

INTERLAYER DESIGN FOR PHOTOVOLTAIC CELLS

BACKGROUND

5 Technical Field

The disclosure relates to a photovoltaic device. More particularly, the disclosure relates to an interlayer of a photovoltaic cell.

Description of Related Art

10 From the past century to date, petrochemical energy is still the major energy source in our life. Petrochemical energy includes gas and oil. Unfortunately, the abundance of petrochemical fuel is limited and has become rare to be a scarce resource. Thus, scientists have challenges to find ways of renewable energy coming from nature resources such as sunlight, wind, rain,
15 tides and geothermal heat.

Today, the environmentally clean and renewable energy is desirable. For example, hydroelectric power is a clear resource of energy. The production of hydroelectric power is through the use of the gravitational force of falling or flowing water. Wind turbines convert wind energy into more useful
20 electric power. However, solar energy is still a type of clean energy and more powerful.

Photovoltaic cells (or solar cells) are photovoltaic devices that convert the sunlight energy directly into electric power by photovoltaic effect. A conventional photovoltaic device has a transparent electrode, amorphous
25 silicon layers (p-layer, i-layer, and n-layer), and a transparent electrode on a

glass substrate in sequential. Upon exposure to light, the semiconductor p-n junction converts the optical energy into electrical energy output.

In conventional technology, a transparent adhesive is usually used as an interlayer to connect layers of a photovoltaic cell or connect photovoltaic cells in a tandem photovoltaic device. However, it is hard to find an ideal transparent adhesive that possesses both good transparency to the needed wavelength range of light and enough binding strength, not to mention other additional requirements, such as good waterproofness, high resistivity, matching refractive index etc.

SUMMARY

Accordingly, in one aspect, the present invention is directed to a tandem solar cell having an interlayer between two photovoltaic cells. The interlayer has a transparent portion covering an active area and an adhesive portion covering a non-active area surrounding the active area. The active area is responsible for absorbing light to generate photocurrent.

When the interlayer directly contacting the bottom photovoltaic cell and the top photovoltaic cell, the transparent portion of the interlayer has a refractive index between the refractive indexes of a directly contacting lower transparent layer in the bottom photovoltaic cell and a directly contacting upper transparent layer in the top photovoltaic cell.

According to an embodiment of this invention, the directly contacting upper transparent layer can be a lower transparent electrode of the top photovoltaic cell.

According to another embodiment of this invention, the directly contacting upper transparent layer can be a semiconductor layer of the top photovoltaic cell when the lower electrode is made of metal fingers.

According to another embodiment of this invention, the directly
5 contacting lower transparent layer can be a upper transparent electrode of the bottom photovoltaic cell.

According to another embodiment of this invention, the directly contacting lower transparent layer can be a semiconductor layer of the bottom photovoltaic cell when the upper electrode is made of metal fingers.

10 In another aspect, this invention directs to a photovoltaic cell having an interlayer and a transparent front cover.

According an embodiment of this invention, the interlayer is between and directly contacts an upper transparent electrode of the photovoltaic cell and the transparent front cover.

15 According to another embodiment of this invention, the interlayer is between and directly contacts a semiconductor layer of the photovoltaic cell and the transparent front cover when the upper electrode is made of metal fingers.

It is to be understood that both the foregoing general description and the following detailed description are by examples, and are intended to provide
20 further explanation of the invention as claimed. Many of the attendant features will be more readily appreciated as the same becomes better understood by reference to the following detailed description considered in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a top view diagram of an interlayer in a photovoltaic cell or a photovoltaic panel according to an embodiment of this invention.

5 Fig. 2A is a cross-sectional diagram of a tandem photovoltaic panel having a interlayer according to an embodiment of this invention.

Fig. 2B is a cross-sectional diagram of a tandem photovoltaic cell having an interlayer according to another embodiment of this invention.

10 Fig. 2C is a cross-sectional diagram of tandem photovoltaic cell having plural interlayers according to yet another embodiment of this invention.

Fig. 3 is a cross-sectional diagram of a photovoltaic cell according to yet another embodiment of this invention.

DETAILED DESCRIPTION

15 The detailed description provided below in connection with the appended drawings is intended as a description of the present examples and is not intended to represent the only forms in which the present example may be constructed or utilized. The description sets forth the functions of the example and the sequence of steps for constructing and operating the example.
20 However, the same or equivalent functions and sequences may be accomplished by different examples.

According to an embodiment of this invention, an interlayer between layers and a photovoltaic cell or between two photovoltaic cells in a tandem solar cell is provided. Instead of using a transparent adhesive to be the

conventional interlayer, a transparent material and an adhesive are used for the new interlayer.

Fig. 1 is a top view diagram of an interlayer in a photovoltaic cell or a photovoltaic panel according to an embodiment of this invention. In Fig. 1, the interlayer 100 has two portions: a transparent portion 110 and an adhesive portion 120. The transparent portion 110 covers an active area, which are responsible for absorbing light to generate photocurrent. The adhesive portion 120 covers a non-active area, which surrounds the active area. Therefore, when the interlayer is applied in a photovoltaic panel having photovoltaic cell arrays thereon, the non-active areas are not limited by the peripheral area of the photovoltaic panel shown in Fig. 1. Fig. 1 is only an exemplary diagram. Accordingly, the designed structure of the interlayer 100 in Fig. 1 can decouple the linking requirements of good transparency and enough binding strength, as well as other additional requirements for conventional interlayer.

Both the transparent portion 110 and the adhesive portion 120 are made of insulating material. In Fig. 1, since the transparent portion 110 covers the active area occupied by the photovoltaic cells, the refractive index of the transparent portion 110 is better to meet the following requirements to increase the light utilization efficiency. It is well known that various semiconductor materials can absorb various wavelength ranges of light. Therefore, the following described optical requirements are based on the absorbed wavelength ranges of the semiconductor materials in the photovoltaic cell or photovoltaic panel. Depending on the material used for the semiconductor layer in a photovoltaic cell, the refractive index of the transparent portion 110 is better to match the refractive indexes of the directly contacting upper and lower

transparent layers for the absorbed wavelength range of the semiconductor layer to reduce the reflection of the incident light. The meaning of the "matching refractive index" is described below in the examples.

In addition, the transmittance of the transparent portion 110 is better to be greater than 80% in the absorbed wavelength range of the incident light for the semiconductor layer of the photovoltaic cell. Thus, the transmittance of the incident light can be greatly increased by choosing a transparent material meeting the requirements above. For example, the material of the transparent portion 110 can be ethylene vinyl acetate (EVA), polyvinyl butyral (PVB), polyethylene terephthalate (PET) or naphthalate polyester (PEN).

In Fig. 1, since the adhesive portion 120 usually covers the peripheral area of a photovoltaic panel, not only the binding strength needs to be good enough, but also the waterproofness needs to be good enough to endure the outdoor environment. For example, the material of the adhesive portion 120 can be ionomer, poly(arylene ether nitrile) or polyurethane.

Fig. 2A is a cross-sectional diagram of a tandem photovoltaic cell having an interlayer according to an embodiment of this invention. In Fig. 2A, the four-terminal tandem photovoltaic cell includes a top photovoltaic cell 200a and a bottom photovoltaic cell 200b. The interlayer 100, having the transparent portion 110 and the adhesive portion 120 as described above in Fig. 1, is disposed between the top photovoltaic cell 200a and the bottom photovoltaic cell 200b in this embodiment.

In Fig. 2A, the top photovoltaic cell 200a sequentially has a first substrate 210, a first electrode 220, a first semiconductor layer 230, and a second electrode 240 from top to bottom. The bottom photovoltaic cell 200b

sequentially has a third electrode 250b, a second semiconductor layer 260, a fourth electrode 270, a reflecting layer 280, and a second substrate 290 from top to bottom. The band gap of the first semiconductor layer 230 is greater than the band gap of the second semiconductor layer 260.

5 The top photovoltaic cell 200a and/or the bottom photovoltaic cell 200b can be a single junction or a multi-junction photovoltaic cell. When the first semiconductor layer 230 and/or the second semiconductor layer 260 is only a thin film, such as a CdTe thin film, a copper indium gallium selenide (CIGS) thin film, a polysilicon thin film, or an amorphous silicon thin film, the top photovoltaic
10 cell 200a and/or the bottom photovoltaic cell 200b is a single junction cell. When the first semiconductor layer 230 and/or the second semiconductor layer 260 has multiple thin films, such as a combination of a GaAs thin film, a Ge thin film and a GaInP₂ thin film, the top photovoltaic cell 200a and/or the bottom photovoltaic cell 200b is a multi-junction cell.

15 The first electrode 220, the second electrode 240, the third electrode 250b, and the fourth electrode 270 are usually made of a transparent conductive material, such as a metal oxide or a complex metal oxide. The metal oxides can be PbO₂, CdO, Ti₂O₃, Ga₂O₃, ZnPb₂O₆, CdIn₂O₄, MgIn₂O₄, ZnGaO₄, AgSbO₃, CuAlO₂, CuGaO₂, or CdO-GeO₂, for example. The complex
20 metal oxide can be AZO (ZnO: Al), GZO (ZnO: Ga), GAZO (ZnO: Ga, Al), ATO (SnO₂: Sb), FTO (SnO₂: F), ITO (In₂O₃: Sn), BZO (BaO: Zr), or BaTiO₃, for example. However, if the fourth electrode 270 is made of non-transparent conductive material, such as a metal, the reflecting layer 280 in Fig. 2A may be omitted.

The reflecting layer 280 in the bottom photovoltaic cell 200b can direct the incident light back to the second semiconductor layer 260 and the first semiconductor layer 230 to further increase the light utilization efficiency.

In Fig. 2A, since the interlayer 100 is disposed between the top photovoltaic cell 200a and the bottom photovoltaic cell 200b, it is the second electrode 240 and the third electrode 250b that directly contact the interlayer 100. The refractive indexes of the interlayer 100, the second electrode 240 and the third electrode 250b are n_i , n_{2c} , and n_{3c} , respectively. Therefore, in order to let the refractive index of the transparent portion 110 match the refractive indexes of the contacting upper and lower transparent layers (i.e. the second electrode 240 and the third electrode 250b), n_i is better to be between n_{2c} and n_{3c} .

Accordingly, when n_{2c} equal to n_{3c} , n_i is better to be equal to n_{2c} and n_{3c} . However, if a transparent insulating material with the refractive index meeting the above requirement is not available, the difference between the refractive index n_i and n_{2c} (or n_{3c}) is better to be less than 0.1 – 0.5 when n_{2c} equal to n_{3c} . For example, ZnO is usually used as a material of the transparent contacts in photovoltaic cells. The refractive index of ZnO is about 1.97. Thus, the material of the transparent portion 120 can be naphthalate polyester (PEN), which has a refractive index of 1.75, for example.

Fig. 2B is a cross-sectional diagram of a four-terminal tandem photovoltaic cell having an interlayer according to another embodiment of this invention. In Fig. 2B, the four-terminal tandem photovoltaic cell includes a top photovoltaic cell 200a and a bottom photovoltaic cell 200c. The interlayer 100, having the transparent portion 110 and the adhesive portion 120 as described

above in Fig. 1, is disposed between the top photovoltaic cell 200a and the bottom photovoltaic cell 200c in this embodiment.

In Fig. 2B, the top photovoltaic cell 200a sequentially has a first substrate 210, a first electrode 220, a first semiconductor layer 230, and a second electrode 240 from top to bottom. The bottom photovoltaic cell 200c sequentially has a third electrode 250c, a second semiconductor layer 260, a fourth electrode 270, a reflecting layer 280, and a second substrate 290 from top to bottom. Unlike the third electrode 250b made of a transparent conductive material in Fig. 2A, the third electrode 250c is made of metal fingers, which is not transparent to light. Therefore, the shape of the third electrode 250c in Fig. 2B is finger-like to increase the transparent area of the photovoltaic cell in Fig. 2B.

Therefore, it is the second electrode 240 and the second semiconductor layer 260 directly contacting the interlayer 100. The refractive indexes of the interlayer 100, the second electrode 240 and the second semiconductor layer 260 are n_i , n_{2c} , and n_{2s} , respectively. Therefore, in order to let the refractive index n_i of the transparent portion 110 match the refractive indexes of the contacting upper and lower transparent layers, n_i is better between n_{2c} and n_{2s} .

Accordingly, when n_{2c} equal to n_{2s} , n_i is better equal to n_{2c} and n_{2s} . However, if a transparent insulating material with the refractive index meeting the above requirement is not available, the difference between the refractive index n_i and n_{2c} (or n_{2s}) is better to be less than 0.1 – 0.5 when n_{2c} equal to n_{2s} .

In addition, it is also possible that the second electrode 240 is also made of metallic fingers, like the third electrode 250c in Fig. 2B. Then, it is the first semiconductor layer 230 and the second semiconductor layer 260 that directly

contact the interlayer 100. Therefore, the refractive index of the transparent portion 110 in the interlayer 100 is determined by the refractive indexes of the first semiconductor layer 230 and the second semiconductor layer 260.

Moreover, it is also possible that only the second electrode 240 is made of metallic fingers. Then, it is the first semiconductor layer 230 and the third electrode 250b that directly contact the interlayer 100. Therefore, the refractive index of the transparent portion 110 in the interlayer 100 is determined by the refractive indexes of the first semiconductor layer 230 and the third electrode 250b.

In Figs. 2A and 2B, since the element with the same reference number means the same or similar things, the related detail descriptions of the elements with the same reference number are omitted here.

Fig. 2C is a cross-sectional diagram of tandem photovoltaic cell having plural interlayers according to yet another embodiment of this invention. In Fig. 2C, the number of the stacked photovoltaic cells 200 in the tandem photovoltaic cell is increased to more than two. For example, when the number of the photovoltaic cells 200 is increased to three, the tandem photovoltaic cell is a six-terminal device. The photovoltaic cells 200 and the interlayers 100 are alternatively stacked to form the tandem photovoltaic cell in Fig. 2C.

In Fig. 2C, each of the photovoltaic cells 200 can be any one of the photovoltaic cell 200a, 200b, 200c, or other variations of the above-described photovoltaic cells. The only difference is that only the photovoltaic cell 200 farthest to the light-incident side, usually the bottom photovoltaic cell, has a reflector. The requirement of the refractive index of the transparent portion 120 of the interlayer 100 is also determined by the two transparent layers

directly contacting the interlayer 100 as discussed above, and thus omitted here.

Fig. 3 is a cross-sectional diagram of a photovoltaic cell according to yet another embodiment of this invention. In Fig. 3, the interlayer 100 is disposed between a transparent front cover 300 and the bottom photovoltaic cell 200b. The front cover can be made of glass, quartz, or a transparent plastic material. The bottom photovoltaic cell 200b sequentially has a third electrode 250b, a second semiconductor layer 260, a fourth electrode 270, a reflecting layer 280, and a second substrate 290 from top to bottom.

Accordingly, it is the transparent front cover 300 and the third electrode 250b that directly contact the interlayer 100 in Fig. 3. Therefore, the refractive index of the transparent portion 110 in the interlayer 100 is determined by the refractive indexes of the front cover (n_f) and the third electrode 250b (n_{3c}). Similarly, in order to let the refractive index of the transparent portion 110 match the refractive indexes of the contacting upper and lower transparent layers, n_i is better to be between n_f and n_{3c} . Accordingly, when n_f equal to n_{3c} , n_i is better equal to n_f and n_{3c} . However, if a transparent insulating material with the refractive index meeting the above requirement is not available, the difference between the refractive index n_i and n_f (or n_{3c}) is better to less than 0.1 – 0.5 when n_f equal to n_{3c} .

Furthermore, if the third electrode 250b is replaced by the third electrode 250c made of metal fingers (not shown in Fig. 3), it is the transparent front cover 300 and the second semiconductor layer 260 that directly contact the interlayer 100 in Fig. 3. Therefore, the refractive index of the transparent portion 110 in the interlayer 100 is determines by the refractive indexes of the

transparent front cover 300 and the second semiconductor layer 260. The determining method has been discussed above, and hence omitted here.

Accordingly, this disclosure discloses an interlayer structure that made of a transparent portion and an adhesive portion. The transparent portion covers
5 active areas occupied by photovoltaic cells, and the adhesive portion covers non-active areas. Therefore, the interlayer structure provided by this disclosure can decouple the linking requirements of good transparency and enough binding strength, as well as other additional requirements for conventional interlayer. The materials of the transparent portion and the
10 adhesive portion can be individually chosen to more easily meet individual requirements for the active areas and non-active areas.

All the features disclosed in this specification (including any accompanying claims, abstract, and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly
15 stated otherwise. Thus, each feature disclosed is one example only of a generic series of equivalent or similar features.

WHAT IS CLAIMED IS:

1. A tandem photovoltaic cell, comprising:

a lower photovoltaic cell;

5 an upper photovoltaic cell above the lower photovoltaic cell; and

an interlayer disposed between the lower photovoltaic cell and the upper photovoltaic cell, the interlayer having a transparent portion covering an active area and an adhesive portion covering a non-active area surrounding the active area, wherein the active area is responsible for absorbing light to generate
10 photocurrent.

2. The tandem photovoltaic cell of claim 1, wherein the transparent portion of the interlayer has a refractive index between the refractive indexes of a directly contacting lower transparent layer in the lower photovoltaic cell and a
15 directly contacting upper transparent layer in the upper photovoltaic cell when the interlayer directly contacting the lower photovoltaic cell and the upper photovoltaic cell.

3. The tandem photovoltaic cell of claim 2, wherein the upper
20 photovoltaic cell comprises:

an upper transparent substrate;

a first transparent electrode below the upper substrate;

a first semiconductor layer below the first transparent electrode; and

a second transparent electrode below the first semiconductor layer,

25 wherein the second transparent electrode is the directly contacting upper layer.

4. The tandem photovoltaic cell of claim 2, wherein the upper photovoltaic cell comprises:

a upper transparent substrate;

5 a first transparent electrode below the upper substrate;

a first semiconductor layer below the first transparent electrode; and

a first metal fingers below the first semiconductor layer, wherein the first semiconductor layer is the directly contacting upper layer.

10 5. The tandem photovoltaic cell of claim 2, wherein the lower photovoltaic cell comprises:

a lower substrate;

a fourth electrode on the lower substrate; and

a second semiconductor layer on the forth electrode; and

15 a third transparent electrode on the second semiconductor layer, wherein the third transparent electrode is the directly contacting upper layer.

20 6. The tandem photovoltaic cell of claim 5, wherein the lower photovoltaic cell further comprises a reflecting layer between the lower substrate and the fourth electrode.

7. The tandem photovoltaic cell of claim 2, wherein the lower photovoltaic cell comprises:

a lower substrate;

25 a fourth electrode on the lower substrate; and

a second semiconductor layer on the forth electrode; and

a second metal fingers on the second semiconductor layer, wherein the second semiconductor layer is the directly contacting upper layer.

5 8. The tandem photovoltaic cell of claim 7, wherein the lower photovoltaic cell further comprises a reflecting layer between the lower substrate and the fourth electrode.

 9. The tandem photovoltaic cell of claim 1, further comprising at least an
10 intermediate photovoltaic cell between the lower photovoltaic cell and the upper photovoltaic cell.

 10. The tandem photovoltaic cell of claim 9, further comprising a second interlayer disposed between the intermediate photovoltaic cell and the upper
15 photovoltaic cell or between the intermediate photovoltaic cell and the lower photovoltaic cell, wherein the second interlayer has a second transparent portion covering the active area and a second adhesive portion covering the non-active area.

20 11. A photovoltaic cell, comprising:

a lower substrate;

a first electrode on the lower substrate;

a semiconductor layer on the first electrode;

a second transparent electrode on the semiconductor layer;

25 a transparent front cover above the second transparent electrode; and

an interlayer disposed between and directly contacting the second transparent electrode and the transparent front cover, the interlayer having a transparent portion covering an active area and an adhesive portion covering a non-active area surrounding the active area, wherein the active area is responsible for absorbing light to generate photocurrent, and wherein the transparent portion has a refractive index between the refractive indexes of the second transparent electrode and the transparent front cover.

12. A photovoltaic cell, comprising:

a lower substrate;

a first electrode on the lower substrate;

a semiconductor layer on the first electrode;

a second electrode made of metal fingers on the semiconductor layer;

a transparent front cover above the second transparent electrode; and

an interlayer disposed between and directly contacting the semiconductor layer and the transparent front cover, the interlayer having a transparent portion covering an active area and an adhesive portion covering a non-active area surrounding the active area, wherein the active area is responsible for absorbing light to generate photocurrent, and wherein the transparent portion has a refractive index between the refractive indexes of the semiconductor layer and the transparent front cover.