

Electrochromic films with edge protection

Abstract

The present application discloses a method for preparing an electrochromic device. The method includes placing an edge protection material on a first and second substrates, placing a first and second interlayers respectively within the edge protection material on the first and second substrates, wherein the edge protection material surrounds edges of the first and second interlayers, and interposing an electrochromic film between the first and second interlayers. The edge protection material prevents chemicals in the first and second interlayers from entering into the electrochromic film.

Classifications

■ B32B17/10

Layered products essentially comprising sheet glass, or glass, slag, or like fibres comprising glass as the main or only constituent of a layer, next to another layer of a specific material of synthetic resin

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Claims (12)

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What is claimed is:

1. An electrochromic device comprising:

an electrochromic film comprising a first electrode layer and a second electrode layer facing the first electrode layer of the electrochromic film, wherein:

an edge of the first electrode layer is cut such that a portion of an inner surface of the second electrode layer is exposed, and

an edge of the second electrode layer is cut such that a portion of an inner surface of the first electrode layer is exposed, the edge of the first electrode layer and the edge of the second electrode layer are opposing edges;

a first edge protection material sealing the exposed portion of the inner surface of the second electrode layer; and

a second edge protection material sealing the exposed portion of the inner surface of the first electrode layer.
2. The electrochromic device of claim 1, wherein:

the first edge protection material is in an L shape, further sealing a side surface of the first electrode layer and a portion of an external surface of the first electrode layer.
3. The electrochromic device of claim 1, wherein:

the second edge protection material is in an L shape, further sealing a side surface of the second electrode layer and a portion of an external surface of the second electrode layer.
4. The electrochromic device of claim 1, wherein:

the first edge protection material and the second edge protection material comprise epoxy.
5. The electrochromic device of claim 1, wherein

the first edge protection material and the second edge protection material comprise electrically conductive material.

6. The electrochromic device of claim 1, wherein:

the first edge protection material and the second edge protection material are cured with heat or ultraviolet light, functioning as oxygen and moisture blockers.

7. The electrochromic device of claim 1, further comprising:

a first substrate;

a second substrate; and

an interlayer between the first substrate and the second substrate, wherein:

the first electrode layer, the second electrode layer, the first edge protection material, and the second edge protection material are laminated within the interlayer.

8. The electrochromic device of claim 1, wherein the first electrode layer and the second electrode layer sandwich a layer of electrochromic material, a layer of electrolyte material, and a layer of charge storage material.

9. The electrochromic device of claim 8, wherein the layer of electrochromic material, the layer of electrolyte material, and the layer of charge storage material are cut in a same way as the edge of the first electrode layer to expose the portion of the inner surface of the second electrode layer.

10. The electrochromic device of claim 8, wherein the layer of electrochromic material, the layer of electrolyte material, and the layer of charge storage material are cut in a same way as the edge of the second electrode layer to expose the portion of the inner surface of the first electrode layer.

11. The electrochromic device of claim 1, wherein the first electrode layer comprises a first electrode layer including tin doped indium oxide (ITO).

12. The electrochromic device of claim 1, wherein the second electrode layer comprises a second electrode layer including tin doped indium oxide (ITO).

Description

CROSS-REFERENCE OF RELATED APPLICATION(S)

This application is a continuation of U.S. patent application Ser. No. 18/152,033 filed on Jan. 9, 2023, which is a continuation of U.S. patent application Ser. No. 16/190,723 filed on Nov. 14, 2018, now issued as U.S. Pat. No. 11,571,878, and titled "ELECTROCHROMIC FILMS WITH EDGE PROTECTION". The entire content of the above-identified applications are incorporated herein by reference.

FIELD OF THE INVENTION

The invention generally relates to electrochromic devices, and in particular, to electrochromic devices with edge protection and methods for making the same.

BACKGROUND

Electrochromism generally refers to a reversible change in optical properties of a material upon application of a potential. In particular, electrochromic materials exhibit a reversible color change due to an electrochemical reduction-oxidation (redox) reaction caused by application of an electric field.

Electrochromic materials are useful for a variety of applications, including photovoltaic devices, field effect transistors, organic light emitting diodes, general printed electronics, anti-glare windows, display systems, etc.

Usually, electrochromic materials are sandwiched between rigid substrates to make devices. The electrochromic films based on flexible substrates have advantages over the traditional electrochromic glasses in terms of weight, ease of transportation, ability to apply on curved surface, etc.

For applications involving smart window technology, the electrochromic materials need to be integrated with a glass substrate (e.g., a glass window) to be serviceable. The integration process usually requires that the electrochromic film be sandwiched between two glass panels with interlayers such as polyvinyl butyral (PVB) and SentryGlas etc. Then, those packages would be pressed and heated at certain pressure and temperature. After the lamination process, the interlayers will be cured and will fix the electrochromic film between glass panels. There are certain additives within the interlayers for the purpose of chemical and physical property modifications. Those additives can infiltrate into the multilayer electrochromic films and adversely affect the electrochromic films. As a result, the performance and lifetime of electrochromic films can be severely compromised.

Therefore, there is a need for an improved design of electrochromic films to address the above and other problems.

SUMMARY

The present disclosure provides a method of preparing an electrochromic film having edge protection to protect the edges of the electrochromic film from being infiltrated by undesired materials as well as oxygen and moisture. An electrochromic film may include a first electrode, a second electrode, an electrochromic material deposited on at least the first electrode, a charge storage layer deposited on the second electrode, and a solid polymer electrolyte disposed between the electrochromic material and the charge storage layer.

An electrochromic film generally may be interposed between two interlayers and laminated between two glass panels. In some embodiments, the edges of electrochromic film and the interlayers are covered by an edge protection material protecting the electrochromic film from being exposed to undesired materials from the interlayers and from the ambient environment. Those undesired materials include certain additives inside the interlayers and oxygen and moisture from the ambient environment, which may adversely affect the performance and lifetime of the electrochromic film.

According to one embodiment of the present disclosure, a method for preparing an electrochromic device includes placing an edge protection material on a first and second substrates, placing a first and second interlayers respectively within the edge protection material on the first and second substrates, wherein the edge protection material surrounds edges of the first and second interlayers, interposing an electrochromic film between the first and second interlayers, wherein the edge protection material prevents chemicals in the first and second interlayers from entering into the electrochromic film. The method may also include pressing the first and second substrates toward each other and heating the first and second interlayers to fix the electrochromic film between the first and second substrates.

According to another embodiment of the present disclosure, an electrochromic film includes a first electrode, a second electrode, an electrochromic material deposited on at least the first electrode, a charge storage layer deposited on the second electrode, and a solid polymer electrolyte disposed between the electrochromic material

and the charge storage layer. In this embodiment, at least edges of the electrochromic material are covered by an edge protection material.

According to yet another embodiment of the present disclosure, an electrochromic device includes a first glass panel, a first interlayer on the first glass panel, a second glass panel, a second interlayer on the second glass panel, and an electrochromic film between the first interlayer and the second interlayer. The electrochromic film may include a first electrode, a second electrode, an electrochromic material deposited on at least the first electrode, a charge storage layer deposited on the second electrode, and a solid polymer electrolyte disposed between the electrochromic material and the charge storage layer. At least edges of the electrochromic material are covered by an edge protection material.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred and non-limiting embodiments of the invention may be more readily understood by referring to the accompanying drawings in which:

FIG. 1 is a simplified schematic of a laminated structure having an electrochromic film disposed therein, according to one exemplary embodiment.

FIG. 2 is a simplified schematic of an electrochromic film, according to one exemplary embodiment.

FIG. 3 is a perspective view of an electrochromic film, according one exemplary embodiment.

FIGS. 4A-4C illustrate a method of preparing an electrochromic film with edge protection according to an exemplary embodiment.

FIG. 5 illustrates a flowchart of a method for preparing an electrochromic device according to an exemplary embodiment.

FIG. 6 illustrate an electrochromic film with edge protection according to an exemplary embodiment.

FIG. 7 illustrates a laminated electrochromic film with edge protection according to one exemplary embodiment.

FIG. 8 illustrates an unlaminated electrochromic film with edge protection according to another exemplary embodiment.

FIG. 9 illustrates another laminated electrochromic film with edge protection according to another exemplary embodiment.

FIG. 10A illustrates performance and lifetime comparison of a laminated electrochromic film with edge protection according to an embodiment and one without edge protection.

FIG. 10B illustrates performance and lifetime comparison of an unlaminated electrochromic film with edge protection according to an embodiment and one without edge protection.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description, certain specific details are set forth in order to provide a thorough understanding of various embodiments of the invention. However, one skilled in the art will understand that the invention may be practiced without these details. Moreover, while various embodiments of the invention are disclosed herein, many adaptations and modifications may be made within the scope of the invention in accordance with the common general knowledge of those skilled in this art. Such modifications include the substitution of known equivalents for any aspect of the invention in order to achieve the same result in substantially the same way.

Unless the context requires otherwise, throughout the present specification and claims, the word “comprise” and variations thereof, such as, “comprises” and “comprising” are to be construed in an open, inclusive sense, that is as “including, but not limited to.” Recitation of numeric ranges of values throughout the specification is intended to serve as a shorthand notation of referring individually to each separate value falling within the range inclusive of the values defining the range, and each separate value is incorporated in the specification as it were individually recited herein. Additionally, the singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise.

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment, but may be in some instances. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

A simplified schematic of a laminated structure with an electrochromic film interposed therein is shown in FIG. 1, according to one exemplary embodiment. For clarity purposes only, the various components of the laminated structure (e.g., substrates, adhesive layers, and electrochromic film) are shown spaced apart.

As shown in FIG. 1, the laminated structure **100** includes a first adhesive interlayer **102** interposed between a first surface **104** of an electrochromic film **106** and a first substrate **108**. The laminated structure **100** also includes a second adhesive interlayer **110** interposed between a second surface **112** of the electrochromic film **106** and a second substrate **114**. As seen in the embodiment of FIG. 1, the first and second surfaces **104**, **112** correspond to opposing surfaces of the electrochromic film **106**.

The first and/or second adhesive interlayers **102**, **110** may include a material (e.g., a thermosetting polymer material) configured to securely bond (e.g., cross-link) the electrochromic film **106** with the first and second substrates **108**, **114**. As such, the first and/or second adhesive interlayers **102**, **110** are configured to keep the laminated structure **100** together even when shattered/broken, and prevent the laminated structure **100** from breaking up into large, sharp pieces.

An exemplary, non-limiting schematic of an electrochromic film **200** is shown in FIG. 2, according to one embodiment. It is important to note that the electrochromic film **200** of FIG. 2 may be implemented in combination with other devices/features/components described herein, such as those described with reference to other embodiments/aspects. The electrochromic film **200** may be used in various applications and/or in permutations, which may or may not be noted in the illustrative embodiments/aspects described herein. For instance, the electrochromic film **200** may include more or less features/components than those shown in FIG. 2, in some embodiments. Additionally, unless otherwise specified, one or more components of the electrochromic film **200** may be of conventional material, design, and/or fabricated using known techniques (e.g., sputtering, chemical vapor deposition (CVD), physical vapor deposition (PVD), plasma-enhanced chemical vapor deposition (PECVD), spray coating, slot-die coating, dip coating, spin coating, printing, etc.), as would be appreciated by skilled artisans upon reading the present disclosure.

As shown in FIG. 2, the electrochromic film **200** includes a first transparent substrate **202** and a second transparent substrate **204** in spaced, parallel relation with each other. The first and second substrates **202**, **204** may have the same or different dimensions, comprise the same or different materials, etc. Suitable materials for the first substrate **202** and/or the second substrate **204** may include, but are not limited to, glass, polymeric materials, plastic materials, and/or other materials which are transparent in at least part of the visible region of the electromagnetic spectrum. In some embodiments, the first and second substrates **202**, **204** may comprise glass.

As also shown in FIG. 2, a first transparent electrically conductive film **206** is deposited on the interior surface **208** of the first substrate **202** to act as an electrode. A second transparent electrically conductive film **210** is also deposited on the interior surface **212** of the second substrate **204** to act as an electrode. The first and second electrically conductive films **206**, **210** may have the same or different dimensions, comprise the same or different material, etc. The first and second electrically

conductive films **206, 210** may also each independently have a single layer or multilayer structure. Suitable materials for the first and second electrically conductive films **206, 210** may include, but are not limited to, tin doped indium oxide (ITO), fluorine doped indium oxide, antimony doped indium oxide, zinc doped indium oxide, aluminum doped zinc oxide, silver nanowires, metal mesh, combinations thereof, and/or other such transparent material exhibiting sufficient electrical conductance. In preferred aspects, the first and second electrically conductive films **206, 210** may each include an electrode layer including tin doped indium oxide (ITO).

The electrochromic device **200** may additionally include an electrical power supply (not shown) configured to supply voltage between the first and second electrically conductive films **206, 210**.

As further shown in FIG. 2, a layer **214** of electrochromic material is deposited on the interior surface **216** of the first electrically conductive film **206**. The layer **214** of electrochromic material is configured to cause a reversible color change upon reduction (gain of electrons) or oxidation (loss of electron) introduced by an applied electrical current. In some embodiments, the layer **214** of electrochromic material may be configured to change from a transparent state to a colored state, or from a colored state to another colored state, upon oxidation or reduction. In some embodiments, the layer **214** of electrochromic material may be a polyelectrochromic material in which more than two redox states are possible, and may thus exhibit several colors.

In some embodiments, the layer **214** of electrochromic material may comprise an organic electrochromic material, an inorganic electrochromic material, a mixture of both, etc. The layer **214** of electrochromic material may also be a reduction colored material (i.e., a material that becomes colored upon acquisition of electrons), or an oxidation colored material (i.e., a material that becomes colored upon the loss of electrons).

In some embodiments, the layer **214** of electrochromic material may include a metal oxide such as MoO_3 , V_2O_5 , Nb_2O_5 , WO_3 , TiO_2 , $\text{Ir}(\text{OH})_x$, SrTiO_3 , ZrO_2 , La_2O_3 , CaTiO_3 , sodium titanate, potassium niobate, combinations thereof, etc. In some embodiments, the layer **214** of electrochromic material may include a conductive polymer such as poly-3,4-ethylenedioxy thiophene (PEDOT), poly-2,2'-bithiophene, polypyrrole, polyaniline (PANI), polythiophene, polyisothianaphthene, poly(o-aminophenol), polypyridine, polyindole, polycarbazole, polyquinone, octacyanophthalocyanine, combinations thereof, etc. Moreover, in some embodiments, the layer **214** of electrochromic material may include materials, such as viologen, anthraquinone, phenocyanine, combinations thereof, etc. Additional examples of electrochromic materials, particularly those including multicolored electrochromic polymers, may be found in U.S. patent application Ser. No. 15/399,839, filed Jan. 6, 2017, the entirety of which is herein incorporated by reference.

As additionally shown in FIG. 2, a charge storage layer **218** is deposited on the interior surface **220** of the second electrically conductive film **210**. Suitable materials for the charge storage layer **218** may include, but are not limited to, vanadium oxide, binary oxides (e.g., CoO , IrO_2 , MnO , NiO , and PrO_x), ternary oxides (e.g., $\text{Ce}_x\text{V}_y\text{O}_z$), etc.

In some embodiments, the charge storage layer **218** may be replaced with an optional second layer of electrochromic material. This optional second layer of electrochromic material may have the same or different dimensions, comprise the same or different composition, etc., as the first layer **214** of electrochromic material.

The electrochromic device **200** also includes an electrolyte layer **222** positioned between the layer **214** of electrochromic material and the charge storage layer **218**. In some embodiments, the electrolyte layer **222** may include a liquid electrolyte as known in the art. In some embodiments, the electrolyte layer **222** may include a solid state electrolyte, including but not limited to, Ta_2O_5 , MgF , Li_3N , LiPO_4 , LiBO_2 - Li_2SO_4 , etc. In some embodiments, the electrolyte layer **222** may include a polymer based electrolyte comprising an electrolyte salt (e.g., LiTFSI , LiPF_6 , LiBF_4 , LiClO_4 , LiCF_3SO_3 , $\text{LiN}(\text{CF}_3\text{SO}_2)_2$, LiSbF_6 , LiAsF_6 , $\text{LiN}(\text{CF}_3\text{CF}_2\text{SO}_2)_2$, $(\text{C}_2\text{H}_5)_4\text{NBF}_4$, $(\text{C}_2\text{H}_5)_3\text{CH}_3\text{NBF}_4$, LiI , etc.), a polymer matrix (e.g., polyethylene oxide, poly(vinylidene fluoride)(PVDF), poly(methyl methacrylate) (PMMA), polyethylene oxide (PEO), poly(acrylonitrile) (PAN), polyvinyl nitrile, etc.), and one or more optional plasticizers (e.g., glutaronitrile, succinonitrile, adiponitrile, fumaronitrile, etc.). Additional examples of electrolyte materials, particularly those including solid polymer electrolytes, may be found in U.S. patent applications Ser. No. 15/399,852, filed Jan. 6, 2017 and Ser. No. 15/487,325, filed Apr. 13, 2017, the entirety of which is herein incorporated by reference.

FIG. 3 is a perspective view of an electrochromic film **300**, according to one exemplary embodiment. The difference between FIG. 2 and FIG. 3 is that in FIG. 3 only the electrochromic film **300** is shown in a perspective view, without the first transparent substrate **202** and the second transparent substrate **204** from FIG. 2. Similar to FIG. 2, the electrochromic film **300** includes a first transparent electrically conductive film **306** and a second transparent electrically conductive film **310**. Between the first transparent electrically conductive film **306** and the second transparent electrically conductive film **310**, the electrochromic film **300** further includes an electrolyte layer **322** positioned between an electrochromic material layer **314** and a charge storage layer **318**. In some embodiments, the polymer electrolyte layer **322** is a solid polymer electrolyte and the solid polymer electrolyte includes an electrolyte salt and a polymer matrix as discussed above with respect to the embodiment in FIG. 2.

FIGS. 4A-4C illustrate a method **400** of preparing a laminated electrochromic device with edge protection according to one exemplary embodiment. FIG. 4A illustrates a process of making a glass panel with edge protection for laminating with an electrochromic film. In FIG. 4A, a glass panel **402** is first prepared. Then four stripes of edge seal **405** made of an edge protection material are positioned on each of the four edges and on top of the glass panel **402**. The edge protection material may be selected from polyvinyl siloxane (PVS), Sentryglas, thermoplastic polyurethane (TPU), ethylene-vinyl acetate (EVA), etc. Next an interlayer **403** is placed on the center of the glass panel **402**, within the area confined by the four stripes of edge seal **405** to form a first interlayer-substrate portion **410**. The interlayer **403** may be made of polyvinyl butyral (PVB), UV Extraprotect PVB, or the like. As mentioned, the interlayer may contain undesired chemicals that may adversely affect the performance and lifetime of the electrochromic film. Usually, those chemicals may infiltrate the electrochromic film through the joint of the films, often via the electrolyte layer. With the edge protection, the interlayer **403**'s edges are sealed and the chemicals will not be able to enter into the electrochromic film. The same process can be used to form another interlayer-substrate. As shown in FIG. 4B, two interlayer-substrate portions **410 a**, **410 b** are formed, each having an interlayer surrounded by edge protection materials. An electrochromic film **401** is positioned and laminated between the two interlayer-substrate portions **410 a**, **410 b**. The electrochromic film **401** can be made as described above with reference to FIGS. 1-3. In FIG. 4C, an electrochromic film **420** with edge protection laminated within two glass panels are shown. The interlayers can be cured by pressing glass panels and heating the electrochromic device.

FIG. 5 illustrates a flowchart **500** summarizing the steps shown in FIGS. 4A-4C. In step **502**, an edge protection material is placed on a first and second substrates. In step **504**, placing a first and second interlayers respectively within the edge protection material on the first and second substrates, wherein the edge protection material surrounds edges of the first and second interlayers. In step **506**, interposing an electrochromic film between the first and second interlayers. The edge protection material may prevent chemicals in the first and second interlayers from entering into the electrochromic film. The method **500** may also include an optional step **508** of pressing the first and second substrates toward each other and heating the first and second interlayers to fix the electrochromic film between the first and second substrates.

FIG. 6 is a sectional view **600** of the two electrochromic films **606** and **610** where their joint and edges are covered by an edge projection material, e.g., a layer of epoxy **605**. In FIG. 6, the two electrochromic films **606** and **610** are sandwiched with an electrochromic material layer **614**, an electrolyte layer **622**, and a charge storage layer **618**. After curing with heat or ultraviolet light, the epoxy **605** can work as an effective oxygen and moisture blocker. Using this method, an electrochromic film roll can be stored in an ambient environment for much longer time without sacrificing performance and lifetime. The epoxy can also be replaced by other suitable materials. In some embodiments, at least edges of one of the first electrode and second electrode, the electrochromic material, the solid polymer electrolyte, and the charge storage layer are covered by the edge protection material.

FIG. 7 illustrates a laminated electrochromic device **700** with edge protection according to one exemplary embodiment. The laminated electrochromic device **700** includes a first substrate **702** (e.g., a glass panel) at the bottom, a second substrate **704** (e.g., a glass panel) at the top, a first interlayer **703** positioned above the first

substrate **702**, a second interlayer **703 b** positioned below the second substrate **704**, an electrochromic film **701**, and edge protection materials **705, 715** between the first substrate **702** and the second substrate **704** and around the interlayers **703 a** and **703 b** and the electrochromic film **701**. The edge protection materials **705, 715** are compatible with the electrochromic film **701** and the substrates but resistant to the chemicals of the interlayers **703 a** and **703 b**. The electrochromic film **701** is prepositioned so that its edges fit the edge protection materials **705, 715**. Followed by normal laminating process such as autoclave, the electrochromic film **701**'s edges will be protected by the edge protection materials **705, 715**.

FIG. **8** illustrates an electrochromic film **800** with edge protection according to another exemplary embodiment. The electrochromic film in FIG. **8** includes two sides **801 a** and **801 b**, one as an anode and the other as a cathode. The upper side **801 a** is covered by an edge protection material on the left side and the lower side **801 b** is covered by an edge protection material on the left side. The electrochromic film **800** with edges covered can be rolled and easily stored in an ambient environment for much longer time without sacrificing performance and lifetime.

FIG. **9** illustrates another electrochromic device **900** with edge protection according to another exemplary embodiment. Similar to FIG. **8**, the electrochromic film in FIG. **9** includes two sides **901 a** and **901 b**, one as an anode and the other as a cathode. The edges of the electrochromic film **901 a** and **901 b** are covered by an edge protection material, e.g., a layer of epoxy **905** and **915**. After curing with heat or ultraviolet light, the epoxy **905** and **915** can work as an effective oxygen and moisture blocker. Then, the electrochromic film can be laminated between two substrates (e.g., glass panels) with a lamination process as described above. Similar to FIG. **7**, the laminated electrochromic device **900** includes a first substrate **902** (e.g., a glass panel), a second substrate **904** (e.g., a glass panel), an interlayer **903** between the first substrate **902** and the second substrate **904**, and the electrochromic film with edge protection laminated within the interlayer **903**.

In some embodiments, the edge protection material, e.g., the epoxy **805/815/905/915**, may be electrically conductive so that it can function as the electrodes in the above-described embodiments. By using an electrically conductive material as the edge protection material, the electrochromic film fabrication process can save one step with respect to fabricating the electrodes. Alternatively, the electrically conductive edge protection material can conduct current to the electrode layer and/or charge storage layer.

FIG. **10A** illustrates performance and lifetime comparison of a laminated electrochromic film with edge protection according to an embodiment and one without edge protection. The curve **1002** is the original performance of a laminated electrochromic film, i.e., performance without degradation. It shows a behavior of normalized transparency as a function of time for a laminated electrochromic film with no degradation. The curve **1004** shows a behavior of normalized transparency as a function of time of a laminated electrochromic film without edge protection. The curve **1006** shows a behavior of normalized transparency as a function of time of a laminated electrochromic film with edge protection. With comparison among curves **1002, 1004** and **1006** in FIG. **10A**, one can find that the device without edge protection (curve **1004**) shows very poor stability. After 1 h speeded degradation at 100° C., the device already slows down in switch response. In contrast, the device with edge protection (curve **1006**) only shows limited sign of degradation after 1 month of speeded degradation stress test. Therefore, with an edge protection, a laminated electrochromic film device can be better protected from degradation.

FIG. **10B** illustrates performance and lifetime comparison of an unlaminated electrochromic film with edge protection according to an embodiment and one without edge protection. The curve **1012** is the original performance of an unlaminated electrochromic film, i.e., performance without degradation. It shows a behavior of normalized transparency as a function of time for an unlaminated electrochromic film with no degradation. The curve **1014** shows a behavior of normalized transparency as a function of time of an unlaminated electrochromic film with edge protection. As shown in FIG. **10B**, after 1 week of speeded degradation stress, the device with edge protection (curve **1014**) still holds a reasonable good switch speed, i.e., similar to the original curve **1012**. Therefore, with an edge protection, an unlaminated electrochromic film can be protected from degradation, leaving a long process window for further lamination process.

This specification describes protecting edges of an electrochromic film that is usually fabricated by a roll-to-roll process with low cost. Since the electrochromic films need to be laminated between substrates (e.g., two glass panels) in their actual application, such as smart windows, without using the methods described above, the selection of lamination interlayer materials would be limited and the storage and transportation would require much more dedicated environment and conditions. The embodiments described above are useful in facilitating the application of electrochromic films in the window industry.

The invention described and claimed herein is not to be limited in scope by the specific preferred embodiments disclosed herein, as these embodiments are intended as illustrations of several aspects of the invention. Indeed, various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims.

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CN104375350A	2014-10-31	2015-02-25	合肥博一环保科技有限公司	Multifunctional controllable electrochromic device and manufacturing method thereof
CN104698715A	2013-12-04	2015-06-10	珠海兴业绿色建筑科技有限公司	All-solid electrochromic device
US20150301367A1	2012-12-06	2015-10-22	Saint-Gobain Glass France	Glazing having electrically switchable optical properties
US20150323849A1	2012-12-17	2015-11-12	Lg Innotek Co., Ltd.	Electrochromic display device, and method for manufacturing same
US20160282645A1	2015-03-26	2016-09-29	Research Frontiers Incorporated	Laminated glazings with improved moisture protection
US20160357082A1	2015-06-03	2016-12-08	Canon Kabushiki Kaisha	Electrochromic element, method of driving the same, an optical filter, lens unit, image pick-up device and window material
US20170299932A1	2016-04-15	2017-10-19	Furcifer Inc.	Solid polymer electrolyte for electrochromic devices
US20170298682A1	2016-04-15	2017-10-19	Furcifer Inc.	Integration of electrochromic films on a substrate
CN107438793A	2015-03-09	2017-12-05	金泰克斯公司	Electrochemical appliance with plastic supporting base
CN108463912A	2016-10-11	2018-08-28	菲尔齐费尔公司	Polymer dielectric and electrochromic device including polymer dielectric
Family To Family Citations				

* Cited by examiner, † Cited by third party

Non-Patent Citations (24)

Title
Communication pursuant to Article 94(3) EPC for European Application No. 23164353.7 mailed on May 22, 2024.
Communication under Rule 71(3) EPC for European Application No. 23 164 353.7 mailed on May 20, 2025.
Communication under Rule 71(3) EPC for European Application No. 23164353.7 mailed on Jan. 15, 2025.
Extended European Search Report for European Patent Application No. 23164353.7 mailed on Jun. 9, 2023.
First Office Action for Chinese Application No. 202310481813.6 mailed on Dec. 31, 2024.
First Search for Chinese Application No. 201911095986.4 mailed on Jul. 15, 2022.
Non-Final Office Action for U.S. Appl. No. 18/326,866 mailed on Dec. 20, 2023.
Notification on Registration for Chinese Application No. 202310481813.6 mailed on Jul. 16, 2025.
Office Action for European Application No. 19206363.4 mailed on Apr. 30, 2021, 5 pages.
Search Report for European Application No. 19206363.4 mailed on Feb. 20, 2020, 9 pages.
Search Report for European Patent Application No. 25165105.5 mailed on Jul. 24, 2025.
Supplemental Search Report for Chinese Application No. 201911095986.4 mailed on Feb. 2, 2023.
Communication pursuant to Article 94(3) EPC for European Application No. 23164353.7 mailed on May 22, 2024.
Communication under Rule 71(3) EPC for European Application No. 23 164 353.7 mailed on May 20, 2025.
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Publication number	Priority date	Publication date	Assignee	Title
Family To Family Citations				
CN112394583B *	2020-09-07	2022-09-16	深圳市光羿科技有限公司	Electrochromic device and preparation method thereof
CN111897172A *	2020-09-01	2020-11-06	深圳市光羿科技有限公司	Electrochromic device and electronic terminal comprising same
WO2022048122A1 *	2020-09-01	2022-03-10	深圳市光羿科技有限公司	Electrochromic device and manufacturing methods therefor
EP4202542A4	2020-09-04	2024-12-04	Shenzhen Guangyi Tech Co., Ltd.	ELECTROCHROMIC DEVICE AND ELECTRONIC DEVICE
WO2022082195A1 *	2020-10-15	2022-04-21	Sage Electrochromics, Inc.	Electrochromic device including a means for mechanical resistance and a process of forming the same
CN114509885A *	2021-05-12	2022-05-17	法国圣戈班玻璃公司	Light modulation structure, light modulation glass and edge sealing process thereof
CN113311627B *	2021-05-31	2023-04-14	Oppo广东移动通信有限公司	Electronic equipment, shell assembly, electrochromic module and manufacturing method thereof
US20250004342A1 *	2023-06-30	2025-01-02	Apple Inc.	Waveguide Display with Sealed Tint Layer

* Cited by examiner, † Cited by third party, ‡ Family to family citation

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US12502870B2	2025-12-23	Electrochromic films with edge protection
US20250289750A1	2025-09-18	Integration of electrochromic films on a substrate
RU2420772C2	2011-06-10	Electrochemical system on plastic substrate
US8259380B2	2012-09-04	Electrodes of electrochemical/electrically-driven devices
KR101535100B1	2015-07-09	Electrochromic smart window and manufacturing method thereof
US20220342268A1	2022-10-27	Electrochromic device having low-resistance transparent electrode structure
CN108604035B	2022-07-01	Integration of electrochromic films on substrates
KR102149672B1	2020-09-02	Electrochromic device
JP2013200373A	2013-10-03	Electrochromic display device and manufacturing method for electrochromic display device
KR20210152888A	2021-12-16	Flexible electrochromic device
CN212675329U	2021-03-09	Electrochromic device and display device
KR102468146B1	2022-11-18	Electrochromic device and manufacturing method thereof
CN117572700A	2024-02-20	Electrochromic devices, electrochromic devices and electrochromic products
US10983408B2	2021-04-20	Display device with electrochromic material
CN114815431A	2022-07-29	Electrochromic device and electronic equipment
KR102042797B1	2019-11-27	Electrochromic device with hybrid electrolyte and method of fabricating the same
CN118584725A	2024-09-03	Glass module manufacturing method and structure thereof

Priority And Related Applications

Parent Applications (1) ▲

Application	Priority date	Filing date	Relation	Title
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US18/152,033	2018-11-14	2023-01-09	Continuation	Electrochromic films with edge protection
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Child Applications (1) ▲

Application	Priority date	Filing date	Relation	Title
US19/393,196	2018-11-14	2025-11-18	Division	Electrochromic films with edge protection

Priority Applications (2) ▲

Application	Priority date	Filing date	Title
US18/606,980	2018-11-14	2024-03-15	Electrochromic films with edge protection
US19/393,196	2018-11-14	2025-11-18	Electrochromic films with edge protection

Applications Claiming Priority (3) ▲

Application	Filing date	Title
US16/190,723	2018-11-14	Electrochromic films with edge protection
US18/152,033	2023-01-09	Electrochromic films with edge protection
US18/606,980	2024-03-15	Electrochromic films with edge protection

Legal Events ▲

Date	Code	Title	Description
2024-03-15	FEPP	Fee payment procedure	Free format text: ENTITY STATUS SET TO UNDISCOUNTED (ORIGINAL EVENT CODE: BIG.); ENTITY STATUS OF PATENT OWNER: SMALL ENTITY
2024-03-18	AS	Assignment	Owner name: FURCIFER INC., CALIFORNIA Free format text: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:CHEN, ZHAO;WANG, JIAN;ZHOU, YAN;REEL/FRAME:066806/0791 Effective date: 20181112
2024-03-26	FEPP	Fee payment procedure	Free format text: ENTITY STATUS SET TO SMALL (ORIGINAL EVENT CODE: SMAL); ENTITY STATUS OF PATENT OWNER: SMALL ENTITY
2024-03-29	STPP	Information on status: patent application and granting procedure in general	Free format text: DOCKETED NEW CASE - READY FOR EXAMINATION
2024-09-24	AS	Assignment	Owner name: LANNRAY OPTOELECTRONICS (ZHENJIANG) CO. LTD., CHINA Free format text: ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNOR:FURCIFER INC.;REEL/FRAME:068681/0150 Effective date: 20240923
2024-12-18	STPP	Information on status: patent application and granting procedure in general	Free format text: NON FINAL ACTION MAILED
2025-01-17	STPP	Information on status: patent application and granting procedure in general	Free format text: NON FINAL ACTION MAILED
2025-07-24	STPP	Information on status: patent application and granting procedure in general	Free format text: RESPONSE AFTER FINAL ACTION FORWARDED TO EXAMINER
2025-07-25	STPP	Information on status: patent application and granting procedure in general	Free format text: ADVISORY ACTION COUNTED, NOT YET MAILED
2025-07-28	STPP	Information on status: patent application and granting procedure in general	Free format text: ADVISORY ACTION MAILED
2025-08-01	STPP	Information on status: patent application and granting procedure in general	Free format text: DOCKETED NEW CASE - READY FOR EXAMINATION
2025-09-29	STPP	Information on status: patent application and granting procedure in general	Free format text: ALLOWED – NOTICE OF ALLOWANCE NOT YET MAILED

			Free format text: NOTICE OF ALLOWANCE MAILED -- APPLICATION RECEIVED IN OFFICE OF PUBLICATIONS
2025-11-19	STPP	Information on status: patent application and granting procedure in general	Free format text: PUBLICATIONS -- ISSUE FEE PAYMENT RECEIVED
2025-11-25	STPP	Information on status: patent application and granting procedure in general	Free format text: PUBLICATIONS -- ISSUE FEE PAYMENT VERIFIED
2025-12-10	STCF	Information on status: patent grant	Free format text: PATENTED CASE

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