving forces, current-controlled driving forces, or both, because Duarte repeatedly describes the driving force for darkening or lightening the electrochromic panel as “voltage and/or current.” (EX1006, Abstract, 9:35-39, 9:49-51.) Thus, Duarte discloses the same types of electrical drive recited in claim 19: external voltage including DC voltage and pulsed voltage, and external current including DC current and pulsed current.

216. A person of ordinary skill in the art would have been motivated to modify the Engfeldt/Pradhan combination to incorporate Duarte’s method of applying voltage and/or current to drive adjustments to the electric charge applied to the electrochromic film in both continuous and pulsed manners. Engfeldt and Pradhan already teach a controller-based electrochromic charging framework using both voltage and current, while Duarte provides a specific and compatible way to use both constant/DC and pulsed voltage and current to improve transition speed, refine control, and reduce the risk of damage. Engfeldt recognizes that increasing

applied voltage can increase charging speed, but warns that the voltage cannot be too high without damaging the device. (EX1004, 14:6-11.) Pradhan likewise teaches using voltage drive and current drive to improve transition performance while avoiding degradation or damage. (EX1005, [0061], [0083], [0172].) Duarte supplies a predictable enhancement to that same framework by teaching that the driving force used to charge or discharge an electrochromic film—whether voltage, current, or both—may be delivered in substantially continuous DC form, in pulsed form, or as a combination of the two during an optical transition. (EX1006, Abstract, 4:42-47, 9:35-39, 9:49-51, 9:58-10:21.)

217. A person of ordinary skill in the art would have understood this modification to be straightforward and technically sensible. All three references concern controller-based electrochromic systems in which external electrical drive is applied to move charge into or out of an electrochromic device to reach a desired optical state. Engfeldt provides the base voltage-driven charging and discharging framework, Pradhan confirms the use of voltage drive and current drive in that framework, and Duarte provides specific continuous and pulsed implementations for voltage and current drive. Incorporating Duarte's continuous/DC and pulsed drive patterns into the Engfeldt/Pradhan system would therefore have involved applying known electrochromic drive waveforms through an existing controller-based electrical-control architecture. A person of ordinary skill in the art would have

expected that modification to operate predictably because it would not require changing the fundamental electrochromic device structure but rather would involve selecting and programming the electrical drive profile used to inject or extract charge during the transition.

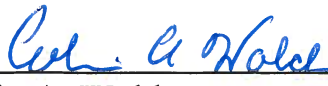
218. Accordingly, in my opinion, a person of ordinary skill in the art would have found it obvious to combine Duarte's teachings with the Engfeldt/Pradhan system such that the applied voltage and the applied current are each delivered as combinations of continuous/DC and pulsed forms, as claim 19 requires.

219. I reserve the right to supplement my opinions in the future to respond to any arguments that Patent Owner raises and to take into account new information as it becomes available to me.

220. I understand and have been warned that willful false statements and the like are punishable by fine or imprisonment, or both (18 U.S.C. § 1001). I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of title 18 of the United States Code.

221. I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Executed on May 15, 2026.


Colin A. Wolden

APPENDIX A

COLIN A. WOLDEN

Curriculum Vitae

EDUCATION

Massachusetts Institute of Technology
Ph. D. in Chemical Engineering, (1995)
M. S. in Chemical Engineering Practice, (1992)

University of Minnesota
B. S. in Chemical Engineering, (1990)

PROFESSIONAL EXPERIENCE

- 8/24 – Present **William K. Coors Distinguished Chair and Professor**
Colorado School of Mines, Department of Chemical and Biological Engineering
Research focuses on the development of new materials with application in renewable energy and sustainability. Current research interests include: (1) thin film photovoltaics; (2) membrane reforming of ammonia and methanol; (3) fusion fuel processing; (4) next generation battery materials.
- 6/22 – Present **Co-founder, Chief Scientific Officer, Blaze Energy Technologies**
- 8/17 – Present **Joint Appointment, National Renewable Energy Laboratory**
- 5/08 – 8/24 **Professor, including Interim Head (1/1/15 - 6/30/15, 1/1/17 - 8/30/17)**
Colorado School of Mines, Department of Chemical and Biological Engineering
- 5/02 – 5/08 **Associate Professor with Tenure**
Colorado School of Mines, Department of Chemical Engineering
- 9/97 – 5/02 **Assistant Professor**
Colorado School of Mines, Department of Chemical Engineering
- 9/95 – 9/97 **National Research Council/Army Research Office Postdoctoral Fellow**
North Carolina State University, Department of Materials Science
Advisors: Dr. John T. Prater (ARO) and Dr. Robert F. Davis (NCSU)
- 5/95 – 9/95 **Station Director, Natick, MA**
MIT School of Chemical Engineering Practice
- 9/90 – 5/95 **Graduate Research Assistant**
MIT Department of Chemical Engineering
Ph.D. Thesis entitled “Critical gas-phase and surface reactions involved in the chemical vapor deposition of diamond.” Research Advisor: Dr. Karen K. Gleason

HONORS, AWARDS, AND PATENTS

- AVS Fellow, 2014.
- CSM Dean’s Excellence Award, 2013.
- E. T. S. Walton Fellow – Science Foundation Ireland, 2010
- Outstanding Educator – Department of Chemical Engineering, 2009
- Order of Omega CSM Outstanding Faculty Award, 2007 CSM “Diggers for Diversity Award”, 2005
- NSF Career Award, 2001
- 3M Corporation Untenured Faculty Award, 2000 and 2001
- NRC/ARO Postdoctoral Fellowship, 1995-1997
- Edward Vivian Prize for Excellence in Chemical Engineering Practice, 1992

- US Patent Application 18/729,083, "Generation of ammonia/hydrogen mixtures and/or hydrogen-enriched fuel mixtures", C.A. Wolden, J. D. Way (2025).
- US Patent Application 18/741,630, "Hydrogen permeable, intermetallic diffusion barriers used in body centered cubic metal membranes", C.A. Wolden, A. Job, J. D. Way (2024).
- US Patent 11,950,436, "All-back-contact photovoltaic devices using cracked film lithography", L.M. Wheeler, K.J. Prince, C.A. Wolden, M.M. Mirzokarimov, C.P. Muzzillo (2024).
- US Patent 11,925,921, "Methods of making YSZ supported catalyst, and methods of using the same", J.D. Way, C.A. Wolden, Z. Zhang, (2024).
- US Patent 11,742,440, "All-back-contact perovskite solar cells", K.J. Prince, C.A. Wolden, L.M. Wheeler, (2023).
- US Patent 11,710,799, "Controlled thermomechanical delamination of thin films", M.O. Reese, D.L. McGott, M.D. Kempe, T.M. Barnes, C.A. Wolden, (2023).
- U.S. Pat. App. 18/097,228, "Generation of Ammonia/Hydrogen Mixtures and /or Hydrogen Enriched Fuel Mixtures", C.A. Wolden, R. Sitar, J. D. Way (2023).
- US Patent App. 17/180,479, "Method of making anhydrous metal sulfide nanocrystals", W. Smith and C.A. Wolden, (2021).
- US Patent 11,090,628, "Catalytic membrane reactor, methods of making the same and methods of using the same for dehydrogenation reactions", J. D.Way and C. A. Wolden (2021).
- US Patent 10399853, "Production of alkali sulfide cathode material and methods for processing hydrogen sulfide", Y. Yang, C. A. Wolden, X. Li, R. Morrish, (2019).
- US Patent 10159969, "Ammonia Synthesis at Moderate Conditions Using Hydrogen Permeable Membrane Reactors," J. D. Way, S.-T. B. Lundin and C. A. Wolden, (2018).
- US Patent 20,150,325,718: "Rapid thermal processing of back contacts for CdTe solar cells", with J. Beach, and T. R. Ohno, (2015).
- US Patent 20,150,315,035: "Electrochromic tungsten oxide for optical modulation and methods of making the same", with C.-P. Li, C. Engrakul, and R. C. Tenent, (2015).
- U. S. Patent 8,623,121, "Stable Catalyst Layers for Hydrogen Permeable Composite Membranes", with J. D. Way, (2014).
- US Patent App.. 61/895,919: "Plasma-assisted nanofabrication of two-dimensional metal dichalcogenide layers", C. A. Wolden and R. M. Morrish, (2014).
- US Patent App. 62/033396: "Methods and Devices for Hydrogen Sulfide Removal with H₂ Co-Generation", Y. Yang, C. A. Wolden, (2014).
- U.S. Patent 8,025,932, "Self-limiting thin film synthesis achieved by pulsed plasma-enhanced chemical vapor deposition", M. T. Seman, C. A. Wolden, (2011).
- US Patent App. 11/161,347: "High Vacuum Plasma-Assisted Chemical Vapor Deposition System", C. Wolden (2006).

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143. W. H. Smith, S. A. Vaselabadi and C. A. Wolden, "Argyrodite superionic conductors fabricated from metathesis-derived Li₂S," *ACS Applied Energy Materials* **5**, 4029-4035 (2022).
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- doped magnesium zinc oxide (GMZO) by reactive co-sputtering", *Journal of Vacuum Science & Technology A* **in press** (2021).
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32. J. Li, J. D. Beach and C. A. Wolden, "Rapid thermal processing of ZnTe:Cu contacted CdTe solar cells," in *40th IEEE Photovoltaic Specialists Conference*, pp. 0085-0089 Denver, CO, (2014).
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24. *Fundamental Gas-Phase and Surface Chemistry of Vapor Phase Materials Processing 3*, Eds. M. T. Swihart, D. G. Goodwin, R. Schmid, M. Sugiyama, and C. Wolden, *ECStranactions*, **2**, (2007).
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19. C. A. Wolden, "Combustion Synthesis of Diamond", Chapter 8 of the *Diamond Films Handbook* (Eds. J. Asmussen and D. Reinhard) Marcel-Dekker, New York, (2002) p. 303-323.
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17. J. Zhou, A. Overmeyer, and C. A. Wolden, "Evaluating the contributions of both catalytic and thermal chemistry in hot-wire chemical vapor deposition", *Proc. Electrochem. Soc.*, **2001-13**, 92 (2001).
16. J. J. Robbins, Y.-J.Huang, M. Bai, T. Vincent, and C. A. Wolden, "An X-ray diffraction investigation of tin oxide deposition and annealing", *Mater. Res. Soc. Symp. Proc.* **666**, F1.7.1 - F1.7.6 (2001).
15. W. Xiao, J. Robbins, C. A. Wolden, and T. Vincent, "Development of optical diagnostics for real time control of tin oxide PECVD", *Proceedings of the 2001 NSF Design and Manufacturing Research Conference* (Society of Manufacturing Engineers, 2001) CD-ROM .
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12. J. M. Kestner, C. A. Wolden, P. V. Meyers, L. Raja, and R. J. Kee, "Atmospheric pressure chemical vapor deposition of CdTe films – First PV devices", in *Proceedings of the 28th IEEE Photovoltaic Specialists Conference*, p. 595-598. (2000).
11. J. J. Robbins, T. Vincent, and C. A. Wolden, "Plasma-enhanced chemical vapor deposition of tin oxide thin films", *Proceedings of the 2000 NSF Design and Manufacturing Research Conference* (Society of Manufacturing Engineers, 2000) CD-ROM.
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8. P. V. Meyers, R. J. Kee, L. Raja, M. Aire and C. A. Wolden, "Atmospheric pressure chemical vapor deposition of CdTe – Reactor design considerations", in *NCPV Photovoltaics Program Review*, (Eds. M. Al-

- Jassim, J. P. Thorthon and J. M. Gee), American Institute of Physics CP462, Woodbury, NY (1999) p. 218-223.
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 6. A. D. Hanser, C. A. Wolden, W. G. Perry, T. Zheleva, E. P. Carlson, P. Hartlieb, and R. F. Davis "Diluent gas effects on properties of AlN and GaN thin films grown by metalorganic vapor phase epitaxy on a(6H)-SiC substrates", *Mater. Res. Soc. Symp. Proc.* **482**, 149 (1998).
 5. S. A. Smith, C. A. Wolden, M. D. Bremser, A. D. Hanser, R. F. Davis, and W. V. Lampert, "Selective and non-selective etching of GaN, (Al,Ga)N, and AlN using an inductively coupled plasma", *Inst. Phys. Conf. Ser.* **156**, 349 (1998).
 4. Z. Sitar, P. C. Yang, W. Liu, R. Schlessner, C. A. Wolden, and J. T. Prater, "Novel approaches to heteroepitaxial nucleation of diamond on nickel", *Proceedings of the 4th NIRIM International Symposium on Advanced Materials*, (1997) p. 7.
 3. "TEM analysis of the phases observed during the growth of oriented diamond on nickel", W. Liu, P. C. Yang, C. A. Wolden, Z. Sitar, R. F. Davis, and J. T. Prater, *Mater. Res. Soc. Symp. Proc.* **423**, 457 (1996).
 2. P. Yang, W. Liu, C. A. Wolden, Z. Sitar, R. F. Davis, and J. T. Prater, "Nucleation and growth of oriented diamond on nickel substrates", *Mater. Res. Soc. Symp. Proc.* **423**, 281 (1996).
 1. C. A. Wolden, G. Zau, W. T. Conner, H. H. Sawin and K. K. Gleason, "A novel molecular beam reactor for the study of diamond surface chemistry", *Mater. Res. Soc. Symp. Proc.* **334**, 123 (1994).

SELECTED INVITED & AWARD-WINNING PRESENTATIONS

- 2025 **Invited Presentation** – DOE Tritium Focus Group, Devens, MA "Direct Internal Recycling Using Palladium Alloy Metal Foil Pumps", C.A. Wolden, 5/14/25.
- 2024 **Invited Presentation** – Renewable Hydrogen Storage and Transport Conference, Los Angeles, CA, "Ammonia as a vector for distributed delivery of UHP hydrogen and clean combustion mixtures", C. A. Wolden, 3/12/24.
- 2023 **Invited Presentation** – Albemarle Lithium, Kings Mountain, NC, "Scalable Synthesis of Metal Sulfide Nanocrystals for Electrochemical Storage Applications", C. A. Wolden, 5/25/23.
- 2023 **Invited Presentation** – Hydrogen Powered Future, University of Oklahoma, "The ongoing saga of Haber & Bosch: Scientists who saved the world, accelerated global warming, and may contribute to climate restoration", C. A. Wolden, 4/28/04.
- 2021 European MRS Meeting, Virtual, D. McGott, "Is 3D/2D passivation a secret to success for polycrystalline thin-film solar cells?", 6/2/21. **Deborah McGott won the Young Researcher Award with this presentation**
- 2021 **Invited Presentation** –Texas Tech University, "The Role of Ammonia in Enabling H₂@Scale", C. A. Wolden, 10/15/21.
- 2019 **Invited Presentation** – Future Leaders in Chemical Engineering, North Carolina State University, "Combinatorial Synthesis of Mg_xZn_{1-x}O (MZO) Thin Films for CdTe Solar Cells", G. Yeung, Y. Samoilenko, and C.A. Wolden, 10/21/19. **Gavin Yeung selected to attend this prestigious conference for undergraduate researchers.**
- 2019 **Invited Presentation** – ARPA-E Fusion Workshop, San Francisco "Advanced Membrane Technologies to Enable an Efficient Tritium Fuel Cycle", C. A. Wolden, 8/13/19.

- 2019 **Invited Presentation** – Posters on the Hill, Washington, D.C., K. Hietala, Y. Zhao, W. Smith, and C. A. Wolden, “Scalable Synthesis of Alkali Sulfide Nanocrystals Using a Bubble Column Reactor”, 5/1/19. **Kristen Hietala one of 60 undergraduates from around the country who were chosen for this prestigious opportunity. Among these she was one of two students selected to receive the Excellence in Engineering award and \$500 from IEEE.**
- 2018 **Invited Presentation** – IOP Advances in Photovoltaics, Loughborough, UK “Advances in Thin Film CdTe-based Solar Cells”, C. A. Wolden, 9/18/18.
- 2017 **Invited Presentation** – South Dakota School of Mines, Department of Chemical and Biological Engineering, Rapid City, SD “Green Manufacturing of Alkali Sulfide Nanocrystals for Next Generation Batteries”, C. A. Wolden, 11/7/17
- 2017 **Invited Presentation** – 2017 AIChE Meeting, Minneapolis, MN “Reactive precipitation of anhydrous alkali sulfide nanocrystals with concomitant abatement of hydrogen sulfide and co-generation of hydrogen”, C. A. Wolden, 11/1/17.
- 2017 **Invited Presentation** - 44th International Conference on Metallurgical Coatings and Thin Films (ICMCTF), San Diego, CA “Accelerated development of CuSb(S, Se)₂ thin film photovoltaics”, C. A. Wolden, 4/24/17.
- 2016 **Invited Presentation** - University of Utah, Department of Materials Science and Engineering, Salt Lake City, UT “The Evolution of Advanced Front Contacts during CdTe Solar Cell Fabrication”, C. A. Wolden, 4/6/16.
- 2016 **Invited Presentation** - University of New Mexico, Department of Chemical and Biological Engineering, Albuquerque, NM “The Role of Oxygenated Cadmium Sulfide Window Layers on High Efficiency CdTe Solar Cells”, C. A. Wolden, 1/27/16.
- 2015 **Invited Presentation** - 8th Sino-US Joint Conference of Chemical Engineering, Shanghai, China, “Development of Earth Abundant Membrane Reactors for Energy Efficient Chemical Processing”, C. A. Wolden, 10/13/15
- 2014 **Invited Presentation** - 47th Meeting of the Korean Vacuum Society, Goseong-gun, South Korea, “Interface Engineering of Advanced Contacts for High Efficiency CdTe Solar Cells” C. A. Wolden, 8/18/14.
- 2013 **Invited Presentation** - 2013 Spring MRS Meeting, San Francisco, CA, “Solution-phase Routes to Cost Reduction for Smart Windows”, C.-P. Li, F. Lin, D. Alie, C. Engrakul, C. A. Wolden, R. M. Richards, S. Shaheen, R. C. Tenent, 4/3/13.
- 2013 **Invited Presentation** - 9th World Congress of Chemical Engineering, Seoul, Korea, “Nanoscale control of film thickness, composition, and conformality using plasma-enhanced chemical vapor deposition”, C. A. Wolden, 8/21/13.
- 2012 Rocky Mountain AVS Symposium, Westminster, CO, “Fabrication and surface functionalization of asymmetric nanopore arrays”, S. Kelkar, R. Patel, D. Chiavetta, S. Retterer, and C. A. Wolden, 9/20/12. **Sanket Kelkar won first place in the Graduate Student Poster competition, \$500 Prize.**
- 2012 **Invited Keynote** - “Nanocomposite smart windows for energy efficient buildings”, C. A. Wolden, Smart Surfaces 2012, Dublin, Ireland, 3/9/12.
- 2012 **Invited Presentation** - “Non-equilibrium Processing of CdTe Absorbers”, C. A. Wolden, Bay Area PV Consortium Annual Meeting, Berkeley, CA, 10/2/12.
- 2011 **Invited Plenary Address** – XVI International Workshop on the Physics of Semiconductor Devices, IIT-Kanpur, India, “Photovoltaic Manufacturing, Present Status, Future Prospects & Research Needs”, C. A. Wolden, 12/22/11.

- 2011 **Invited Presentation** - Kansas State University, Manhattan, KS, “Carbide Composite Membranes for Hydrogen Purification”, C. A. Wolden, 11/8/11.
- 2011 **Invited Presentation** - 58th AVS Symposium, Nashville, TN, “Plasma Deposition of Carbide-Based Composite Membranes for Hydrogen Purification”, C. A. Wolden, 11/3/11.
- 2011 **Invited Presentation** - CU Materials & Nanoscience Seminar, “Activation of Hematite Nanorod Arrays for Photoelectrochemical Water Splitting”, C. A. Wolden, 2/12/11.
- 2010 Student Poster Session, Rocky Mountain AVS, “Carburization of Molybdenum (VI) Oxide for Synthesis of Mixed Alcohols from Syngas”, A. Pickerell, J. Hensley, J. D. Way, and C. A. Wolden, 9/10. **Anna was awarded best Poster and \$500 prize.**
- 2009 56th AVS International Symposium, San Jose, CA, “Room Temperature Synthesis of Silica and SiO₂-TiO₂ Composites for use as Barrier and Anti-Reflection Coatings”, P. C. Rowlette and C. A. Wolden, 11/09. **Pieter Rowlette won the Thin Film Division Graduate Student Award with this presentation.**
- 2009 RM-AVS Graduate Poster Competition, Westminster, CO: “Self-Limiting Deposition of Anatase TiO₂ for Photocatalytic Applications”, N. G. Kubala, F. Wang, and C. A. Wolden, 9/09. **Nick Kubala won first place and a \$500 cash award.**
- 2009 RM-AVS Graduate Poster Competition, Westminster, CO: “Nanoscale Engineering of Mixed Metal Oxide Thin Films for Electronic and Solar Applications”, P. C. Rowlette, M. Canon, and C. A. Wolden, 4/09. **Pieter Rowlette won second place and a \$250 cash award.**
- 2009 **Invited Presentation** - Society of Vacuum Coaters TechCon, Santa Clara, CA “Fundamental Understanding of Pulsed PECVD Through Diagnostics and Modeling”, Colin A. Wolden, 5/09.
- 2009 **Invited Presentation** - Department of Chemical and Biological Engineering, University of Connecticut, “Nanoscale Engineering of Mesoscopic Structures”, Colin A. Wolden, 2/09.
- 2008 **Invited Presentation** - Department of Chemical and Biological Engineering, Drexel University, “Nanoscale Engineering of Mesoscopic Structures”, Colin A. Wolden, 10/08.
- 2008 **Invited Presentation** - 2008 AIChE Annual Meeting, Philadelphia, PA, “Applying Lessons Learned from an Etching Lab: The Roll of O Atoms in PECVD”, C. A. Wolden, 11/08. Special symposium honoring the distinguished career of Professor Herb Sawin.
- 2008 **Invited Participant** – Scientific Challenges in Solar Energy Conversion and Storage Workshop, Sponsored by the Institute for Mathematics and Its Applications, Minneapolis, MN. 11/1/08.
- 2008 **Invited Presentation** - Department of Chemical and Biological Engineering, Drexel University, “Nanoscale Engineering of Mesoscopic Structures”, C. A. Wolden, 10/08.
- 2008 **Invited Presentation** - Eindhoven Technical University, Dept. of Applied Physics, “Self-Limiting Synthesis of Metal Oxide Thin Films by Pulsed PECVD,” C. A. Wolden, 1/08.
- 2007 54th AVS International Symposium, Seattle, WA, “Engineering Plasma-Enhanced Chemical Vapor Deposition to Deliver Self-Limiting Deposition of Metal Oxide Thin Films”, M. T. Seman, S. Agarwal, J. J. Robbins and C. A. Wolden, 10/07. **(Michael T. Seman received the AVS Graduate Research Award with this presentation.)**
- 2006 **Invited Presentation** - Applied Materials, Santa Clara, CA, “Formation of Chalcogen Containing Plasmas and Their Use in the Synthesis of Thin Film Photovoltaic Absorbers”, C. A. Wolden, 9/06.

- 2006 **Invited Presentation** - Applied Materials, Santa Clara, CA, “PECVD Synthesis of Metal Oxides: Precursors, Plasma Chemistry, and Achieving ALD Control with Continuous Processing”, C. A. Wolden, 9/06.
- 2006 **Invited Presentation** - Applied Materials, Santa Clara, CA, “Electrochromic Films and Devices Produced by Plasma-enhanced Chemical Vapor Deposition”, C. A. Wolden, 9/06.
- 2005 **Invited Presentation -)** Intel Corporation, Portland, OR, “Development of Plasma Assisted Co-Evaporation (PACE) for thin film semiconductors”, S. Kosaraju and C. A. Wolden, 5/05.
- 2005 **Invited Presentation** - National Renewable Energy Laboratory, Golden, CO, “Development of Plasma Assisted Co-Evaporation (PACE) for thin film photovoltaics”, S. Kosaraju and C. A. Wolden, 5/05.
- 2005 Society of Vacuum Coaters, Denver, CO, “Development of Plasma Assisted Co-Evaporation (PACE) for thin film deposition”, S. Kosaraju, I. Repins, and C. A. Wolden, 4/05. (**Invited to present in the Heureka! session, describing breakthrough technology**)
- 2004 **Invited Presentation** - National Institute of Standards and Technology, Boulder, CO, “Molecular Engineering of Oxide Chemical Vapor Deposition”, C. A. Wolden, 12/04.
- 2004 Materials Research Society Fall Meeting, Boston, MA, “Controlled Nitrogen Incorporation in ZnO Films Grown by Plasma Assisted Chemical Vapor Deposition”, T. M. Barnes, J. Leaf, K. Olson and C. A. Wolden, 12/04. (**Teresa Barnes received the MRS Graduate Student Gold Award with this presentation.**)
- 2004 51st International AVS Symposium, Anaheim, CA, “HVP-CVD: A Novel Chemical Vapor Deposition Approach for Zinc Oxide Synthesis”, T. M. Barnes, C. Fry, J. Leaf, and C. A. Wolden, (**Teresa Barnes received the AVS Semiconductor Division Graduate Research Award with this presentation.**)
- 2004 **Invited Presentation** -University of California Santa Barbara, Inorganic Chemistry Seminar Series, “Transparent Electronic Oxides: Theoretical Design & Experimental Synthesis”, C. A. Wolden, 4/04.
- 2003 **Invited Presentation** - National Renewable Energy Laboratory, “Plasma Synthesis of Metal Oxide Films for Solar Energy Applications”, C. A. Wolden 7/03.
- 2001 American Vacuum Society Regional Conference, Arvada, CO, “Plasma Enhanced Chemical Vapor Deposition of Electrochromic Tungsten Oxide”, A. Chorney and C. A. Wolden, 8/01. (**as an undergraduate Anna Chorney received 3rd place in the Student Poster Competition competing primarily against graduate students**).
- 2001 Materials Research Society Spring Meeting, San Francisco, CA, “Characterization of Chalcocites produced by Thermal and Plasma-assisted Sulfurization”. C. C. Fischer and C. A. Wolden, 4/01. (**Chris Fischer was awarded the Outstanding Poster in the nationwide Undergraduate Materials Research Initiative competition**).
- 2000 **Invited Presentation** - 3M Corporate Research Center, St. Paul, MN, “Synthesis of Electronic Oxides”, C.A. Wolden, 11/00.
- 1998 **Invited Presentation** - Gordon Research Conference on Diamond, Oxford, England, “Diamond Growth at the Center of the C-H-O Phase Diagram: Nucleation, Growth, Texture Development” C. A. Wolden, 8/98.

STUDENTS SUPERVISED

- Postdoctoral Scholars (12 to date)
 - Dr. Mingyuan Cao, 2024 - 2025
 - Dr. Rok Sitar, 2023, CEO, Blaze Energy Technologies
 - Dr. Jolie Lucero, 2020 – 2021, Los Alamos National Laboratory
 - Dr. Javishk Shah, 2019 – 2022, HyET NoCarbon
 - Dr. Tommy Fuerst, 2019, Idaho National Laboratory
 - Dr. Simona Ligouri, 2017, Faculty - Clarkson University
 - Dr. Santosh Sahoo, 2013, ASML
 - Dr. Rachel Morrish, 2010-2015, Faculty - Colorado School of Mines
 - Dr. Joe Beach, 2012-2015, Founder - Starfire Energy
 - Dr. William Rance, 2014, Lohnstar Optics
 - Dr. Pieter Rowlette, 2010, Intel
 - Dr. Fengli Wang, 2008 – 2009, Shenzhen Smoore Technology Limited
- Graduate Students: Supervised 28 PhD and 22 MS students advised to date.
 - Michael Aire (ME Chemical Engineering, 5/99) - Non-thesis Masters: Project included initial design and construction of APCVD reactor for CdTe. – Newmont Mining
 - Yoxa Mahathongdy (MS Materials Science, 7/99) - “Statistical optimization & analysis of vapor CdCl₂ Processing for CdS/CdTe solar cells” – Corning
 - Joshua Robbins (MS Chemical Engineering, 9/00) - “Plasma enhanced chemical vapor deposition and physical characterization of tin oxide thin films”. – PhD Candidate, CSM
 - Jie Zhou (PhD Chemical Engineering, 10/01) – “The kinetics of hot-wire chemical vapor deposition of Teflon-like films”. – Advanced Solar Power
 - Weican Xiao (MS Engineering, 7/02, co-advised with Tyrone Vincent) – “*In-situ* optical diagnostics of tin oxide thin film synthesis during plasma enhanced chemical vapor deposition”: – Unknown
 - James Kestner (PhD - Materials Science, 7/03) – “Development and analysis of vapor transport deposition of Cadmium Telluride Thin Films”: – Boeing
 - Joshua Robbins (PhD Chemical Engineering, 7/03) – “Development and analysis of plasma-enhanced chemical vapor deposition of transparent conducting oxides”; – Founder, New Terrain Brewing
 - Michael Seman (MS Chemical Engineering, 5/04) – “Electrochemical and optical characterization of electrochromic tungsten oxide synthesized by PECVD”; – PhD Candidate, CSM
 - Teresa Barnes (PhD Chemical Engineering, 12/04) – “Development of high vacuum plasma-assisted chemical vapor deposition and its application to semiconducting zinc oxide”; – NREL
 - Sreenivas Kosaraju, (PhD Chemical Engineering, 8/05) – “Plasma-assisted co-evaporation synthesis of wide band gap semiconductors” ; – Intel
 - Wenli Yang, (PhD Chemical Engineering, 12/06) – “Plasma-enhanced chemical vapor deposition of titanium oxide thin films for dielectric applications”; – Stion
 - Scott Szymanski, (MS Chemical Engineering, 7/07) – “Self-limiting growth of aluminum oxide thin films by pulsed plasma-enhanced chemical vapor deposition”; – Whiting Petroleum
 - Mike Seman, (PhD Chemical Engineering, 12/07) – “Pulsed plasma-enhanced chemical vapor deposition of metal oxide thin films: Application to electrochromics”; – Co-founder, Resource X
 - Pieter Rowlette, (PhD Chemical Engineering, 12/09) – “Pulsed plasma-enhanced chemical vapor deposition of mixed metal oxides and nanolaminates” ; – Intel
 - Anna Pickerel, (Non Thesis MS Chemical Engineering, 12/10) Project based on synthesis of carbide catalysts for alcohol synthesis from biofuels. – Teacher
 - Nick Kubala, (MS Chemical Engineering, 12/09) – “Self-limiting growth of titanium oxide thin films by pulsed plasma-enhanced chemical vapor deposition”; – Align Midstream
 - Chris Lange, (MS Electrical Engineering, (5/11) “Design and construction of a diagnostic suite for fundamental studies of pulsed PECVD”; – Tacuna Systems LLC
 - Trupti Gawai, (Non Thesis MS Chemical Engineering, 5/11) Project based on pulsed PECVD of oxide films. – Micron
 - Rakhi Patel, (PhD Chemical Engineering, 8/12) – “Pulsed plasma-enhanced chemical vapor deposition of hybrid organic-inorganic nanolaminates”; – Intel
 - Zhaowang Zong, (MS Chemical Engineering, 9/13) – “Electrochromic transistors”; – CSM PhD candidate.

- Chi-ping Li, (PhD Materials Science, 1/14) – “Scalable synthesis of mesoporous electrochromic tungsten oxide”; –Taiwan OLED manufacturer.
- Jon Kintner: (Non Thesis MS Engineering, 5/14) Project based on CdTe solar cells. – Starfire Energy.
- Christopher Sentman (MS Chemical Engineering, 8/14) – “Pulsed PECVD Synthesis of metal dichalcogenide thin films for sustainable energy applications”; –Poet Biofuels
- Dan Cooney, (MS Chemical Engineering, 9/14) – “Development of BCC metal membranes for H₂ separation”; – ADA Technology
- Sanket Kelkar, (PhD Chemical Engineering, 8/15) – “Design and Fabrication of Asymmetric Nanopores using Pulsed PECVD”; – Micron
- Daniel Meysing, PhD Chemical Engineering, 8/15) – “Development of Ternary Oxides for Use in Advanced Front Contacts in Cadmium Telluride Solar Cells by Magnetron Sputtering”; – First Solar.
- Adam Welch, (PhD Materials Science, 12/15) – “CuSb(S,Se)₂ Based Thin Film Heterojunction Photovoltaic Devices”; – Starfire Energy
- Jason Trevithick, (MS Chemical Engineering, 6/16) – “Activation of CdTe solar cells using molecular chlorine”; – Micron
- Jiaojiao Li, (PhD Materials Science, 8/16) – “Development of ZnTe Cu Contacted CdTe Solar Cells”; – Reel Solar Inc.
- Sean T. B. Lundin, (PhD Chemical Engineering 9/17, co-advised with J. D. Way) – “Material and Operational considerations for effective use of palladium composite hydrogen separation membranes. – University of Tokyo
- Tommy Fuerst, (PhD Chemical Engineering, 12/18, co-advised with J. D. Way) – “Catalytic Coatings for Vanadium-Based Hydrogen Membranes”, Idaho National Laboratory
- Yangzhi Zhao, (PhD Materials Science, 9/19, co-advised with Y. Yang), – “Scalable synthesis of lithium sulfide nanocrystals for next generation battery technologies”, - IonBlox, Rath Award Finalist
- Yegor Samoileko, (PhD Chemical Engineering, 1/20), “Development of II-VI ternary alloys for CdTe based solar cells”, Advanced Energy
- Courtney Clark (MS Materials Science, 5/20) Non-thesis Masters: Techno-Economic Analysis and Scale-Up of Lithium Sulfide Production for Use in Next Generation Batteries– Los Alamos National Laboratory
- Zhenyu Zhang, (PhD Chemical Engineering, 12/20, co-advised with J. D. Way), “Design and optimization of catalytic membrane reactors for efficient ammonia synthesis and decomposition”, Cronwell
- Gavin Yeung, (MS Chemical Engineering, 8/21) , “Development of emitter layers for cadmium selenide telluride-based solar cells”, Rocket Lab
- Deborah Clayton-Warwick, (PhD Materials Science, 12/21, co-advised with M. O. Reese), “Development and application of novel thermomechanical liftoff technique for CdTe solar cells”. First Solar – Rath Award Winner
- Will Smith, (PhD Chemical Engineering, 12/22), “Synthesis of Metal Sulfide Compounds for Solid State Electrolytes using Metathesis Reactions”, A123 Systems
- Adam Job, (MS Chemical Engineering, 6/23), “Interfacial Engineering of Dense Metal Membranes for Stable and Cost-Effective Hydrogen Purification in Fusion Relevant Environments”, Ash Grove Cement
- Kevin Prince, (PhD Chemical Engineering, 8/23), “Interfacial engineering and Alternative device architectures for perovskite photovoltaics”,Helmholtz-Zentrum Berlin
- Rok Sitar, (PhD Chemical Engineering, 8/23), “Development of catalytic membrane reformer technology as a compact, energy efficient solution for on-site generation of hydrogen and ammonia/hydrogen fuel blends”, CEO Blaze Energy Technologies
- Liz Golonski, (MS, Chemical Engineering, 5/24), “Analysis of nitrogen oxide emissions produced during combustion of cracked-ammonia fuels”, West Point
- Chao Li, (PhD, Chemical Engineering, 8/24), “Palladium-based metal foil pumps for direct internal recycling of hydrogen isotopes in the fusion fuel cycle”, Marathon Fusion
- Saeed Ahmadi Vasselabadi, (PhD, Chemical Engineering, 12/24), “Solution synthesis of sodium-based multinary chalcogenides for next-generation battery applications”, Virginia Tech University
- Cameron Burst, (MS, Materials Science, 8/25), “Composite titanium-vanadium membranes for high temperature hydrogen purification”, Mines
- Sean Mathews, (MS, Chemical Engineering 8/25), “Evaluation of nickel-based perovskite catalyst for low temperature ammonia decomposition”
- Andrea Mathew, PhD Candidate, Materials Science
- Nolan Kelley, PhD Candidate, Chemical Engineering

- Ben Ivie, PhD Candidate, Advanced Energy Systems
- Garrett Strain, MS Candidate, Chemical Engineering
- Vitor Camacho, PhD Candidate, Chemical Engineering
- Created and supervised undergraduate research opportunities for 78 students (with graduate school attended)
 - Class of 1999: Andrew Barleben
 - Class of 2000: Robert Alexander, Logan Hagaman (California Institute of Technology)
 - Class of 2001: Darren Odom, Devin Dyar, Jim Huang
 - Class of 2002: Dustin Rice, Amanda Overmeyer (CSM), Chris Fischer (MIT), Mailasu Bai (CSM), Brent Lutz (University of Florida), Michael Eaton (CSM), Stephen Kelley (Stanford), Anna Chorney (Penn State)
 - Class of 2003: James Esteban, Jason Litzinger, Nathan Torres
 - Class of 2004: Jackie Leaf, Steve Hand, Cassandra Fry (CSM)
 - Class of 2005: Kyle Olson, John Harvey
 - Class of 2006: Joey Marino, Alex Monson, Hideto Hagiya, Scott Szymanski (CSM)
 - Class of 2007: Audrey Nelson, James Condon
 - Class of 2008: David Richards (Purdue), Nick Kubala (CSM)
 - Class of 2009: Olivia Bromley, Amy Dubetz (Tulane)
 - Class of 2010: Marilou Canon, Rambert Nahm (Cornell), Cody Willingham (CSM)
 - Class of 2011: Bas van de Loo (TU/e), Rene Vervuurt (TU/e), Alex Sale, Donal Finegan (University College London)
 - Class of 2012: Sterling Parks, Sara Chmelka, Karl Brennan (Cornell), Amanda Fankel
 - Class of 2013: Becky Silverstein, David Chiavetta, Maria O'Brien (Trinity College Dublin), Aisling Brazel
 - Class of 2014: Amy Goldstein, Trevor Haak, Eoin McMullan, Sirichat Rojnirun
 - Class of 2015: Colm O'Riada (University of Cambridge)
 - Class of 2016: Alice Brennan, Miranda McCeig
 - Class of 2017: Emily White
 - Class of 2018: Elias Petsalis (CSM), Lucy Fitzgerald
 - Class of 2019: Kristen Hietala, Gavin Yeung (CSM)
 - Class of 2020: Daisy Fuchs (CU), Sarah Livingston
 - Class of 2021: Hope Wikoff, Arthur Harris, Jerry Birnbaum, Isaiah Thurman
 - Class of 2022: Jane Turek, Ben Reinecke
 - Class of 2023: Alexandria D'Aquila, Katie Palmer (CSM), Gordon Huang, Sean Mathews (CSM)
 - Class of 2024: Izzy Roszell, Cameron Burst (CSM), Emma Neuroth (CSM)
 - Class of 2025: Kagan Killough (Bordeaux), Brynn Benham
 - Current Students: Ben Bauerle, Caroline Hufnagel, John Braford, Vivian Aldinger, Gwenyth Lemon, Ceiwen Wick

RESEARCH CONTRACTS

I have been the PI or co-PI on initiatives on awards valued at ~\$21.6M to CSM (my portion ~\$15.5M). The sources include an array of sources including NSF, DOE, ARPA-E, and private industry. The Table below summarizes research contracts secured in the past decade.

Project Title	Amount / Dates	Source	Collaborators
Direct Internal Recycling for High Field and Spherical Tokamaks	\$2,592,472 7/15/25 – 7/14/30	DOE	Scott Walton (NRL) Sub: \$597K
High Throughput Testing of Metal Foil Pumps	\$360,000 6/1/25 – 5/31/28	INL	
Synthesis and Characterization for CdTe	\$210,000 12/18/24 - 12/17/27	NREL	Matt Reese (NREL)
Low-cost III-V solar cells through mechanical spalling and substrate reuse	\$270,000 10/1/24 -9/30/27	NREL	PI C. Packard
INFUSE: Testing of Engineered Membranes in Fusion-Relevant Metal Foil Pumps	\$100,000 9/1/24 - 8/31/25	DOE	
Scalable, Low-Cost Hydrogen Delivery Systems	\$987,954 1/1/24 -12/31/26	EERE	
Green Hydrogen Laboratory	\$3,000,000	DOE	PI R. J. Kee

	1/1/24 -12/31/26		
Fabrication and Characterization of Tandem Photovoltaics Architectures	\$70,000 1/1/23 – 6/30/24	NREL	Lance Wheeler (NREL)
Distributed Production of Green Hydrogen	\$200,000 1/1/23 – 12/31/24	COEDIT	
Ammonia/Hydrogen Fuel for Clean Combustion	\$35,000 5/1/22 - 8/31/23	COEDIT	
Manufacturing of Metal Sulfides for Next Generation Batteries	\$379,765 9/1/22 -8/31/25	NSF	
CdTe Core	\$209,720 9/28/21 – 8/27/24	NREL	Matt Reese (NREL)
Interfacial-engineered Membranes for Efficient Tritium Extraction	\$1,397,972 1/1/21- 6/30/24/	ARPA-E	Sub: INL (\$260K)
Nanomaterials for Next Generation Solid State Batteries	\$141,293 11/21/19 - 12/31/21	COEDIT / SolidPower	
Intensification and Integration of Hydrogen and Ammonia Production	\$2,247,676 1/1/19 – 7/11/24	ARPA-E	Co-PI J.D. Way
Interdigitated Back Contact Solar Cells for Switchable Photovoltaic Windows	\$206,454 1/1/19 - 9/30/21	DOE/NREL	Lance Wheeler (NREL)
Development of advanced materials and characterization techniques for hydrogen carriers	\$527,119 1/1/19 – 9/30/23	NREL	PI B. Trewyn
High Specific Power Solar Cells	\$227,000 1/1/18 – 12/31/21	ONR/NREL	Matt Reese (NREL)
Continuous Manufacturing of Anhydrous Metal Sulfide Nanocrystals	\$387,192 9/15/18 -8/30/21	NSF	
Methane Aromatization in a Membrane Reactor	\$34,679 5/1/18 -10/9/18	TDA Research	
Addressing Unresolved Scientific Challenges for CdTe-based Solar Cells	\$336,051 7/15/17 - 6/30/20	NSF	
Membrane Reactor Synthesis of Ammonia at Moderate Conditions	\$500,000 10/1/16 – 7/31/18	ARPA-E	PI J.D. Way
Earth Abundant Membrane Reactors for Efficient Chemical Processing	\$329,615 5/1/15 - 4/30/19	NSF	Co-PI J.D. Way
Scalable Manufacturing of Nanostructured Lithium Sulfide	\$39,000 4/1/16 – 4/30/18	COEDIT	Co-PI Y. Yang
Accelerating Development of CdTe Solar Cells	\$125,000 12/1/16 – 6/30/17	BAPVC	Co-PIs T. Ohno, J. Beach
Advanced Membranes for Tritium Purification	\$155,000 9/1/15 - 8/31/18	DOE NEUP	Co-PI J.D. Way
MRI: Acquisition of a coupled optical and scanning probe microscopy facility for advanced materials research	\$328,114 5/1/15 -12/31/18	NSF	Co-PI K. Neeves
Flexible Multi-Functional Coatings to Enable Advanced Optoelectronics	\$150,000 1/1/14 – 12/31/15	COEDIT	
Low-cost highly transparent flexible low-e coating film	\$50,000 10/1/13 – 9/30/14	ITN Energy	
Non-Equilibrium Processing of CdTe Absorbers to Enable 20% Efficiency	\$599,724 1/1/13 – 12/31/15	BAPVC	Co-PIs T. Ohno, J. Beach
Rapid Development of Earth-Abundant Thin Film Solar Cells	\$179,456 1/22/13 -1/21/16	NREL	Andriy Zakutayev (NREL)
Fabrication of Pd Ternary Alloy Membranes	\$200,000 8/8/12 – 12/31/15	Pall Corporation	PI J.D. Way
Synthesis of Stoichiometric Pyrite Photovoltaic Absorbers	\$196,000 6/1/12 -5/31/2015	NSF	
High Temperature, Roll-to-Roll CdTe Superstrate	\$219,843	NREL	Teresa Barnes

Devices Using Flexible Glass	1/1/12 – 8/31/15		(NREL)
Catalyzing Innovation and Collaboration for Photovoltaics Research and Development: An NSF Workshop	\$58,925 3/19/10 -1/31/12	NSF	
Asymmetric Nanopores for Fundamental Studies of Hindered Transport	\$304,912 9/1/10– 8/31/14	NSF	
Integration of Electro-Catalysts With Nanostructured Absorbers for Photoelectrochemical Production of Hydrogen	\$45,454 9/1/10– 8/31/14	CRSP	
Metal Carbide Catalysts for Synthesis of Alcohols from Synthesis Gas	\$85,098 1/1/14– 1/14/11	NREL	PI J.D. Way
Nanoporous, Metal Carbide, Surface Diffusion Membranes for High Temperature Hydrogen Separation	\$998,543 10/1/09 - 9/30/13	DOE	PI J.D. Way