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(54) Title: PHOTOVOLTAIC MODULE

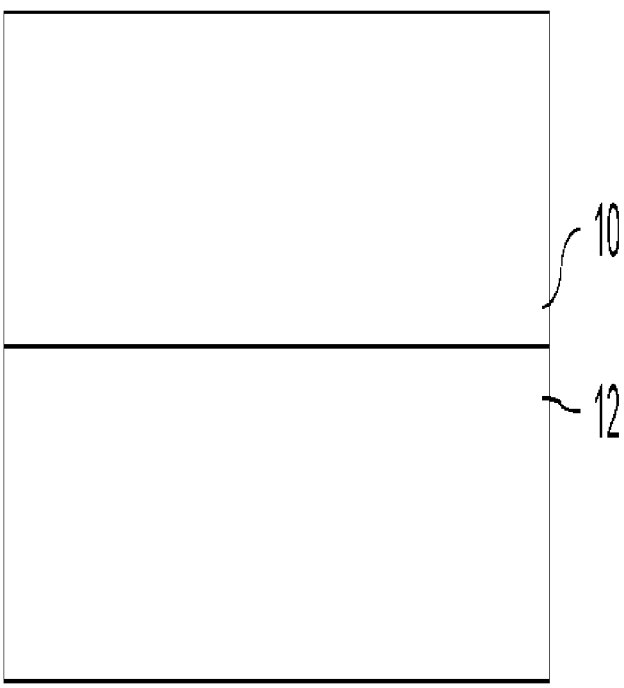

Fig. 1

(57) Abstract: The invention relates to a photovoltaic module, comprising a transparent substrate (12) as a front cover element, a photosensitive semiconductor layer (16), a lamination layer (10) and a back layer (14) as a back cover element, wherein the lamination layer (10) comprises reflective properties. Further, the invention relates to a method for manufacturing such a photovoltaic module.

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Description

Photovoltaic module

Technical Field

[0001] The invention relates to a photovoltaic module and a method for manufacturing such a photovoltaic module.

Background Art

[0002] Photovoltaic energy is reaching industrial maturity and in order to accelerate this process and allow photovoltaic energy investments amortize earlier, any kind of cost reduction in module production is important. In another aspect, durability and long-term stability against environmental influences of photovoltaic modules, also called photovoltaic panels, is a central factor. The invention described hereinafter addresses both aspects with a special view on silicon based thin film photovoltaic modules, but may also be applied for any other type of photovoltaic application needing a durable seal against atmospheric and all other agents affecting the photovoltaic module’s life cycle or performance.

[0003] Photovoltaic devices, photoelectric conversion devices or solar cells are devices which convert light, especially sunlight into direct current (DC) electrical power. For low-cost mass production thin film solar cells are being of interest since they allow using glass, glass ceramics or other rigid or flexible substrates as a base material or a base substrate instead of crystalline or polycrystalline silicon. The solar cell structure, i.e. the layer sequence responsible for or capable of the photovoltaic effect is being deposited in thin layers. This deposition may take place under atmospheric or vacuum conditions. Deposition techniques are widely known in the art, such as PVD, CVD, PECVD, APCVD, Hot Wire deposition, all being used and known in semiconductor technology.

[0004] A silicon based thin-film solar cell generally includes a first electrode, one or more semiconductor thin-film p-i-n or n-i-p based junctions, and a second electrode, which are successively stacked on a substrate. Each p-i-n junction or thin-film photoelectric conversion unit includes an i-type layer sandwiched between a p-type layer and an n-type layer (p-type =

positively doped, n-type = negatively doped). The i-type layer, which is a substantially intrinsic semiconductor layer, occupies the most part of the thickness of the thin-film p-i-n junction. Photoelectric conversion occurs primarily in this i-type layer.

[0005] Thin film cells have been fabricated from microcrystalline, amorphous, compound or semiconductor material, as for instance Si, other than single crystal semiconductor material or other technologies as for instance CIG/CIGS and Cd-Te. All of them can be deposited in situ upon a substrate by chemical vapour deposition, sputtering or other suitable deposition techniques. In use, these cells are assembled in a photovoltaic module which must withstand the rigors of the environment and handling in commerce.

[0006] A photovoltaic module usually comprises a front cover element also called front side, a photosensitive semiconductor layer also called photovoltaic cell, an adhesive layer, a metallic back reflector and a back cover element also called back side. In US 5,008,062 a photovoltaic module is described. The module comprises front and back sides and edges forming a perimeter and at least one photovoltaic cell capable of converting radiation incident on the front of the module to electrical energy, the module being partially encapsulated in a unitary, reaction-injected molded elastomer which forms a seal against a portion of the front side of the panel bordering the perimeter, and continues around the perimeter and seals against at least a portion of the back side. The back reflector is one of those layers that enhance relative efficiency by 10 % or more and in US 5,008,062 it is a layer on its own. Nowadays the back reflector is gaining more and more importance. Current metallization back reflector solutions offer good reflection properties but the cost and the time consuming separate processes and equipment required for the scope, do not allow for much cost reduction in this area.

Disclosure of Invention

[0007] It is an object of the invention to provide a photovoltaic module and a method for manufacturing such a photovoltaic module being able of reducing the processing steps and a reduction of manufacturing costs.

[0008] The solution of the object is achieved by the features of the independent claims. Preferred embodiments are given by the dependent claims.

[0009] The photovoltaic module according to the invention comprises a transparent substrate as a front cover element, a photosensitive semiconductor layer, a lamination layer and a back layer as a back cover element, wherein the lamination layer comprises reflective properties.

[0010] The term photovoltaic module refers to a combination of a sheet of transparent material or other lamina forming the front cover element, for example a front glass, an array or group of photovoltaic cells formed as one or more photosensitive semiconductor layers interconnected to provide an output of electrical energy, and a back layer, for example a back glass, comprising different sub layers. The whole structure forms a device capable of transforming incident radiation to electrical current. Such modules traditionally comprise a transparent substrate usually known in the art as front glass, and an active layer which comprises layers of transparent conductors, photovoltaic active material, cell-connecting circuits, metals or reflecting coating which together form an operative photovoltaic module. Thus, on the back photovoltaic modules have traditionally included a sheet of glass or laminated plastic materials like combinations of Tedlar, PET, aluminum film, PVDF, or other rigid material to protect the photovoltaic cell, with the various lamina being bonded together by a dielectric layer for instance plasticized polyvinyl butyryl (PVB) or ethylene vinylacetate (EVA). In case latter dielectric layer is transparent, the opposite order, with the lamina material facing the sun, covered by a front glass or not, is possible. Further it is an option to arrange all other not transparent layers underneath the photovoltaic active layer on a back glass or any other suitable substrate. The order of deposition of such layers is not limited to latter example. Instead of a back reflector being arranged between the lamination layer and the back layer, the lamination layer itself comprises reflective properties so that, according to the inventive solution, a back reflector is not needed any more. Thus, material costs can be reduced and the time of manufacturing such a photovoltaic module can be reduced essentially. The lamination layer is made of a polymer material with a high UV stability, low permeability characteristics, especially regarding moisture, electrical isolation, adhesion and chemical stability. Especially the high UV stability of the lamination layer improves the life cycle of photovoltaic modules essentially. Thus, the lamination layer has bonding and reflective characteristics. The lamination layer is preferably a lamination foil which can be easily laminated on the back layer or the front layer comprising the photosensitive semiconductor layer.

[0011] It is preferred according to an embodiment of the invention, that the color of the lamination layer is white. Thus, the lamination layer may have the best possible reflectivity properties with a reflectivity of 1 preferably without any absorption or transmission characteristics. The relative increase of efficiency for an amorphous photovoltaic module with such a lamination layer may be up to 15 %, for amorph/microcrystalline (micromorph) modules up to 45%. The white color may comprise reflective pigments for example metals like Al, Zn, Cr, Ag, Ti or metal oxides like SiO_2, TiO_2, $BaSO_4$ and/or ZrO_2.

[0012] To improve the UV absorption characteristics of the lamination layer when the color of the lamination layer is white, the back layer preferably provides high absorption characteristics. Black or other very dark colored paint can be applied on the back side or back layer and preferably on the transparent substrate, for example a front glass, at the perimeter edges where no photovoltaic cell or photosensitive semiconductor layer is present. Alternatively, it is possible to use a black or very dark colored back layer or glass and deposing a butyle paste around the perimeter of the module sticking over a black polymeric laminate in order to improve at the same time the weathering properties of the photovoltaic module using the excellent sealing characteristics of those materials.

[0013] However, if a metallic back reflector is desired or required instead of a white reflector, using differently coloured laminating materials can provide advantages regarding the basic raw materials and improved UV absorption since some colours other than white usually have better behaviour regarding such type of rays.

[0014] The lamination layer is preferably a polyolefin based polymer. A polyolefin is a semi-crystalline thermoplastic polymer produced from a simple olefin also called an alkene with the general formula C_nH_{2n} as a monomer. For example, polyethylene is the polyolefin produced by polymerizing the olefin ethylene. For example polyethylene (PE), polypropylene (PP), polybutylene terephthalate (PBT), polyethylene terephthalate (PET) and polyamid (PA) may be used for the polyolefin based polymer. The permeability to water vapour of such a polyolefin based polymer of the lamination layer is preferably less than 5 g/m² per day, most preferred less than 2 g/m² per day. The adhesion strength to glass is preferably above 30 N over 15 mm in width. Further, the Pummel test value (Pummel adhesion level) is preferably > 6. The Pummel test is used to determine the adhesion or bonding between the lamination layer and the front cover element or the back cover element. A specimen is cooled if necessary and pummeled with a hammer on the laminated side. Further the resistivity of the polymer is preferably > 10^{12} Ω, most preferred > 10^{14} Ω. The damp heat resistance for the lamination layer or foil is preferably > 80 %, most preferred > 90 %, under “85 °C 85 % RH x 1000 h” standardized test conditions. The heat recycle test resistance of the lamination layer is preferably > 80 %, most preferred > 90 %, after 200 cycles from -40 °C to 85 °C. In order to address environmental concerns, the lamination layer is preferably recyclable or nontoxically disposable after the economic life-span of the photovoltaic module, e. g. 20 years, at the end-costumer’s site. Further, the lamination layer provides an environmental friendly production. However, polyolefin based polymers have to be treated on the module at temperatures above 150 °C and could therefore compromise the photosensitive semiconductor layer. Therefore a diligent control of the temperature gradient is required, especially in quick and high volume production oriented equipment.

[0015] According to a further preferred embodiment of the invention, the lamination layer at least partially encapsulates the photovoltaic module. Usually, after the initial assembly of the elements and layers which comprise the photovoltaic module, the edges of the module have traditionally been smoothed to provide a flush edge surface. After lamination and/or sealing of the edges, the module can be enclosed in a peripheral frame of aluminium, steel, polymer or other rigid frame material. This method of sealing and framing the periphery of the module has been necessary to isolate the solar cell from the environment, and to provide a frame for the mechanical strengthening of the module and to provide a border to permit ease of handling and the attachment of connector boxes and the like for attachment to an external electrical circuit. For example, a solar module with a hardened foil back layer sandwiched between polyvinyl fluoride resin sheets, and framed in rigid peripheral framing is shown in U.S. Pat. No. 4,401,839. While existing methods for the production and framing of photovoltaic modules have provided significant improvements in solar cell technology over the years, it has been a goal to simplify the lamination and manufacture of such modules and provide for a stronger module and a more resistant seal to protect the edges or back cover element of photovoltaic modules. For example, the lamination steps have previously required a considerable expenditure of labor and processing steps. To simplify the lamination and manufacture of such modules and provide for a stronger module and a more resistant seal to protect the edges or back cover element of photovoltaic modules, according to the invention, the lamination layer itself at least partially encapsulate the photovoltaic module, since the lamination layer provides very good bonding and sealing characteristics. Thus, the lamination layer preferably is not only arranged between the front cover element and the back cover element but also at least partially surrounds the front cover element and the back cover element. If the lamination layer is additionally white colored the step of providing a back reflector and the manufacturing step of encapsulating and lamination can be simplified into a single one. If the lamination layer is a polyolefin based polymer the lamination layer as an encapsulating layer provides good characteristics against permeability, particularly regarding moisture, as well as aging and delamination.

[0016] It is further preferred that the back layer is a float glass. Float glass is a sheet of glass made by floating molten glass on a bed of molten tin. This method gives the sheet uniform thickness and very flat surfaces. The float glass providing industry usually works with a glass width starting at 3200 mm and ending at 3600 mm depending on market and technological factory requirements. Since the width of the most used glasses in the thin film market is usually around 1100 mm, a back glass ranging between said at least 3200 mm up to the preferred 3600 mm can exactly encapsulate 3 photovoltaic actively coated front glasses, thus reducing waste of glass producers to a minimum very close to zero.

[0017] Moreover, it is preferred to provide means for establishing external electrical connection to the photosensitive semiconductor layer, preferably including an internal portion electrically connected to the photosensitive semiconductor layer and an external portion extending from the photovoltaic module. The lamination layer preferably encapsulates at least the internal portion of such connecting means.

[0018] The lamination layer may further comprise a stiffening structure. The stiffening structure may be for example a metal, fibrous or polymeric sheets or girders, which may be included within the lamination layer or the polymer of the lamination layer. Thus, a composite solution is provided adding rigidity to the photovoltaic module.

[0019] In another aspect, the present invention is directed to a method for manufacturing a photovoltaic module comprising the steps of a) providing a transparent substrate as a front cover element, b) putting a photosensitive semiconductor layer on the transparent substrate, and c) providing a back layer as a back cover element, d) wherein a lamination layer comprising reflective properties is laminated between the transparent substrate with the photosensitive semiconductor layer on it and the back layer.

[0020] As has been described above, advantageously adding a back reflector being arranged between the lamination layer and the back layer of the photovoltaic module is not needed any more, since the lamination layer itself provides reflective properties. Thus, material costs can be reduced and the time of manufacturing such a photovoltaic module can be reduced essentially.

[0021] The preferred embodiments and advantages of the method according to the invention correspond to those described for the photovoltaic module of the invention above.

[0022] The inventive method preferably comprises a further step e), where the sandwich structure of the front cover element, the semiconductor layer, the lamination layer and the back cover element is evacuated. The front cover element and the back cover element is preferably a glass material. To avoid bubbles or crinkles the air filling the space between the front cover element and the back cover element may be removed by the evacuation process. To achieve this, the sandwich may be introduced in a sealable and evacuable enclosure which is operatively connected to vacuum pumps. The duration of the evacuation is preferably < 30 min, most preferred < 15 min.

[0023] After the evacuation of the photovoltaic module preferably a further processing step f) is provided, wherein the photovoltaic module, especially the sandwich structure, is pressed by a pressing process. The pressing of the photovoltaic module enables an optimized bonding between the lamination layer and the front cover element and the back cover element. Preferably, step f) comprises a pressing time between 100 s and 400 s, most preferred between 200 s and 300 s. Moreover, in step f) a pressure between 200 mbar and 15 bar, preferably between 2 bar and 7 bar, most preferred between 4,5 bar and 5,5 bar is preferably used.

[0024] According to a further preferred embodiment of the invention, in step d), step e) and/or step f) a process temperature between 50 °C and 200 °C, preferably between 140 °C and 160 °C is used. To avoid a damage of the photosensitive semiconductor a layer, it is advantageously to provide a process temperature as low as possible during the whole lamination process, evacuation process and/or pressing process.

[0025] After the pressing of the photovoltaic module in step f) the photovoltaic module is preferably cooled in a further step g). The cooling is advantageously in order to avoid unwanted stresses particularly in the front cover element and the back cover element. Moreover, the photosensitive semiconductor layer may be protected for damages by this cooling step. The cooling may be performed for example by a cooling gas or air ventilation.

[0026] Further, it is possible to include a stiffening structure into the lamination layer. The stiffening structure may be for example a metal, metal particles, fibrous or polymeric sheets or girders, which may be included within the lamination layer or the polymer of the lamination layer. Thus, a composite solution is provided adding rigidity to the photovoltaic module.

Brief Description of Drawings

[0027] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment described hereinafter.

[0028] In the drawings:

[0029] Fig. 1 shows a section schematic view of a photovoltaic module according to an embodiment of the invention;

[0030] Fig. 2 shows a top view of three photovoltaic modules according to an embodiment of the invention laminated at one back glass.

[0031] In order to produce a thin film photovoltaic module with a glass-glass laminate structure as shown in Fig. 1 a foil with properties as described above is to be used as a lamination layer 10 between a front cover element 12, provided as a front glass, and a back cover element 14, provided as a back glass. In order to achieve this, the method according to the invention requires putting the foil 10 between the front glass 12 with a photosensitive semiconductor layer 16 on it on the front glass 12 or on the back glass 14.

[0032] To avoid bubbles or crinkles the air filling the space between the two sheets of glass 12, 14 has to be essentially removed. To achieve this, the glass-foil-glass arrangement is advantageously introduced in a sealable and evacuable enclosure which is operatively connected to vacuum pumps. An evacuation time of less than 30 min, e. g. 15 min is sufficient to reach an adequate pressure level before the next step in the lamination process, the pressing, can be started.

[0033] The process temperature for laminating this material with glass shall not exceed 200°C, preferably 160°, in order not to damage the active cell structure. Therefore, in a preferred embodiment the temperature has to be held between 50°C and 180°C, further preferred between 140°C and 160°C during the whole pressing process - depending on the kind of material used. Lowering of the temperature is generally and particularly beneficial to avoid damages of the photovoltaic active cell 16 that is deposited on the front glass 12 and in direct contact with the heated lamination layer 10.

[0034] The pressing time is chosen to be less than 400 s, for instance 200 s to 300 s at a pressure between 200 mbar and 15 bar depending on the lamination equipment. A so called laminator allows to combine several of the process features described: Evacuation, heating and pressing. Advantageously such a laminator allows the treatment of several such glass-foil-glass arrangements at once, e. g. in a stack. The following parameters are beneficial in such a laminator:

[0035] Example for a glass-glass-laminate:
Module/stack size 1300mm x 1100 mm x 7 mm
Lamination foil thickness 600 µm to 1000 µm, preferably 800 µm

[0036] Pressure (setup) 2 bar to 7 bar, preferably 4.5 bar to 5.5 bar
Start temperature 140 °C -160 °C
Evacuation time 3 min - 5 min
Pressing time 3 min - 5 min

[0037] This example shall not be understood to be limiting regarding the use of a stack laminator. Autoclave equipment, membrane laminator, calander laminator or any other equipment suitable for lamination known by a person skilled in the art can be used as well with comparable parameter ranges within the scope of the invention described.

[0038] At the end of the pressing step a ventilation step (pressure adaption to atmospheric level) of at least 10 seconds has to be established in order to avoid damages to the laminated photovoltaic module due to stresses implied by the raise of pressure. Finally a cooling step is advantageously foreseen in order to avoid unwanted stresses particularly in the glasses 12, 14. Known cooling techniques can be successfully applied such as cooling gas, air ventilation and so on.

[0039] In order to provide a good reflective property the foil 10 used is white or whitish. Such a high-reflectivity foil 10, together with a semitransparent back electrode does not need a separately deposited metallic layer in order to reflect not absorbed light back into the active cell for enhancing the photovoltaic semiconductor layer 16 performance. This reflection allows a relative increase of the efficiency up to 15% for a-Si modules end up to 45% for micromorph modules.

[0040] Using lamination equipment or a suitable autoclave like for float glass applications allows glass widths of more than 3300 mm. As shown in Fig. 2, this way up to three or more photovoltaic modules 18, 20, 22 of standard size, for example with a width of about 1100 mm for each photovoltaic module 18, 20, 22, may be laminated at once on one common back glass 14. This way and with reference to the previously introduced module dimension of 1300 mm x 1100 mm, waste of glass can be completely avoided. According to the invention a single back glass 14 of 3310 mm width can be used without the need to cut the float glass and discard unusable edge strips. In this case a float glass factory product of 3300 mm standard width needs to be cut only in one dimension resulting in drastic glass waste reduction. Taking into account the energy necessary to produce glass, any waste of glass has to be avoided.

[0041] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive, the invention is not limited to the disclosed embodiments.

[0042] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an” does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. Photovoltaic module, comprising
   a transparent substrate (12) as a front cover element,
   a photosensitive semiconductor layer (16),
   a lamination layer (10) and
   a back layer (14) as a back cover element,
   wherein the lamination layer (10) comprises reflective properties.
2. Photovoltaic module according to claim 1, wherein the color of the lamination layer (10) is white.
3. Photovoltaic module according to claim 1, wherein the lamination layer (10) is a polyolefin based polymer.
4. Photovoltaic module according to claim 1, wherein the lamination layer (10) at least partially encapsulates the photovoltaic module.
5. Photovoltaic module according to claim 1, wherein the back layer (14) is a float glass.
6. Photovoltaic module according to claim 1, wherein means for establishing external electrical connection to the photosensitive semiconductor layer (16) is provided.
7. Photovoltaic module according to claim 1, wherein the lamination layer (10) comprises a stiffening structure.
8. A method for manufacturing a photovoltaic module comprising the following steps:
   a) providing a transparent substrate (12) as a front cover element,
   b) putting a photosensitive semiconductor layer (16) on the transparent substrate, and
   c) providing a back layer (14) as a back cover element,
   d) wherein a lamination layer (10) comprising reflective properties is laminated between the transparent substrate (12) with the photosensitive semiconductor layer (16) on it and the back layer (14).
9. Method for manufacturing a photovoltaic module according to claim 8, wherein in a step e) an evacuation process is provided.
10. Method for manufacturing a photovoltaic module according to claim 8, wherein in a step f) a pressing process is provided.

11. Method for manufacturing a photovoltaic module according to claim 10, wherein step f) comprises a pressing time between 100 s and 400 s, preferably between 200 and 300 s.
12. Method for manufacturing a photovoltaic module according to claim 10, wherein in step f) a pressure between 200 mbar and 15 bar, preferably between 2 bar and 7 bar, most preferred between 4,5 bar and 5,5 bar is used.
13. Method for manufacturing a photovoltaic module according to claim 8, wherein in step d), step e) and/or step f) a process temperature between 50 °C and 200 °C, preferably between 140 °C and 160 °C is used.
14. Method for manufacturing a photovoltaic module according to claim 8, wherein in a step g) the photovoltaic module is cooled.
15. Method for manufacturing a photovoltaic module according to claim 8, wherein a stiffening structure is included into the lamination layer (10).

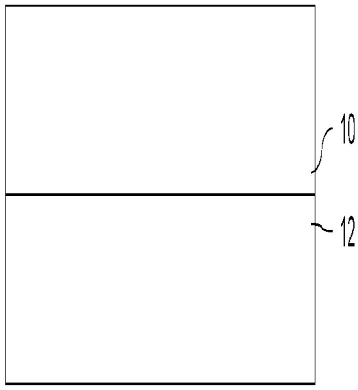

Fig. 1

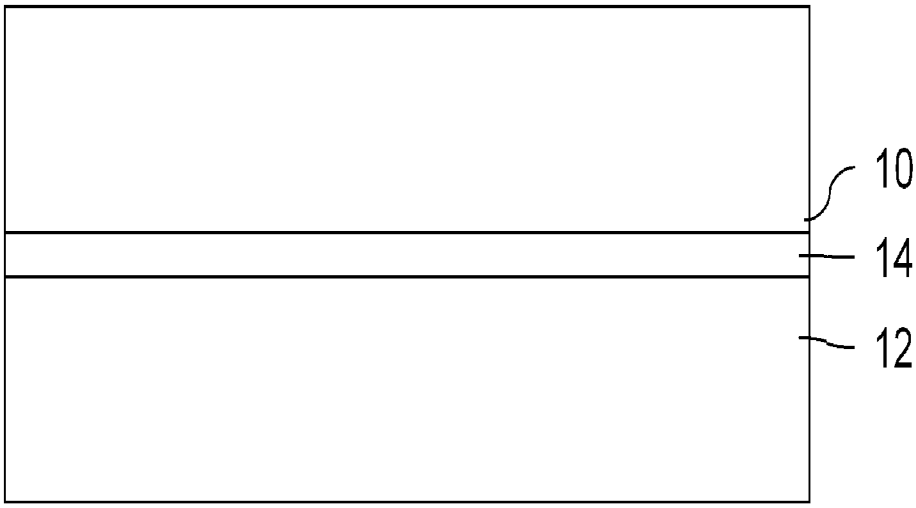

Fig. 2