

A BACK-CONTACT SOLAR CELL

FIELD OF THE INVENTION

5 The present invention relates to a back-contact solar cell and a method of manufacturing a back-contact solar cell.

BACKGROUND OF THE INVENTION

10 Solar cells based on perovskite materials represent a promising development in photovoltaic technology. Known perovskite solar cells have a light-absorbing (e.g. photoactive) layer that comprises a perovskite-structured compound (e.g. a perovskite layer). Perovskite-structured compounds typically include a hybrid organic-inorganic lead, or tin, halide-based material, that are configured to absorb solar radiation

15 Known perovskite solar cells typically employ a mesoscopic, or planar heterojunction, device architecture in which the perovskite layer is sandwiched between an electron-transport layer (ETL) and a hole-transport layer (HTL) e.g. a p-i-n or n-i-p junction structure. Other types of solar cells can also employ a mesoscopic, or planar heterojunction, device architecture, for example, copper indium gallium selenide (CIGS) solar cells (where the perovskite layer in the above architecture is replaced by a CIGS layer), copper zinc tin sulphide (CZTS) solar cells (where the perovskite layer in the above architecture is replaced by a CZTS layer), or amorphous silicon (a-Si) solar cells (where the perovskite layer in the above architecture is replaced by an a-Si layer). To complete the device structure, electrodes are positioned on the front and back sides of the solar cell. A first electrode is arranged adjacent the electron transport layer (e.g. an electron-collecting / negative electrode) and a second electrode is arranged adjacent the hole-transport layer (e.g. a hole-collecting / positive electrode), with each electrode being configured to extract charge carriers from the respective transport layers, when the solar cell is in use.

30 The device layers are built-up sequentially onto a substrate (e.g. a glass substrate) which is typically transparent to allow solar radiation to reach the light-absorbing layer. A transparent conducting oxide (TCO) is used for at least one of the electrodes, to enable illumination of the active layers from the TCO side of the device. A counter electrode is arranged on the opposite side of the device, which is typically made of a metal, or metal alloy.

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A known problem of such device structures is that the deposition of multiple layers can increase the risk of introducing defects into the solar cell, which can reduce the charge carrier extraction efficiency. In particular, the deposition of a charge carrier layer onto the perovskite layer requires a high temperature deposition method (and/or post deposition heat treatment), at
5 which the perovskite materials are thermally unstable. Moreover, parasitic adsorption of photons by the layers of the cell that photons must travel through to reach the perovskite layer reduces the solar cell's efficiency.

An alternative device architecture involves co-positioning the charge-transport layers and the
10 electrodes on one side of the solar cell (e.g. the back side) in an interdigitated configuration. Such device architectures can remove the need to deposit materials onto the perovskite layer. However, a problem with this type of device structure is that it involves the at least partial removal (e.g. abrasion or etching) of the charge-transport, charge-collecting electrode, and/or
15 perovskite layers, which can damage them and thereby increase the number of defects within the solar cell. The greater the number of defects within a given solar cell is, the lower the efficiency of the cell will be because of the recombination of charge carriers that can occur at defects.

The present invention aims to address one or more of the above problems with existing solar
20 cells.

SUMMARY OF THE INVENTION

A first aspect of the present invention provides a back-contact solar cell, comprising: a
25 substrate; a first solar cell portion and a second solar cell portion arranged on the substrate, wherein each of the first and second solar cell portions comprises: a light-absorber element; a back-contact structure interposed between the light-absorber element and the substrate; and an insulator assembly; wherein: the back-contact structure comprises a first electrode and a second electrode arranged on the substrate; and each of the first and second electrodes is
30 electrically connected to the light-absorber element; and wherein the insulator assembly comprises, for each solar cell portion, a first insulator that insulates the associated first electrode from the associated second electrode; wherein the first solar cell portion is electrically connected in series with the second solar cell portion.

35 By providing the first insulator between the first and second electrodes of each respective solar cell portion, this allows the solar cell portions to be connected in series across the substrate.

The resulting device architecture means that there is no need to destructively remove (e.g. by abrasion or etching) any part of the light-absorber elements, which thereby reduces the likelihood of forming defects in the solar cell. The back-contact structure also removes the need to provide a 'front' electrode formed of a transparent conductive material. For example,
5 each of the electrodes may be formed from a non-transparent conductive material (e.g. a metal or metal alloy), which may have a lower electrical resistance. Reducing the electrical resistance of the electrodes can increase the performance of the solar cell. Furthermore, by removing the need for a front electrode, the back-contact structure also reduces shading of the light-absorber element and thereby increases the optical efficiency of the solar cell.

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Optional features will now be set out. These are applicable singly or in any combination with any aspect.

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The solar cell may have a first and a second dimension (e.g. a width and a height, respectively), which are both parallel to a planar surface of the substrate upon which the solar cell portions may be arranged. The plurality of solar cell portions may be arranged (e.g. deposited) on an upper (e.g. front) surface of the substrate (upon which light is incident in normal use). The solar cell may extend substantially across the entire length and/or the entire width of the substrate. The solar cell may comprise a third dimension (e.g. a height) which is perpendicular to the first
20 and second dimensions, and is also perpendicular to the upper surface of the substrate upon which the solar cell is arranged.

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The solar cell may comprise two or more solar cell portions arranged on the substrate. The first and second solar cell portions may be arranged adjacently to each other in a first direction which is parallel to the first dimension of the substrate (e.g. a widthways direction of the substrate). The plurality of solar cell portions may be arranged in a row (i.e. in the width direction) across the substrate. Each of the plurality of solar cell portions may extend in a second direction that is perpendicular to the first dimension of the substrate (e.g. a lengthways direction of the substrate). Accordingly, each of the composite elements of each solar cell
30 portion (e.g. the light-absorber element, and the back-contact structure) may also extend across the substrate in the second direction. The solar cell may comprise a thickness (or height) that is measured in a third direction that is perpendicular to both the first and second directions (e.g. parallel to the third dimension of the substrate).

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In an exemplary arrangement, the solar cell may comprise a third solar cell portion that comprises the same components as the first and second solar cell portions. The third solar cell

portion may be arranged adjacently to the second solar cell portion such that the second solar cell portion is interposed between the first and third solar cell portions in the first direction. The third solar cell portion may be electrically connected in series to the second solar cell portion.

5 The second electrode of the first solar cell portion may be directly connected to the first electrode of the second solar cell portion, which facilitates the series electrical connection between the first and second solar cell portions. The second electrode of the first solar cell portion may be formed integrally with the first electrode of the second solar cell portion. In this way, the electrodes of adjacently positioned solar cell portions may be formed together, which
10 increases the robustness and reliability of the electrical series connections within the solar cell. This also electrically connects these electrodes without any additional steps being required. In exemplary arrangements comprising a third solar cell portion, the second electrode of the second solar cell portion may be connected to (e.g. formed integrally with) the first electrode of the third solar cell portion.

15 The light-absorber element may be configured with a front surface (upon which light is incident in normal use) and a back surface, opposite the front surface. The back surface may be configured to contact the back-contact structure. It will be appreciated that a back-contact structure defines a contact arrangement of the solar cell in which the electrodes (e.g. the
20 positive and negative electrodes) are both arranged on the back side of the solar cell (upon which light is not incident in normal use). For example, the electrodes may only be arranged on the back side of the solar cell (e.g. with no electrodes arranged on the front side of the solar cell).

25 The first insulator may define a first insulator portion or first insulator element. The insulator assembly may comprise a plurality of first insulators (e.g. comprising at least one first insulator for each of the first and second solar cell portions). The first insulator may be directly interposed between the first and second electrodes of at least one, or each, of the solar cell portions.

30 The first insulator may be interposed between the light-absorber element and the substrate. Accordingly, the light-absorber element may be arranged on top of the first insulator. The first insulator may be configured to insulate at least a portion of the light-absorber element from the first and/or second electrodes i.e. the portion of the light-absorber element in contact with the first electrode may be separated from the portion of the light-absorber element in contact with
35 the second electrode. For example, the first insulator may space apart the portion of the light-absorber element in contact with the first electrode from the portion of the light-absorber

element in contact with the second electrode in the first direction by virtue of the width of the first insulator in the first direction. In this way, the first insulator is configured to prevent short circuiting between the electrodes via the light-absorber element.

5 The first insulator for each solar cell portion may be interposed between the first electrode and second electrode of that solar cell portion in the first direction (e.g. which is parallel to the first dimension of the substrate). In this way, the first and second electrodes may be provided in the same plane as each other that is parallel to the front surface of the substrate (e.g. only offset from each other in the first direction). The first insulator may extend in the second
10 direction (e.g. which is substantially perpendicular to the first direction, and substantially parallel to the second dimension of the substrate). The first insulator may comprise a first dimension (e.g. a width) and a second dimension (e.g. a length) that are aligned with the respective first and second dimensions of the substrate. The second dimension (e.g. the length) of first insulator may extend substantially (e.g. entirely) across the substrate.
15 Accordingly, the first and second electrodes of each cell portion may be separated along their lengths by the first insulator, to thereby prevent short circuiting within each solar cell portion.

The insulator assembly may comprise a second insulator that insulates the light-absorber element of the first solar cell portion from the light-absorber element of the second solar cell portion. In this way, the second insulator may be configured to insulate between the light-absorber elements of adjacently positioned solar cell portions. The insulator assembly may comprise a plurality of second insulators, optionally with each pair of adjacent light-absorber elements having a second insulator interposed therebetween (e.g. in a solar cell comprising n solar cell portions connected in series, the insulator assembly may comprise at least $n-1$
25 second insulators). For example, where the solar cell comprises only the first and second solar cell portions, the solar cell may comprise a single second insulator insulating the light-absorber elements of the solar cell portions from each other. In another example, a pair of second insulators may be arranged either side of a given solar cell portion to form electrically insulating bulkheads (i.e. the insulator assembly comprising $n+1$ second insulators). The number of
30 second insulators relative to the number of solar cell portions may be dependent on how the solar cells are cut following fabrication. The pair of second insulators prevent leakage of charge carriers between the light-absorber element of the second solar cell portion and the light-absorber element of the adjacently positioned solar cell portions (e.g. the light-absorber elements of the first and third solar cell portions).

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The second insulator may be interposed between the light-absorber elements of the first and second solar cell portions in the first direction of the substrate. The second insulator may extend in the second direction. Accordingly, the first insulator may be substantially parallel to the second insulator. In this way, the light-absorber elements of the first and second solar cell portions may be provided in the same plane as each other that is parallel to the front surface of the substrate (e.g. only offset from each other in the first direction).

The second electrode of the first solar cell portion and/or the first electrode of the second solar cell portion may be interposed between the second insulator and the substrate. Accordingly, the second insulator may be arranged on a front surface of at least one of the second electrode of the first solar cell portion and the first electrode of the second solar cell portion.

The second insulator may comprise a first dimension (e.g. a width) and a second dimension (e.g. a length) that are aligned with the respective first and second dimensions of the substrate. The second dimension (e.g. the length) of second insulator may extend substantially (e.g. entirely) across the substrate in the second direction. Accordingly, the light-absorber elements of neighbouring solar cell portions may be separated along their lengths by the second insulator, to thereby prevent short circuiting between neighbouring solar cell portions.

The back-contact structure may further comprise a first charge-transport element configured in use to transport a first charge carrier from the light-absorber element to the first electrode. The back-contact structure may further comprise a second charge-transport element configured in use to transport a second charge carrier from the light-absorber element to the second electrode. The first insulator for each solar cell portion may insulate the first charge-transport element from the second charge-transport element (e.g. of each of the first and second solar cell portions). The first charge-transport element may be arranged on the first electrode (e.g. (vertically) interposed between the first electrode and light-absorber element). The second charge-transport element may be arranged on the second electrode (e.g. (vertically) interposed between the second electrode and light-absorber element).

In some embodiments, the first insulator for each solar cell portion is directly interposed between the associated first charge-transport element and associated the second charge-transport element. Accordingly, the first and second charge-transport elements (e.g. within each of the first and second solar cell portions and between adjacent solar cell portions) may be separated and thereby insulated from each other by the first and second insulators.

The first insulator for each solar cell portion may comprise a height that is measured in the third direction (e.g. which is perpendicular to the front surface of the substrate on which the solar cell portions are arranged). At least one, or each, of the charge-transport elements in a solar cell portion (e.g. the first and/or second solar cell portion) may comprise a height that is less than the height of the first insulator for that solar cell portion. At least one, or each, of the first and second electrodes in a solar cell portion (e.g. the first and/or second solar cell portion) may comprise a height that is less than the height of the first insulator for that solar cell portion. The first insulator may be at least as tall as one of the charge-transport elements arranged on top of (e.g. vertically) one of the electrodes. The first insulator may comprise a height that is at least as great as the combined height of the first electrode and the first charge-transport element (e.g. when arranged one on top of the other). The height of the first insulator may be at least as great as the combined height of the second electrode and the second charge-transport element (e.g. when arranged one on top of the other). Accordingly, the first insulator may be configured to prevent charge carriers from flowing from the first electrode of one of the solar cell portions to the second charge-transport element of the same solar cell portion, and vice versa. Similarly, the first insulator may also be configured to prevent charge carriers from flowing from the second electrode of the solar cell portion to the first charge-transport element of that solar cell portion, or vice versa, and/or from the first electrode of the solar cell portion to the second charge-transport element of that solar cell portion, or vice versa.

In an exemplary arrangement, the second insulator may insulate the second charge-transport element of the first solar cell portion from the first charge-transport element of the second solar cell portion. The second insulator may be arranged between adjacent charge-transport elements of the first and second solar cell portions. Accordingly, the adjacent charge transport elements may be spaced apart by the second insulator in the first direction, with the second insulator interposed therebetween (such that there is no direct contact between the second and first charge-transport elements, only being indirectly connected via the second and first electrodes).

The light absorber element of a solar cell portion may be arranged (e.g. disposed or deposited) on at least one of the first and second charge transport elements of that solar cell portion, to enable the respective charge carriers to be extracted from the light-absorber element. The second insulator may comprise a height that is measured in the third direction (e.g. which is perpendicular to the front surface of the substrate on which the solar cell portions are arranged). At least one, or each, of the charge-transport elements of a solar cell portion may comprise a height that is less than the height of the second insulator. The light-absorber

element of a solar cell portion may comprise a height that is less than the height of the second insulator. The second insulator may be at least as tall as the height of the light-absorber element arranged on top of one of the charge-transport elements (i.e. the front surface of the second insulator may be spaced further from the substrate than the front surface of the light-absorber element).

The second insulator may comprise a height that is at least as great as the combined height of the light-absorber element and the first charge-transport element of the first solar cell portion (e.g. when stacked vertically). The height of the second insulator may be at least as great as the combined height of the light-absorber element and the second charge-transport element of the second solar cell portion. In this way, the second insulator may be configured to prevent charge carriers from flowing from the light-absorber element of one solar cell portion to the charge-transport element of the second solar cell portion (and vice versa).

The solar cell may be electrically coupled to an external circuit (e.g. when the solar cell is to be used). In particular, the external circuit may be electrically connected to the electrodes of a pair of solar cell portions that are arranged at the lateral sides of the solar cell (e.g. the lateral sides of the substrate). For example, one of the first and second electrodes (e.g. a positive electrode) of a first solar cell portion that is arranged at a first lateral side of the solar cell may be connected to a positive terminal of the electrical circuit, and the other of the first and second electrodes (e.g. a negative electrode) of a second solar cell portion that is arranged at a second lateral side of the solar cell (opposite the first lateral side) may be connected to a negative terminal of the electrical circuit. As described above, the first and second solar cell portions may be connected in series (e.g. with a further solar cell portion connected in series between the first and second solar cell portions) to complete the electrical circuit.

When the solar cell is in use, a photon of light may be absorbed by the light-absorber element of the first solar cell portion, thereby generating an exciton (e.g. an electron-hole pair). The exciton may dissociate to form separate positive and negative charge carriers (e.g. an electron and a hole) which flow to the respective positive and negative electrodes of the first solar cell portion. In an exemplary arrangement, the first electrode is a positive electrode that is connected to a positive terminal of the external electrical circuit and the second electrode is a negative electrode that is connected in series with the positive electrode (e.g. first electrode) of the second solar cell portion. In this case, the hole is extracted to the positive terminal of the external electrical circuit via the positive electrode of the first solar cell portion. The electron flows towards the negative electrode of the first solar cell portion. From there, the electron

flows through the second solar cell portion (e.g. sequentially, through the positive electrode, the light-absorber element and the negative electrode) before being collected by the negative terminal of the external electrical circuit. Accordingly, the photo-generated holes in the second solar cell portion are directed on a flow path through the first solar cell portion to the positive terminal of the electrical circuit, whereas photo-generated electrons in the second solar cell portion are conducted directly to the negative terminal of the electrical circuit.

At least one, or each, of the first and second solar cell portions may comprise a passivating element / layer (e.g. an encapsulant layer) arranged on the light-absorber element. As such, the light-absorber element may be interposed between the passivating element and the substrate. The passivating element may be formed of an optically transparent material (e.g. SiO_x , SiC , SiN_x , or SiO_xN_y , where x and y are positive numbers, or LiF , or MgF_2). The passivating element may comprise an air and/or liquid impermeable material. As such, the passivating element may encapsulate the other components of the solar cell, and thereby prevent the ingress of moisture and/or air into the solar cell. The passivating element of the first solar cell portion may be insulated from the passivating element of the second solar cell portion by the second insulator e.g. the second insulator may be interposed between the adjacent passivating elements in the first direction.

The substrate may be an intrinsic semiconductor material such as silicon (e.g. a silicon wafer), or an insulator such as silicon dioxide (e.g. glass). It will be appreciated that the substrate is primarily configured to support (e.g. mechanically or structurally support) the other elements of the solar cell, and it does not contribute to the photovoltaic output of the device.

The insulator assembly (e.g. the first and/or second insulators) may comprise an electrically insulating material. Accordingly, the insulator assembly may comprise a polymer material (e.g. polyvinyl acetate, polyimide, poly(methyl methacrylate), polystyrene, or CYTOP®). The polymer materials may be deposited using a liquid deposition method (e.g. screen or inkjet printing). For example, the insulator assembly may be formed of a polymer material which is deposited from a liquid precursor, or suspension (e.g. a polymer resin, or ink).

Alternatively, the insulator assembly may comprise an inorganic material such as silicon oxide material (SiO_x , e.g. SiO_2), or a silicon nitride material (SiN_x , e.g. Si_3N_4). These inorganic materials may be formed by way of a vapour deposition process (e.g. plasma-enhanced vapour deposition, PCVD).

The first and second electrodes may be formed of an electrically conductive material such that they enable the flow of electrical charge carriers from the charge-transport elements to an external circuit of the solar cell. One of the first and second electrodes may define a positive electrode, and the other of the first and second electrodes may define a negative electrode. At least one, or each, of the first and second electrodes may comprise a metal, such as silver (Ag), gold (Au), aluminium (Al), or copper (Cu), or metal alloy, e.g. an alloy comprising silver (Ag), gold (Au), aluminium (Al), or copper (Cu).

The charge-transport elements may define layers (or layer portions) of the back-contact structure. The first charge-transport element may be interposed between the first electrode and the light-absorber element. The second charge-transport element may be interposed between the second electrode and the light-absorber element. Each of the charge-transport elements may be configured as a buffer between the light-absorber element and the corresponding electrodes, such that they may be configured to cause selective carrier extraction therefrom.

One of the first and second charge-transport elements may comprise a p-type semiconductor configured to transport positive charge carriers from the light-absorber element to the positive electrode. The other of the first and second charge-transport elements may comprise an n-type semiconductor configured to transport negative charge carriers from the light-absorber element to the negative electrode. The p-type semiconductor may be configured to prevent electrons from being extracted to the positive electrode, whereas the n-type semiconductor may be configured prevent holes being extracted to the negative electrode. Accordingly, the charge-transport element comprising a p-type semiconductor may define a hole-transport element, and the charge-transport element that comprises an n-type semiconductor may define an electron-transport element.

Together, the negative electrode and the electron-transport element may define a p-type contact (or negative electrode assembly) of the back-contact structure. Similarly, the positive electrode and the hole-transport element may define an n-type contact (or positive electrode assembly) of the back-contact structure.

The n-type semiconductor may be selected from a group of inorganic compounds including tin oxide (SnOx, e.g. SnO2), titanium oxide (TiOx, e.g. TiO2), zinc oxide (ZnOx, e.g. ZnO), tungsten oxide (WOx, e.g. WO3), barium titanate (BaTiO3), niobium oxide (Nb2O5), strontium titanate (SrTiO3), tantalum oxide (Ta2O5), zinc titanate (ZnTiO3), copper titanate (CuTiO3).

Each of these inorganic compounds may be doped with at least one of niobium (Nb), strontium (Sr), aluminium (Al) and zinc (Zn). Alternatively, the n-type semiconductor may be selected from a group of organic compounds including carbon 60 (C60) and Phenyl-C61-butyric acid methyl ester (PCBM).

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The p-type semiconductor may be selected from a group of inorganic compounds including molybdenum oxide (MoOx e.g. MoO3), vanadium oxide (Vox, e.g. V2O5), nickel oxide (NiO), copper oxide (CuOx, e.g. CuO or Cu2O), tungsten oxide (WO3). Each of these inorganic compounds may be doped with at least one of lithium (Li), magnesium (Mg), chromium (Cr), gallium (Ga). Alternatively, the p-type semiconductor may be selected from a group of hybrid inorganic/organic compounds including copper (II) phthalocyanine (CuPc), CuSCN, Spiro-OMeTAD, Spiro-TTB, PTAA, PEDOT-PSS, P3HT, 2PACz, and MeO-2PACz.

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It will be appreciated that any of the metal oxide compounds (e.g. the n-type and p-type semiconductor materials) may be provided in a stoichiometric, non-stoichiometric, or doped form.

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The back-contact solar cell may be a back-contact perovskite solar cell, the light-absorber element comprising a perovskite structured compound. Alternatively, the back-contact solar cell may be a back-contact copper indium gallium selenium (CIGS) solar cell, the light-absorber element comprising a solid solution of copper indium selenide and copper gallium selenide. Alternatively, the back-contact solar cell may be a back-contact copper zinc tin sulphide (CZTS) solar cell, the light-absorber element comprising a CZTS compound. Alternatively, the back-contact solar cell may be a back-contact amorphous silicon (a-Si) solar cell, the light-absorber element comprising a-Si. Alternatively, the back-contact solar cell may be a back-contact CdTe solar cell.

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The perovskite-structured compound of the light-absorber element has a general formula of ABX₃. Accordingly, component A may comprise an organic monovalent cation comprising at least one of MA (CH₃NH₃⁺), FA [HC(NH₂)₂⁺], EA (CH₂CH₃NH₃⁺), Cs⁺ and Rb⁺. Component B may comprise transition metal divalent cation comprising at least one of lead (Pb²⁺) and tin (Sn²⁺). Component X may comprise a monovalent anion comprising at least one of fluoride (F⁻), chloride (Cl⁻), bromide (Br⁻) and iodide (I⁻).

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The solid solution of copper indium selenide and copper gallium selenide may have a general formula CuIn_xGa_(1-x)Se₂, where the value of x can vary from 1 to 0.

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The CZTS compound may have a general formula $\text{Cu}_2\text{ZnSnS}_4$.

5 Where the light absorber element comprises amorphous silicon, the amorphous silicon may be hydrogenated amorphous silicon.

According to a second aspect there is provided a method of manufacturing a back-contact solar cell. The method comprises: providing a substrate; arranging a first solar cell portion and a second solar cell portion on the substrate; arranging an insulator assembly on the substrate; and electrically connecting the first solar cell portion to the second solar cell portion in series. The step of arranging each of the first and second solar cell portions comprises arranging a back-contact structure by arranging a first electrode and a second electrode on the substrate such that said first and second electrodes are spaced apart. The step of arranging the insulator assembly comprises arranging a first insulator for each solar cell portion interposed between the associated first electrode and the associated second electrode to insulate said first electrode from said second electrode. Arranging each solar cell portion further comprises: arranging a light-absorber element of the solar cell portion on the back-contact structure such that the back-contact structure is interposed (e.g. at least partially interposed) between the light-absorber element and the substrate; and electrically connecting the light-absorber element to the first and second electrodes.

The method may comprise connecting (e.g. electrically connecting) the second electrode of the first solar cell portion directly to the first electrode of the second solar cell portion. The method may comprise forming the second electrode of the first solar cell portion and the first electrode of the second solar cell portion such that they are not spaced apart, for example, the method may comprise forming the second electrode of the first solar cell portion integrally with the first electrode of the second solar cell portion such as to electrically connect them. For example, the first and second electrodes may be deposited together as an integrally formed conductive element. The conductive element may comprise two portions that define the second electrode of the first solar cell portion and the first electrode of the second solar cell portion.

In some embodiments, the first insulator is deposited after the first and second electrodes are formed on the substrate. The first insulator may be deposited in a channel between the first and second electrodes (e.g. in a channel which is provided between the first and second electrodes of the second solar cell portion). Accordingly, the method may comprise depositing

the first insulator in the channel. The method may further comprise forming the channel between the first and second electrodes of at least one of the first and second solar cell portions. The method may comprise depositing the first electrode spaced apart from the second electrode to provide the channel therebetween. In this way, the channel between the first and second electrodes may be formed by spacing apart the first and second electrodes on the surface of the substrate. Alternatively, the channel may be formed by a destructive process, such as selective abrasion and/or etching.

In an alternative embodiment, the first insulator is deposited prior to arranging the first and second electrodes on the substrate. The first insulator thereby defines the space between the subsequently deposited first and second electrodes.

The step of arranging the light-absorber element may comprise, for each solar cell portion, depositing the light-absorber element on the associated first insulator such that the first insulator is interposed between the substrate and the light-absorber element. Accordingly, the first insulator prevents the light-absorber layer from being deposited within the channel between the electrodes, and thereby prevents shorting circuiting between the first and second electrodes.

The insulator assembly may comprise a second insulator configured to insulate the light-absorber element of the first solar cell portion from the light-absorber element of the second solar cell portion. Accordingly, the step of arranging the insulator assembly may comprise arranging the second insulator such that the second electrode of the first solar cell portion and/or the first electrode of the second solar cell portion is interposed between the second insulator and the substrate; and the step of arranging each of the first and second solar cell portions may further comprise arranging the light-absorber element of the first solar cell portion and the light-absorber element of the second solar cell portion such that the second insulator is interposed therebetween.

Alternatively to the step of arranging each of the first and second solar cell portions further comprising arranging the light-absorber element of the first solar cell portion and the light-absorber element of the second solar cell portion such that the second insulator is interposed therebetween, where the light-absorber elements are deposited prior to the second insulator, the second insulator may be configured to insulate the light-absorber elements from each other by the method comprising: forming a channel between the light-absorber element of the first solar cell portion and the light-absorber element of the second solar cell portion; and depositing

the second insulator in the channel. The method of forming the channel may comprise depositing the light-absorber element of the first solar cell portion apart (i.e. spaced apart) from the light-absorber element of the second solar cell portion to form the channel therebetween.

5 The method may comprise depositing the second insulator on the second electrode of the first solar cell portion and/or the first electrode of the second solar cell portion. The second insulator may be at least partially deposited on each of the second electrode of the first solar cell portion and the first electrode of the second solar cell portion.

10 In exemplary arrangements that comprise more than two solar cell portions (e.g. a third solar cell portion), the insulator assembly may comprise a plurality of second insulators, as described above. The step of arranging the insulator assembly may further comprise arranging a second insulator such that the second electrode of the second solar cell portion and/or the first electrode of the third solar cell portion is interposed between said second insulator and the
15 substrate; and the step of arranging each of the second and third solar cell portions may further comprise arranging the light-absorber element of the second solar cell portion and the light-absorber element of the third solar cell portion such that said second insulator is interposed therebetween.

20 Alternatively to the step of arranging each of the first and second solar cell portions further comprising arranging the light-absorber element of the first solar cell portion and the light-absorber element of the second solar cell portion such that the second insulator is interposed therebetween, where the light-absorber elements are deposited prior to the plural second insulators, a second insulator may be configured to insulate the second and third light-absorber
25 elements from each other by the method comprising: forming a further channel between the light-absorber element of the second solar cell portion and the light-absorber element of the third solar cell portion, and depositing said second insulator in the channel. In this way, the second insulator may be configured to electrically insulate the light-absorber elements from each other, to prevent short circuiting within the solar cell structure, and to ensure that charge
30 carriers are directed on the preferred path through each of the solar cell portions that are connected together in series.

As described above, each of the first and second solar cell portions may comprise a first charge-transport element, which may be arranged on the first electrode of that solar cell
35 portion. Accordingly, the step of arranging the back-contact structure may further comprise arranging the first charge-transport element on the first electrode. The first charge-transport

may be configured in use to transport a first charge carrier from the light-absorber element to the first electrode.

As described above, each of the first and second solar cell portions may comprise a second charge-transport element, which may be arranged on the second electrode of that solar cell portion. Accordingly, the step of arranging the back-contact structure may further comprise arranging the second charge-transport element on the second electrode. The second charge-transport element may be configured in use to transport a second charge carrier from the light-absorber element to the second electrode. The method may further comprise arranging the first charge-transport element on the first electrode and arranging the second charge-transport element on the second electrode such that the first insulator for the solar cell portion is interposed between the first charge-transport element and the second charge-transport element. Alternatively, where the first insulator is deposited after the charge-transport elements, the method may comprise the steps of: forming a channel between the second charge-transport element and the first charge-transport element; and depositing the first insulator in the channel.

The second insulator may be interposed (e.g. directly interposed) between the second charge-transport element of the first solar cell portion and the first charge-transport element of the second solar cell portion. In this way, the second insulator may be arranged to insulate between the charge-transport elements of adjacently positioned solar cell portions.

Accordingly, the first and second charge-transport elements of the same solar cell portion (e.g. the second solar cell portion) may be separated and insulated from each other by the first insulator interposed therebetween (e.g. the first insulator may be arranged in a first channel between the first and second charge-transport elements of the same solar cell portion). Also, the second charge-transport element of the first solar cell portion may be separated and insulated from the first charge-transport element of the second solar cell portion by the second insulator interposed therebetween (e.g. the second insulator arranged in a second channel between the second charge-transport element of the first solar cell portion and the first charge-transport element of the second solar cell portion).

To provide such insulation, the step of arranging the back-contact structure of the first solar cell portion may further comprise arranging the second charge-transport element on the second electrode such that the second charge transport element is interposed between the first insulator for the first solar cell portion and the second insulator; and/or the step of arranging

the back-contact structure of the second solar cell portion may further comprise arranging the first charge-transport element on the first electrode such that the first charge-transport element is interposed between the first insulator for the second solar cell portion and the second insulator.

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Alternatively, where the charge-transport elements are deposited before depositing the first and/or second insulators, the method may comprise depositing the charge-transport elements apart from each other, before then depositing the first and/or second insulators in the respective channels.

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The first and/or second insulator(s) may be deposited prior to depositing the light-absorber element of at least one of the first and second solar cell portions. In an alternative embodiment, only the first insulator may be formed prior to depositing the light-absorber element.

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It is advantageous for the first and second insulators to be deposited prior to depositing the charge-transport elements and light-absorber elements of the solar cell portions. This is because the first and second insulators can then provide a bank structure or trench to assist in controlling the deposition of the charge-transport elements and light-absorber elements, particularly when a solution processing method (e.g. ink jet printing) is used to deposit the charge-transport elements and light-absorber elements. Adjacent first and second insulators may provide the bank structure for the charge-transport elements. Adjacent second insulators may provide the bank structure for the light-absorber elements. Moreover, where the insulators are formed of an organic material, it is desirable to use a high-temperature annealing process on the insulators, however subjecting the charge-transport layers and light-absorber elements to the high temperatures of the annealing process is undesirable because of the damage to these layers caused by the high temperatures (e.g. structure degradation and introduction of defects); thus, depositing the first and second insulators prior to depositing the charge-transport elements and light-absorber elements of the solar cell portions is particularly advantageous where the insulators formed of an organic material.

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The insulator assembly (e.g. the first and second insulators) may be formed using a solution processing method, as described above. For example, the insulator assembly may be deposited from a precursor solution, such as a polymer resin, or ink.

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Each of the first and second electrodes may comprise an electrically conductive material (e.g. a metal, or metal alloy). The conductive material may be deposited using a vapour deposition

process (e.g. sputtering, atomic layer deposition (ALD), or chemical vapour deposition (CVD)). A deposition mask may be used to control the deposition process so that electrodes are deposited onto the correct underlying surface of the substrate. The electrodes may be arranged so as to be in direct contact with the substrate (e.g. with no intermediate elements disposed between the electrodes and the substrate).

The first and second electrodes may be deposited together (e.g. concurrently), such that the second electrode of the first solar cell portion is integrally formed with the first electrode of the second solar cell portion.

The charge-transport elements may comprise inorganic and/or organic semiconductor materials, as described above. The inorganic semiconductor materials may be deposited using a vapour deposition process (e.g. plasma enhanced vapour deposition, sputtering, ALD, CVD). The inorganic semiconductor materials also may be solution processed (e.g. printing, such as ink jet printing). Such solution processing may use inorganic colloid ink. The organic semiconductor materials, or compounds, may be solution processed (e.g. deposited in a liquid form, or from a liquid precursor, e.g. printing). Alternatively, the organic semiconductor materials, or compounds, may be deposited using a vapour deposition process (e.g. thermal evaporation). A deposition mask may be used to control the vapour deposition process(es) so that the charge-transport element(s) is/are deposited onto the correct underlying surface(s) of the solar cell.

Where the light-absorber element is a perovskite light-absorber element, the light-absorber element may be formed using a dry process or solution processing method. A solution process, for example, may comprise the perovskite-structured compound being deposited from a precursor solution using any solution processing method selected from a list of spin coating, knife coating, slit continuous coating and solution spraying. A dry process, for example, may comprise the perovskite-structured compound being deposited by thermal evaporation, CVD, ALD, or sputtering.

The back-contact structure, the insulator assembly, and the light-absorber layer may be sequentially deposited on the substrate (e.g. on an upper surface of the substrate). The method may comprise depositing / arranging at least one, or each of, the light-absorber element, the insulator assembly, and the first and second charge-transport elements using only additive manufacturing processes. For example, the method may comprise using only additive processes in arranging each light-absorber element, arranging the insulator assembly, and

electrically connecting the first solar cell portion to the second solar cell portion in series. The first and second electrodes may be deposited using an additive and/or a destructive manufacturing process. Accordingly, the whole solar cell may be formed using only additive processes in order to reduce the number of defects in the solar cell compared to known back-contact solar cell manufacturing methods.

In its broadest aspects, the present invention is directed towards a solar cell, and to a method of manufacturing a solar cell, which comprises a first solar cell portion and a second solar cell portion arranged on a substrate. Each of the first and second solar cell portions may comprise a light-absorber element and a back-contact structure interposed between the light-absorber element and the substrate. The solar cell further comprises an insulator assembly. The back-contact structure may comprise: a first electrode and a second electrode arranged on the substrate, wherein each of the first and second electrodes are electrically connected to the light-absorber element. The insulator assembly comprises, for each solar cell portion, a first insulator that insulates the associated first electrode from the associated second electrode, and wherein the first solar cell portion is electrically connected in series with the second solar cell portion.

The light-absorber element may comprise a perovskite structured compound, or material. Alternatively, the light-absorber element may comprise a different photoactive material (e.g. CIGS, CZTE, a-Si).

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 that exhibits a substantially linear current-voltage (I-V) characteristic).

It will be understood that when an element such as a layer, film, portion, 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. Furthermore, when an element is described as being 'interposed' between two other elements, then it can be directly interposed between those elements, or there may be additional intervening elements. In contrast, when an element is described as being 'directly' interposed between two other

elements, then there are no intervening elements (e.g. there are only those three elements arranged together with one element interposed between the others).

The skilled person will appreciate that except where mutually exclusive, a feature or parameter described in relation to any one of the above aspects may be applied to any other aspect. Furthermore, except where mutually exclusive, any feature or parameter described herein may be applied to any aspect and/or combined with any other feature or parameter described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects and embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic cross-sectional view of a back-contact solar cell according to a first aspect of the present invention;

Figure 2 is a top view of the solar cell shown in Fig. 1;

Figures 3 to 8 are cross-sectional views depicting the steps of an exemplary fabrication process associated with the solar cell of Fig. 1; and

Figure 9 is a flowchart illustrating a method for forming a back-contact solar cell, according to a second aspect 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.

An exemplary back-contact solar cell 10 will now be described with reference to Figs. 1 and 2. Fig. 1 depicts a transverse section of the solar cell 10, whereas Fig. 2 illustrates a top (e.g. front) view of the solar cell 10 shown in Fig. 1. The transverse section shown in Fig. 1 is taken along the dashed line A – A', as shown in Fig. 2. The solar cell 10 has a length, L, which is the vertical dimension of Fig. 2, and a width, W, which is the horizontal dimension of Fig. 2.

The solar cell 10 is divided into a plurality of solar cell portions 12, or solar cell sections, by an insulator assembly 14 comprising a plurality of insulators 14a, 14b, or insulator portions. The solar cell portions 12 are electrically connected together in series, as will be described below.

5 The insulators 14a, 14b are configured so that no destructive manufacturing processes are required to form the solar cell, as will be described in more detail below.

Since the plurality of solar cell portions 12 are arranged together on a common substrate, they are described herein as forming part of a single solar cell 10. However, it will be appreciated

10 that the plurality of solar cell portions 12 may (functionally) define a plurality of 'solar cells' that are connected together to define a string of interconnected solar cells.

The solar cell 10 has a front surface 16 (upon which light is incident in normal use) and a rear surface 18 opposite the front surface 16. The dashed arrows at the top of Fig. 1 show the

15 direction of the solar radiation that is incident upon the solar cell 10. Hence, the front surface 16 is configured in use to substantially face the sun.

For convenience, only the components of one of the solar cell portions 12 is labelled in Fig. 1. However, it will be appreciated that each of the solar cell portions 12 are configured in

20 substantially the same way. Each of the solar cell portions 12 comprises a back-contact structure 22 overlaying the substrate 20, portions of the back-contact structure 22 being separated from each other by an insulator assembly 14. A light-absorber element 24, or layer, overlies the back-contact structure 22, and an encapsulant 26 (e.g. passivation layer) overlies the light-absorber element 24. In some examples, the light-absorber element 24 is a perovskite

25 light-absorber element, alternatively, the light-absorber element 24 may be a copper indium gallium selenide (CIGS) light-absorber element, a copper zinc tin sulphide (CZTS) light-absorber element, an amorphous silicone (a-Si) light-absorber element, or a CdTe light-absorber element.

30 The solar cell 10 comprises a substrate 20 on which each of the solar cell portions 12 are arranged. Each of the solar cell portions 12 extend in a lengthways direction of the solar cell 10 (in a vertical direction as shown in Fig. 2). The solar cell portions 12 are arranged in rows that extend across the width of the solar cell 10 (in a horizontal direction as shown in Fig. 2). The solar cell portions 12 in each row are connected in series by their respective back-contact

35 structures 22 to form a 'string' of interconnected solar cell portions. For example, a first solar

cell portion 12a is arranged adjacent to, and connected in series with, a second solar cell portion 12b, as shown in Figs. 1 and 2.

The back-contact structure 22 of each solar cell portion 12 comprises a p-type contact and an n-type contact. The p-type contact includes a positive electrode 30 and a hole-transport element 32, the hole-transport element 32 stacked vertically on top of the positive electrode 30 (as shown in Fig. 1). Similarly, the p-type contact includes a negative electrode 40 and an electron-transport element 42, the electron-transport element 42 stacked vertically on top of the negative electrode 40.

The positive and negative electrodes 30, 40 of the associated each solar cell portion 12 are arranged directly on the substrate 20. The hole-transport element 32 overlies the positive electrode 30 and the electron-transport element 42 overlies the negative electrode 40. The light-absorber element 24 overlies each of the hole and electron transport elements 32, 42. Accordingly, the hole- and electron-transport elements 32, 42 are interposed between the light absorber element 24 and the positive and negative electrodes 30, 40, respectively.

The negative electrode 40 of the first solar cell portion 12a is formed integrally with the positive electrode 30 of the second solar cell portion 12b, such that the first and second solar cell portions 12a, 12b are connected together in series.

In use, the solar cell 10 is electrically coupled to an external circuit (not shown). Specifically, the external circuit is electrically connected to the electrodes of the solar cell portions that are arranged at the lateral sides of the solar cell 10. The positive electrode 30 of the solar cell portion 12 that is arranged at a first lateral side of the solar cell 10 (shown on the furthest left in Fig. 1) is connected to a positive terminal of the electrical circuit. Also, the negative electrode 40 of the solar cell portion 12 arranged at the opposite lateral side of the solar cell 10 (i.e., the first solar cell portion 12a) is connected to a negative terminal of the electrical circuit. The solar cell portions that are arranged at the lateral sides of the solar cell 10 are connected in series (e.g. via the intervening solar cell portions 12) to complete the electrical circuit.

As described above, the insulator assembly 14 includes a plurality of insulators 14a, 14b. In general, the insulators 14a, 14b are configured to define a pathway through the solar cell portions 12 for charge carriers that are generated during operation of the solar cell 10. The insulators 14a, 14b also define a charge-carrier pathway between the solar cell portions 12 that are electrically coupled together in series.

5 A first insulator 14a of the insulator assembly 14 is configured to prevent the flow of charge carriers between the hole- and electron-transport elements 32, 42 and between the positive and negative electrodes 30, 40 of a solar cell portion 12 (e.g. between the p-type contact and the n-type contact of each solar cell portion 12).

10 To achieve this, each first insulator 14a is positioned on the front surface of the substrate 20 and arranged between the positive and negative electrodes 30, 40 of an associated solar cell portion. The positive and negative electrodes 30, 40 are also positioned on the front surface of the substrate 20. Also, the hole- and electron-transport elements 32, 42 of each solar cell portion 12 are separated from each other by the associated first insulator 14a. In particular, the hole- and electron-transport elements 32, 42 and the positive and negative electrodes 30, 40 are separated from each other by the first insulator 14a in a widthways direction of the substrate 20, as shown in Fig. 1. Each first insulator 14a also extends in a lengthways direction of the substrate 20, as shown in Fig. 2. Each first insulator 14a has a height that is measured in a direction that is perpendicular to the front surface of the substrate 20 (i.e., the vertical direction in Fig. 1). The height of the first insulator 14a is at least as great as the combined height of the positive electrode 30 and the hole-transport element 32 and/or the combined height of the negative electrode 40 and the electron-transport element 42. In this way, a front surface of the first insulator 14a (i.e. the surface of the first insulator 14a facing away from the substrate 20) is positioned at a greater vertical distance from the substrate 20 than the vertical distance from the substrate 20 to a front surface of the charge-transport elements 32, 42 that are vertically stacked on the electrodes 30, 40 of the associated solar cell portion.

25 The first insulator 14a is interposed between the light-absorber element 24 and the substrate 20. In this way, the light-absorber element 24 is arranged on top of (e.g. vertically above) the first insulator 14a.

30 A second insulator 14b of the insulator assembly 14 is configured to prevent leakage of charge carriers between the hole- and electron-transport elements 32, 42 and the light absorbing elements 24 of neighbouring solar cell portions 12. To achieve this, the second insulator 14b is arranged between the electron-transport element 42 of the first solar cell portion 12a and the hole-transport element 32 of the second solar cell portion 12b. The second insulator 14b is also arranged between the light-absorber elements 24 of the first and second solar cell portions 12a, 12b. Accordingly, the light-absorber elements 24 of neighbouring solar cell portions 12 are spaced apart by the second insulator 14b in a widthways direction of the solar

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cell 10, as shown in Fig. 1. The second insulator 14b extends in a lengthways direction of the substrate 20 beyond the respective lengths of the light-absorber elements 24 and the charge-transport elements 32, 42, as shown in Fig. 2.

5 The second insulator 14b, is positioned on a front surface (i.e. a surface facing away from the substrate 20) of the electrodes 30, 40, which the charge-transport elements are also positioned on. The second insulator 14b has a height that is measured in a direction that is perpendicular to the front surface of the substrate 20 (i.e., the vertical direction in Fig. 1). The height of the second insulator 14b is greater than the combined height of the light-absorber element 24 and the hole-transport element 32 of the second solar cell portion 12b (which, in the case of the arrangement in Fig. 2, are stacked vertically together) and is greater than the combined height of the light-absorber element 24 and the electron-transport element 42 of the first solar cell portion 12a. In this way, a front surface of the second insulator 14b (i.e. the surface of the second insulator 14b facing away from the substrate 20) is positioned at a greater vertical distance from the substrate 20 than the vertical distance from the substrate 20 to a front surface of the light-absorbing elements 24 that are vertically stacked on the charge-transport elements 32, 42 either side of the second insulator 14b in the width direction.

Each of the solar cell portions 12 are separated from adjacent solar cell portions 12 by second insulators 14b. For example, a pair of second insulators 14b are arranged either side of the first solar cell portion 12a. These second insulators 14b define electrically insulating bulkheads that prevent leakage of electrons and holes between the first solar portion 12a (e.g. the hole and electron transport elements 32, 42 and the light absorbing element 24 of the first solar portion 12a) and the neighbouring solar cell portions 12.

25 According to an exemplary arrangement of the solar cell 10, the substrate 20 is made of an intrinsic semiconductor material (e.g. silicon). The hole-transport element 32 is formed of a p-type semiconductor (e.g. NiOx), whereas the electron-transport element 42 is formed of an n-type semiconductor (e.g. SnOx). As described above, the positive and negative electrodes 30, 40 of adjacently positioned solar cell portions 12 are formed integrally. The combined positive and negative electrodes 30, 40 are formed of a metal (e.g. gold, Au, or Silver, Ag).

Where the light-absorber element 24 is a perovskite light-absorber element (i.e. comprises a perovskite-structured compound), the perovskite-structured compound of the light-absorber element 24 has a general formula of ABX_3 . Component A is an organic monovalent cation (e.g. methyl ammonium ion, $CH_3NH_3^+$) or inorganic cation (e.g. Caesium, Cs^+), and component B is

a transition metal divalent cation (e.g. lead, Pb^{2+} ; or Tin, Sn^{2+}). Component X is a monovalent anion (e.g. fluoride, F^- ; bromide, Br^- ; iodide, I^- ; or chloride Cl^-).

5 The encapsulant layer 26 is formed of an optically transparent material (e.g. SiO_x , or a metal oxide).

10 In such a solar cell 10, the absorption of photons by the hybrid perovskite material 216 is followed by the formation and dissociation of excitons. The separated charges move towards the respective p-type and n-type contacts. The hole and electron transport elements 32, 42 enhance the charge separation within each solar cell portion 12. For example, electrons are selectively injected into the electron-transport element 42 and then extracted from the solar cell portion 12 by the negative electrode 40. Similarly, the holes are injected into the hole-transport element 32 and then extracted by the positive electrode 30. The flow of charges within the solar cell 10 is depicted by the curved dashed arrows shown in Fig. 1.

15 An exemplary method 100 of manufacturing the back-contact solar cell 10 will now be described with reference to Figs. 3 to 8, which shows cross-sectional views depicting the different stages of the method 100, and also with reference to Fig. 9, which is a flowchart outlining the constituent method steps 102 to 114.

20 The method 100 commences with step S102 in which a substrate 20 is provided on to which the solar cell 10 can be deposited. The substrate 20 is made of a semiconductor material (e.g. silicon), or an insulating material (e.g. glass).

25 The method 100 proceeds with method step S104 in which the positive and negative electrodes 30, 40 of the solar cell portions 12 are deposited onto the substrate 20. In an exemplary method, the positive and negative electrode 30, 40 are deposited by a vapour deposition process (e.g. sputtering), in which a selective mask may be used to produce the patterned arrangement. The pattern of the positive and negative electrodes is shown in Fig. 3
30 the resulting arrangement defining the back-contact structure 22 of the solar cell 10. In an alternative exemplary method 100, a film of conductive material (e.g. metal) is deposited and then selectively etched (e.g. using photolithography) to leave behind the combined positive and negative electrode formations 30, 40. In this case, the etching process used to pattern the electrodes is the only destructive manufacturing process used during the method 100. As such,
35 each of the remaining components of the solar cell 10 are formed by additive manufacturing steps.

The method 100 proceeds with method step S106, which involves arranging a first insulator 14a of the insulator assembly between the positive and negative electrode 30, 40 of each of the respective solar cell portions 12, as shown in Fig. 4. Specifically, the insulator 14a is deposited from a liquid precursor (e.g. a polymer resin) that is printed on the substrate 20 and allowed to cure (e.g. solidify). The liquid precursor is configured to flow into the trenches, or channels, that are formed in the previous method step S104 between the electrodes 30, 40. Once the liquid precursor has cured, it forms an insulator 14a arranged between the positive and negative electrodes 30, 40 of each of the solar cell portions 12.

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Following on from method step S106, a second insulator 14b of the insulator assembly is deposited onto the solar cell 10 at step S108. In particular, second insulators 14b are deposited such that each pair of adjacent light-absorber elements will have a second insulator interposed therebetween, for example, at least $(n-1)$ second insulators 14b, where n is the number of solar cell portions 12, are deposited onto the solar cell 10. Each second insulator 14b is arranged between adjacent first insulators 14a and is provided on the front surface of a first electrode 30 and/or second electrode 40 such that said electrode(s) is interposed between said second insulator 14b and the substrate 20. The second insulator 14b is formed of the same material as the first insulator 14a, and is deposited using the same method as described above in method step S106.

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In the subsequent method steps S110, a hole-transport element 32 is deposited onto the positive electrode 30 of each of the solar cell portions 12 as shown in Fig. 6. Also, an electron-transport element 42 is deposited onto the negative electrode 40 of each of the solar cell portions 12, as also shown in Fig. 6. Aside from the outermost charge-transport elements 32, 42 in the width direction of the solar cell 10, each charge-transport element 32, 42 is interposed between adjacent first and second insulators 14a, 14b. Each first insulator 14a insulates the hole-transport element 32 of a solar cell portion 12 from the electron-transport element 42 of that solar cell portion. The charge-transport elements 32, 42 form part of the back-contact structure 22 of each solar cell portion 12. The hole and electron transport elements 32, 42 are formed of doped semiconductor materials (as described above).

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Where the solar cell 10 is, for example, a perovskite solar cell, the charge-transport elements 32, 42 can be deposited using a wet printing process (e.g. ink jet, slot die coating). Alternatively, where the solar cell is, for example, a CIGS, CZTS or a-Si solar cell, or where it is a perovskite solar cell, these charge-transport elements 32, 42 can be deposited using a vapour deposition

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process (e.g. plasma enhanced chemical vapour deposition, PECVD). The hole- and electron-transport elements 32, 42 are deposited sequentially, and in any order. In the case of vapour deposition, a deposition mask is used to control the process so that each transport element is formed on the correct surface (e.g. the corresponding positive or negative electrode 30, 40),
5 as will be understood by the skilled person. In the case of wet printing, a masking process is not required; it can be appreciated that the first and second insulators 14a, 14b that extend above the front surface of the electrodes 30,40 can assist in constraining the liquid precursor forming the charge-transport elements as it is deposited on the electrodes 30, 40 during wet printing.

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Subsequently, in method step S112 a light-absorber element 24 is arranged onto the back-contact structure 22. In particular, the light-absorber element 24 is deposited onto the hole and electron transport elements 32, 42 of each of the respective solar cell portions 12, as shown in Fig. 7. The light absorber element can be deposited by a wet printing process (e.g. ink jet,
15 slot die coating) or a vapour deposition process (e.g. thermal evaporation, chemical vapour deposition (CVD), atomic layer deposition (ALD)).

The method 100 then proceeds to step S114, which involves arranging an optically transparent passivation layer (e.g. an encapsulant 26) on the light-absorber element 24 of each of the solar cell portions 12, as shown in Fig. 8. The passivation layer can be deposited by vapour
20 deposition (e.g. thermal evaporator, electron-beam deposition, CVD, ALD).

In the drawings, the thickness of sheets, layers, films, etc., are exaggerated for clarity. Furthermore, it will be understood that when an element such as a layer, film, region, or
25 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.

CLAIMS

1. A back-contact solar cell, comprising:
a substrate;
5 a first solar cell portion and a second solar cell portion arranged on the substrate,
wherein each of the first and second solar cell portions comprises
a light-absorber element; and
a back-contact structure interposed between the light-absorber element and the
substrate, wherein:
10 the back-contact structure comprises a first electrode and a second
electrode, the first and second electrodes arranged on the substrate; and
each of the first and second electrodes is electrically connected to the
light-absorber element; and
an insulator assembly comprising, for each solar cell portion, a first insulator that
15 insulates the associated first electrode from the associated second electrode; and
wherein the first solar cell portion is electrically connected in series with the second
solar cell portion.
2. The back-contact solar cell according to claim 1, wherein the second electrode of the
20 first solar cell portion is formed integrally with the first electrode of the second solar cell portion
such as to electrically connect them.
3. The back-contact solar cell according to claim 1 or 2, wherein the first insulator for each
25 solar cell portion is directly interposed between the first electrode and the second electrode of
that solar cell portion.
4. The back-contact solar cell according to any one of the preceding claims, wherein the
first insulator for each solar cell portion is interposed between the light-absorber element of
that solar cell portion and the substrate.
- 30 5. The back-contact solar cell according to any one of the preceding claims, wherein the
first insulator for each solar cell portion is interposed between the first electrode and second
electrode of that solar cell portion in a first direction that is substantially parallel to a first
dimension of the substrate, and wherein each first insulator extends in a second direction that
35 is substantially perpendicular to the first direction.

6. The back-contact solar cell according to any one of the preceding claims, wherein the insulator assembly further comprises a second insulator that insulates the light-absorber element of the first solar cell portion from the light-absorber element of the second solar cell portion.

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7. The back-contact solar cell according to claim 6, wherein the second electrode of the first solar cell portion and/or the first electrode of the second solar cell portion is interposed between the second insulator and the substrate.

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8. The back-contact solar cell according to any one of the preceding claims, wherein the back-contact structure further comprises:

a first charge-transport element configured in use to transport a first charge carrier from the light-absorber element to the first electrode; and

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a second charge-transport element configured in use to transport a second charge carrier from the light-absorber element to the second electrode; and

wherein the first insulator for each solar cell portion insulates the first charge-transport element from the second charge-transport element.

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9. The back-contact solar cell according to claim 8, wherein the first insulator for each solar cell portion is directly interposed between the associated first charge-transport element and the associated second charge-transport element.

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10. The back-contact solar cell according to claim 9, wherein, in the first and/or second solar cell portions:

the first charge-transport element is directly interposed between the first electrode and the light-absorber element, and the second charge-transport element is directly interposed between the second electrode and the light-absorber element; and

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the first insulator for that solar cell portion comprises a height that is at least as great as the combined height of the first electrode and the first charge-transport element, and/or wherein the height of the first insulator for that solar cell portion is at least as great as the combined height of the second electrode and the second charge-transport element.

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11. The back-contact solar cell according to any one of the preceding claims, wherein each of the first and second solar cell portions comprises a passivating element arranged on the light-absorber element such that the light-absorber element is interposed between the passivating element and the substrate.

12. The back-contact solar cell according to any one of the preceding claims, wherein the back-contact solar cell is a back-contact perovskite solar cell, each light-absorber element comprising a perovskite structured compound.
- 5
13. The back-contact solar cell according to claim 12, wherein the perovskite-structured compound of the light-absorber element has a general formula of ABX_3 ;
- wherein A comprises an organic monovalent cation comprising at least one of MA ($CH_3NH_3^+$), FA ($HC(NH_2)_2^+$), EA ($CH_2CH_3NH_3^+$), Cs^+ and Rb^+ ;
- 10
- wherein B comprises transition metal divalent cation comprising at least one of lead (Pb^{2+}) and tin (Sn^{2+}); and
- wherein X comprises a monovalent anion comprising at least one of fluoride (F^-), chloride (Cl^-), bromide (Br^-) and iodide (I^-).
- 15
14. A method of manufacturing a back-contact solar cell, the method comprising:
- providing a substrate;
- arranging a first solar cell portion and a second solar cell portion on the substrate;
- arranging an insulator assembly on the substrate; and
- electrically connecting the first solar cell portion to the second solar cell portion in
- 20
- series; and
- wherein:
- arranging each solar cell portion comprises arranging a back-contact structure by arranging a first electrode and a second electrode on the substrate such that said first and second electrodes are spaced apart;
- 25
- arranging the insulator assembly comprises arranging a first insulator for each solar cell portion interposed between the associated first electrode and the associated second electrode to insulate said first electrode from said second electrode; and
- arranging each solar cell portion further comprises:
- arranging a light-absorber element of the solar cell portion on the back-contact
- 30
- structure such that the back-contact structure is interposed between the light-absorber element and the substrate; and
- electrically connecting the light-absorber element to the first and second electrodes.

15. The method according to claim 14, wherein the method comprises forming the second electrode of the first solar cell portion integrally with the first electrode of the second solar cell portion such as to electrically connect them.
- 5 16. The method according to claim 14 or 15, wherein:
arranging a first electrode and a second electrode on the substrate comprises providing a channel between the first and second electrodes; and
arranging the insulator assembly comprises depositing the first insulator in the channel.
- 10 17. The method according to claim 16, wherein the method comprises depositing the first electrode spaced apart from the second electrode to provide the channel therebetween.
18. The method according to any one of claims 14 to 17, wherein arranging the light-absorber element comprises, for each solar cell portion, depositing the light-absorber element
15 on the associated first insulator such that the first insulator is interposed between the substrate and the light-absorber element.
19. The method according to any one of claims 14 to 18, wherein the insulator assembly comprises a second insulator configured to insulate the light-absorber element of the first solar cell portion from the light-absorber element of the second solar cell portion by:
20 the step of arranging the insulator assembly comprising arranging the second insulator such that the second electrode of the first solar cell portion and/or the first electrode of the second solar cell portion is interposed between the second insulator and the substrate; and
the step of arranging each of the first and second solar cell portions further comprising
25 arranging the light-absorber element of the first solar cell portion and the light-absorber element of the second solar cell portion such that the second insulator is interposed therebetween.
20. The method according to any one of claims 14 to 19, wherein arranging the back-contact structure further comprises arranging a first charge-transport element on the first
30 electrode, the first charge-transport being configured in use to transport a first charge carrier from the light-absorber element to the first electrode.
21. The method according to claim 20, wherein arranging the back-contact structure further
35 comprises arranging a second charge-transport element on the second electrode, the second

charge-transport element being configured in use to transport a second charge carrier from the light-absorber element to the second electrode.

22. The method according to claim 21, wherein arranging the back-contact structure further
5 comprises arranging the first charge-transport element on the first electrode and arranging the second charge-transport element on the second electrode such that the first insulator for the solar cell portion is interposed between the first charge-transport element and the second charge-transport element.

10 23. The method according to claim 21 or 22 as dependent on claim 19, wherein:
arranging the back-contact structure of the first solar cell portion further comprises arranging the second charge-transport element on the second electrode such that the second charge-transport element is interposed between the first insulator for the first solar cell portion and the second insulator; and/or

15 arranging the back-contact structure of the second solar cell portion further comprises arranging the first charge-transport element on the first electrode such that the first charge-transport element is interposed between the first insulator for the second solar cell portion and the second insulator.

20 24. The method according to any of claims 14 to 23, wherein only additive processes are used in arranging each light-absorber element, arranging the insulator assembly, and electrically connecting the first solar cell portion to the second solar cell portion in series.

25 25. The method according to any one of claims 14 to 24, wherein the back-contact solar cell is a back-contact perovskite solar cell, each light-absorber element comprising a perovskite structured compound.