

Photoelectrochemical Photovoltaic Panel and Method to Manufacture thereof.

5 TECHNICAL FIELD

This invention relates to photoelectrochemical photovoltaic cells (PPC). More particularly, the invention relates to photoelectrochemical photovoltaic modules of large size (both flexible and rigid) that include
10 plurality of the PEC integrated in one photovoltaic source.

Examples of the PEC are disclosed in the following patent specifications:

US4927721, Photoelectrochemical cell; Michael Graetzel and
15 Paul Liska, 1990.

US5350644, Photovoltaic cells; Michael Graetzel, Mohammad K Nazeeruddin and Brian O'Regan, 1994.

US5525440, Method of manufacture of photo-electrochemical cell and a cell made by this method; Andreas Kay, Michael
20 Graetzel and Brian O'Regan, 1996.

US5728487, Photoelectrochemical cell and electrolyte for this cell; Michael Graetzel, Yordan Athanasov and Pierre Bonhote, 1998.

WO 98/05084, Photoelectrochemical cell, S. Brodie et al.

25 US6297900- Electrophotochromic Smart Windows and Methods, Gavin Tulloch and Igor Skryabin, 2000.

US6555741- Methods to Implement Interconnects in Multi-cell Regenerative Photovoltaic Photoelectrochemical Devices, G.Phani, I.Skryabin and J.Hopkins, 2001

30 US6664623 - Methods to Implement Sealing and Electrical Connections to Single Cell and Multi-cell Regenerative Photovoltaic Photoelectrochemical Devices, G.Phani, J.Hopkins, D.Vittorio, I.Skryabin, 2002

BACKGROUND OF THE INVENTION

Photoelectrochemical Photovoltaic Cells (PPC), as of
5 the type disclosed in the above patents, are typically
fabricated in a laminate arrangement between two
substrates. In a typical arrangement, at least one
substrate is transparent to visible light and comprises a
transparent support (typically glass for rigid modules and
10 plastic - for flexible modules) to which a transparent
electrically conductive (TEC) coatings is applied. Another
substrate is not necessarily transparent to visible light.
Various materials suitable for non-transparent substrate
are described in the prior art, including:

- 15 • Thin metallic films supported by glass, ceramic or
polymer,
- Metallic foils,
- Metallic mesh,
- Carbon based conductors.

20

However, the TEC coatings, which usually comprise a metal
oxide(s), have high resistivity when compared with normal
metal conductors, resulting in high resistive losses for
25 large area cells. Thus, in practical application, these
cells are combined in modules.

Dimensions of the modules are limited, however, by
necessity to maintain uniform thickness of a module
30 (typically 20-50 micrometers). In order to make a large
photovoltaic photoelectrochemical panel (PPP) the modules
are electrically connected and laminated between two
additional large panes, one of which is being transparent.

(see, for example, Australian design No2093/2002). Manufacture of such panels, however, requires additional manufacturing equipment and procedures.

5 OBJECTIVE OF THE INVENTION

Objective of this invention is to provide cost effective large size photovoltaic photoelectrochemical panel.

10 SUMMARY OF THE INVENTION

Generally the present invention provides for a Photoelectrochemical Photovoltaic Panel (PPP) comprising one shared substrate and a number of individual
15 substrates. The shared substrate is an electrical conductor or is at least partially coated by an electrically conducting material. Similarly, individual substrates are all electrical conductors or at least partially coated with an electrically conducting material.

20 In one embodiment the shared substrate is transparent to at least a part of solar radiation.

In another embodiment at the individuals substrates are all transparent to at least a part of solar radiation.

In further embodiment the individual substrates and
25 the shared substrate (hereafter - the substrates) are all transparent to at least a part of solar radiation.

In yet a further embodiment said electrically conducting material is a transparent electronic conductor (TEC), for example fluorine doped tin oxide or indium-tin
30 oxide.

Photoelectrochemical photovoltaic cells (PPC) are formed between the shared substrate and the individual

substrates. Each PPC includes a photosensitive electrode, a counter electrode and an electrolyte dispensed between the photosensitive electrode and the counter electrode. The photosensitive electrode typically comprises nano-
5 particulate wide band semiconductor (for example - titanium dioxide), photosensitised by a thin layer of dye.

In one embodiment the photosensitive electrodes of the PPC are supported by the shared substrate whereas the
10 counter electrodes of the PPC - by the individual substrates.

In another embodiment only some of the photosensitive electrodes are supported by the shared substrate and the remaining photosensitive electrodes are
15 supported by the individual substrates.

In the practical realisation of the invention the shared substrate is substantially larger than each of the individual substrates allowing for a significant number of
20 PPC to be formed in one panel. Although the invention has no specific restrictions on the shape of the shared substrate, rectangular shape is advantageous for the purpose of use and manufacture, especially - for roll-to-roll manufacture, which is preferable when the shared
25 substrate and all the individual substrates are made of flexible material.

In one aspect of the invention, the shared substrate is divided into electrically isolated regions; each region
30 opposes at least one adjacent individual substrate and the PPC are formed between the individual substrate and the opposing isolated region of the shared substrate.

In one embodiment in accordance with this aspect of the invention at least one of the substrates is made of glass coated by Transparent Electronic Conductor (TEC).

In another embodiment in accordance with this aspect
5 of the invention, at least one of the substrates is made of polymeric material coated by TEC.

In still another embodiment, at least one of the substrates is made of metal or metal alloy. Preferential metals include titanium, tungsten, nickel, zinc or alloys
10 such as stainless steel.

In yet another embodiment at least one of the substrates is made of metal coated by impermeable nitride (e.g. TiN).

In a further embodiment, at least one of the
15 substrates comprises metal foil or metallic mesh.

In still a further embodiment, at least one of the substrates comprises polymeric sheet coated by metal or laminated with metallic foil.

In yet a further embodiment the shared substrate
20 comprise polymeric material coated by TEC and all the individual substrates comprise metal foil.

In the preferred embodiment the shared substrate is made of polymeric material coated by TEC and all the individual substrates comprise metallic foil, wherein said
25 photosensitive electrodes of said PPC are formed on the individual substrates and counter electrodes - on the shared substrate.

The invention provides for various shapes and dimensions of the individual substrates, it is
30 preferential, however, to utilise the individual substrates (and PPC electrodes) of circular shape in order to minimise resistive losses. Another advantage of the circular shape is in minimisation of perimeter for a given

area of the PPC electrodes, since each of the PPC needs to be sealed along the perimeter of the individual substrate. Dimensions of each PPC depend on the type of conductor. Dimensions of the individual substrate depend on
5 resistivity of selected TEC material. It has been established that for full sun operations diameter of each PPC must not exceed 10-15 mm if resistivity of the TEC material is around 10 Ohms/square.

In the preferred embodiment the individual substrates
10 are electrically connected to selected electrically isolated regions of the common substrate. This allows for electrical connections between the PPC to form two terminal power source of the PPP. It is advantageous to connect the PPC in such a way that both negative and
15 positive terminals of the power source are located on the shared substrate.

In another aspect of the invention a pattern of a second electrically conductive material is created on at
20 least one substrate. This material is selected to have conductivity higher than that of the first electrically conductive material. The second electrically conductive material enhances conductivity of the substrate without significant reduction of its optical transparency.
25 Examples of the secondary conductive material include metal (for example, Ag, Cu, Au) tracks deposited on the substrate using screen-printing, vacuum mask deposition, electroplating, etc.

In one embodiment, the electrically conductive
30 material is protected by an impermeable protective layer of glazing or polymeric material. This protection is especially important when said electrically conductive material is exposed to said electrolyte of PPC.

In another embodiment the pattern of the second electrically conductive material is created by varying the thickness of the first conducting material in such a way that regions of the substrate where high optical transmittance is required (under or opposite the photosensitive electrodes) are coated by the relatively thin TEC (the first electrically conductive material), whereas other regions of the substrates, where high electrical conductance is required, are coated by a thick electrically conductive material or (the second electrically conductive material).

According to another aspect of the invention, small holes are prepared either in the shared substrates or in the common substrate. The holes are used for filling the cells with said electrolyte. The holes are further sealed with a polymeric material, preferably by the laminate that comprises a hot melt polymeric material and a metal foil.

From yet a further aspect of the invention, at least one isolated region of the shared substrate is further subdivided into electrically isolated subregions and the opposing individual substrate is also divided into electrically isolated subregions, with each said PPC being formed between parts of two opposing subregions (one on the shared substrate and another on the individual substrate) and said adjacent PPC are electrically interconnected in series by an interconnecting material.

To enable connections of cells in series, the interconnecting material is placed between a separate part of the sub region adjacent to the photosensitive electrode of n-th said PPC and a separate part of the sub region adjacent to said counter electrode of (n+1)-th PPC.

In one embodiment the interconnecting material comprises metallic particles, and/or graphite flakes.

In another embodiment the said interconnecting material comprises metal wire, wire braid or wire plait.

5 In yet another embodiment the said electrically interconnecting material comprises metallic mesh.

In a further embodiment electrically conducting components of the interconnecting material are protected from electrolyte of PPC by impermeable electrically
10 insulating material, preferably - polymeric material, in which said conducting components are embedded.

In the preferred embodiment said polymeric material is hot melt material.

15 In one process the insulating hot melt material is melted and adhered to both substrates due to the heat generated in metallic interconnecting material. The invention provides for passing electrical current through the interconnecting material in order to generate heat
20 sufficient for melting and adhesion of the hot melt material. In preferred process the heat is generated by an inductive action of an electromagnetic field.

Specific attention is given to the spaces that formed
25 between the individual substrates when they attached to the common substrate.

In one embodiment these spaces are filled with an hermetic sealant.

In another embodiment humidity absorbing material
30 (e.g. - molecular sieves) is placed in these spaces; to ensure long term stability of the photoelectrochemical devices.

In yet another embodiment these spaces are fully or partially filled with a solvent of the same chemical nature as that used for an electrolyte in the photoelectrochemical cells. This is to minimise long term degradation effects caused by the loss of solvent in the cells.

BRIEF DESCRIPTION OF DRAWINGS

10 Having broadly portrayed the nature of the present invention, embodiments thereof will now be described by way of example and illustration only. In the following description, reference will be made to the accompanying drawings in which:

15 Figure 1 is a 3D diagrammatic representation of a PPP formed in accordance with the first example of the invention.

Figure 2 is an enlarged partial cross-section of a Photoelectrochemical Photovoltaic Panel formed in accordance with the first example of the invention.

20 Figure 3 is an enlarged partial cross-sectional view of a PPP formed in accordance with the second example of the invention.

Figure 4 is a partial plan representation of a PPP formed in accordance with the second example of the invention.

Figure 5 is a 3D diagrammatic representation of the flexible shared substrate of PPP formed in accordance with the third example of the invention.

30 Figure 6 is a 3D diagrammatic representation of the flexible PPP formed in accordance with the third example of the invention.

DETAILED DESCRIPTION OF DRAWINGS

5

With reference to Figure 1, a 3D diagrammatic representation of a PPP is shown. The panel comprises twelve individual substrates 2 and a shared substrate 1. The substrates are coated by TEC (fluorine doped tin oxide) layer 3. The electrically isolated regions of the transparent electrical conductor 3 are formed by removing said conductor along the isolation lines 4. This procedure utilizes laser radiation and can be applied to all the substrates; 3D representation in Fig. 1 allows visualisation of these lines only on the shared substrate. The PPC are formed between parts of the isolated regions 5 of the common substrate and opposing isolated regions of the isolated substrate. The PPC are interconnected to form 2 terminal power output of the PPP. The terminals are created by depositing Ag bus-bars 6. Also shown a plane A, cross-sectional representation in which is shown in Figure 2.

With reference to Figure 2, cross section that includes three individual glass substrates is shown. The shared substrate 2 (also- glass) and the individual substrates 1 are coated by TEC layer 3. The electrically isolated regions are formed by removing TEC material along the lines 4. Counter electrodes 7 (ultra-thin layer of Pt based catalyst) is formed on parts of the electrically isolated regions of the individual substrates 1, using standard screen-printing technique. Photosensitized electrodes 8 are formed on parts of the isolated regions

3a of the shared substrate 2. The photosensitized electrodes 8 comprise nano-particulate layer of titanium dioxide (15 microns thick) photosensitized by Ru-based dye. Formation (by screen-printing followed by firing) and
5 photosensitization of the nano-particulate layer of titanium dioxide was performed in accordance with standard procedures well known in the prior art. The PPC were interconnected by interconnecting material 9 that comprises W particles embedded into silicone based matrix
10 and filled by redox electrolyte 10 through small filling holes in the shared substrate (not shown). External negative and positive terminals 8 are created by application of Ag bus-bars.

15 With reference to Fig. 3, cross-sectional representation of the second example depicts only one individual substrate 1. All the numbered elements in this figure are as per Fig. 1 and Fig. 2. This example is different from the first example of the invention in that the
20 photosensitized electrodes here are formed on the individual substrates and counter electrodes - on the common substrate.

With reference to Figure 4 a partial planar view of a PPP
25 depicting only 1 individual substrate is presented. Additionally, sealing material 11 and filling holes 12 are shown. The holes were used for vacuum back filling of the cells with an electrolyte.

30 With reference to Figure 5 a shared flexible substrate 2 is prepared in accordance with third example of the invention. The substrate comprises plastic sheet coated by transparent electronic conductor 3. The transparent

- 12

electronic conductor 3 is divided into four electrically isolated regions by the isolation lines 4. To enhance electrical conduction of TEC material and to provide for electrical connection four Ag bus-bars 6 are deposited
5 onto the TEC as shown in the figure. On parts of three (out of four) isolated regions of the shared substrate the circularly shaped counter electrodes 7 are formed such as 8 equally spaced counter electrodes belong to each of the three isolated regions. This will provide for 8 PPC in
10 each isolated region of the shared substrate that will be connected in parallel. Three groups of 8 PPC will be connected in series as further demonstrated in Figure 6.

With reference to Figure 6 a flexible PPP is prepared in
15 accordance with the third example of the invention. The patent utilizes pre-prepared shared substrate (shown in details in Fig. 5) and 24 individual substrates 1. Each individual substrate comprises Ti foil, on which a photosensitized electrode is formed. The individual
20 substrates sealed with the shared substrate in such a way that the photosensitive electrodes of the individual substrates oppose counter electrodes of the shared substrates. The 24 PPC are formed by filling spaces between the photosensitized electrodes and opposing
25 counter electrodes with a redox electrolyte. The cells are connected in parallel in groups of three by external electrical connectors 13 and in series (in groups of 3) by electrical jumps 14. The positive and negative electrical terminal of the PPP are also shown.

Claims

1. A Photoelectrochemical Photovoltaic Panel (PPP)
5 comprising a number of individual substrates and a shared substrate (the substrates), wherein
 - the substrates are electrical conductors or at least partially coated by an electrically conducting material,
 - 10 ▪ at least one substrate is substantially transparent to at least a part of solar radiation (optically transparent),
 - Photoelectrochemical Photovoltaic Cells (PPC), each comprising a photosensitive electrode, a counter electrode and an electrolyte dispensed
15 between the photosensitive electrode are formed between the shared substrate and the individual substrates
2. A PPP according to claim 1, wherein at least one
20 substrate comprises optically transparent material coated by a Transparent Electrical Conductor (TEC).
3. A PPP according to claim 2, wherein said optically transparent material comprise glass or plastic.
4. A PPP according to claim 2 and claim 3, wherein said
25 TEC comprises fluorine doped tin oxide, indium tin oxide or metallic mesh.
5. A PPP according to claim 1, wherein all the substrates are optically transparent.
6. A PPP according to claim 1, wherein the shared
30 substrate comprises metal sheet or foil and all the individual substrates are optically transparent.

7. A PPP according to claim 1, wherein the individual substrates comprise metal sheet or foil and the shared substrate is optically transparent.
8. A PPP in accordance with claim 1 wherein said
5 photosensitive electrode comprises nano-particulate wide band semiconductor (for example - titanium dioxide), photosensitised by a thin layer of dye and electrically connected to one of the substrates or its electrically conducting material.
- 10 9. A PPP in accordance with claim 1 wherein said photosensitive electrodes of PPC are supported by the shared substrate.
10. A PPP in accordance with claim 1 wherein at least a
15 part of said photosensitive electrodes of PPC are supported by the shared substrate and photosensitive electrodes of remaining PPC are supported by the individual substrates.
11. A PPP in accordance with claim 1, wherein said shared substrate is of rectangular shape.
- 20 12. A PPP in accordance with claim 1, wherein said individual substrates are of rectangular or circular shape.
13. A PPP in accordance with claim 1, wherein the shared
25 substrate is divided into electrically isolated regions; each region opposes at least one adjacent individual substrate and the PPC are formed between the individual substrate and the opposing isolated region of the shared substrate.
14. A PPP in accordance with claim 13, claim 4 and claim
30 7, wherein the shared substrate is made of polymeric material coated by TEC and all the individual substrates comprise metallic foil, wherein said photosensitive electrodes of said PPC are formed on

the individual substrates and counter electrodes - on the parts of said electrically isolated regions of the shared substrate.

- 5 15. A PPP in accordance with claim 14, wherein the individual substrates are electrically connected to selected electrically isolated regions of the common substrate.
- 10 16. A PPP in accordance with claim 2, wherein electrical conductance of TEC material is enhanced by application of a pattern of second electrically conductive material.
17. A PPP in accordance with claim 16, wherein said pattern of the second conducting material comprises metallic tracks formed on TEC layer.
- 15 18. A PPP in accordance with claim 17, wherein said metallic tracks are protected by an impermeable protective layer of glazing or polymeric material.
- 20 19. A PPP in accordance with claim 16 wherein said second conductive material is created by increasing the thickness of TEC coating in such a way that regions of the substrate where high optical transmittance is required (under or opposite the photosensitive electrodes) are coated by the relatively thin TEC (the first electrically conductive material), whereas other regions of the substrates, where high electrical conductance is required, are coated by a thick TEC (the second electrically conductive material).
- 25 20. A PPP in accordance with claim 13 wherein small holes are prepared in the individual and/or shared substrates; said holes being used for filling the PPC with the electrolyte.
- 30

21. A PPP in accordance with claim 20, wherein after filling the PPC with the electrolyte the holes are sealed by a polymeric material.
22. A PPP in accordance with claim 21, wherein said
5 polymeric material comprises hot melt material laminated with metallic foil.
23. A PPP in accordance with claim 13, wherein at least one isolated region of the shared substrate is further subdivided into electrically isolated subregions and
10 the opposing individual substrate is also divided into electrically isolated subregions, with each said PPC being formed between parts of two opposing subregions (one on the common substrate and another on the separate substrate) and said adjacent PPC are
15 electrically interconnected in series by an interconnecting material.
24. A PPP in accordance with claim 23, wherein the interconnecting material is placed between a separate part of the sub region adjacent to photosensitive
20 electrode of n-th said PPC and a separate part of the sub region adjacent to counterelectrode of (n+1)-th PPC.
25. A PPP in accordance with claim 23, wherein said interconnecting material comprises metallic particles
25 and/or graphite flakes.
26. A PPP in accordance with claim 23, wherein interconnecting material comprises metal wire, metallic mesh, wire braid or wire plait.
27. A PPP in accordance with claim 25 or claim 26 wherein
30 said interconnecting material is protected from electrolyte of PEC by impermeable electrically insulating material, preferably - polymeric material, in which said conducting components are embedded.

28. A PPP in accordance with claim 27, wherein said polymeric material is hot melt material.
29. A PPP in accordance with claim 28, wherein said hot melt is melted and adhered to the opposing substrates due to the heat generated in the interconnecting material.
30. A PPP in accordance with claim 29, wherein the heat is generated by an inductive action of electromagnetic field.
31. A PPP in accordance with claim 13 wherein spaces that formed between the individual substrates when they are attached to the shared substrate are sealed with a hermetic sealant.
32. A PPP in accordance with claim 31, wherein said spaces are filled with a humidity absorbing material such as molecular sieves.