

PHOTOVOLTAIC DEVICE AND METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This utility application claims priority to Taiwan Application Serial Number
5 102107813, filed March 06, 2013, and Taiwan Application Serial Number
102147056, filed December 19, 2013 which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the invention

The invention relates to a photovoltaic device and method of manufacturing the same,
10 and particularly to, a photovoltaic device capable of inhibiting potential-induced
degradation (PID) effect and method of manufacturing the same.

2. Description of the prior art

Recently, more studies have shown that the reliabilities and performance of
photovoltaic devices and laminated modules can be significantly adversely affected
15 by PID (Potential Induced Degradation) effect. The manufacturers of such devices
are therefore devoted to develop photovoltaic devices and laminated modules that are
capable of inhibiting PID effect. As early as 2005, the Sunpower Corporation found
PID effect occurred in the n-type silicon based photovoltaic devices. The laminated
modules made from the n-type silicon-based photovoltaic devices are used under hot
20 and humid environment for a long time and are operating under high voltage
(potential) such that leakage current flows between glasses and laminated materials,
and a large number of charges are accumulated on the surface of the photovoltaic

devices which deteriorate the surface passivation and the front junction of the photovoltaic devices. These leakage current, charge accumulation and surface passivation and front junction deterioration result in the performance characteristics of the photovoltaic devices, e.g., fill factor (FF), short circuit current density (J_{sc}),
5 open-circuit voltage (V_{oc}), etc., to substantially decrease, and therefore, the performances of the laminated modules made from the photovoltaic devices are below accepted standard. Above decay phenomena are called PID effects.

As for silicon-based photovoltaic devices, some prior arts adjust the refractive index of SiN_x anti-reflective layer to achieve the purpose of inhibiting PID effect. However,
10 this approach will slightly sacrifice the effectiveness of the SiN_x anti-reflective layer. That is to say, the light transmission property of the SiN_x anti-reflective layer will decrease. In addition, this approach is not necessarily applicable to other types of photovoltaic devices.

Some papers have pointed out that the PID effects can generally be divided into the
15 following three modes: the effect of surficial active region of the semiconductor material; the performance degradation and diversion phenomena of semiconductor junctions; and the electrolytic corrosion and metal ions migration. In general, the PID effect mostly starts from the edge of the photovoltaic device. Therefore, how to inhibit PID effect occurred in the photovoltaic device and laminated module made
20 therefrom, especially for the PID effect starting from the side of the photovoltaic device, to prolong the useful life of the photovoltaic device is the diligence direction of the people skilled in this field.

SUMMARY OF THE INVENTION

Accordingly, one scope of the invention is to provide a photovoltaic device capable
25 of inhibiting PID effect and method of manufacturing the same.

A photovoltaic device according to a preferred embodiment of the invention includes

a semiconductor structure combination and a first protection layer. The semiconductor structure combination has a plurality of side surfaces, and includes a p-n junction, an n-p junction, a p-i-n junction, an n-i-p junction, a tandem junction, a multi-junction, or other type of junction. In particular, the first protection layer is formed to overlay the side surfaces of the semiconductor structure combination. Thereby, the first protection layer is capable of inhibiting the PID effect of the photovoltaic device of the invention.

Further, the photovoltaic device of the invention also includes a second protection layer. The second protection layer is formed to overlay the first protection layer.

A method of manufacturing a photovoltaic device in accordance with a preferred embodiment of the invention is, firstly, to prepare a semiconductor structure combination, where the semiconductor structure combination has a plurality of edge surfaces, and includes a p-n junction, an n-p junction, a p-i-n junction, an n-i-p junction, a tandem junction, a multi-junction, or other type of junction. Finally, the method of the invention is to form a first protection layer to overlay the side surfaces of the semiconductor structure combination.

Distinguishable from the prior art, the first protection layer overlaying the side surfaces of the semiconductor structure combination is capable of inhibiting the PID effect of the photovoltaic device of the invention.

The advantage and spirit of the invention may be understood by the following recitations together with the appended drawings.

BRIEF DESCRIPTION OF THE APPENDED DRAWINGS

FIG. 1A is a cross-sectional view of a photovoltaic device according to a preferred embodiment of the invention.

FIGS. 2 through 3 illustratively show, via sectional views, the procedures of a method according to a preferred embodiment of the invention to manufacture a photovoltaic device.

5 FIGS. 4 through 7 illustratively show, via sectional views, the procedures of the first example of the method of the invention to manufacture a silicon-based photovoltaic device.

FIGS. 8 through 9 illustratively show, via sectional views, the procedures of the first example of the method of the invention to manufacture a silicon-based photovoltaic device.

10 FIGS. 10 through 11 illustratively show, via sectional views, the procedures of the first example of the method of the invention to manufacture a silicon-based photovoltaic device.

FIGS. 12 through 13 illustratively show, via sectional views, the procedures of the first example of the method of the invention to manufacture a silicon-based
15 photovoltaic device.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, FIG. 1 schematically shows a photovoltaic device 1 according to a preferred embodiment of the invention via a sectional view.

20 As shown in FIG. 1, the photovoltaic device 1 of the invention includes a semiconductor structure combination 10 and the first protection layer 12. The semiconductor structure combination 10 has a plurality of side surfaces 102, and includes a p-n junction, an n-p junction, a p-i-n junction, an n-i-p junction, a tandem junction, a multi-junction, or other type of junction. That is to say, the photovoltaic device 1 of the invention can be a mono-crystalline silicon photovoltaic device, a

mono-like-crystalline silicon photovoltaic device, a multi-crystalline or polycrystalline silicon photovoltaic device, a GaAs-based photovoltaic device, an amorphous silicon thin film photovoltaic device, a microcrystalline silicon (μ -Si) thin film photovoltaic device, a CdS thin film photovoltaic device, a CdTe thin film photovoltaic device, a CuInSe₂ (CIS) thin film photovoltaic device, a Cu(In,Ga)Se₂ (CIGS) thin film photovoltaic device, a dye-sensitized thin film photovoltaic device, etc. In FIG. 1, only a junction 104 is illustrated in the semiconductor structure combination 10 as representative.

In particular, the first protection layer 12 is formed to overlay the plurality of side surfaces 102 of the semiconductor structure combination 10. Thereby, the first protection layer 12 is capable of inhibiting the PID effect of the photovoltaic device 1 of the invention.

In one embodiment, the first protection layer 12 can be formed of aluminum oxide, titanium oxide, zirconium oxide, hafnium oxide, or a mixture therebetween.

In one embodiment, first protection layer 12 has a thickness in a range of from 0.2 nm to 100 nm.

Also as shown in FIG. 1, further, the photovoltaic device 1 of the invention also includes a second protection layer 14. The second protection layer 14 is formed to overlay the first protection layer 12.

In one embodiment, the second protection layer 14 can be formed of silicon nitride, silicon oxynitride or a mixture therebetween.

Referring to FIGS. 2 through 3, these drawings illustratively show, via sectional views, the procedures of a method according to a preferred embodiment of the invention to manufacture a photovoltaic device 1 as shown in FIG. 1.

As shown in FIG. 2, firstly, the method of the invention is to prepare a semiconductor

structure combination 10, where the semiconductor structure combination 10 has a plurality of side surfaces 102, and includes a p-n junction, an n-p junction, a p-i-n junction, an n-i-p junction, a tandem junction, a multi-junction, or other type of junction. In FIG. 2, only a junction 104 is illustrated in the semiconductor structure combination 10 as representative.

Finally, as shown in FIG. 3, the method of the invention is formed a first protection layer 12 to overlay the plurality of side surfaces 102 of the semiconductor structure combination 10.

Further, the method of the invention is to form a second protection layer 14, which overlays the first protection layer 12, to complete the structure of the photovoltaic device 1 as shown in FIG. 1.

Hereinafter will describe in detail the structures and manufacturing of some examples of silicon-based photovoltaic devices embodied according to the photovoltaic device 1 and manufacture thereof of the invention.

Referring to FIGS. 4 through 7, these drawings schematically show the structure and manufacturing of the first example of the silicon-based photovoltaic device 1 embodied according to the invention via cross-sectional views.

As shown in FIG. 4, firstly, the method of the first example of the invention is to prepare a semiconductor structure combination 10, where semiconductor structure combination 10 has a plurality of side surfaces 102, a front surface 106 and a back surface 108 opposite to the front surface 106. In FIG. 4, only a junction 104 is illustrated in the semiconductor structure combination 10 as representative. The prepared semiconductor structure combination 10 includes a silicon substrate 101 of a first conductive type. The silicon substrate 101 can be a mono-crystalline silicon substrate, a mono-like-crystalline silicon substrate or a multi-crystalline or polycrystalline silicon substrate, etc. The thickness of the silicon substrate 101 can

be, but not limited to, in a range of about from 150 μm to 230 μm .

The semiconductor structure combination 10 also includes the junction 104. The available types of the junction 104 have been described in detail hereinabove, and will be not described herein.

- 5 Also as shown in FIG. 4, the method of the invention is further to treat the front surface 106 by a texturing treatment. That is to say, the front surface 106 is a textured surface. The texturing of the front surface 106 can be implemented by etching of an acid or alkali solution to form rough structures such as pyramid structures on the front surface 106. The textured front surface 106 serves as a light-incident surface, and can effectively lower the reflectivity of incident light.
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- Typical surface texturing technologies are practiced to form V-shaped grooves or pyramid structures, where the roughness of the textured surface is from micrometer scale to sub-centimeter scale. With increasing photoelectric conversion efficiency of the photovoltaic device as demanded, there has been technology developed to enhance the roughness of light-incident surface of the photovoltaic device to nanometer scale, where the morphology of the light-incident surface of the photovoltaic device exhibits distribution of nanorods which have a very high aspect ratio(depth $\sim 1\ \mu\text{m}$, width $\sim 100\ \text{nm}$). Broadband ultralow reflection ($< 5\%$) can be achieved in the case of the textured light-incident surface in nanometer scale of the photovoltaic device over a wavelength range from 300 nm to 1000 nm.
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- In the first example, the method of the invention is to implant impurity dopants into a region underneath the textured front surface 106 to a semiconductor region 103 of a second conductive type which serves as an emitter of the silicon-based photovoltaic device. In one embodiment, the impurity dopants can be boron, phosphorus, arsenic, etc. The implantation of mentioned-above impurity dopants can be performed by thermal diffusion in furnace, screen printing, spin coating, spraying, and so on followed by high temperature anneal to drive in the dopants into the semiconductor
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substrate.

In one embodiment, the silicon substrate 101 can be p-type, and the semiconductor region 103 can be n-type. In another embodiment, the silicon substrate 101 can be n-type, and the semiconductor region 103 can be p-type.

5 As shown in FIG. 5, next, the method of the first example of the invention is to form a first protection layer 12 to overlay the plurality of side surfaces 102 of the semiconductor structure combination 10. Moreover, the method of the first example of the invention is to extend the first protection layer 12 also to the edge of the front surface 106, and to extend the first protection layer 12 the edge of the back surface
10 108.

In one embodiment, the coverage distance of the first protection layer 12 extending to the edge of the front surface 106 is, but not limited to, in a range of about from 0.1 mm to 100 mm. The coverage distance of the first protection layer 12 extending to the edge of the back surface 108 is, but not limited to, in a range of about from 0.1
15 mm to 100 mm. The thickness range and composition of the first protection layer 12 have been described in detail hereinabove, and will be not described herein.

In one embodiment, the formation of the first protection layer 12 can be performed by a plasma-enhanced chemical vapor deposition (PECVD) process, an atmospheric pressure chemical vapor deposition (APCVD) process, a metalorganic chemical
20 vapor deposition (MOCVD) process, an atomic layer deposition (ALD) process, or a physical vapor deposition (PVD) process.

Also as shown in FIG. 5, to protect the first protection layer 12 from being contaminated by metal elements in post-formed electrodes, further, the method of the first example of the invention is to form a second protection layer 14 to overlay the
25 first protection layer 12. The composition of the second protection layer 14 has been described in detail hereinabove, and will be not described herein.

As shown in FIG. 6, afterward, the method of the first example of the invention is to form an anti-reflective layer 16 to overlay the front surface 106 and the first protection layer 12 on the edge of the front surface 106. In one embodiment, the formation of the anti-reflective layer 16 can be performed by a chemical vapor deposition (CVD) process, a physical vapor deposition (PVD) process, etc. In addition, the anti-reflective layer 16 not only can lower the recombination rate of carriers at the surface of the silicon-based photovoltaic device 1, but also enhance photocurrent of the silicon-based photovoltaic device 1 and achieve protection effects for silicon-based photovoltaic device 1, e.g., anti-scratch, anti-moisture, etc.

As shown in FIG. 7, next, the method of the first example of the invention is to form a front electrode 17 on the anti-reflective layer 16 on the front surface 106, where the front electrode 17 ohmically contacts the front surface 106. In one embodiment, the front electrode 17 can be formed by sintering predetermined metal paste (e.g., silver paste) which is first applied on the front surface 106 by local screen printing or coating. During sintering, glass frit in the metal paste passes through the anti-reflective layer 16 to contact the silicon of the front surface 106, and further to achieve ohmic contact between the front electrode 17 and the front surface 106. In another embodiment, the method of the first example of the invention is to form grooves on the anti-reflective layer 16 where the front surface 106 within the grooves is exposed, and then to form front electrode 17 in the grooves to overlay the exposed front surface 106.

Also as shown in FIG. 7, afterward, the method of the first example of the invention is to form at least one back bus bar 18 on the back surface 108.

Also as shown in FIG. 7, finally, the method of the first example of the invention is to form a back electrode 19 to overlay the back surface 108 other than the at least one back bus bar 18 to complete the silicon-based photovoltaic device 1 of the first example. In one embodiment, it can apply predetermined metal paste on the anti-reflective layer 16 and the back surface 108 by local screen printing or coating, and

then perform a co-firing at a temperature range of from 570°C to 840°C to complete the front electrode 17, the at least one back bus bar 18 and the back electrode 19.

The silicon-based photovoltaic device 1 will be packaged into a module. During use of the packaged module made from the silicon-based photovoltaic device 1, the first protection layer 12 overlaying the plurality of side surfaces 102 of the semiconductor structure combination 10 can protect against charges accumulated on packaged materials (typically ethylene-vinyl acetate (EVA) or glass) into the silicon substrate 101 of the first conductive type along the surface of the first protection layer 12. Thereby, the first protection layer 12 can effectively inhibit the PID effect of the photovoltaic device 1 of the invention, especially for the PID effect starting from the side surfaces 102 of the silicon-based photovoltaic device 1.

Referring to FIGS. 8 through 9, these drawings schematically show the structure and manufacturing of the second example of the silicon-based photovoltaic device 1 embodied according to the invention via cross-sectional views.

The method of the second example of the invention is substantially similar to the method of the first example, and therefore, hereinafter only describes the difference between the method of the second example and the method of the first example. As shown in FIG. 8, the method of the second example of the invention is to extend the first protection layer 12 also to the edge of the back surface 108 and to overlay the front surface 106.

Also as shown in FIG. 8, the method of the second example of the invention is to form an anti-reflective layer 16 to overlay the first protection layer 12 on the front surface 106. Also as shown in FIG. 8, the method of the second example of the invention is to form a second protection layer 14 to overlay the first protection layer 12.

As shown in FIG. 9, finally, the method of the second example of the invention is to form a front electrode 17 on the anti-reflective layer 16, where the front electrode

ohmically contacts the front surface 106. The method of the second example of the invention is also to form at least one back bus bar 18 on the back surface 108, and to form a back electrode 19 to overlay the back surface 108 other than the at least one back bus bar 18 to complete the silicon-based photovoltaic device 1 of the second example. In one embodiment, the method of the second example of the invention can achieve ohmic contact between the front electrode 17 and the front surface 106 with glass frit in the metal paste through the anti-reflective layer 16 to make the front electrode 17 contact the silicon of the front surface 106 during sintering. In another embodiment, the method of the second example of the invention is to form grooves on the anti-reflective layer 16 and the first protection layer 12 where the front surface 106 within the grooves is exposed, and then to form the front electrode 17 in the grooves to overlay the exposed front surface 106.

Referring to FIGS. 10 through 11, these drawings schematically show the structure and manufacturing of the third example of the silicon-based photovoltaic device 1 embodied according to the invention via cross-sectional views.

The method of the third example of the invention is substantially similar to the method of the first example, and therefore, hereinafter only describes the difference between the method of the third example and the method of the first example. As shown in FIG. 10, the method of the third example of the invention is extend the first protection layer 12 also to the edge of the front surface 106 and to overlay the back surface 108.

Also as shown in FIG. 10, the method of the third example of the invention is to form an anti-reflective layer 16 to overlay the front surface 106 and the first protection layer 12 on the edge of the front surface 106. Also shown in FIG. 10, the method of the third example of the invention is to form a second protection layer 14 to overlay the first protection layer 12.

Next, the method of the third example of the invention is to form at least one back

bus bar 18 on the first protection layer 12 on the back surface 108, where the at least one back bus bar 18 ohmically contacts the back surface 108. For example, as shown in FIG. 10, the method of the third example of the invention is to form at least one groove 122 on the first protection layer 12 overlaying the back surface 108, where the back surface 108 within the at least one groove is exposed. Next, as shown in FIG. 11, the method of the third example of the invention is to form the at least one back bus bar 18 in the at least one groove 122 to overlay the exposed back surface 108. Alternatively, without formation of the groove 122, the method of the third example of the invention can achieve ohmic contact between the at least one back bus bar 18 and the back surface 108 with glass frit in the metal paste through the first protection layer 12 to contact the back surface 108 during sintering.

As shown in FIG. 11, finally, the method of the third example of the invention is to form a front electrode 17 on the anti-reflective layer 16, where the front electrode 17 ohmically contacts the front surface 106. The method of the third example of the invention is also to form the at least one back bus bar 18, and a back electrode 19 to overlay the first protection layer 12 overlaying the back surface 108 other than the at least one back bus bar 18 to complete the silicon-based photovoltaic device 1 of the third example. In one embodiment, the method of the third example of the invention can achieve ohmic contact between the front electrode 17 and the front surface 106 with glass frit in the metal paste through the anti-reflective layer 16 and the first protection layer 12 to make the front electrode 17 contact the silicon of the front surface 106 during sintering. In another embodiment, the method of the third example of the invention is to form grooves on the anti-reflective layer 16 and the first protection layer 12 where the front surface 106 within the grooves is exposed, and then to form the front electrode 17 in the grooves to overlay the exposed front surface 106.

Referring FIGS. 12 through 13, these drawings schematically show the structure and manufacturing of the fourth example of the silicon-based photovoltaic device 1 embodied according to the invention via cross-sectional views.

The method of the fourth example of the invention is substantially similar to the method of the first example, and therefore, hereinafter only describes the difference between the method of the fourth example and the method of the first example. As shown in FIG. 12, the method of the fourth example of the invention is extend the first protection layer 12 also to overlay the front surface 106 and to overlay the back surface 108.

Also as shown in FIG. 12, the method of the fourth example of the invention is to form an anti-reflective layer 16 to overlay the first protection layer 12 on the front surface 106. Also as shown in FIG. 12, the method of the fourth example of the invention is to form a second protection layer 14 to overlay the first protection layer 12.

Afterward, the method of the fourth example of the invention is to form at least one back bus bar 18 on the first protection layer 12, where the at least one back bus bar 18 ohmically contacts the back surface 108. For example, as shown in FIG. 12, the method of the fourth example of the invention is to form at least one groove 122 on the first protection layer 12 overlaying the back surface 108, where the back surface 108 within the at least one grooves 122 is exposed. Next, as shown in FIG. 13, the method of the fourth example of the invention is to form the at least one back bus bar 18 in the at least one groove 122 to overlay the exposed back surface 108. Alternatively, without formation of the groove 122, the method of the fourth example of the invention can achieve ohmic contact between the at least one back bus bar 18 and the back surface 108 with glass frit in the metal paste through the first protection layer 12 to contact the back surface 108 during sintering.

As shown in FIG. 13, finally, the method of the fourth example of the invention is to form a front electrode 17 on the anti-reflective layer 16, where the front electrode 17 ohmically contacts the front surface 106. The method of the fourth example of the invention is also to form the at least one back bus bar 18, and a back electrode 19 to overlay the first protection layer 12 overlaying the back surface 108 other than the at

least one back bus bar 18 to complete the silicon-based photovoltaic device 1 of the fourth example. In one embodiment, the method of the fourth example of the invention can achieve ohmic contact between the front electrode 17 and the front surface 106 with glass frit in the metal paste through the anti-reflective layer 16 and the first protection layer 12 to make the front electrode 17 contact the silicon of the front surface 106 during sintering. In another embodiment, the method of the fourth example of the invention is to form grooves on the anti-reflective layer 16 and the first protection layer 12 where the front surface 106 within the grooves is exposed, and then to form the front electrode 17 in the grooves to overlay the exposed front surface 106.

Hereinafter will describe the PID test result of some silicon-based photovoltaic devices of type A, some silicon-based photovoltaic devices of type B and some silicon-based photovoltaic devices of type C. The silicon-based photovoltaic devices of type A are manufactured according to the method of the third example of the invention, their structures are as shown in FIG. 11. The silicon-based photovoltaic devices of type B are manufactured according to the prior art by adjusting the refractive index of SiN_x anti-reflective layer to achieve the purpose of inhibiting PID effect. The silicon-based photovoltaic devices of type C are typical silicon-based photovoltaic devices without function of inhibiting PID effect. The PID test of those silicon-based photovoltaic devices the invention is performed by the packaged modules made therefrom, and is performed for 96 hours at a temperature of 85 °C and relative humidity of 85%.

Referring to table 1, the initial photoelectric conversion efficiencies and the photoelectric conversion efficiencies, the decay ratios and the shunt resistances (R_{shunt}) after PID test of the silicon-based photovoltaic device of type A, the silicon-based photovoltaic device B and the silicon-based photovoltaic device of type C are listed in table 1. The shunt resistance of the silicon-based photovoltaic device depends on the amount of leakage current of the silicon-based photovoltaic device, i.e., more shunt resistance means less leakage current.

Table 1

	initial photoelectric conversion efficiency	photoelectric conversion efficiency after PID test	decay ratio (%)	$R_{shunt}(\Omega)$
silicon-based photovoltaic devices of type A	17.70%±0.31%	17.48%±0.29%	1.24%	491.79
silicon-based photovoltaic devices of type B	17.46%±0.19%	16.98%±0.20%	2.72%	135.67
silicon-based photovoltaic devices of type C	17.05%±0.35%	12.82%±4.61%	25.00%	8.67

Data listed in table 1 prove that the photoelectric conversion efficiencies of the silicon-based photovoltaic devices of type A and type B all are higher than those of the silicon-based photovoltaic devices of type C, and the silicon-based photovoltaic devices of type A and type B all are capable of effectively inhibiting the PID effects. The silicon-based photovoltaic devices of type C have significantly large decay ratios, and very low shunt resistances. Because the silicon-based photovoltaic devices of type B slightly sacrifice the effectiveness of the anti-reflective layer, the photoelectric conversion efficiencies of the silicon-based photovoltaic devices of type B are slightly lower than those of the silicon-based photovoltaic devices of type A. The decay ratios of the silicon-based photovoltaic devices of type B are higher than those of the silicon-based photovoltaic devices of type A. The shunt resistances of the silicon-based photovoltaic devices of type B are obviously less than those of the silicon-based photovoltaic devices of type A. Obviously, the effectiveness of inhibiting PID of the photovoltaic device of the invention is superior to that of the photovoltaic device of the prior arts. Moreover, the photovoltaic device and method

of fabricating such photovoltaic device of the invention can be broadly applied for various types of photovoltaic devices.

With the example and explanations above, the features and spirits of the invention will be hopefully well described. Those skilled in the art will readily observe that
5 numerous modifications and alterations of the device may be made while retaining the teaching of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A photovoltaic device, comprising:
 - a semiconductor structure combination, having a plurality of side surfaces, and comprising one selected from the group consisting of a p-n junction, an n-p junction, a p-i-n junction, an n-i-p junction, a tandem junction and a multi-junction; and
 - a first protection layer, formed to overlay the side surfaces of the semiconductor structure combination, wherein the first protection layer is capable of inhibiting potential-induced degradation effect of the photovoltaic device.
2. The photovoltaic device of claim 1, wherein the first protection layer is formed of one selected from the group consisting of aluminum oxide, titanium oxide, zirconium oxide, hafnium oxide and a mixture therebetween.
3. The photovoltaic device of claim 2, further comprising a second protection layer, formed to overlay the first protection layer, wherein the second protection layer is formed of one selected from the group consisting of silicon nitride, silicon oxynitride and a mixture therebetween.
4. The photovoltaic device of claim 2, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, the front surface is treated by a texturing treatment, the first protection layer also extends to a first edge of the front surface and a second edge of the back surface, said photovoltaic device further comprises:
 - an anti-reflective layer, being formed on the front surface and overlaying the first protection layer on the first edge of the front surface;
 - a front electrode, being formed on the anti-reflective layer and ohmically contacting the front surface;

at least one back bus bar, formed on the back surface; and

a back electrode, formed to overlay the back surface other than the at least one back bus bar.

- 5 5. The photovoltaic device of claim 2, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, the front surface is treated by a texturing treatment, the first protection layer also extends to an edge of the back surface and to overlay the front surface, said photovoltaic device further comprises:

10 an anti-reflective layer, formed to overlay the first protection layer on the front surface;

a front electrode, being formed on the anti-reflective layer and ohmically contacting the front surface;

at least one back bus bar, formed on the back surface; and

15 a back electrode, formed to overlay the back surface other than the at least one back bus bar.

- 20 6. The photovoltaic device of claim 2, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, the front surface is treated by a texturing treatment, the first protection layer also extends to an edge of the front surface and to overlay the back surface, said photovoltaic device further comprises:

an anti-reflective layer, being formed on the front surface and overlaying the first protection layer on the edge of the front surface;

a front electrode, being formed on the anti-reflective layer and ohmically contacting the front surface;

25 at least one back bus bar, being formed on the first protection layer on the back surface and ohmically contacting the back surface; and

a back electrode, formed to overlay the first protection layer on the back surface other than the at least one back bus bar.

7. The photovoltaic device of claim 2, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, the front surface is treated by a texturing treatment, the first protection layer also extends to overlay the front surface and to overlay the back surface, said photovoltaic device further comprises:

an anti-reflective layer, formed to overlay the first protection layer on the front surface;

a front electrode, being formed on the anti-reflective layer and ohmically contacting the front surface;

at least one back bus bar, being formed on the first protection layer on the back surface and ohmically contacting the back surface; and

a back electrode, formed to overlay the first protection layer on the back surface other than the at least one back bus bar.

8. A method of manufacturing a photovoltaic device, comprising the steps of:

preparing a semiconductor structure combination, wherein the semiconductor structure combination has a plurality of edge surfaces, and comprises one selected from the group consisting of a p-n junction, an n-p junction, a p-i-n junction, an n-i-p junction, a tandem junction and a multi-junction; and

forming a first protection layer to overlay the side surfaces of the semiconductor structure combination, wherein the first protection layer is capable of inhibiting potential-induced degradation effect of the photovoltaic device.

9. The method of claim 8, wherein the first protection layer is formed of one

selected from the group consisting of aluminum oxide, titanium oxide, zirconium oxide, hafnium oxide and a mixture therebetween.

10. The method of claim 9, further comprising the step of forming a second protection layer to overlay the first protection layer, wherein the second protection layer is formed of one selected from the group consisting of silicon nitride, silicon oxynitride and a mixture therebetween.

11. The method of claim 9, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, said method further comprises the steps of:

10 treating the front surface by a texturing treatment;

 extending the first protection layer also to a first edge of the front surface and a second edge of the back surface;

 forming an anti-reflective layer to overlay the front surface and the first protection layer on the first edge of the front surface;

15 forming a front electrode on the anti-reflective layer, wherein the front electrode ohmically contacts the front surface;

 forming at least one back bus bar on the back surface; and

 forming a back electrode to overlay the back surface other than the at least one back bus bar.

20 12. The method of claim 9, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, said method further comprises the steps of:

 treating the front surface by a texturing treatment;

 extending the first protection layer also to an edge of the back surface and to

25 overlay the front surface;

forming an anti-reflective layer to overlay the first protection layer on the front surface;

forming a front electrode on the anti-reflective layer, wherein the front electrode ohmically contacts the front surface;

5 forming at least one back bus bar on the back surface; and

forming a back electrode to overlay the back surface other than the at least one back bus bar.

13. The method of claim 9, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, said method
10 further comprises the steps of:

treating the front surface by a texturing treatment;

extending the first protection layer also to an edge of the front surface and to overlay the back surface;

15 forming an anti-reflective layer to overlay the front surface and the first protection layer on the edge of the front surface;

forming a front electrode on the anti-reflective layer, wherein the front electrode ohmically contacts the front surface;

20 forming at least one back bus bar on the first protection layer on the back surface, wherein the at least one back bus bar ohmically contacts the back surface; and

forming a back electrode to overlay the first protection layer other than the at least one back bus bar.

14. The method of claim 9, wherein the semiconductor structure combination also has a front surface and a back surface opposite to the front surface, said method
25 further comprises the steps of:

treating the front surface by a texturing treatment;

extending the first protection layer also to overlay the front surface and to overlay the back surface;

5 forming an anti-reflective layer to overlay the first protection layer on the front surface;

forming a front electrode on the anti-reflective layer, wherein the front electrode ohmically contacts the front surface;

10 forming at least one back bus bar on the first protection layer on the back surface, wherein the at least one back bus bar ohmically contacts the back surface; and

forming a back electrode to overlay the first protection layer on the back surface other than the at least one back bus bar.