ELECTRODE ASSEMBLY FOR A SOLAR MODULE

FIELD OF THE DISCLOSURE

The present disclosure relates to electrode assemblies for solar cells and solar modules, and to solar cells and solar modules including such electrode assemblies.

BACKGROUND

A typical solar module for providing electrical energy from sunlight comprises an array of solar cells, each comprising a photovoltaic element, or substrate. The solar cells are typically connected so that electrical current is routed via a plurality of finger electrodes on front and rear surfaces of each cell to a series of wider, perpendicular busbar electrodes which are printed on the front and rear sides of the cell. From the busbar electrodes, the electrical current flows to a junction box along a series of copper ribbons, each one soldered to a respective busbar electrode.

A general aim for solar cell development is to attain high conversion efficiency balanced by a need for reduced production costs. Efforts to achieve this have focussed on the electrode connections between the solar cells in a solar cell module and the properties of the semiconductor substrate.

SUMMARY

In a first aspect, the present invention comprises an electrode assembly for a solar cell, the electrode assembly comprising: an insulating (e.g. electrically insulating) optically transparent film; and a plurality of longitudinally extending, laterally spaced conductive elements (which may be referred to herein as electrodes, wires or ribbons) arranged parallel to one another on a surface of the film, each conductive element having a generally rectangular cross-sectional shape, wherein a width of each conductive element is between 0.15 mm and 0.5 mm and a depth, thickness or height of each conductive element is between 0.1 mm and 0.3 mm, and wherein the width of each conductive element is greater than the depth of each conductive element. In use in a solar cell, as described herein, the conductive elements collect current from the solar cell (e.g., via finger electrodes of the solar cell). In known arrangements, such conductive elements are generally provided in the form of wires having a circular cross-sectional shape. However, by providing the conductive elements with a generally rectangular shape with the dimensions as specified according to the present invention, a similar electrical performance (e.g., resistance, conductance) may be obtained while also providing improved durability of the solar module by increasing the effective thickness of an encapsulating layer as described herein. For example, an effective thickness may be a thickness of the encapsulant layer between the electrode assembly and a front plate (e.g. glass plate) of the solar module. Alternatively, the manufacturing cost of a solar module may be decreased by allowing the amount of encapsulant used in the solar module to be reduced whilst maintaining a specified or required durability, for example, whilst maintaining an effective thickness of the encapsulant layer compared to known arrangements. For the avoidance of doubt, the term “cross-

sectional shape" is used to describe the shape of a section of a conductive element in a plane that is perpendicular to the (longitudinal) extension of that conductive element.

Each of the conductive elements may comprise a width, an axial length, and a depth (e.g., thickness or height). Each of the conductive elements may be configured such that its axial length is substantially greater than its width and/or depth. The width and axial length of the conductive elements may be measured in perpendicular directions aligned with a plane of the surface of the solar cell upon which the conductive elements are arranged (e.g., the front or back surface of the solar cell). The depth (e.g., thickness or height) may be measured in a direction which is perpendicular to the same plane of the solar cell. The terms "longitudinally" (defined by the direction of the conductive elements) and "laterally" refer to directions that are substantially perpendicular to one another.

The conductive element(s) may be formed of an electrically conductive material, such as a metallic or metallic alloy material, which may include at least one of Ag, Al, Au, and Cu.

The term "on", as used herein, for example in the phrase "on a surface", is intended to encompass both direct and indirect arrangement on an element such as e.g. a layer, film, or region. Thus, the phrase "on a surface" encompasses arrangements in which one or more intervening layers are provided or, alternatively, in which no intervening layers are provided. In contrast, when an element is referred to as being "directly on" another element (e.g. "directly on the surface"), there are no intervening elements present. Accordingly, the electrode assembly may be arranged directly or indirectly on the conductive surface of a solar cell, as described below.

The terms 'conductive' and 'insulating' as used herein, are expressly intended to mean electrically conductive and electrically insulating, respectively. The meaning of these terms will be particularly apparent in view of the technical context of the invention, being that of photovoltaic solar cell devices.

By 'generally rectangular' it should be understood that each conductive element has a width that is greater than its thickness, and the cross-sectional shape of the conductive element has two pairs of opposing faces or edges, with two long faces which oppose one another, and two short faces which oppose one another. In use, the two long faces are configured to contact one of the solar cell and the insulating optically transparent film. For example, the long faces may comprise a lower face (which may be configured to contact a solar cell, where the electrode assembly is applied to an upper surface of a solar cell), an upper face (which is arranged to oppose the lower face, and configured to contact the film where the electrode assembly is applied to an upper surface of a solar cell). The two short faces may be referred to herein as lateral faces. The main dimension of the long faces generally corresponds with the width of the conductive element, and is greater than the main dimension of the short faces (which generally corresponds with a depth of the conductive element). It should be noted that the opposing faces or edges are not strictly required to be flat, planar, or parallel with one another, and any suitable configuration may be chosen. For example, each conductive element may comprise short faces which are curved, such that the cross-sectional shape of each conductive element is a truncated circle, or pill- or capsule- shaped. That is, the short faces may be convex, such that they bulge outwardly. By

a truncated circle, it may be understood that upper and lower (i.e., opposing) segments are removed from a circle cross-sectional shape to provide flat/planar long surfaces and curved short surfaces which oppose one another. In particular, the width of the flat/planar surfaces may be greater than the depth/thickness of the curved surfaces. In use, one of the flat surfaces is arranged to contact the solar cell. Such an arrangement may be easier and cheaper to manufacture than a conductive element having a strictly rectangular cross-sectional shape. In examples, each conductive element may be coated with an alloy coating which, when heated, flows to connect (e.g. electrically connect) the conductive element to a surface of a solar cell (e.g., as a solder). By being provided with curved lateral faces in this way, the alloy coating may more easily flow from the short faces and be directed towards the long face in contact with the solar cell to form electrical contact with the solar cell.

Optionally, each conductive element may be coated with an alloy coating which comprises an alloy having a low melting point, for example, a lower melting point than the conductive element. The coating may be configured, in use, to solder the conductive elements to the respective surfaces of the solar cells to which they are welded. Each conductive element may comprise a conductive metal, or metal alloy. For example, each conductive element may comprise copper, or silver. Each of the conductive elements may be coated with an alloy coating which comprises an alloy having a low melting point i.e. a melting point lower than the melting point of the conductive metal/metal alloy forming the core of the conductive element. For example, the melting point of the alloy coating may be 250°C or less, such as 200°C or less. Each conductive element may be completely coated in the alloy coating, or at least partially coated on a side, or sides, which faces the layered structure of the solar cell (when arranged thereon). The coating may comprise a metal alloy formed of at least two or more components. The coating alloy may be at least one of a lead based, tin based and bismuth-based alloy. The coating may comprise a 2-phase, 3-phase, or more complex metal alloy. The coating may be formed of a metal alloy comprising at least one of Cu, Ag, Bi, Cd, Ga, In, Pb, Sn, Ti, etc. The coating may also comprise an electrically conductive material which is formed of metallic, or alloy particles embedded within an organic matrix. The coating alloy may be a solder material, for example, and may be an alloy comprising any one or more of Cu, Ag, Ob, Si, or Sn. For example, the coating may comprise any one or more of SnAgCu, SnBiAg, SnPbBi, SnIn, or SnBi. The alloy coating may have a thickness of less than 50, or less than 25 μm, for example 20 μm, 10 μm or 5 μm. Optionally, the alloy coating may have a thickness of at least 5 μm, or at least 10 μm, or at least 20 μm. Optionally, the alloy coating may have a thickness (e.g. maximum thickness) of between 5 μm and 50 μm. Additionally, by the conductive elements having a generally rectangular cross-sectional shape, the amount of alloy coating (e.g. solder) used to electrically attach (e.g. electrically connect) the conductive elements to the surfaces of the solar cell may be reduced, because the electrically conductive element lies closer to the surface of the solar cell across the surface to be attached to the solar cell compared to an electrically conductive element having a round cross-sectional shape. This can provide up to a 20% reduction in the amount of alloy coating used in the solar module.

In certain examples, the alloy coating may be predominantly disposed on at least one of the long faces of each conductive element. That is, the alloy coating may be predominantly disposed on one or both

of the faces of the elongate conductive element which is arranged to be in contact with either a solar cell or the film. By 'predominantly' it will be understood that a thickness of the alloy coating may be greater on a long face than on one or both of the short faces, or that the alloy coating may be completely absent from one or both of the short faces. In one example, the alloy coating may be present only on a long face which contacts the solar cell. This may allow the manufacturing cost of the electrode assembly and, as a result, of a solar cell and solar module, to be reduced by reducing the amount of alloy coating which is required. Coating the conductive element in this way may be aided by providing each conductive element with the generally rectangular cross-sectional shape as described above.

Optionally, the width of each conductive element is 0.24 mm and the depth or thickness of each conductive element is 0.18 mm. It has been found that such an arrangement may be particularly suitable to replace conventional wires having a circular cross-sectional shape (and, for example, a diameter of 0.23mm), by providing a limited trade-off between the shadowing effect of the conductive element (i.e., the area of the solar cell which light is not able to reach due to the area which is physically covered by the conductive element) and the electrical properties of the conductive element, each of which are close to conventional wires for these dimensions, while providing the durability advantages linked with the encapsulant as described herein. In another example, the width of each conductive element is 0.3 mm and the depth or thickness of each conductive element is 0.15 mm. In another example, the width of each conductive element is 0.285 mm and a thickness of each conductive element is 0.15 mm.

Optionally, the insulating optically transparent film may be unitary film formed of a polymeric material. For example, the insulating optically transparent film may be a film as described in WO 2023126154 A1, the contents of which are incorporated herein by reference in their entirety. By 'unitary film' it will be understood, in general, that the film may have a unitary construction (i.e. it may be formed of a single layer of material, not a plurality of discrete layers), and is formed of a polymeric material. The polymeric material may be formed from a polymer resin which comprises at least one of a polyolefin elastomer (POE), polyvinylbutyral (PVB) hydrocarbon ionomer, thermoplastic organo-silicon, silicon rubber, polyurethane, thermoplastic silicone elastomer (TPSE) and ethylene-vinyl acetate (EVA). The polymeric material is selected to encompass the following characteristics: high ductility, low electrical conductivity, high optical transparency, thermal stability, and resistance to shrinkage. Of course, it will be appreciated that, in other examples, the insulating optically transparent film may be provided with a plurality of layers, such as a film layer which comprises the electrically conductive elements, and an adhesive layer for attaching the film layer to the conductive elements, and for attaching the electrode assembly to a solar cell. The conductive elements may be attached (e.g. adhered) to the film. The conductive elements may be partially embedded in the film such that a surface of each conductive element protrudes from the surface of the film. Alternatively, the conductive elements may be completely embedded in the film.

Each conductive element may be continuous (i.e. without breaks) and may extend across a substantial portion of (e.g. substantially fully across) the film. Each conductive element may extend substantially from one edge of the film to an opposite edge of the film without discontinuities. Each conductive element may extend beyond at least one of the edges of the film. In some embodiments, references to

conductive elements herein may be references to only portions of those conductive elements that are arranged on the surface of the layered structure.

The film may be rectangular. The film may have a long dimension and a short dimension. The conductive elements may extend in the direction of the short dimension (i.e. the longitudinal direction may be in the direction of the short dimension). In such embodiments, the lateral direction may therefore be in the direction of the long dimension. Alternatively, the conductive elements may extend in the direction of the long dimension, and the lateral direction may be in the direction of the short dimension.

In embodiments where the film is not a unitary film, the surface of the film (i.e. facing the conductive elements) may be coated with a transparent seal layer (e.g. an adhesive layer). The seal layer may be configured to be in a non-adhering state at room temperature and may be configured to enter an adhering state when heated (i.e. to a temperature above room temperature). Accordingly, during fabrication of the solar cell, the film may be heated so that the seal layer softens to enable adherence of the film to the conductive elements due to an application of force. In this way, the conductive elements may be at least partially embedded in the seal layer. Additionally or alternatively, the film (e.g. a portion or surface of the film configured to contact the solar cell) may be configured to be in a non-adhering state at room temperature and may be configured to enter an adhering state when heated (i.e. to a temperature above room temperature). Accordingly, during fabrication of the solar cell, the film may be heated and soften to enable adherence of the film to the conductive elements due to an application of force. In this way, the conductive elements may be at least partially embedded in the film. In this embodiment, no seal layer may be present.

The film may be configured to provide adhesion between the solar cell and the conductive elements so that the conductive elements are correctly spaced on the solar cell. In this way, the film enables the conductive elements to be correctly aligned with the solar cell.

The film may provide a mechanical connection between the conductive elements and the solar cell. In an exemplary arrangement, the film may not cover all the respective front and/or back surface(s) of the solar cell. For example, the film may not extend completely across at least one dimension (e.g., the length and/or width) of the solar cell. Alternatively, the film may cover the entire surface of the solar cell, for example, the film may extend completely across the width and/or length of the solar cell.

The film may be configured such that at least a portion of at least one of the first and second surfaces of the conductive elements is exposed from the film to form an electrical contact with the respective front and back surfaces of the first and second solar cells.

The conductive elements may be attached to a solar cell facing surface of the film. For example, the film may be deformable when heated to allow the conductive elements to be at least partially embedded in the solar cell facing surface. Alternatively, the solar cell facing surface of the film may be coated with an adhesive which adheres the conductive elements to the film.

Optionally, the electrode assembly may comprise between 3 and 30 longitudinally extending, laterally spaced conductive elements. For example, the electrode assembly may comprise 20 conductive elements.

The plurality of conductive elements may be evenly spaced (i.e. equi-spaced). That is, there may be a consistent spacing between each adjacent pair of conductive elements in the plurality of conductive elements. The plurality of conductive elements may alternatively be unevenly spaced. That is, the lateral spacing between at least one pair of adjacent conductive elements may be greater than the lateral spacing between another pair of adjacent conductive elements. Where a first pair of conductive elements has a greater spacing therebetween than a second pair of conductive elements (of the plurality of conductive elements), the first pair of conductive elements may include the second conductive element and the second pair of conductive elements may include the first conductive element.

The plurality of conductive elements may be substantially parallel to one another.

Each conductive element may have a substantially constant cross-sectional area along its length. Each conductive element may have a substantially constant cross-sectional shape along its length.

A first distance may be defined between two adjacent conductive elements of the plurality of conductive elements (e.g. a first conductive element and an adjacent conductive element). When the conductive elements are evenly spaced, the first distance may represent the (even) spacing between each of the conductive elements (i.e. each conductive element may be spaced from adjacent conductive elements by the first distance).

The first distance may be between 8 mm and 10 mm or between 8.5 mm and 10 mm, or between 9 mm and 9.5 mm, or about 9.3 mm.

For the avoidance of doubt, references to distances and or spacing between conductive elements and/or edges herein are to be taken as lateral distances/spacing (i.e. taken in a direction perpendicular to the axial extension of the conductive elements). Further, (lateral) distances involving one or more conductive elements should be taken from a central axis of the conductive element. As an example, reference to a distance between two adjacent conductive elements is the distance between the central axis of one conductive element and the central axis of the other adjacent conductive element. As a second example, reference to a distance between a conductive element and an edge (of a film or layered structure) is a reference to the lateral distance between the central axis of the conductive element and the edge. As may be appreciated, in this second example, the central axis of the conductive element may be spaced from (e.g. above) the surface of the component (e.g. film or layered structure) of which the edge forms a part of. In such cases, emphasised that a reference to such a distance is a reference to the lateral component of the distance between the central axis and the edge (i.e. the distance should be taken parallel to the surface).

The electrode assembly may further comprise at least one electrically conductive element (e.g., a busbar) which is mounted to a surface of the solar cell, and a separate wire (e.g., a cable, or ribbon) which electrically couples the conductive element to a circuit that is external to the solar cell. For example, the electrode assembly may comprise a copper cable which connects a plurality of busbars arranged on the front surface of the first solar cell to a plurality of busbars arranged on the back surface of the second solar cell.

In a second aspect, the present invention provides a solar cell assembly comprising: a layered structure comprising a photovoltaic element and a conductive surface; and an electrode assembly comprising a plurality of longitudinally extending, laterally spaced conductive elements (e.g. wires or ribbons) arranged parallel to one another on a surface of the film, each conductive element having a generally rectangular cross-sectional shape, wherein a width of each conductive element is between 0.15 mm and 0.5 mm and a thickness (e.g. depth or height) of each conductive element is between 0.1 mm and 0.3 mm, and wherein the width of each conductive element is greater than the thickness of each conductive element, the electrode assembly arranged on the conductive surface of the layered structure such that the conductive elements are in ohmic contact with the conductive surface. The electrode assembly may be arranged such that one of the wider faces (specifically a lower face, as described above) is in ohmic contact with the conductive surface, in order to provide a greater contact surface area between the conductive elements and the conductive surface to more effectively collect current from the conductive surface. The electrode assembly may be an electrode assembly as described above with respect to the first aspect, for example.

An insulating optically transparent insulating film, in examples where it is present, may overlie the conductive elements (i.e. the conductive elements may be provided between the film and the conductive surface). The film (also referred to as a foil) may provide means for maintaining the conductive elements in their spaced arrangement during mounting onto the conductive surface. The film may be configured to retain the electrode assembly on the surface of the layered structure (thereby maintaining ohmic contact between the conductive elements and the conductive surface). The electrode assembly may be referred to as a foil (or film) and wire assembly when it includes such a film (and when the conductive elements are in the form of wires).

The solar cell may comprise a transparent conductive oxide (TCO) layer. For example, the anti-reflection layer may be formed of a transparent conductive oxide material, such as indium tin oxide (ITO). A surface of the substrate (e.g., the substrate's front and/or back surface(s)) may be textured. The TCO layer may be configured to increase lateral carrier transport to the electrode arranged on the respective surface of the layered structure.

At least one, or each of the layers within the solar cell's layered structure may substantially conform with the substrate's textured surface, such that the anti-reflection layer defines a textured outer surface of the solar cell (e.g., the solar cell's front and/or back surface).

The solar cell may comprise an electrode (e.g., a finger electrode) arranged opposite the layered structure and configured to extract photo-generated charge carriers from the solar cell. The electrode may be arranged such that at least one of the elements of the layered structure (e.g., a charge collector and/or passivation element) is interposed between the electrode and the substrate.

The conductive surface may comprise a plurality of finger electrodes (e.g. conductive elements/members). Each finger electrode may be elongate and may extend in a substantially lateral direction. The conductive elements (of the electrode assembly) may extend across the plurality of finger electrodes in a longitudinal direction. In this respect, the finger electrodes may be substantially perpendicular to the conductive elements.

The finger electrodes may comprise a printed conductive material. The printed conductive material may enable the formation of fine (i.e. narrow width and small depth) finger electrodes on the surface of the layered structure.

The finger electrodes may be distributed substantially evenly across the conductive surface. Thus, for example, a region between an outermost conductive element and an edge of the conductive surface may have the same number of finger electrodes as a region between two adjacent conductive elements. In other words, the conductive surface may be free of redundancy lines (extending from one or both of the opposed longitudinal edges of the conductive surface that are parallel to the conductive elements).

The layered structure may comprise a front surface (e.g. frontmost surface) upon which light is incident in use, and a rear surface (e.g. rearmost surface) opposite the front surface.

The conductive surface may be a front surface (light incident surface) of the layered structure. Thus, the electrode assembly may be arranged on the front surface of the layered structure (i.e. on the finger electrodes of the conductive surface), and the conductive elements may extend across the front surface of the layered structure (i.e. across the finger electrodes). Such an electrode assembly may be referred to as a front electrode assembly.

In other embodiments, the conductive surface may be a rear surface of the layered structure. Thus, the electrode assembly may be arranged on the rear surface of the layered structure, and the conductive elements may extend across the rear surface of the layered structure (i.e. on the finger electrodes of the conductive surface). Such an electrode assembly may be referred to as a rear electrode assembly.

The solar cell assembly may comprise both front and rear electrode assemblies (and the layered structure may comprise both front and rear conductive surfaces).

The layered structure may comprise multiple layers including the photovoltaic element. The photovoltaic element may comprise a semiconductor material. Thus, the photovoltaic element may be a semiconductor substrate. The semiconductor substrate may be formed of crystalline silicon (e.g. a monocrystalline silicon wafer). The substrate may be configured with a first conductivity type (e.g. n-type) and the layered structure may comprise a collector layer which is configured with a second

conductivity type (e.g. a p-type) that is opposite the first conductivity type, and thus forms a p-n junction with the substrate. According to such an arrangement, the collector layer may define a minority charge carrier collector layer (e.g. a hole-collector layer) of the solar cell.

During operation of the solar cell, a plurality of electron-hole pairs are produced by light incident on the substrate. When the substrate is n-type and the minority charge carrier collector layer is p-type (e.g. a hole-collector layer), the separated holes and electrons move to the p-type hole-collector layer and the n-type substrate, respectively. Accordingly, the holes operate as majority charge carriers in the p-type hole-collector layer, and the electrons operate as majority charge carriers in the n-type substrate.

According to an alternative arrangement, the substrate may be p-type and the minority charge carrier collector layer may be n-type (e.g. an electron-collector layer), thus forming a p-n junction with the substrate. In this instance, the separated electrons and holes move to the n-type electron-collector layer and the p-type substrate, respectively.

The collector layer may define a majority charge carrier collector layer configured with the first conductivity type (e.g. n-type), which is the same as that of the substrate. For example, both the substrate and the majority charge carrier collector layer may be n-type, such that the majority charge carrier collector layer defines an electron-collector layer. As such, the majority charge carrier collector layer may be configured to selectively screen, or extract, charge carriers from the substrate. Accordingly, when the solar cell is in use, the electrons produced by light incident on the substrate may be collected in the electron-collector layer, wherein they operate as majority charge carriers.

The collector layer may be arranged on a first surface of the substrate. The layered structure of the solar cell may further comprise a second collector layer (e.g. a back-field layer), arranged on a second surface of the substrate, opposite the first surface. The first and second surfaces may define the front and back (or rear) surfaces of the substrate, respectively. The layered structure of the solar cell may further comprise a passivation layer arranged between the substrate and the respective first and second collector layers.

According to an exemplary arrangement, the substrate may be formed from an n-type monocrystalline silicon wafer, which exhibits longer lifetime characteristics compared to a p-type monocrystalline silicon wafer. The front collector layer may comprise an amorphous material (e.g. amorphous silicon) which is at least partially doped so as to be n-type. The back collector layer may comprise an amorphous material (e.g. amorphous silicon) which is at least partially doped so as to be p-type. In other embodiments, the back collector layer may be at least partially doped so as to be n-type and the front collector layer may be at least partially doped so as to be p-type.

Such an arrangement may contribute towards the formation of a heterojunction technology (HJT) type solar cell, which is so defined because it combines two different materials to create a charge separating p-n junction. Alternatively, the solar cell may comprise a multi-junction (e.g. tandem) solar cell, which is so defined because it comprises two or more charge separating junctions and two or more charge-

generating photon absorbing layers. Of course, the layered structure may take others forms (e.g. the solar cell assembly may not be a heterojunction solar cell).

The electrode assembly may be arranged such that the collector layer is interposed between the electrode assembly and the substrate.

When the collector layer is arranged on a back (e.g. backmost) surface of the substrate, the electrode assembly may be arranged on a back surface of the layered structure, to define a back electrode of the solar cell. When the collector layer is arranged on a front (e.g. frontmost) surface of the substrate, the electrode assembly may be arranged on a front surface of the layered structure, to define a front electrode of the solar cell. The solar cell may comprise a front electrode assembly arranged on the front surface of the front layered structure and a back electrode assembly arranged on the back surface of the back layered structure.

The semiconductor substrate may comprise crystalline silicon (c-Si). When the semiconductor substrate is an n-type semiconductor, the semiconductor material may be configured to contain impurities of a group V element such as phosphor (P), arsenic (As), and antimony (Sb). When the semiconductor material is a p-type semiconductor material, it may contain impurities of a group III element such as boron (B), gallium (Ga), and indium (In). Alternatively, the semiconductor material may be formed of materials other than silicon.

A surface of the layered structure e.g. the front surface may be textured to form an uneven surface or a surface having uneven characteristics. In this instance, an amount of light incident on the layered structure increases because of the textured surface of the layered structure, and thus the efficiency of the solar cell assembly may be improved.

The layered structure may further comprise an anti-reflection layer, or coating, arranged at the front and/or rear surfaces of the layered structure. The, or each, anti-reflection layer may have a single-layered structure or a multi-layered structure. The anti-reflection layer may be formed of silicon nitride (SiNx) and/or silicon oxide (SiOx). Alternatively, the anti-reflection layer may be formed of a transparent conductive oxide (TCO), such as indium tin oxide (ITO), which has been textured to provide an anti-reflective surface. The anti-reflection layer may advantageously reduce the reflectance of light incident on the solar cell assembly and increase selectivity of a predetermined wavelength band, thereby increasing the efficiency of the solar cell assembly.

In a third aspect, the present invention provides a solar module comprising at least one solar cell; a front plate and a back plate which are arranged, respectively, on the front and back sides of the at least one solar cell, wherein at least one of the front plate and the back plate is transparent; and an encapsulant arranged between the front plate, the back plate, and the at least one solar cell to prevent the ingress of moisture into the solar module. The solar cell is a solar cell as described above with respect to the second aspect. That is, the solar cell comprises a layered structure comprising a photovoltaic element and a conductive surface; and an electrode assembly comprising a plurality of

longitudinally extending, laterally spaced conductive elements (e.g. wires or ribbons) arranged parallel to one another on a surface of the film, each conductive element having a generally rectangular cross-sectional shape, wherein a width of each conductive element is between 0.15 mm and 0.5 mm and a thickness (e.g., depth or height) of each conductive element is between 0.1 mm and 0.3 mm, and wherein the width of each conductive element is greater than the thickness of each conductive element, the electrode assembly arranged on the conductive surface of the layered structure such that the conductive elements are in ohmic contact with the conductive surface. The electrode assembly may further comprise an insulating optically transparent film, as described above with respect to the first aspect, for example. By utilising conductive elements with the specified shape, a similar electrical performance (e.g., resistance) as conventional wires (having a circular cross-sectional shape) may be obtained while also providing improved durability of the solar module by increasing the effective thickness of an encapsulating layer as described herein. Alternatively, the manufacturing cost of a solar module may be decreased by allowing the amount of encapsulant to be reduced whilst maintaining a specified or required durability.

In particular, solar modules are exposed to numerous changes in environmental conditions, in particular changes in temperature, during their life. The materials which make up the solar module expand in high temperatures, and contract in low temperature, and the degree to which each material expands and contracts is different. This can cause problems with the solar module, in particular when conductive elements start to separate from the conductive surface of a solar cell, and so no longer have electrical connection. Another problem can arise where conductive elements pull away from the conductive surface and disrupt the front plate or the back plate. These can become particularly prominent issues over time, with repeated cycles of expansion and contraction. In order to counter these effects, and reduce the incidence of this problem, it has been found that the ‘margin’, or depth/thickness of the encapsulant layer is particularly important. In particular, the depth/thickness of the encapsulant layer which is present between the conductive element and the front or back plate is important. However, reducing the amount of encapsulant which is used is also an important consideration in order to reduce the cost of manufacturing a solar module.

By providing conductive elements having the specified, generally rectangular, cross-sectional shape according to examples of the present invention, a given ‘margin’ or depth of the encapsulant layer can be maintained, ensuring a required degree of resiliency and lifespan of the solar module, while using less encapsulant material, or the resiliency and lifespan of the solar module can be increased while using the same amount of encapsulant material. The effective thickness, or margin, of the encapsulant may thereby be maintained whilst using less encapsulant material.

At least one or each of the front and back plates may be formed of glass (e.g., a glass sheet).

Optionally, a depth of the encapsulant between the front plate or the back plate and an insulating optically transparent film of a solar cell, at a region away from a conductive element, is at least twice the thickness of the conductive element. That is, the depth of the encapsulant between the front plate or the back plate and an insulating optically transparent film of a solar cell, at a region away from a

conductive element, may be at least 0.2 mm, and may be at least 0.6 mm, such as 0.5 mm (500 μm) or 0.4 mm (400 μm), for example. In an embodiment, the encapsulant has approximately a 350 grammage of density.

In an example, a depth of the encapsulant between the front plate or the back plate and an insulating optically transparent film of a solar cell, at a region away from a conductive element, is at least 0.4 mm (400 μm), such as 0.5 mm (500 μm).

Optionally, a depth of the encapsulant between the front plate or the back plate and the insulating optically transparent film of the solar cell, at the conductive element, is at least 0.2 mm (200 μm). For example, the depth may be around 0.22 mm (220 μm).

Optionally, distance between the front plate or the back plate and a conductive element of a solar cell, is at least 0.3 mm (300 μm). For example, the distance may be around 0.32 mm (320 μm).

The at least one solar cell assembly may comprise a plurality of solar cell assemblies, each according to the second aspect. The solar cell assemblies may be electrically coupled to one another, for example, in series and/or in parallel.

In exemplary arrangements which comprise a plurality of solar cells, the solar cells may be connected so that electrical current is conducted, via an electrode assembly, from one solar cell to another.

The electrode assembly may be arranged to connect a front surface of a first solar cell to a back surface of a second solar cell. The electrode assembly may comprise a first section for contacting the front surface of the first solar cell (i.e., a front connector), a second section for contacting the back surface of the second solar cell (i.e., a back connector), and a third section configured to connect (e.g., directly, or indirectly) the first section to the second section. The third section may, in this way, define an interconnector configured to electrically couple together the respective first and second sections (i.e., the front and back connectors).In exemplary arrangements in which the electrode assembly comprises a plurality of conductive elements, the first section of each of the conductive elements may together define the front connector. Similarly, the second sections may define the back connector.

The plurality of solar cell assemblies may comprise first and second solar cell assemblies, the conductive elements of the first solar cell assembly being electrically coupled to the conductive elements of the second solar cell assembly. Accordingly, the plurality of conductive elements may form an electrical connection between two or more solar cell assemblies in the solar cell module.

The plurality of conductive elements may comprise pairs of electrically coupled conductive elements, each pair comprising a first conductive element forming part of the first solar cell assembly and a second conductive element forming part of the second solar cell assembly. The first and second conductive elements may be electrically coupled together by a third conductive element (e.g. a copper ribbon) to allow current to flow between the first and second conductive elements. The third conductive element may be substantially parallel or substantially perpendicular to the first and second conducting elements.

The first, second and third conductive elements may be integrally formed to form a single integrally formed element (e.g. wire). Configuring the conductive elements in this way removes the need to provide separate connections (such as copper ribbons) between neighbouring solar cells, which thereby reduces the number and complexity of manufacturing steps required to fabricate the solar cell assembly.

Alternatively, the first and second conductive element (and third conductive element when present) may be separately formed but electrically coupled together.

The first conductive element may contact a front conductive surface of the layered structure of the first solar cell assembly, and the second conductive element may contact a rear conductive surface of the second solar cell assembly. The third conductive element, when present, may thus extend from the front surface of the layered structure of the first solar cell assembly to the rear surface of the layered structure of the second solar cell assembly.

As discussed above, the electrode assemblies of each solar cell assembly may comprise an insulating optically transparent film or films. The conductive elements are received between these films and respective conductive surfaces of corresponding solar assemblies. The films of one solar cell assembly may be separate from the films of another solar cell assembly. Thus, each first conductive element may be received between a first film and the front surface of the layered structure of the first solar cell assembly, and each second conductive element may be received between a second film and the rear surface of the layered structure of the second solar cell assembly. Each third conductive element may extend between the first and second films (i.e. may not be attached/received on either of the first and second films).

As may be appreciated, the second solar cell assembly may be coupled to a third solar cell assembly in a similar manner (i.e. conductive elements extending from the front conductive surface of a layered structure of the second solar cell assembly to the rear conductive surface of a layered structure of the third solar cell assembly). In this way, a row or string of coupled solar cell assemblies may be formed.

Each of the solar cells may comprise a length, a width, and a depth. The length of the solar cell may be less than its width, and the depth may be less than both the width and the length. The longitudinal and transverse directions across the front and back surfaces of the solar cell may be parallel with the length and width directions of the solar cell, respectively. Hence, the plurality of conductive elements may be configured to extend across the length of the solar cell, and to be spaced along its width.

Each of the conductive elements may be configured to extend lengthwise relative to the surface of the solar cell upon which it is overlaid, in a longitudinal direction. The conductive elements may be spaced apart in a transverse direction relative to the solar cell surface to define longitudinal-extending spaces between the conductive elements. The conductive elements may be parallel or substantially parallel to one another. The conductive elements may be equally or substantially equally spaced in the transverse direction. Accordingly, the plurality of conductive elements may form an array of parallel, transversely spaced (e.g., equally spaced) conductive elements.

The electrode assembly may be configured to form an electrical connection with a conductive surface (or a conductive portion of a surface) of the first and second solar cells. As described above, the conductive elements of the electrode assembly may be configured to optimise the optoelectronic properties of the front and/or back connectors, e.g., their electric current collection and solar cell shading characteristics.

Each of the solar cells' conductive surface(s) may comprise a plurality of finger electrodes which extend substantially across the respective solar cell surfaces. The finger electrodes may be formed using a printed material, which enables them to be conveniently deposited onto the surfaces of the solar cells.

The solar module may comprise a housing (e.g., a structural frame, or support) which houses a plurality of solar cells.

The solar module may comprise electrical circuitry comprising an electrical connector which is connected, at one end, to a junction box which may be arranged on the back side of the solar module (e.g., mounted to the back plate of a module housing). The electrical circuitry may comprise a further connector to connect between the junction box and the solar cells arranged within the module (e.g., an internal connector). The electrical circuity may further comprise at least one diode (e.g., bypass diodes) which regulates the flow of charge between the solar cells and/or between the solar module and the external electrical circuit. Components of the electrical circuitry may be arranged within the junction box and/or within the module housing itself.

According to a particular type of solar module, the solar cells may be arranged within a common transverse plane of the solar module. Accordingly, the widthwise and lengthwise dimensions of the plurality of solar cells may lie in the same plane. The first and second solar cells may be spaced apart by a gap in an in-plane direction (e.g., a lengthways and/or widthways direction) of the solar module. In this situation, the electrical connector (e.g., conductive elements, or wires) extend from the first solar cell to the second solar cell across a transition region (e.g., a gap) which is formed between the separated solar cells.

According to a particular type of solar module, the solar cells may be arranged in a 'gapless' configuration in which the front surface of the first solar cell is partially overlapped by the back surface of the second solar cell. In this situation, the electrical connector (e.g., conductive elements, or wires) extend from the first solar cell to the second solar cell across the overlapping region. It is to be understood that in a first direction of the module (e.g., one of a lengthways or widthways direction) adjacent cells may be arranged in a gapless configuration; however, in a second direction of the module, orthogonal to the first direction, (e.g., the other of the widthways or lengthways directions), adjacent cells may be spaced by a gap.

The at least one solar cell may comprise a substantially planar structure. For example, the solar cell may comprise a length and/or a width which is substantially greater than its depth.

The at least one solar cell may comprise a first (i.e., front) surface, upon which light from a radiative source (e.g., the sun) is incident during normal use, and a second (i.e., back) surface that is opposite the front surface. That is, the front surface may be configured in use to face the sun, whereas the back surface may be configured in use to face away from the sun.

The at least one solar cell may comprise a plurality of layers, or elements, including a photovoltaic element, wherein at least one of the plurality of layers is formed of a semiconductor material.

The photovoltaic element (or layer) may define a substrate on which other layers of the solar cell are arranged (e.g., deposited). The photovoltaic element may comprise crystalline silicon (e.g., monocrystalline, or polycrystalline silicon). According to an exemplary arrangement, the photovoltaic element defines a crystalline silicon wafer which has been cut from an ingot, as will be understood by the skilled person.

It will be appreciated that the solar cell may be configured to define any type of solar cell structure. For example, the solar cell may define a heterojunction type solar cell. Alternatively, the solar cell may define a tandem junction solar cell.

The front and/or the back surface(s) of the solar cell may be textured to form a textured surface corresponding to an uneven surface (e.g., a surface having uneven characteristics). In this instance, an amount of light incident on the solar cell increases because of the textured surface of the solar cell, and thus the efficiency of the solar cell is improved.

The at least one solar cell may have a substantially rectangular front and/or back surface. The solar cell may comprise four straight sides arranged at right angles to each other. At least one, or each, of the corners between the sides may be square, or pointed. Alternatively, the corners may be chamfered (or rounded), so as to define a pseudo-rectangular shape.

In exemplary arrangements in which the at least one solar cell is formed from a semiconductor wafer (e.g., a crystalline silicon wafer), the dimensions of the solar cell may substantially correspond to that of the wafer (e.g., a whole wafer silicon cell). The at least one solar cell may be formed from a wafer which is cut into a plurality of sections. For example, the substantially planar wafer may be cut along an in-plane direction (e.g., a width or length direction of the wafer) to define a cut solar cell (e.g., a half-cut solar cell).

As outlined above, the solar cell may be configured with a generally layered structure which may further include one or more charge collection elements, or layers, (e.g., a charge collector), configured to extract charge carriers from the substrate. The solar cell may be provided with a hole collector and an electron collector (i.e., electron/hole collectors) arranged on opposite sides of the substrate (e.g., on its front and back surfaces, respectively).

The solar cell may further comprise an anti-reflection element, layer, or coating, arranged opposite the charge collector (e.g., such that the charge collector is interposed between the anti-reflection layer and

the substrate). One anti-reflection layer may be on the front side of the cell. Another anti-reflection layer may be on the back side of the cell. The anti-reflection layer advantageously reduces the reflectance of light incident on the solar cell and increases selectivity of a predetermined wavelength band, thereby increasing the efficiency of the solar cell.

The solar cell may further include one or more passivation elements, which are configured to passivate the interface between the substrate and a respective charge collector. The passivation element may be interposed between the substrate and the respective charge collector.

The substrate may divide the solar cell into a front portion which is forward (i.e., in front of) of the substrate, and a back portion which is rearward of the substrate. According to an exemplary arrangement, the solar cell may define a back junction solar cell (and, in particular, a back-junction heterojunction solar cell, in which the electron collector forms part of the front portion, and the hole-collector forms part of the back portion.

During operation of the solar cell, incident light (e.g., directly from the sun) may pass through the front portion, the substrate and then the back portion. Alternatively, light may also be incident on the solar cell from a rearward direction (e.g., due to reflection of sun light by a surface behind the cell) such that it passes first through the back portion, then the substrate and then the front portion. In this way, the solar cell may be configured as a bifacial solar cell.

At least one, or each, of the solar cell's constituent elements may be configured with a width, a length, and a depth. The width and length of each element may be measured in perpendicular directions that are aligned with the front and back surfaces of the substrate. The depth may be measured in a direction that is perpendicular to the front and back substrate surfaces. At least one, or each of the elements may be configured such that its width and/or length may be substantially greater than its depth.

According to an exemplary arrangement, the substrate may be formed from a monocrystalline silicon wafer. At least one of the constituent elements of the solar cell (e.g., the charge collector) may comprise an amorphous semiconductor material (e.g., amorphous silicon, a-Si).

At least one of the constituent elements of the solar cell (e.g., the substrate and/or the charge collector) may be at least partially doped with a prescribed conductivity type. The passivation element may be configured with no conductivity type such that it forms an intrinsic layer (e.g., non-doped) between the collector layer and the substrate.

It will be understood that the terms 'conductive' and 'insulating' as used herein, are expressly intended to mean electrically conductive and electrically insulating, respectively. The meaning of these terms will be particularly apparent in view of the technical context of the disclosure, being that of photovoltaic solar cell devices. It will also be understood that the term 'ohmic contact' is intended to mean a non-rectifying electrical junction (i.e., a junction between two conductors which exhibits a substantially linear current–voltage (I-V) characteristic).

The preceding summary is provided for purposes of summarising some examples to provide a basic understanding of aspects of the subject matter described herein. Accordingly, the above-described features should not be construed to narrow the scope or spirit of the subject matter described herein in any way. Moreover, the above and/or proceeding examples may be combined in any suitable combination to provide further examples, except where such a combination is clearly impermissible or expressly avoided. Optional features may be applicable singly or in combination with any aspect. Other features, aspects, and advantages of the subject matter described herein will become apparent from the following text and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects, features, and advantages of the present disclosure will now be described by way of example only, with reference to the appended drawings in which like numerals denote like elements.

Figs. 1a and 1b are schematic plan views of a solar cell module including a plurality of solar cells, wherein Fig. 1a is a front view and Fig. 1b is a back view;

Fig. 2a is a close-up schematic sectional side view of the solar module of Fig. 1a, showing a first solar cell coupled to a second solar cell by an electrode assembly;

Fig. 2b is a plan view of the first and second solar cells shown in Fig. 2a;

Fig. 3 is a schematic sectional side view of a solar cell of the solar cell module of Fig. 1a;

Fig. 4A is a top view of a solar cell that is an example of the invention;

Fig. 4B is a side cross-section view of the solar cell of Figure 4A;

Fig. 5 is a cross-section view of a conductive element that may be used in examples of the invention;

Fig. 6 is a cross-section view of a conventional solar module; and

Fig. 7 is a cross-section view of a solar module that is an example of the present invention.

DETAILED DESCRIPTION

Aspects and embodiments of the present disclosure will now be discussed with reference to the accompanying figures. Further aspects and embodiments will be apparent to those skilled in the art.

Figs. 1a and 1b show a solar cell module 1000 (e.g., solar panel) according to the present disclosure. The solar cell module 1000 includes a plurality of solar cells (including a first solar cell 20 and a second

solar cell 30) which are arranged within a housing 1002 (e.g., a structural frame, or support) of the solar module 1000, as will be described in more detail below. The solar cells are sandwiched between a front plate 1004 and a back plate 1008 of the solar module housing 1002, as is shown in Fig. 2a.

The solar module 1000 includes electrical circuitry (e.g., an electrical assembly) to enable electrical power to be extracted from the solar cells arranged inside the module housing 1002. The electrical circuitry includes a pair of electrical connectors 1012 (as shown in Fig. 1b) which couple the module 1000 to an external circuit (e.g., two adjacent solar modules). The external connector 1012 is connected, at one end, to a junction box 1010 which is arranged on the back side of the solar module 1000 (e.g., mounted to the back plate 1008). At least one further connector provides an electrical connection between the junction box 1010 and the solar cells which are arranged within the module 1000 (e.g., an internal connector). The electrical circuity may include at least one diode (e.g., bypass diodes) which regulates the flow of charge between the solar cells and/or between the solar module and the external electrical circuit. The electrical circuitry components can be arranged within the junction box and/or within the module housing itself. It will be appreciated that the solar module may comprise a plurality of connectors and/or junction boxes as appropriate.

The solar module 1000 has a length which is the horizontal dimension of Figs. 1a and 1b, a width which is the vertical direction of Figs. 1a, 1b and 2a, and a height (or thickness, or depth) which is substantially into the page of Figs. 1a, and 1b, and the vertical direction of Fig 2a.

According to the exemplary arrangement shown in Fig. 1a, the solar module 1000 includes ninety-six solar cells arranged in a rectangular array comprising six rows and sixteen columns (arranged horizontally and vertically, in Fig. 1a, respectively). It will be appreciated that the solar module 1000 may be configured with any number of solar cells (e.g., arranged in different array shapes, and comprising different numbers of columns and rows), without departing from the scope of the present disclosure. At least some of the solar cells are electrically coupled together (e.g., in series) to form a solar cell string. The solar module 1000 includes a plurality of solar cell strings. At least some of the strings are electrically coupled together in series. Two or more of the strings may be coupled together in parallel. Different strings may be connected together using one or more cross-connectors which are mounted within the solar module housing 1002.

The front plate 1004 of the module housing 1002 comprises a transparent (e.g., glass) sheet which is configured to allow light to pass through into a central chamber 1006 in which the solar cells are mounted. The arrows at the top of Fig. 2a show the direction of the solar radiation which is incident upon the solar module 1000 during use. The back plate 1008 is arranged to enclose the solar cells 20, 30 within the central chamber 1006. In one embodiment, the back plate 1008 comprises a reflective sheet which reflects any light incident upon its front surface (i.e., front facing surface) back towards the solar cells. In another embodiment, the back plate 1008 is transparent to allow light to pass through into the central chamber 1006. The central chamber 1006 is filled with an encapsulating material (i.e., the

shaded area shown in Fig. 2a) which prevents ingress of fluid entrants which could degrade the solar module's performance.

Figs. 2a and 2b show a solar cell assembly 10 according to the present disclosure, which is arranged within the housing 1002 of the solar module 1000. In particular, Fig. 2a is a close-up schematic sectional side view of the solar module 10, taken along line A-A shown in Fig. 1a. The solar cell assembly 10 includes the first solar cell 20, the second solar cell 30 and an electrode assembly 12 (e.g., an electrical connector) which is arranged to electrically couple a front surface 22 of the first solar cell 20 to a back surface 34 of the second solar cell 30.

The solar cell assembly 10 is one of a plurality of solar cell assemblies which are arranged within the housing 1002. For example, a front surface 32 of the second solar cell 30 is electrically coupled to the back surface of a third solar cell by a second electrode assembly 14, and a third electrode assembly 16 couples a back surface 24 of the first solar cell 20 to the front surface of a fourth solar cell. It will be understood that the second and third solar cells in this arrangement are electrically coupled together by the second electrode assembly 14 to define a second solar cell assembly. The first, second, third and fourth solar cells are thereby coupled together in series by the electrode assemblies 12, 14, 16 to define a string of solar cells.

Each of the solar cells 20, 30 has a length which is the horizontal dimension of Figs. 2a and 2b, a height (or thickness, or depth) which is the vertical direction of Fig. 2a, and a width which is the vertical direction of Figs. 2a and 2b. Each of the front surfaces 22, 32 of the respective solar cells define a surface upon which light is incident when the solar cell assembly 10 is in use. The back surfaces 24, 34 each define a surface which is opposite to the respective front surface 22, 32.

The solar cells 20, 30 each have a substantially rectangular front and/or back surface (e.g., the solar cell comprises four straight sides arranged at right angles to each other). At least one, or each, of the corners between the sides may be square, or pointed (as shown in Fig. 2b). Alternatively, the corner may be chamfered (or rounded), so as to define a pseudo-rectangular shape. In exemplary arrangements in which the solar cells are each formed from a semiconductor wafer (e.g., a crystalline silicon wafer), then the dimensions of each solar cell may substantially correspond to that of a single wafer (e.g., a whole wafer silicon cell). The solar cells may be formed from a wafer which is cut into a plurality of sections. For example, the planar wafer may be cut along an in-plane direction (e.g., a width or length direction) to define a cut solar cell (e.g., a half-cut solar cell).

The first and second solar cells 20, 30 are spaced apart along the same parallel transverse plane of the solar module 1000 (as shown in Fig. 2a), such that their widthwise and lengthwise dimensions lie in parallel with each other. The electrode assembly 12 extends horizontally along the front surface 22 of the first solar cell 20, it then extends downwards and across a transition region (e.g., diagonally)

between the solar cells, before it then extends in a horizontal direction along the back surface 34 of the second solar cell 30.

Each solar cell 20, 30 includes a layered structure (as is described below in relation to Fig. 3) arranged between its respective front and back surfaces. The layered structure is a multi-layer semiconductor assembly which includes a photovoltaic element (or layer) which is configured to generate electrical charge carriers from the absorption of incident radiation. Each of the solar cells includes finger electrodes arranged on their respective front and back surfaces. The finger electrodes are each configured to form an electrical connection between the solar cell's layered structure and an electrical connector (e.g., the electrode assemblies 14, 16), to enable extraction of electrical charge carriers generated by the solar cell.

Fig. 3 is a cross-sectional side view of a solar cell 50 of the solar cell assembly 10, and solar module 1000 described above in relation to Figs. 1a to 2b. The solar cell 50 has a first (i.e., front) surface 52, upon which light from a radiative source (e.g., the sun) is incident during normal use, and a second (i.e., back) surface 54 that is opposite the front surface 52. That is, the front surface 52 may be configured in use to face the sun, whereas the back surface 54 may be configured in use to face away from the sun.

The front and back solar cell surfaces 52, 54 are each provided with an electrically conductive electrode 56, 58 (e.g., a front electrode 56 and a back electrode 58, respectively), which are configured to extract charge carriers from the solar cell 50. The electrodes 56, 58 are formed of silver, or another suitably conductive material.

The solar cell 50 has a generally layered structure which comprises, among other layers, a photovoltaic element which defines a semiconductor substrate 60. The substrate 60 divides the solar cell 50 into a front portion 62 that is forward (i.e., in front of) of the substrate 60, and a back portion 64 that is rearward of the substrate 60.

The front portion 62 (also referred to herein as a front layered structure) is arranged on the front side of the substrate 60 and the back portion 64 (also referred to herein as a back layered structure) is arranged on the back side of the substrate 60. It will be understood that the layered structure may be formed by sequentially depositing the constituent layers onto the respective front and back surfaces of the substrate 60.

Each of the constituent layers of the front and back portions 62, 64 are configured with a width, a length, and a depth (e.g., thickness or height). The width and length of each layer is measured in perpendicular directions that are aligned with the front and back surfaces of the substrate 60. For each layer, each of its width and length is substantially greater than its depth, which is measured in a direction that is perpendicular to the front and back substrate surfaces.

During operation of the solar cell 50, incident light passes through the front portion 62, the substrate 60 and then the back portion 64. Alternatively, light may also be incident on the solar cell 50 from a rearward direction such that it passes first through the back portion 64, then the substrate 60 and then the front portion 62. In this way, the solar cell 50 may be configured as a bifacial solar cell.

The solar cell 50 includes one or more charge collection elements/layers (e.g., charge collectors), which are configured to extract charge carriers from the substrate 60. The solar cell 50 is provided with an electron-collector 66 and a hole-collector 68 (i.e., electron/hole collectors) arranged on opposite sides of the substrate 60. According to this exemplary arrangement, the solar cell 50 is a back junction solar cell (and, in particular, a back-junction heterojunction solar cell). As such, the electron-collector 66 forms part of the front portion 62, and the hole collector 68 forms part of the back portion 64.

The substrate 60 is formed of crystalline silicon (c-Si), e.g., monocrystalline, polycrystalline silicon. According to the illustrated example, the substrate 60 is an n-type monocrystalline silicon wafer which forms a p-n junction with the p-type hole-collector 68. The electron-collector 66 is doped to be n-type, such that it is configured to extract electrons from the substrate 60. The electron and hole collectors 66, 68 are each formed of hydrogenated amorphous silicon (a-Si:H) material, which is doped with corresponding elements in order to achieve the prescribed conductivity type, as would be understood by the skilled person.

The solar cell 50 further includes one or more passivation elements, which are configured to passivate the interface between the substrate 60 and the respective charge collector elements (e.g., the electron or hole collectors). As such, the passivation elements are generally interposed between the substrate and the respective charge collectors. In the illustrated arrangement, the front layered structure 62 comprises a front-passivation layer 70, which is interposed between the front surface of the substrate 60 and the electron-collector 66. A back-passivation layer 72, of the back layered structure 64, is interposed between the hole-collector 68 and the back surface of the substrate 60. The electron-collector 66 is arranged on a front surface of the front-passivation layer 70 and the hole collector 68 is arranged on a back surface of the back-passivation layer 72. Each of the passivation layers 70, 72 are formed of a substantially intrinsic (i.e., non-doped) semiconductor material (e.g., undoped amorphous silicon material).

The solar cell 50 is further provided with a transparent-conductive oxide (TCO) element arranged on an outer surface (e.g., the outermost surfaces) of the solar cell 50. According to the exemplary arrangement, a front TCO layer 74 and a back TCO layer 76 are arranged at the front and back surfaces of the respective layered structures 62, 64. The front and back TCO layers 74, 76 are each formed of a transparent conductive oxide, such as indium tin oxide (ITO).

The front and back surfaces of the substrate 60 are textured, as would be understood by the skilled person. The subsequent layer(s) of the solar cell (e.g., the electron and hole collectors 66, 68 and the TCO layers 74, 76) each follow the textured profile of the substrate's surfaces. Accordingly, the textured TCO layer 74, 76 provides an anti-reflective outermost surface of the solar cell 50. The front electrode 56 is arranged at a front textured surface of the front-TCO layer 74 and a back electrode 58 is provided at a back textured surface of the back-TCO layer 76, as shown most clearly in Fig. 3.

Figs. 4A and 4B illustrate a solar cell assembly 100 that includes front 101 and rear 101' electrode assemblies arranged on respective front and rear sides of a layered structure 102 comprising a photovoltaic element (not shown) and front 111 and rear conductive surfaces. For brevity only the front electrode assembly 101 is discussed below, but it should be appreciated that the description equally applies to the rear electrode assembly 101' (and for that reason similar reference numerals have been used to label the rear electrode assembly 101').

The front electrode assembly 101 comprises an electrically insulating optically transparent film 103 and a plurality of laterally spaced conductive elements 104a-104f arranged side by side on a surface of the film 103. As will be described further below, the electrode assembly 101 is configured for arrangement on front conductive surface 111 of the layered structure 102 of the solar cell assembly 100 for extracting electrical current generated by a photovoltaic element of the layered structure 102 (in response to light incident on the solar cell assembly 100).

The film 103 is a unitary film as described in WO 2023126154 A1, the contents of which are incorporated herein by reference in their entirety. By 'unitary film' it will be understood, in general, that the film 103 has a unitary construction (i.e. it is formed of a single layer of material, not a plurality of discrete layers), and is formed of a polymeric material.

Each of plurality of conductive elements 104a-104f has a generally rectangular cross-sectional shape (as can be seen from Fig. 4B). That is, the conductive elements 104a-104f have two long faces, which are across the width of the conductive element, and two short faces which are along the depth of the conductive element 104a-104f. The plurality of conductive elements 104a-104f are also evenly spaced, parallel to one another, and extend in a longitudinal direction (the vertical direction in Figs. 4A and 4B). Although only six conductive elements 104a-104f are shown, it should be appreciated that a number of (intermediate) conductive elements are omitted from the figures for clarity. For example, each electrode assembly may comprise a total of between 3 and 30 conductive elements. The cross-sectional shape of each conductive element is described below with respect to Fig. 5.

Although not illustrated, these conductive elements 104a-104f are arranged on a plurality of finger electrodes of the front conductive surface 111 of the layered structure, which extend perpendicularly with respect to the conductive elements 104a-104f. The finger electrodes are evenly distributed across

the surface and carry current from the layered structure 102 to the conductive elements 104a-104f for extraction of the current from the solar cell assembly 100 by the conductive elements 104a-104f.

The layered structure 102 comprises a multi-layer semiconductor assembly including a photovoltaic element in the form of a semiconductor substrate which is sandwiched between a front collector layer and a back collector layer. As such, the front collector layer and the back collector layer are arranged at opposite sides of the substrate. For example, the layered structure may be substantially as described above with respect to Fig. 3.

Fig. 5 shows a cross-sectional view of a conductive element 120 which may be used in examples of the present invention. For example, the conductive element 120 may be used as a conductive element 104 in an electrode assembly as described above with respect to Figs. 4A and 4B. The conductive element 120 has a width 122 and a depth 124 (e.g., a thickness or height), and also has an axial length which extends into the page of Fig. 5, such that the conductive element 120 is a longitudinally extending element. The width 122 of the conductive element 120 is greater than its depth 124. In particular, the width 122 may be in a range of between 0.15 mm and 0.5 mm, and the depth 124 may be in a range of between 0.1 mm and 0.3 mm. These dimensions give the conductive element 120 a generally rectangular cross-sectional shape.

The conductive element 120 has planar long faces 126a, 126b (which may be referred to herein as upper and lower faces) which oppose one another, and curved short faces 128a, 128b (which may be referred to herein as lateral faces) which oppose one another. The curved short faces 128a, 128b are slightly convex, giving the cross-sectional shape of the conductive element 120 the appearance of a truncated circle, which is generally capsule-shaped. In use (i.e., when applied to a solar cell as described above with respect to Figs. 4A and 4B), the conductive element 120 is arranged with the width 122 parallel to the surface of the solar cell, such that a lower face 126b of the conductive element 120 is in contact with the surface of the solar cell. In this way, a greater surface area of the conductive element 120 is in contact with the surface of the solar cell in order to carry electrons. The conductive element 120 is formed from a conductive material, such as copper.

As shown in Fig. 5, the conductive element is coated with an alloy coating 130, shown by the shaded area around the conductive element 120. The coating 130 is predominantly disposed on the long faces 126a, 126b of the conductive element 120, with comparatively little coating 130 present on the short faces 128a, 128b. That is, the depth of the coating 130 is greater on the long faces 126a, 126b than on the short faces 128a, 128b. In particular, the depth/thickness of the coating 130 on the long faces 126a, 126b is around 25 μm, whereas on the short faces 128a, 128b it may be around only 5 μm. In this way, the coating 130 is predominantly present on the faces of the conductive element 120 which may contact the surface of a solar cell, as the coating 130 is configured to solder the conductive element 120 to the surface of a solar cell. Being disposed in this way thereby reduces the cost of the solar cell by reducing the amount of coating 130 which is required. The coating 130 may comprise a metal alloy formed of at

least two or more components. The coating alloy may be at least one of a lead based, tin based, silver based, copper based and bismuth-based alloy, for example.

Known conductive elements are generally provided in the form of wires with a circular cross-section. A comparison of conductive elements configured as shown in Fig. 5, with such known conductive elements will now be made, with reference to Table 1 and Table 2.

Configuration	Width (mm)	Thickness (mm)	Length (mm)	No. of conductive elements	Shadowed area (mm^2)	Shadowed area (% of electrode assembly area)
Round	0.23	0.23	105	20	483	2.2%
Generally rectangular	0.285	0.15	105	20	598.5	2.7%
Generally rectangular	0.24	0.18	105	20	504	2.3%

Table 1

Table 1 shows a comparison of known conductive elements, having a circular cross-section (round configuration), with two conductive elements having a generally rectangular cross-section, as examples of the present invention. For the comparison, an electrode assembly is considered, the electrode assembly comprising a foil or film having a width of 210 mm and a length of 105 mm, with 20 conductive elements arranged thereon (e.g., as described above with respect to Figs. 4A and 4B). The shadowed area is the total area of the foil which is covered by the conductive elements, and which therefore cannot receive light, such that the area of the solar cell cannot contribute to generation of electricity. It will therefore be appreciated that a smaller shadowed area is therefore generally preferred, though trade-offs may be made for other advantages.

As can be seen in Table 1, the conventional conductive element (round) shadows a total area of 483 mm^2 which is 2.2% of the area of the foil. In comparison, a conductive element according to the present invention, having a generally rectangular cross-sectional shape of width 0.285 mm shadows a total area of 2.7% of the area of the foil, and with a width of 0.24 mm the total area of the foil which is shadowed is 2.3%. It can therefore be seen that while a width of 0.285mm shadows a substantially larger area (0.5% larger than the conventional conductive element), the generally rectangular cross-section with a width of 0.24mm shadows a similar area as the conventional conductive element (only 0.1% larger). However, this increased shadowed area is countered by the increased cross-sectional area, which leads to decreased resistance (or, equivalently, increased conductance) as described below with respect to Table 2. In addition, by placing a planar or flat face in contact with the surface of a solar cell (e.g., as described above), the greater shadowed area provided by the present invention may also correspond with greater uptake of electrons from the solar cell, which may improve performance.

Configuration	Width (mm)	Depth (mm)	Area (mm^2)
Round	0.23	0.23	0.0415
Generally rectangular	0.285	0.15	0.0428
Generally rectangular	0.24	0.18	0.0432

Table 2

Table 2 shows a comparison of known conductive elements, having a circular cross-section (round configuration), with two conductive elements having a generally rectangular cross-section, as examples of the present invention. Dimensions of the conductive elements are given, as well as the resulting cross-sectional area.

The resistance of a conductive element is found by the equation:

$$R = \frac{\rho L}{A}$$

where R is the resistance of the conductive element, ρ is the resistivity of the conductive element, L the length of the conductive element, and A the cross-sectional area of the conductive element. It will therefore be appreciated that, assuming the conductive elements are made of the same material (e.g., copper), and have the same length (e.g., 105 mm), the conductive element having a higher cross-sectional area will have a lower resistance, and will therefore improve performance of a solar cell and solar module. In particular, in the case of the generally rectangular conductive element having a width of 0.24 mm, this improvement comes with a similar shadowed area, as described with respect to Table 1, such that the trade-off for improved resistance is minor.

Considering Table 2, it can therefore be seen that a generally rectangular conductive element, according to the present invention, may have a greater cross-sectional area and so lower resistance than a conventional conductive element, thereby having a lower resistance. In addition, the surface area of the conductive element in contact with the surface of the solar cell may increase and improve uptake of electrons from the solar cell.

Fig. 6 is a cross section view of a conventional solar module 200, wherein the conductive elements 210, 210' have a circular cross-sectional shape. The solar module 200 may be generally configured as described above with respect to Figs. 1a and 1b. Fig. 6 shows a cross-section view through a solar cell 220 which is arranged below a front plate 205, the solar cell 220 having a first electrode assembly on an upper surface therefore, and a second electrode assembly on a lower surface thereof, similar to the arrangement described above with respect to Fig. 4B. Between the front plate 205 and the electrode assembly on the upper surface of the solar cell 220 is arranged an encapsulant 225 to prevent the ingress of moisture into the solar module 200. Encapsulant 225' is also arranged between the lower surface of the solar cell 220 and a back plate (note shown).

Each electrode assembly comprises a plurality of longitudinally extending, laterally spaced conductive elements 210, 210', and an insulating optically transparent film 230, 230' which overlies the conductive elements 210, 210' for maintaining the conductive elements 210, 210' in their spaced arrangement during mounting to the solar cell 220. Each of the conductive elements 210, 210' has a circular cross-sectional shape, with a diameter of 0.23 mm. Each conductive element 210, 210' also has an alloy coating 215, 215' which, as shown in Fig. 6, has flowed under heating in order to solder the conductive element 210, 210' to the surface of the solar cell 220.

The depth of the encapsulant 225, 225' is important to the durability of lifespan of the solar module 200. Generally, a deeper encapsulant 225, 225' layer may increase the lifespan of the solar module 200, but increases the cost of manufacturing the solar module 200.

Arrow A indicates the depth of the encapsulant 225 between the front plate 205 and the insulating optically transparent film 230, at the conductive element 210. In this example, the depth of the encapsulant as indicated by arrow A is 170 µm.

Arrow B indicates the depth distance between the front plate 205 and the conductive element 210 (i.e., the depth including the encapsulant 225 and the film 230 between the front plate 205 and the conductive element 210). In this example, the distance as indicated by arrow B is 270 µm.

Arrow C indicates the depth of the encapsulant 225 between the front plate 205 and the insulating optically transparent film 230, at a region away from the conductive element 210. In this example, the depth of the encapsulant as indicated by arrow C is 500 µm.

Fig. 7 is a cross section view of a solar module 300 which is an example of the present invention, wherein the conductive elements 310, 310' have a generally rectangular cross-sectional shape. For example, the conductive elements 310, 310' have a cross-sectional shape as described above with respect to Fig. 5. In particular, as shown in Fig. 7, the conductive elements 310, 310' have a generally rectangular cross-sectional shape with a width of 0.24 mm and a depth of 0.18 mm. The solar module 300 may be generally configured as described above with respect to Figs. 1a and 1b. Fig. 7 shows a cross-section view through a solar cell 320 which is arranged below a front plate 305, the solar cell 320 having a first electrode assembly on an upper surface thereof, and a second electrode assembly on a lower surface thereof, similar to the arrangement described above with respect to Fig. 4B. Between the front plate 305 and the electrode assembly on the upper surface of the solar cell 320 is arranged an encapsulant 325 to prevent the ingress of moisture into the solar module 300. Encapsulant 325' is also arranged between the lower surface of the solar cell 320 and a back plate (note shown). The encapsulant 325, 325' is a polymer resin, for example comprising a polyolefin elastomer (POE).

Each electrode assembly comprises a plurality of longitudinally extending, laterally spaced conductive elements 310, 310', and an insulating optically transparent film 330, 330' which overlies the conductive

elements 310, 310' for maintaining the conductive elements 310, 310' in their spaced arrangement during mounting to the solar cell 320. Each conductive element 310, 310' also has an alloy coating which has flowed under heating in order to solder the conductive element 310, 310' to the surface of the solar cell 320.

The depth of the encapsulant 325, 325' is important to the durability of lifespan of the solar module 300. Generally, a deeper encapsulant 325, 325' layer may increase the lifespan of the solar module 300, but increases the cost of manufacturing the solar module 300. However, by providing conductive elements 310, 310' having a generally rectangular cross-section as described herein, the effective thickness of the encapsulant 325, 325' may be maintained while using less of the encapsulant material, reducing the cost of manufacturing the solar module 300. Alternatively, in other examples, the effective thickness may be increased while using the same amount of encapsulant material.

Arrow A indicates the depth of the encapsulant 325 between the front plate 305 and the insulating optically transparent film 330, at the conductive element 310. In this example, the depth of the encapsulant as indicated by arrow A is 220 μm. It will be appreciated that this is an increase in depth of 50 μm from the conventional arrangement described above with respect to Fig. 6.

Arrow B indicates the distance between the front plate 305 and the conductive element 310 (i.e., the depth including the encapsulant 325 and the film 330 between the front plate 305 and the conductive element 310). In this example, the distance indicated by arrow B is 320 μm. It will be appreciated that this is an increase of 50 μm from the conventional arrangement described above with respect to Fig. 6.

As a result of this increase, the solar module 300 will have increased durability and a longer lifespan when compared with the conventional solar module 200. In particular, the increased depth of the encapsulant 325 in this region ensures that expansion and contraction of the conductive element 310 due to cycles of heating and cooling is less likely to disrupt the front plate 305 over time, increasing the longevity of the solar module 300. In other examples, the durability of the solar module 300 may be maintained relative to that of the conventional solar module 200 by reducing the overall thickness of the encapsulant layer by 50 μm, which would reduce the manufacturing costs.

Arrow C indicates the depth of the encapsulant 325 between the front plate 305 and the insulating optically transparent film 330, at a region away from the conductive element 310. In this example, the depth of the encapsulant as indicated by arrow C is 500 μm (greater than twice the depth of the conductive element 310). This is the same as the convention solar module 200 described above, and so it will be appreciated that the increased durability of the solar module 300 is provided without requiring a significant increase in the amount of encapsulating material which is used.

EXAMPLES

Experimental data illustrating the improvement in solar cell reliability arising from the present invention is discussed below in relation to first and second example solar modules and a comparative example solar module subjected to different degradation simulation treatments.

The first example solar module comprises at least one solar cell, an electrode assembly, a front plate and a back plate which are arranged, respectively, on the front and back sides of the at least one solar cell, and an encapsulant arranged between the front plate, the back plate, and the at least one solar cell. The electrode assembly comprises an insulating optically transparent film; and a plurality of longitudinally extending, laterally spaced conductive elements arranged parallel to one another on a surface of the film, each conductive element having a generally rectangular cross-sectional shape, wherein a width of each conductive element is 0.285 mm and a thickness of each conductive element is 0.15 mm. Each electrode assembly is arranged in ohmic contact with a conductive surface of a respective solar cell. In the first example solar module, the thickness of encapsulant between the front plate and the at least one solar cell is 400 µm and the thickness of encapsulant between the back plate and the at least one solar cell is 400 µm. The encapsulant in the first example solar module is a polyolefin elastomer.

The second example solar module comprises the same structure as the first example solar module, but with a thickness of encapsulant between the front plate and the at least one solar cell of 450 µm and the thickness of encapsulant between the back plate and the at least one solar cell is 450 µm.

The comparative example solar module comprises at least one solar cell, an electrode assembly, a front plate and a back plate which are arranged, respectively, on the front and back sides of the at least one solar cell, and an encapsulant arranged between the front plate, the back plate, and the at least one solar cell. The electrode assembly comprises an insulating optically transparent film; and a plurality of longitudinally extending, laterally spaced conductive elements arranged parallel to one another on a surface of the film, each conductive element having a generally circular cross-sectional shape, wherein a diameter of each conductive element is 0.23 mm. Each electrode assembly is arranged in ohmic contact with a conductive surface of a respective solar cell. In the comparative example solar module, the thickness of encapsulant between the front plate and the at least one solar cell is 500 µm and the thickness of encapsulant between the back plate and the at least one solar cell is 500 µm. The encapsulant in the comparative example solar module is a polyolefin elastomer.

It is noted that the comparative example solar module is identical to both the first and second example solar modules except with reference to the cross-sectional shape of the conductive elements, the thickness of the conductive elements, the width of the conductive elements, the thickness of the encapsulant between the front plate and the at least one solar cell, and the thickness of the encapsulant between the back plate and the at least one solar cell.

Table 3 provides data on the performance of the First and Second Example solar modules and the Comparative Example solar module following a degradation simulation treatment. The degradation simulation treatment is a Humidity Freeze test in accordance with IEC 61215. The test conducted comprises a cycle of injecting moisture into the solar module by increasing the temperature from ambient (25°C) to 85°C with a relative humidity of 85%, then reducing the temperature to -40°C, and then increasing the temperature ambient again, with this cycle being repeated 10 times. The dwell time at 85°C and 85% relative humidity is at least 20 hours, the dwell time at -40°C is at least 30 minutes. The purpose of test is to assess the module's durability and reliability as well as its performance. When the temperature rises, plastic materials in the module become more vulnerable to moisture. Polymer materials can change their physical properties and increase moisture permeability, and in some cases, moisture may remain in the module. When the temperature decreases, any humidity remaining inside of modules can freeze and form ice. This can cause physical damages to the solar module and/or its components due to the volume expansion of about 10% between liquid water and ice.

Table 3 reports the percentage reduction in the power output of the solar modules at the maximum power point (Pmp) between (i) the power output prior to the humidity freeze test and (ii) the power output following the humidity freeze test. Two samples of each example and comparative example were subjected to testing and the mean percentage reduction in power output at the maximum power point taken.

Configuration	% reduction in Pmp following Humidity Freeze Test
First Example	2.28
Second Example	2.37
Comparative Example	2.50

Table 3

Surprisingly, as illustrated in Table 3, the Comparative Example solar module has the largest % reduction in power output following the treatment, indicating that the Comparative Example solar module is less durable than the First Example and Second Example solar modules; this is despite the Comparative Example having the greatest thickness of encapsulant. The % reduction in power output for the First Example and Second Example are similar. The First Example and Second Example solar modules also have a reduced cost per module compared to the Comparative Example, as a result of comprising a smaller volume of encapsulant per module, even accounting for the increased cross-sectional area of the conductive elements.

It is to be understood that the present disclosure is not limited by specific construction details or process steps set forth in the following description and accompanying drawings. Rather, it will be apparent to those skilled in the art having the benefit of the present disclosure that the systems, apparatuses and/or

methods described herein could be embodied differently and/or be practiced or carried out in various alternative ways.

Unless otherwise defined herein, scientific and technical terms used in connection with the presently disclosed inventive concept(s) shall have the meanings that are commonly understood by those of ordinary skill in the art, and known techniques and procedures may be performed according to conventional methods well known in the art and as described in various general and more specific references that may be cited and discussed in the present specification.

All examples implementing the present disclosure can be made and executed without undue experimentation in light of the present disclosure. While particular examples have been described, it will be apparent to those of skill in the art that variations may be applied to the systems, apparatus, and/or methods and in the steps or in the sequence of steps of the methods described herein without departing from the concept, spirit, and scope of the inventive concept(s). All such similar substitutions and modifications apparent to those skilled in the art are deemed to be within the spirit, scope, and concept of the inventive concept(s) as defined by the appended claims.

In the drawings, the thickness of layers, films, elements etc., are exaggerated for clarity. Furthermore, it will be understood that when an element such as a layer, film, region, or substrate is referred to as being “on” another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly on” another element, there are no intervening elements present.

The use of the term “a” or “an” in the claims and/or the specification may mean “one,” as well as “one or more,” “at least one,” and “one or more than one.” As such, the terms “a,” “an,” and “the,” as well as all singular terms, include plural referents unless the context clearly indicates otherwise. Likewise, plural terms shall include the singular unless otherwise required by context.

The use of the term “or” in the present disclosure (including the claims) is used to mean an inclusive “and/or” unless explicitly indicated to refer to alternatives only or unless the alternatives are mutually exclusive. For example, a condition “A or B” is satisfied by any of the following: A is true (or present), and B is false (or not present), A is false (or not present), and B is true (or present), and both A and B are true (or present).

As used in this specification and claim(s), the words “comprising, “having,” “including,” or “containing” (and any forms thereof, such as “comprise” and “comprises,” “have” and “has,” “includes” and “include,” or “contains” and “contain,” respectively) are inclusive or open-ended and do not exclude additional, unrecited elements or method steps.

Unless otherwise explicitly stated as incompatible, or the physics or otherwise of the embodiments, examples, or claims prevent such a combination, the features of examples disclosed herein, and of the claims, may be integrated together in any suitable arrangement, especially ones where there is a beneficial effect in doing so. This is not limited to only any specified benefit, and instead may arise from an "ex post facto" benefit. This is to say that the combination of features is not limited by the described forms, particularly the form (e.g., numbering) of example(s), embodiment(s), or dependency of claim(s). Moreover, this also applies to the phrase "in one embodiment," "according to an embodiment," and the like, which are merely a stylistic form of wording and are not to be construed as limiting the following features to a separate embodiment to all other instances of the same or similar wording. This is to say, a reference to 'an,' 'one,' or 'some' embodiment(s) may be a reference to any one or more, and/or all embodiments, or combination(s) thereof, disclosed. Also, similarly, the reference to "the" embodiment may not be limited to the immediately preceding embodiment. Further, all references to one or more embodiments or examples are to be construed as non-limiting to the claims.

The present disclosure may be better understood in view of the following explanations, wherein the terms used that are separated by "or" may be used interchangeably:

CLAIMS

1. An electrode assembly for a solar cell, the electrode assembly comprising:

an insulating optically transparent film; and

a plurality of longitudinally extending, laterally spaced conductive elements arranged parallel to one another on a surface of the film, each conductive element having a generally rectangular cross-sectional shape, wherein a width of each conductive element is between 0.15 mm and 0.5 mm and a thickness of each conductive element is between 0.1 mm and 0.3 mm, and wherein the width of each conductive element is greater than the depth of each conductive element.

2. An electrode assembly according to claim 1, wherein each conductive element comprises opposing lateral faces which are curved, such that the generally rectangular cross-sectional shape of each conductive element is a truncated circle.

3. An electrode assembly according to claim 1 or claim 2, wherein each conductive element is coated with an alloy coating which comprises an alloy having a lower melting point than the conductive element.

4. An electrode assembly according to claim 3, wherein the thickness of the coating is less than 50 μm.

5. An electrode assembly according to claim 3 or claim 4, wherein the coating is predominantly disposed on at least one of the long faces of each conductive element.

6. An electrode assembly according to any preceding claim, wherein the width of each conductive element is 0.24 mm and the depth of each conductive element is 0.18 mm.

7. An electrode assembly according to any preceding claim, wherein the insulating optically transparent film is a unitary film formed of a polymeric material.

8. An electrode assembly according to any preceding claim, comprising between 3 and 30 longitudinally extending, laterally spaced conductive elements.

9. A solar cell assembly comprising:

a layered structure comprising a photovoltaic element and a conductive surface; and

an electrode assembly comprising a plurality of longitudinally extending, laterally spaced conductive elements arranged parallel to one another on a surface of the film, each conductive element having a generally rectangular cross-sectional shape, wherein a width of each conductive element is between 0.15 mm and 0.5 mm and a thickness of each conductive element is between 0.1 mm and 0.3

mm, and wherein the width of each conductive element is greater than the thickness of each conductive element,

the electrode assembly arranged on the conductive surface of the layered structure such that the conductive elements are in ohmic contact with the conductive surface.

10. A solar cell assembly according to claim 9, wherein the electrode assembly is an electrode assembly according to any one of claims 1 to 8.

11. A solar module comprising:

at least one solar cell assembly according to claim 9 or claim 10;

a front plate and a back plate which are arranged, respectively, on the front and back sides of the at least one solar cell, wherein at least one of the front plate and the back plate is transparent; and

an encapsulant arranged between the front plate, the back plate, and the at least one solar cell to prevent the ingress of moisture into the solar module.

12. The solar module according to claim 11, wherein a depth of the encapsulant between the front plate or the back plate and an insulating optically transparent film of a solar cell, at a region away from a conductive element, is at least twice the thickness of the conductive element.

13. The solar module according to claim 11 or claim 12, wherein a depth of the encapsulant between the front plate or the back plate and an insulating optically transparent film of a solar cell, at a region away from a conductive element, is at least 400 μm.

14. The solar module according to any one of claims 11 to 13, wherein a depth of the encapsulant between the front plate or the back plate and the insulating optically transparent film of the solar cell, at the conductive element, is at least 200 μm.

15. The solar module according to any one of claims 10 to 13, wherein a distance between the front plate or the back plate and a conductive element of a solar cell, is at least 300 μm.