alignment steps. Developments have shown that with the deposition of a nano-crystalline layer alone, the detection of such structures, necessary for the alignment of the conductive contact structures, is not at all reliable and would not be possible to be used to realize IBC cells at an industrial level.

Summary of the invention

The ~~present~~ claimed invention proposes to improve commonly known standard alignment techniques to align deposition masks and a wafer during the PECVD step of the fabrication of photovaltaic cells. Therefor, the claimed invention provides fiducial marks that avoid current alignment techniques which rely solely on the need of an absolute mask-to-wafer positioning. The claimed invention as described herein is about how to provide novel and improved fiducial marks that enable the visibility of the fiducial, in reflection and/or in transmission,~~-~~ in the PECVD step for later processing even if the fiducial mark is made of the same material as the base substrate and at the same time very thin.

~~In~~According to a first aspect ~~the invention relates to~~, there is provided a silicon structured device, that is used in a fabrication process of ~~as~~ an intermediate product to make interdigitated back contact (IBC) photovoltaic devices and modules. The silicon structured device comprises:

- a silicon-based substrate being of p-type or n-type doping and having a first face defining a horizontal X-Y plane and a vertical direction Z orthogonal to said horizontal X-Y plane;
- an intrinsic amorphous silicon layer a-Si:H(i) situated on said first face;
    - a first patterned silicon layer, situated on said intrinsic amorphous silicon layer a-Si:H(i) layer, comprising a first array of distinct and separated amorphous layer islands so that between the amorphous layer islands non-coated, intrinsic amorphous silicon (a-Si:H(i)) layer portions are provided that define an array of
        - interstices, said first patterned silicon layer having the same doping as the doping of the silicon-based substrate~~.~~,

~~A.~~ a second patterned nano-crystalline silicon layer in contact with said first patterned silicon layer, comprising a second array of second layer portions, each of said second layer portions being in contact with one of said first layer portions and forming an array of silicon structures~~.~~,

wherein

~~A~~said second array of second layer portions is of the same type of doping than said first patterned silicon layer~~.~~,

and wherein ~~A~~at least one of ~~the~~said silicon structures constitutes a fiducial mark having, in a predetermined wavelength range, a different optical reflectivity R1, defined to the side away from said substrate, than the reflectivity R0 of said intrinsic amorphous silicon (a-Si:H(i)) layer portions. ~~s~~Said fiducial mark may have also a different optical transmittivity T1 than the transmittivity T0 of said intrinsic amorphous silicon (a-Si:H(i)) layer portions, said optical transmissivity (T1).

The advantage of the use of a silicon structured device of the claimed invention, in the fabrication of photovoltaic devices and modules according to the claimed invention, is that only the dedicated additional deposition of a pure amorphous silicon layer of a certain and dedicated thickness between the intrinsic layer and the doped nano-crystalline layer guarantees a sufficient optical contrast to enable a reliable detection of the localized silicon structures. This solves a long-standing fabrication problem. In prior art photovoltaic device that rely on the deposition of a nano-crystalline layer alone, the optial detection of the structures, necessary for the alignment of the conductive contact structures, would be very difficult to achieve and would not be possible to be used in an industrial fabrication process. Indeed, the growth of a nano- micro- or protocrystalline layer cannot be controlled directly and the contrast between the structured (masked) silicon contacts and non-structured silicon contacts is totally insufficient and cannot be used in a production environment.

In an ~~embodiment~~example the absolute value of (R1-R0)/R0 is between 0.001 and 0.5, preferably between 0.005 and 0.1, more preferable between 0.09 and 0.2 for at least one wavelength, R0 and R1 being defined for wavelengths between 300nm and 1000nm.

In an ~~embodiment~~example the silicon structured device comprises at least two fiducials.

In an ~~embodiment~~example at least one of said fiducials has a different shape and/or or different dimension, in at least one cross section plane (XY, YZ, XZ), than the shape and/or the dimension of the silicon structures that provide, in the photovoltaic device of the claimed invention electric charge collecting structures.

In an ~~embodiment~~example the silicon structured device comprises at least 2 fiducial marks having a different shaped cross section in at least one plane parallel to said horizontal X-Y plane.

~~The invention is also achieved by~~ According to a second aspect, there is provided a photovoltaic device comprising the silicon structured device as described in the first aspect. The photovoltaic device comprises an additional silicon layer ~~that~~ is ~~arranged~~present on said second patterned nano-crystalline silicon layer, said additional silicon layer forming mesas covering and that covers said silicon structures and said interstices. The additional silicon layer has a doping of the other type than the first patterned silicon layer and defines mesas on the silicon structures. The mesa on said at least one fiducial has a reflectivity R3 than the reflectivity of said interstices R2 so that and wherein said at least one fiducials are optically detectable by optical means through said additional silicon layer.

In an ~~embodiment~~example of the photovoltaic device, a transparent and conductive second layer is present on said additional silicon layer, covering said mesas and said third layer interstices, so that the at least one coated fiducial has a reflectivity R5 different than the reflectivity R4 of its surroundings and so that said at least one coated fiducial is optically detectable by optical means through said additional silicon layer and said second full area layer.

~~The invention is also achieved by~~ According to a third aspect, there is provided a photovoltaic module comprising at least one photovoltaic device as described in the second aspect. The photovoltaic module comprises electrical conducting elements, preferably electrical conducting layers or wires.

~~The invention is also achieved by~~ According to a fourth aspect, there is provided a method for manufacturing of a silicon structured device as described in the first aspect, comprising the steps (a-c) of:

a. providing a silicon-based substrate having an n-type or a p-type doping and comprising an intrinsic amorphous a-Si:H(i) layer situated on a first face of said silicon-based substrate;

b. realizing, on predetermined areas of said intrinsic layer, a first deposition of an n-type or p-type amorphous silicon layer, so as to create a patterned

amorphous silicon layer comprising a plurality of distinct and separated amorphous layer islands separated by interstices;

c. realizing on each of said amorphous layer islands a second deposition of a nano-crystalline layer having the same doping type as said amorphous layer, so as to create on top of each of said amorphous layer islands, nano-crystalline layer portions, to form an array of photovoltaic structures, while choosing the thickness (t) of said first amorphous layer portions so that at least one fiducial is formed that has a different optical reflectivity (R1), defined to the side away from said substrate, than the reflectivity (R0) of the said intrinsic amorphous silicon (a-Si:H(i)) layer portions.

~~The invention is also achieved by~~ According to a fifth aspect, there is provided a method ~~to realize a photovoltaic device. In an embodiment of the method to~~ of realize~~e~~ing a photovoltaic device comprising the steps of: providing a silicon structured device fabricated according to the steps defined in the fourth aspect, performing after step **c**, **a step d** ~~is performed~~ consisting in depositing, on top of the silicon structures, and said intrinsic amorphous silicon (a-Si:H(i)) layer portions, a full area semiconductor layer, having a doping type different than the doping type of said second nano-crystalline layer so that said at least one fiducial may be detected by optical means through said full area semiconductor layer. After having executed step a photovoltaic device is formed that allows to separate the electric charges generated by the absorbed photons.

In an ~~embodiment~~example, after said **step d**, a **step e** is realized consisting in depositing a second layer on top of said semiconductor layer and so that said at least one fiducial may be detected by optical means through said full area semiconductor layer and second full area layer.

In an ~~embodiment~~example the thickness t2 of said second layer is chosen so that, by constructive interference, reflected light off said at least one fiducial is transmitted through said second layer, in at least one wavelength range defined in the UV, visible or infrared optical spectrum.

In an ~~embodiment~~example the realization of said at least one fiducial is made by using a mask comprising at least one conical shape aperture, said conical shape being

defined in at least one plane orthogonal to said horizontal X-Y plane and so that at least one fiducial has a greater height (h) than said electric charge collection structures.

In an ~~embodiment~~example the deposition of said amorphous layer islands and the deposition of the nanocrystalline layer islands are made through the same mechanical mask.

~~The invention is also achieved by~~ According to a sixth aspect, there is provided a use of a silicon structured device, as described in the first aspect, to realize a photovoltaic device.

~~The invention is also achieved by the~~ According to a seventh aspect, there is provided use of at least one photovoltaic device, as described in the second aspect, to realize a photovoltaic module.

Brief description of the drawings

The present invention will now be described in reference to the enclosed drawings where:

Fig. 1 is a schematic cross-section view of a portion of a silicon structured device of the invention comprising fiducials each made of a portion of a-Si:H(n) layer and a portion of a nc-si:H(n) layer. The figure also illustrates an array of silicon structures that are the base of electric charge collecting structures of the photovoltaic devices and modules according to the invention;

Fig. 2 is a schematic cross-section view of a fabrication step of a portion of a photovoltaic device, illustrating a mechanical shadow mask for realizing an optical detectable fiducial realized by the superposition, through the mask, of a portion of a a-Si:H(n) layer and a portion of a nc-si:H(n) layer;

Fig. 3 is a schematic cross-section view of an embodiment of a fabrication step of a portion of a photovoltaic device, illustrating a mechanical shadow mask for realizing an optical detectable fiducial realized by the superposition, through the mask, of a portion of a a-Si:H(n) layer and a portion of a nc-si:H(n) layer, the mask layer comprising two conical shaped apertures;

Claims

1. A silicon structured device ~~(1)~~, designed to be used in a fabrication process of an interdigitated back contact (IBC) photovoltaic device, comprising:

- a silicon-based substrate ~~(3)~~ being of p-type or n-type doping and having a first face ~~(3a)~~ defining a horizontal X-Y plane and a vertical direction Z orthogonal to said horizontal X-Y plane;
- an intrinsic amorphous silicon layer a-Si:H(i) ~~(5)~~ situated on said first face ~~(3a)~~;
- a first patterned silicon layer ~~(2)~~, situated on said intrinsic amorphous silicon layer a-Si:H(i) layer ~~(5)~~, comprising a first array of distinct and separated amorphous layer islands ~~(2a-2g)~~ so that between the amorphous layer islands ~~(2a-2g)~~ non-coated intrinsic amorphous silicon (a-Si:H(i)) layer portions ~~(5a-5f)~~ are provided that define an array ~~(2')~~ of interstices ~~(2a'-2g')~~, said first patterned silicon layer ~~(2)~~ having the same doping as the doping of the silicon-based substrate ~~(3)~~,
- a second patterned nano-crystalline silicon layer ~~(4)~~ in contact with said first patterned silicon layer ~~(2)~~, comprising a second array of second layer portions ~~(4a-4g)~~, each of said second layer portions ~~(4a-4g)~~ being in contact with one of said first layer portions ~~(2a-2g)~~ and forming an array ~~(40)~~ of silicon structures ~~(12a-12g)~~,

wherein

said second array of second layer portions ~~(4a-4g)~~ is of the same type of doping than said first patterned silicon layer ~~(2)~~,

and wherein at least one of said silicon structures ~~(12a, 12g)~~ constitutes a fiducial mark ~~(10)~~ having, in a predetermined wavelength range, a different optical reflectivity (R1), defined to the side away from said substrate ~~(3)~~, than the reflectivity (R0) of said intrinsic amorphous silicon (a-Si:H(i)) layer portions ~~(5a-5f)~~.

2. The silicon structured device ~~(1)~~ according to claim 1, wherein the absolute value of (R1-R0)/R0 is between 0.001 and 0.5, preferably between 0.005 and 0.1, more preferable between 0.09 and 0.2 for at least one wavelength, said optical reflectivities R0, R1 being defined for wavelengths between 300nm and 1000nm.

3. The silicon structured device ~~(1)~~ according to claim 1 or claim 2, comprising at least two fiducials ~~(10, 10')~~.

4. The silicon structured device ~~(1)~~ according to any one of claims 1 to 3 wherein at least one of said fiducials ~~(10,10')~~ has a different shape and/or or different dimension, in at least one cross section plane (XY, YZ, XZ), than the shape and/or the dimension of said silicon structures ~~(12b-12f)~~.

5. The silicon structured device ~~(1)~~ according to claim 3 or claim 4, comprising at least 2 fiducial marks ~~(10, 10')~~ having a different shaped cross section in at least one plane parallel to said horizontal X-Y plane.

6. A photovoltaic device comprising a silicon structured device ~~(1)~~ according to any one of claims 1-5, wherein an additional silicon layer ~~(50)~~ is present on said second patterned nano-crystalline silicon layer ~~(4)~~, said additional silicon layer ~~(50)~~ forming mesas ~~(50a-50e)~~ covering said silicon structures ~~(12a-12f)~~ and said interstices ~~(5a-5f)~~, said additional silicon layer ~~(50)~~ having a doping of the other type than said first patterned silicon layer ~~(2)~~, the mesa ~~(50a)~~ on said at least one fiducial ~~(10)~~ having a different reflectivity R3 than the reflectivity R2 of said interstices ~~(5a-f)~~ so that said at least one fiducial ~~(10)~~ is optically detectable by optical means through said additional silicon layer ~~(50)~~.

7. The photovoltaic device according to claim 6 wherein a transparent and conductive second layer ~~(60)~~ is present on said additional silicon layer ~~(50)~~, second layer ~~(60)~~ covering said mesas ~~(50a- 50g)~~ and said third layer interstices ~~(50b-50f)~~ so that the at least one coated fiducial ~~(50a, 50g)~~ has a reflectivity R5 different than the reflectivity R4 of its surroundings and so that said at least one coated fiducial ~~(10)~~ is optically detectable by optical means through said additional silicon layer ~~(50)~~ and said second layer ~~(60)~~.

8. A photovoltaic module comprising at least one photovoltaic device according to claim 6 or 7.

9. Method for manufacturing of a silicon structured device ~~(1)~~ according to any one of claims 1 to 5, comprising the steps **(a-c)** of:

a. providing a silicon-based substrate ~~(3)~~ having an n-type or a p-type doping and comprising an intrinsic amorphous a-Si:H(i) layer ~~(5)~~ situated on a first face ~~(3a)~~ of said silicon-based substrate ~~(3)~~;

b. realizing, on said intrinsic layer ~~(5)~~, a first deposition of an n-type or p-type amorphous silicon layer ~~(2)~~, so as to create a patterned amorphous silicon layer ~~(2)~~ comprising a plurality of distinct and separated amorphous layer islands ~~(2a-2g)~~ separated by interstices ~~(2a'-2'g)~~;

c. realizing on each of said amorphous layer islands ~~(2a-2g)~~ a second deposition of a nano-crystalline layer ~~(4)~~ having the same doping type as said amorphous layer ~~(2)~~, so as to create on top of each of said amorphous layer islands ~~(2a-2g)~~, nano-crystalline layer portions ~~(4a-4g)~~, to form an array of silicon structures ~~(12a-12f)~~, while choosing the thickness ~~(t)~~ of said first amorphous layer portions ~~(2a-2g)~~ so that at least one fiducial ~~(10)~~ is formed that has a different optical reflectivity (R1), defined to the side away from said substrate ~~(3)~~, than the reflectivity (R0) of the said intrinsic amorphous silicon (a-Si:H(i)) layer portions ~~(5a-5f)~~.

10. Method according to claim 9 wherein the deposition of said amorphous layer islands ~~(2a-2g)~~ and the deposition of the nanocrystalline layer islands ~~(4a-4g)~~ are made through the same mechanical mask.

11. Method of realizing a photovoltaic device comprising the steps of:

- providing a silicon structured device 1 fabricated according to the steps of claims 9 or 10;

- performing after **step c**, **a step d** consisting in depositing, on top of the silicon structures ~~(12a-12f)~~, and said intrinsic amorphous silicon (a-Si:H(i)) layer portions ~~(5a-5f)~~, a full area semiconductor layer ~~(50)~~, having a doping type different than the doping type of said second nano-crystalline layer ~~(4)~~ so that said at least one fiducial ~~(10, 10')~~ may be detected by optical means through said full area semiconductor layer ~~(50)~~.

12. Method according to claim 11, wherein after said **step d**, a **step e** is realized consisting in depositing a second layer ~~(60)~~ on top of said semiconductor layer ~~(50)~~ and so that said at least one fiducial ~~(10, 10')~~ may be detected by optical means through said full area semiconductor layer ~~(50)~~ and second layer ~~(60)~~.

13. Method according to claim 12, wherein the thickness ~~(t2)~~ of said second layer ~~(60)~~ is chosen so that, by constructive interference, reflected light off said at least one fiducial ~~(10, 10')~~ is transmitted through said second layer ~~(60)~~, in at least one wavelength range defined in the UV, visible or infrared optical spectrum.

14. Method according to any one of claims 9 to 13, wherein the realization of said at least one fiducial ~~(10, 10')~~ is made by using a mask ~~(100')~~ comprising at least one conical shape aperture, said conical shape being defined in at least one plane orthogonal to said horizontal X-Y plane and so that at least one fiducial ~~(10, 10')~~ has a greater height ~~(h)~~ than said electric charge collection structures ~~(12b-12f)~~.

15. Use of a silicon structured device ~~(1)~~ according to any one of claims 1 to 5 to realize a photovoltaic device.

16. Use of at least one photovoltaic device according to claim 6 or 7 to realize a photovoltaic module.