

FILM HANDLING

FIELD OF THE DISCLOSURE

- 5 The present disclosure relates to a film handling device, a film handling system for manufacturing an electrode assembly for a solar cell assembly, and a method of manufacturing an electrode assembly for a solar cell assembly.

BACKGROUND

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Solar modules for providing electrical energy from sunlight comprise an array of cells, each comprising a photovoltaic element, or substrate. The solar cells are typically connected so that electrical current is routed, via an electrical connector, from a front surface of one solar cell to a back surface of a second solar cell, or vice versa. Each of the electrical connectors
15 comprises a plurality of electrically conductive elements (e.g. interconnecting wires) which form an electrical connection with electrodes arranged on the respective front and back surfaces of the solar cells.

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 electrical
20 connections between the solar cells. One approach has been to provide foil-wire electrodes which connect directly to finger electrodes arranged on the surface of each solar cell. The foil-electrode is constructed by overlaying a foil onto a plurality of connecting wires so that the foil is brought into contact with the connecting wires. Heat and pressure are applied to the foil to
25 thermally bond the foil to the connecting wires, and thereby form the foil-wire electrode.

The foil-wire electrode is then coupled between two solar cells by first overlaying a first end of the foil-wire electrode onto a surface of a first solar cell such that the connecting wires are interposed between the foil and the solar cell surface. Heat and pressure are applied to
30 thermally bond the foil to the solar cell surface. A second end of the foil-wire is connected to the surface of a second solar cell in the same manner. Accordingly, the foil-wire electrode provides a means of forming an electrical connection between the solar cells.

During the construction of the foil-wire electrode, the foil is transported to the connecting wires,
35 and then overlaid thereupon by a conveying assembly, or gripper, which grips the film as it is being transferred from a loading position to the required position overlaying the connecting wires.

The film handling device includes a substrate comprising a plurality of holes which are fluidly connected to source of vacuum. The vacuum provides a suction force which adheres the film to the substrate during transit. Once the film has arrived at the desired location, the negative gas pressure is removed allowing the film to detach from the gripper and thereby be overlaid
5 onto the connecting wires. Once the film is arranged in position, the gripper is removed and sent to pick up another film ready for placing on a different section of the connecting wires.

A problem of such systems is that the film can sometimes remain at least partially attached, or stuck, to the gripper when the gripper moves away from the connecting wires. This may
10 result in shifting the film's position on the connecting wires and/or damage to at least a portion of the film, which requires the manufacturing process to be paused so that the film's condition and its position on the connecting wires can be investigated. This leads to costly downtime for the manufacturing assembly. Also, in some situations, the film may become damaged due to being caught by the gripper to such an extent that the film must therefore be discarded leading
15 to an increase in the wastage of materials and overall production costs.

In view of the foregoing, there is a need to improve the method of manufacturing the electrode assembly for a solar cell assembly and the devices and systems used in said method.

20 SUMMARY

According to a first aspect of the disclosure there is provided a film handling device for manufacturing an electrode assembly for a solar cell assembly, the electrode assembly comprising a film and a plurality of electrically conductive elements (e.g., wire portions, or
25 wires) for arranging on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the film handling device comprises;

a substrate comprising a contact surface for contacting the film;
characterised in that at least a portion of the contact surface comprises an anti-
30 adhesion material for reducing adherence of the contact surface to the film.

A technical advantage of the film handling device according to the first aspect is that the contact surface comprises an anti-adhesion material which facilitates the film separation from the substrate, and thereby reduces the chance of unnecessary and costly delays to the
35 construction of the electrode assembly.

An anti-adhesion material may be defined as any material which has a static coefficient of friction with respect to polished stainless steel, that is determined to be within a range of between 0.05 and 0.4. The static coefficient of friction may be measured in accordance with the ISO 8295:1995 standard.

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By contrast, a known film handling device is configured with a film contacting surface which includes an 'adhesive' material (i.e., a material with a high coefficient of friction). It would be readily understood that such 'adhesive' materials include rubber type material (e.g. silicone rubber), which exhibit static coefficients of friction, with respect to polished stainless steel, of at least 0.8 (e.g. 0.8 to 1.2).

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It will be appreciated that friction between two objects represents a resistive force that prevents the two objects from sliding freely against each other. The static coefficient of friction μ_s defines the ratio of the magnitude of the maximum static frictional force F_s (i.e. the maximum force that can be exerted parallel to the interface between the two objects before movement is initiated at that interface) divided by the magnitude of the normal force F_N (i.e. the force acting perpendicular to said interface to push the objects together at the interface therebetween). The static coefficient of friction of the contact surface can be determined by placing two of the contact surfaces together to form an interface, and then dividing the force parallel to the interface that must be exerted on one of said objects to initiate movement at the interface by the normal force being exerted on that object at the interface.

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It will be appreciated that the determination of the static coefficient of friction between two substances can be influenced by a number of factors other than the material composition of the substances. For example, surface finish (e.g. roughness), surface condition and the presence of oxides, lubricants and other surface films may affect the results of such measurements. Also, atmospheric conditions may play a role, including humidity, temperature, and the presence of dust particles. Accordingly, the static coefficient of friction may be measured in accordance with the ISO 8295:1995 standard.

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According to a second aspect of the disclosure there is provided a film handling device for manufacturing an electrode assembly for a solar cell assembly, the electrode assembly comprising a film and a plurality of electrically conductive elements (e.g., wire portions, or wires) for arranging on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the film handling device comprises;

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a substrate comprising a contact surface for contacting the film;

characterised in that one or more protuberances are arranged on the contact surface of the substrate for reducing a contact area between the contact surface and the film.

A technical advantage of the film handling device according to the second aspect is that the one or more protuberances reduce the area of the film which is arranged in contact with the underlying contact surface of the substrate. Accordingly, the protuberance reduces the static friction between the film and the contact surface of the substrate, which thereby enables the film to be more readily released from the film handling device during the fabrication of the electrode assembly.

The film may comprise a first surface for contacting the electrically conductive elements and a second surface for contacting the contact surface of the substrate. The first and second surfaces of the film may face in opposite directions. Accordingly, the contact surface of the film handling device is configured to contact the second surface of the film and configured not to (directly) contact the electrically conductive elements. In this way, the film is interposed between the contact surface and the electrically conductive elements when the film is brought into contact with (e.g. deposited onto) the electrically conductive elements.

A third aspect of the disclosure is provided with a film handling system for manufacturing an electrode assembly for a solar cell assembly, the electrode assembly comprising a film and a plurality of electrically conductive elements (e.g., wire portions, or wires) for arranging on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the film handling system comprises; a film handling device comprising a substrate, the substrate comprising a contact surface for contacting the film and one or more openings in the contact surface;

characterised in that the film handling system comprises a positive-pressure generator which is fluidly coupled to the one or more openings and is configurable, in use, to apply a positive fluid (e.g. gas) pressure to the film on the contact surface of the film handling device to push the film away from the contact surface.

A technical advantage of the film handling system according to the third aspect is that the positive gas pressure acts upon the film to ensure that the film separates from the substrate. A further advantage of the third aspect is that it resolves the problem of films sticking to the substrate through a minimal modification to the system. For example, the third aspect may not require significant modification to the film handling device, since the positive air pressure may be directed towards the film through an opening which is already provided in the substrate.

For example, the opening which may be configured to deliver a negative gas pressure to secure the film to the substrate.

Each of the first, second and third aspects according to the present disclosure provide an alternative solution to the problem of a film sticking to the substrate of a film handling device during the manufacture of an electrode assembly. It will be appreciated that at least one, two or each, of the three aspects may be used to overcome the problem with known film handling devices and systems.

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

As described above, at least a portion of the contact surface may comprise an anti-adhesion, non-wetting material for reducing adherence of the contact surface to the film. The static coefficient of friction, with respect to polished stainless steel, of the anti-adhesive, non-wetting material may be between 0.05 and 0.4, optionally between 0.05 and 0.2. The static coefficient of friction, with respect to polished stainless steel, of the anti-adhesive, non-wetting material may be greater than or equal to 0.05, greater than or equal to 0.10, greater than or equal to 0.15, greater than or equal to 0.20, greater than or equal to 0.25, greater than or equal to 0.30, or greater than or equal to 0.35. The static coefficient of friction, with respect to polished stainless steel, of the anti-adhesive, non-wetting material may be less than or equal to 0.10, less than or equal to 0.15, less than or equal to 0.20, less than or equal to 0.25, less than or equal to 0.30, less than or equal to 0.35, or less than or equal to 0.4.

The anti-adhesive material may be a non-wetting material. A non-wetting material may be defined as a substantially hydrophobic material. For example, a material whose surface forms a contact angle with water of greater than 90°. The non-wetting material may have a surface that forms a contact angle with water of greater than or equal to 100°, greater than or equal to 105°, greater than or equal to 110°, greater than or equal to 115°, greater than or equal to 120°, or greater than or equal to 125°. The contact angle of the non-wetting material with water may be measured according to ISO standard ISO 15989:2004.

The anti-adhesive (and, optionally, non-wetting) material may comprise a fluorinated polymeric material. The anti-adhesive (and, optionally, non-wetting) material may comprise polytetrafluoroethylene (e.g., Teflon®), perfluoroalkoxy alkanes (PFA), or polypropylene.

The substrate may be coated in a coating which defines the contact surface, wherein at least a portion of the coating comprises an anti-adhesion (and, optionally, non-wetting) material. Alternatively, the substrate may be substantially formed of an anti-adhesion (and, optionally) non-wetting material.

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The anti-adhesive material may have a maximum service temperature greater than or equal to 230°C, for example greater than or equal to 240°C, greater than or equal to 250°C, greater than or equal to 260°C, greater than or equal to 270°C, or greater than or equal to 280°C. The maximum service temperature may be defined as the Vicat Softening Temperature (measured according to ISO 306).

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The substrate of the film handling device may comprise a planar element, platform, or structure, as would be understood by the skilled person. The contact surface may be planar, i.e., substantially flat.

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The substrate may comprise one or more openings in the contact surface. The one or more openings may be configured, when in use, to be fluidly coupled to an external gas pressure generating means (e.g. a positive-pressure and/or negative pressure generator). The substrate may comprise one or more internal fluid passageways which may be connectable to the pressure generating means. The substrate may comprise a network of fluid passageways fluidly coupled to a plurality of openings in the contact surface.

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The one or more openings may be elliptical (e.g. circular). The one or more openings may be configured with a maximum radius of at least 0.3 mm and up to 0.5 mm. The one or more openings may each be configured with a maximum radius of greater than or equal to 0.30 mm, greater than or equal to 0.35 mm, greater than or equal to 0.40 mm, greater than or equal to 0.45 mm, or up to 0.50 mm. The one or more openings may each be configured with a maximum radius of less than or equal to 0.50 mm, less than or equal to 0.45 mm, less than or equal to 0.40 mm, less than or equal to 0.35 mm, or down to 0.30 mm.

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In exemplary arrangements in which the film handling device may be couplable to a positive-pressure generator and a negative-pressure generator, a first set of openings may be used to detach the film from the film contact surface, and a second set of openings may be used to hold the film onto the film contact surface. For example, the first and second openings may be fluidly couplable (e.g. separately couplable) to the positive-pressure and negative-pressure generators, respectively. In alternative exemplary arrangements in which the film handling device may be couplable to a positive-pressure generator and a negative-pressure generator,

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the one or more openings may each be fluidly couplable to both the positive-pressure and negative-pressure generators.

5 The substrate may comprise one or more protuberances arranged on the substrate for reducing a contact area between the contact surface and the film. The one or more protuberances may define at least part of the contact surface of the substrate.

10 The, or each, protuberance may comprise a cross-sectional profile in a plane perpendicular to the substrate that narrows (e.g. tapers) as the protuberance extends away from the remainder of the substrate. That is, a distal end (or tip) of the, or each, protuberance may be narrower than a proximal end (or base) of the protuberance that is adjacent the remainder of the substrate. The, or each, protuberance may comprise a side wall which defines an angle with a main body of the substrate (i.e. the remainder of the substrate not including the one or more protuberances). The side wall may connect the distal end (or tip) to the proximal end (or base).

15 The, or each, protuberance's side wall may be configured such that the angle with the main body of the substrate (e.g. a planar surface from which the protuberance extends) is at least 95° and/or up to 115°. By way of example, the angle may be greater than or equal to 95°, greater than or equal to 100°, greater than or equal to 102°, greater than or equal to 104°, greater than or equal to 106°, greater than or equal to 108°, greater than or equal to 110°, or

20 greater than or equal to 112°. By way of example, the angle may be less than or equal to 97°, less than or equal to 100°, less than or equal to 102°, less than or equal to 104°, less than or equal to 106°, less than or equal to 108°, less than or equal to 110°, or less than or equal to 112°, or less than or equal to 115°.

25 The, or each, protuberance may comprise an end portion (e.g. a distal end portion) which is extended furthest from the substrate. The end portion may define a peak, tip, or uppermost end, of the protuberance, for example when the contact surface is facing in a substantially vertically upwards direction. A depressed, or recessed, or concave region may be formed in the end portion of the, or each, protuberance. In an embodiment, the distal end face of the

30 protuberance, which may be substantially parallel to the contact surface but spaced therefrom, is modified so as to include the depressed region. The depressed region may define a portion of the contact surface on the protuberance that forms a concavity extending away from the film when the film is positioned on the contact surface during use (e.g. forms a concavity extending towards the main portion of the substrate) to create a void between the film and the

35 contact surface at the end portion of the protuberance. The depressed region may be configured with a depth of at least 3 mm and/or up to 5 mm. The depressed region may comprise a concave surface. The concave surface may comprise a uniform curvature in at

least one direction, for example, where the protuberance is elongate (e.g. having a length extending in the width direction of the substrate), the curvature may be uniform when measured transversely across the width of the protuberance (e.g. in the length direction of the substrate). The curvature may be defined as having a radius of curvature of about 3 mm.

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An opening of the one or more openings may be arranged in the depressed region. In this way, the opening may be configured to deliver negative and/or positive pressure directly to the film which contacts the protuberances. The negative pressure may be used to suck the film towards the contact surface, whereas the positive pressure may be used to push the film away from the contact surface.

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The one or more protuberances may have substantially elongate forms, for example, to form a rib or ridge. The elongate form may have a length and a width, and the length may be large in comparison to the width. The length of the protuberance may be substantially aligned with the width of the substrate and/or the width of the protuberance may be substantially aligned with the length of the substrate; the length of the substrate may be greater than the width of the substrate. The protuberance may extend across at least a part of the contact surface of the substrate in a longitudinal direction of the protuberance (e.g. in the width direction of the substrate). The, or each, protuberance may have a width greater than or equal to 1.0 mm, greater than or equal to 1.5 mm, greater than or equal to 2.0 mm, or greater than or equal to 2.5 mm. The, or each, protuberance may have a width less than or equal to 3 mm, less than or equal to 2.5 mm, less than or equal to 2.0 mm, or less than or equal to 1.5 mm.

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The depressed region may extend in the longitudinal direction of the protuberance (e.g. along the length of the protuberance) to define a channel for receiving an electrically conductive element (e.g., of the plurality of conductive elements of the electrode assembly). The channel may extend substantially along a majority or an entirety of the length of the protuberance. The channel may be aligned, when in use, with a respective conductive element. Accordingly, the channel can be used to guide and retain the conductive element in the correct bonding alignment with the film.

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The substrate may have a length and a width, the length being greater than the width. The one or more protuberances may extend in a transverse direction substantially across the width of the contact surface of the substrate.

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The substrate may comprise a plurality of protuberances. Each of the protuberances may be configured to extend widthwise relative to the contact surface of the substrate (e.g. the length

direction of the protuberance aligned with the width direction of the substrate), in a transverse direction. The protuberances may be spaced apart in a longitudinal direction relative to the substrate contact surface to define transverse-extending spaces (e.g. valleys) between the protuberances (e.g. ridges). The protuberances may be parallel or substantially parallel to one another. The protuberances may be equally or substantially equally spaced in the longitudinal direction of the contact surface of the substrate. Accordingly, the plurality of protuberances may form an array of parallel, longitudinally spaced (e.g. equally spaced) protuberances.

The film handling device, according to any of the preceding statements, may form part of a film handling system for manufacturing an electrode assembly for a solar cell. The film handling system may further comprise a negative-pressure generator (e.g. vacuum generator). The negative-pressure generator may be fluidly coupled to the one or more openings of the substrate. The film handling system may further comprise a conveying assembly or a conveyor. The conveying assembly may be mechanically connected to the film handling device and configured to move the film handling device from a film-loading position to a film-unloading position.

In an exemplary arrangement, the film handling device comprises a support structure or a connector for fixing (e.g. directly or indirectly) the film handling device to the conveying assembly so that the film handling device can be conveyed or translated by the conveying assembly. The support structure and the substrate may be formed integrally, or as separate components.

When the substrate of the film handling device comprises one or more fluid passageways connecting one or more openings arranged on the substrate's contact surface, the fluid passageway may extend through the support structure to fluidly couple the opening to an external fluid (e.g. gas) pressure generating means.

The support structure may be formed of a rigid material, such as stainless steel, in order to provide structural support for the substrate during the manufacturing of the electrode assembly (e.g., when stamping together the film with the plurality of conductive elements). The support structure may comprise a substrate connecting end, or back plate, which is mechanically coupled (e.g. bonded) to a rear surface of the substrate, opposite the contact surface of the substrate. A connecting end of the support structure may be mechanically couplable (e.g., connected in use) to the conveying assembly. The connecting end of the support structure may comprise a removable fastener, such as a bolt or screw fastener, to allow removal of the film handling device from the conveying assembly.

As described above, the film handling system may comprise a positive-pressure generator (e.g. a blower or compressor) which may be fluidly coupled to the one or more openings in the substrate. The positive-pressure generator may be configured to provide a positive pressure of at least 0.1 MPa and up to 0.9 MPa. The positive-pressure generator may be configured to provide a positive pressure of greater than or equal to 0.1 MPa, greater than or equal to 0.2 MPa, greater than or equal to 0.3 MPa, greater than or equal to 0.4 MPa, greater than or equal to 0.5 MPa, greater than or equal to 0.6 MPa, greater than or equal to 0.7 MPa, or greater than or equal to 0.8 MPa. The positive-pressure generator may be configured to provide a positive pressure of less than or equal to 0.2 MPa, less than or equal to 0.3 MPa, less than or equal to 0.4 MPa, less than or equal to 0.5 MPa, less than or equal to 0.6 MPa, less than or equal to 0.7 MPa, or less than or equal to 0.8 MPa.

The system may comprise the negative-pressure generator (e.g. a vacuum pump, configurable, in use, to apply a negative gas pressure to the film on the contact surface of the film handling device. The negative-pressure generator may be configured to provide a negative pressure of at least 0.1 MPa and up to 0.9 MPa. The negative-pressure generator may be configured to provide a negative pressure of greater than or equal to 0.1 MPa, greater than or equal to 0.2 MPa, greater than or equal to 0.3 MPa, greater than or equal to 0.4 MPa, greater than or equal to 0.5 MPa, greater than or equal to 0.6 MPa, greater than or equal to 0.7 MPa, or greater than or equal to 0.8 MPa. The negative-pressure generator may be configured to provide a negative pressure of less than or equal to 0.2 MPa, less than or equal to 0.3 MPa, less than or equal to 0.4 MPa, less than or equal to 0.5 MPa, less than or equal to 0.6 MPa, less than or equal to 0.7 MPa, or less than or equal to 0.8 MPa.

The system may comprise a switching assembly configured to switch between applying a positive gas pressure and a negative gas pressure to the film. It will be understood that the phrase 'positive gas pressure' is used herein to refer to a positive pressure gradient that is applied to film handling device (e.g., to the one or more openings) such as to generate a fluid (e.g. gas) flow and which is sufficient to push, detach, release, propel, and/or urge the film from the contact surface of the substrate. Similarly, the phrase 'negative gas pressure' is used herein to refer to a negative pressure gradient which, when applied to the film handling device such as to generate a fluid (e.g. gas) flow, is sufficient to hold, suck and/or pull the film on the contact surface.

The system (e.g. the switching assembly) may comprise a controller which is connected to at least one of the negative-pressure generator and positive-pressure generator and configured

to turn at least one of the generators on and off. For example, the controller may be configured to switch off one of the generators and switch on the other of the generators, independently and/or simultaneously. This way the controller can configure the system to either blow or suck gas through the one or more openings in the contact surface.

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Alternatively, or additionally, the switching assembly may comprise one or more valves which are operable to switch the fluid connection of the one or more openings between the negative-pressure generator and the positive-pressure generator.

10 The positive-pressure generator may comprise a compressed dry air system. The positive-pressure generator may comprise a blower or compressor. The positive-pressure generator may comprise a pressure vessel and a valve for opening and closing the pressure vessel. The negative-pressure generator may comprise a vacuum pump.

15 The system may comprise a conveying assembly configured to convey the film handling device from a film-loading position to a film-unloading position.

According to a fourth aspect of the present disclosure, there is provided a method of manufacturing an electrode assembly for a solar cell, the electrode assembly comprises a film and a plurality of electrically conductive elements (e.g., wire portions, or wires) for arranging
20 on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the method comprises;

loading a film onto a film handling device at a film-loading position;
25 conveying the film handling device to a film-unloading position adjacent to a plurality of electrically conductive elements; and

depositing the film onto the plurality of electrically conductive elements at the film-unloading position;

characterised in that depositing the film comprises applying a positive fluid (e.g. gas)
30 pressure (e.g. to one or more openings in a contact surface of the film handling device) to detach the film from the film handling device.

The method of depositing the film may comprise applying a negative gas pressure to the film during a process of thermally bonding the film to the plurality of electrically conductive
35 elements, e.g. to improve the adhesion of the film to the wires. The method of depositing the film may comprise applying the positive gas pressure to release the thermally bonded film from the film handling device, e.g. to push to joined film and wire combination from the film

handling device. Optionally, the positive gas pressure is applied only once the film has been at least partially bonded to the conductive elements. This prevents the film from sticking to the film handling device as the film handling device is separated from the film (e.g. to return to the film-loading position). The positive gas pressure may be applied immediately after the film is bonded to the conductive elements. The negative gas pressure may be simultaneously removed from the film as the positive gas pressure is applied. The method of applying a positive gas pressure to the film may comprise directing a positive air flow to the film, to release the film from the film handling device once the film is bonded to the plurality of conductive elements.

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The method of depositing the film may comprise switching the fluid connection of the one or more openings between a negative-pressure generator (e.g. vacuum generator) and a positive-pressure generator (e.g. blower).

15 The method of loading the film onto the film handling device may comprise applying a negative fluid (e.g. gas) pressure to one or more openings of a substrate of the film handling device to attach the film to a film contact surface of the substrate, e.g. by sucking the film to the contact surface.

20 Prior to the method step of loading the film onto the film handling device, the method may comprise conveying the film handling device to a film-loading position.

The method may comprise thermally bonding the film to the plurality of conductive elements whilst a negative gas pressure is exerted upon the film. The negative gas pressure flattens (e.g. sucks) the film against the contact surface of the film handling device and thereby ensures a strong bond is formed between the film and the conductive elements.

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At least one, or each, of the plurality of conductive elements may be thermally bonded to the film, when in use. The film may be further configured to attach the conductive elements to the solar cell surface (e.g. provide a mechanical connection between conductive elements and the solar cell). In an embodiment, the plurality of conductive elements may be laterally spaced from each other, e.g. positioned in a parallel and side-by-side fashion; the film may be configured to maintain the lateral spacing of the conductive elements, such that the conductive elements are correctly aligned on the solar cell surface. In an exemplary arrangement, the film may not cover all the respective front and/or back surface(s) of the solar cell on to which it is overlaid.

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According to a fifth aspect of the present disclosure, there is provided a method manufacturing a solar cell assembly. The method may comprise heating and/or applying pressure to the film to adhere (e.g. to laminate) the film to the conductive elements and/or the surface of a solar cell. The method may comprise attaching the film to the conductive elements prior to
5 overlaying, and/or attaching, the conductive elements to the solar cell. The method of attaching the film to the conductive elements may be performed during the method of coupling the associated conductive elements to the surfaces of the solar cell. In this way, the method of attaching the film to the conductive elements (e.g. the application of heat and/or pressure to the film) may also comprise attaching the film to an associated surface of the solar cell.

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During fabrication of the solar cell assembly, heat and/or pressure may be applied to the film so that the material the film is formed of softens to enable adherence of the film to the conductive elements due to an application of force. The film may be formed of a polymeric material. In this way, the conductive elements may be at least partially embedded in the film.

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At least a portion of the surface of each conductive element may remain exposed to enable an ohmic connection to be formed with a respective surface of the solar cell.

The film may be configured to provide structural support for the conductive elements when the elements are being handled, prior to being arranged onto the solar cell. The film may be
20 configured such that at least a portion of one or more of the conductive elements is exposed from the film to form an ohmic contact with the respective surface of the solar cell.

When the electrode assembly is installed on the solar cell surface, the film may deform to conform to the shape of the conductive elements sandwiched between the film and the solar
25 cell. In other words, the surface of the film may form ridges/protuberances over the conductive elements and may be substantially planar in regions with no conductive elements. In this way, the film, once installed on the solar cell surface, may comprise a conductive element contacting region which has a non-planar profile.

30 According to an exemplary arrangement, the solar cell assembly may comprise a first solar cell and a second solar cell. The electrode assembly may be configured to electrically connect the first solar cell to the second solar cell. In particular, the one or more conductive elements may be configured to electrically couple a front surface of the first solar cell with a back surface of the second solar cell.

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The method may comprise arranging the second solar cell so that its back surface faces in a substantially upward direction. The method may further comprise overlaying a first section of

the electrode assembly onto the back surface of the second solar cell such that the second surface of the one or more conductive elements is arranged in contact with the back surface. The method may further comprise connecting (e.g., electrically and/or mechanically) the second surface of the one or more conductive elements onto the back surface of the second solar cell. The method may comprise overlaying the front surface of the first solar cell onto a second portion of the electrode assembly such that the first surface of the one or more conductive elements is arranged in contact with the front surface. The method may further comprise connecting (e.g. electrically and/or mechanically) the first surface of the one or more conductive elements onto the front surface of the first solar cell.

The solar cells may each comprise a back (e.g. backmost) surface and a front (e.g. frontmost) surface being opposite the back surface. Accordingly, the method may comprise arranging a portion of the electrode assembly onto the back surface of the second solar cell to define a back connector. The method may further comprise arranging another portion of the electrode assembly onto the front surface of the first solar cell to define a front connector.

The conductive elements may be coated in a solderable material (e.g. one or more of tin, cadmium, gold, silver, palladium and rhodium) which has a melting point which is lower than the materials from which the conductive elements are formed.

The method may comprise applying heat and/or pressure to (e.g. soldering) the first portion of the conductive elements (i.e. of the front connector) to form an ohmic contact with the conductive surface of the first solar cell (e.g. the finger electrode), upon which the conductive element is overlaid. The method may comprise applying heat and/or pressure (e.g. soldering) the second portion of the conductive elements (i.e. of the back connector) to form an ohmic contact with the conductive surface of the second solar cell (e.g. the finger electrode), upon which the conductive element is overlaid.

The method may comprise first attaching one of the front and back connectors to the respective first and second solar cells, then attaching the other of the front and back connectors to the other of the respective first and second solar cells.

The method may further comprise arranging (e.g. depositing) a plurality of finger electrodes on at least one, or each, of the front and back surfaces of the first and second solar cells. It will be understood that the method of arranging the finger electrodes may be performed prior to connecting the electrode assembly to the solar cells. The finger electrodes may be formed using a printed material, which enables the finger electrodes to be conveniently deposited onto

the surfaces of the solar cells. The printed material may be formed using a printable precursor, such as a conductive paste which may comprise a mixture of metal powder (e.g. Ag, Al, Au powder) and glass frit suspended in a solvent. The printable precursor/conductive paste may be fired, or cured, to form the printed finger electrodes. Alternatively, the finger electrodes may be deposited by various other methods including evaporation, plating, printing etc. The front and back finger electrodes may be deposited simultaneously (i.e. using a single deposition process) or they may be deposited separately.

According to a sixth aspect of the present disclosure, there is provided an electrode assembly manufactured according to the method of any of the preceding statements. The electrode assembly may comprise a plurality of electrically conductive elements (e.g. wire portions, or wires) and at least one substantially transparent and substantially electrically insulating film.

According to a seventh aspect of the present disclosure, there is provided a solar cell assembly comprising one or more solar cells and an electrode assembly manufactured according to the method of any one of the preceding statements.

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 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. The first and second aspects may be combined into a single film handling device. The third aspect may be combined with the first and/or second aspects into a single film handling system.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described by way of example only, with reference to the Figures, in which:

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

5 **Fig. 2** is an isometric view of the electrode assembly coupled to the first solar cell, as shown in Fig. 1;

Figs. 3 to 6 are side views of a film handling system according to an aspect of the present disclosure, showing the different stages of a method of manufacturing the solar cell assembly;

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Fig. 7 is a flowchart illustrating a method of manufacturing a solar cell assembly, as shown in Figs. 3 to 6;

15 **Figs. 8A and 8B** are isometric and plan views of a film handling device, according to an aspect of the present disclosure, which is used in the film handling system, as shown in Figs. 3 to 6;

Fig. 8C is a transverse-sectional view of the film handling device taken along the dashed line A-A, as shown in Fig. 8B;

20 **Fig. 9** is an isometric view of a substrate of a film handling device according to an aspect of the present disclosure; and

Figs. 10 and 11 are enlarged side and perspective views, respectively, of a protuberance arranged on the substrate, as shown in Fig. 9.

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DETAILED DESCRIPTION

30 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.

The present disclosure is primarily directed towards a film handling device and a film handling system for manufacturing a solar cell assembly. To place these aspects in their proper context, an exemplary solar cell assembly 10, as manufactured according to a method of the present disclosure, will first be described with reference to Figs. 1 and 2.

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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 (e.g. with no intervening elements) or indirectly on the other element (e.g. with intervening elements). In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present.

Fig. 1 shows the solar cell assembly 10 arranged within a support assembly 102 of a solar module 100 (e.g. a solar panel). The solar cell assembly 10 includes a first solar cell 20, a second solar cell 30 and an electrode assembly 12 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 electrode assembly 12 comprises a plurality of conductive elements which are configured to provide an improved electrical pathway between the first and second solar cells 20, 30, whilst also enhancing the light scattering and absorption conditions at the front surface 22 of the first solar cell 20.

A first portion of the electrode assembly 12 is arranged to contact the front surface 22 of the first solar cell 20 to define a front connecting portion, or front connector 12a, of the electrode assembly 12. A second portion of the electrode assembly 12 contacts the back surface 34 of the second solar cell 30 to define a back connecting portion, or back connector 12b, of the electrode assembly 12. The first and second connectors 12a, 12b are electrically coupled together by a third interconnecting portion 12c which bends between the respective front and back surfaces 22, 34 of the adjacently positioned solar cells 20, 30 of the solar cell assembly 10.

The solar cell assembly 10 is one of a plurality of solar cell assemblies which are arranged within the support assembly 102. For example, a front surface 32 of the second solar cell 30 is electrically coupled to the back surface of a third solar cell (not shown) by a second electrode assembly 14. Also, a third electrode assembly 16 is provided to couple a back surface 24 of the first solar cell 20 to the front surface of a fourth solar cell (not shown).

It will be understood, for example, 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 plurality of solar cells 20, 30 are thereby coupled together by the electrode assemblies 12, 14, 16 to define a single string.

A front plate 104 of the support assembly 102 comprises a transparent (e.g. glass) sheet which is configured to allow light to pass through into a central chamber 106 in which the solar cell assembly 10 is mounted. The arrows at the top of Fig. 1 show the direction of the solar radiation which is incident upon the solar cell assembly 10.

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A back plate 108 of the support assembly 102 is arranged to enclose the solar cell assembly 10 within the central chamber 106. The back plate 108 comprises a reflective sheet which is configured to reflect any light which is incident upon its upper surface, back towards the solar cell assembly 10. The central chamber 106 is filled with an encapsulating material (the shaded area shown in Fig. 1) which prevents ingress of external liquid or gaseous entrants.

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Fig. 2 is an isometric view of the first solar cell 20 with the electrode assembly 12 attached to its front surface 22. It will be appreciated that the first and second solar cells 20, 30 are substantially the same, yet only the first solar cell 20 is shown in Fig. 2, for illustrative purposes.

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Each of the first and second solar cells 20, 30 has a length (L), a width (W), and a height (H), as shown in Fig. 2. The first and second solar cells 20, 30 are arranged in a common transverse plane (as shown in Fig. 1) such that their widthwise and lengthwise dimensions, respectively, lie in parallel with each other. Each of the front surfaces 22, 32 of the respective solar cells define a surface on 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, as shown in Fig. 1.

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Each solar cell 20, 30 includes a layered structure (not shown) 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. The first solar cell 20 includes a first plurality of finger electrodes (not shown) arranged on its front surface 22 (i.e. front finger electrodes), and a second plurality of finger electrodes arranged on its back surface 24 (i.e. back finger electrodes). Similar, the second solar cell 30 includes a first plurality of finger electrodes arranged on its front surface 32, and a second plurality of finger electrodes arranged on its back surface 34. The front and back finger electrodes are each configured to conduct away the respective electrical charge carriers generated by the absorption of incident radiation.

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The electrode assembly 12 comprises a plurality of conductive elements 18, as shown in Fig. 2. The conductive elements 18 are configured to form an ohmic contact with finger electrodes

arranged on the front and back surfaces 22, 34 of the first and second solar cells, respectively. The conductive elements 18 each have an integral elongate form, such as a wire, which is formed of an electrically conductive material. For example, the conductive elements 18 comprise a metallic alloy material, which includes at least one of Ag, Al, Au and Cu. The
5 conductive elements 18 are each arranged within an optically transparent insulating film 40, as shown most clearly in Fig. 2.

A first portion 18a of the plurality of conductive elements 18 defines the front connector 12a of the electrode assembly 12. A second portion 18b of the plurality of conductive elements 18
10 defines the back connector 12b of the electrode assembly 12. Accordingly, each of the plurality of conductive elements 18 extends from the front connector 12a to the back connector 12b of the electrode assembly 12. A third portion 18c of the plurality of conductive elements 18 is configured to electrically couple together the respective first and second portions 12a, 12b.

15 Each of the conductive elements 18 defines a current collector of the electrode assembly 12. Furthermore, the conductive elements 18 are configured to collect charge carriers from the front finger electrodes of the first solar cell 20 and transport them to the back-finger electrodes 38 of the second solar cell 30, or vice versa. Each of the conductive elements 18 comprises a width, length, and depth (or length and diameter, where the conductive elements 18 are
20 (cylindrical) wires). The length of each conductive elements 18 defines an axial length which is substantially greater than its width and depth (or diameter, where the conductive elements 18 are (cylindrical) wires).

Although this is not shown in the figures, the pluralities of front and back finger electrodes are
25 arranged to extend across the solar cells 20, 30 in the transverse direction (i.e., in a direction parallel to the width W of the first solar cell 20, as shown in Fig. 2) and are equally spaced apart in the longitudinal direction (i.e., in a direction parallel to the length L of the first solar cell 20, as shown in Fig. 2). The dimensions of each finger electrode are substantially the same as that of every other finger electrode.

30 The finger electrodes arranged on each of the front and back surfaces of the solar cells 20, 30 are aligned in parallel with each other, and with a corresponding finger electrode on the opposite side of the solar cell. Each of the pluralities of front and back finger electrodes comprises twelve electrodes. The finger electrodes are formed of an electrically conductive
35 material, which is formed of a metallic alloy comprising Ag. It will be understood that the electrically conductive material is a printed material, which enables the finger electrodes to be conveniently deposited onto the respective surfaces of the solar cells.

The first and second portions 18a, 18b of the plurality of conductive elements 18 are parallel and extend lengthwise relative to the front and back surfaces 22, 24, 32, 34 of the solar cells, in a longitudinal direction (i.e., in a direction parallel to the length L of the first solar cell 20, as shown in Fig. 2). The conductive elements 18 are also equally spaced apart in a transverse direction relative to the front and back surfaces 22, 24, 32, 34 (i.e., in a direction parallel to the width W of the first solar cell 20, as shown in Fig. 2) to define longitudinal-extending spaces between the conductive elements 18. Accordingly, each one of the first and second portions 18a, 18b defines an array of parallel, transversely spaced conductive elements 18.

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Each of the first portions 18a of the plurality of conductive elements 18 are axially aligned with the corresponding second portions 18b of the conductive elements 18 of the same electrode assembly 12. Also, the second portions 18b of conductive elements 18 of the first electrode assembly 12 are axially aligned with the first portions 18a of the conductive elements 18 of the second electrode assembly 14, with the second solar cell 30 interposed between. Accordingly, the pluralities of front and back finger electrodes are arranged perpendicular to the first and second portions 18a, 18b of the plurality of conductive elements 18.

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The number of conductive elements 18 of the electrode assembly 12 is preferably between 4 and 20. According to the embodiment described herein the first electrode assembly 12 has twelve conductive elements 18, as shown in Fig. 2. It will be appreciated that, in some other embodiments, a different number of conductive elements and/or finger electrodes may be present, without departing from the scope of the present disclosure.

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The conductive elements 18 each have a circular transverse cross-sectional shape (i.e. transverse to the axial length of the conductive element 18). However, the conductive elements 18 may be configured with different cross-sectional shapes, without departing from the scope of the present disclosure.

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Each of the conductive elements 18 comprises a first surface 50 which is configured to electrically contact the front surface 22 of the first solar cell 20, as shown in Fig. 1. Each conductive element 18 also comprises a second surface 52 configured to electrically contact the back surface 34 of the second solar cell 30, as shown in Fig. 1.

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Each of the conductive elements 18 is formed from a single wire portion (i.e. the first and second portions 18a, 18b of each conductive element 18 are integrally formed with each other). In this way, the conductive elements 18 provide a direct electrical connection between

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the first and second solar cells 20, 30, which increases the flow of current therebetween. The plurality of conductive elements 18 are covered in a coating (not shown) which is configured, when in use, to solder the respective first and second surfaces 50, 52 to a respective surface of the solar cells 20, 30 upon which they are overlaid. The coating is an electrically conductive material having a melting point which is lower than that of the conductive element 18.

It will be appreciated that Fig. 2 shows the first portion 18a of the conductive elements 18 on the front surface 22 of the first solar cell 20 (i.e. the front connector 12a of the electrode assembly 12). An equivalent second portion 18b of the same conductive elements 18 is also arranged on the back surface 34 of the second solar cell 30 (i.e. the back connector 12b of the electrode assembly 12).

The film 40 has a thickness of at least 25 μm , optionally at least 55 μm and/or up to 180 μm . The film 40 is thinner than the conductive elements 18. For example, the conductive elements 18 have a thickness of between 200 μm and 300 μm .

The first and second portions 18a, 18b of the plurality of conductive elements 18 are each arranged in separate film portions, which are arranged on the front and back surfaces 22, 34 of the respective solar cells. For example, the front connector 12a comprises a first film portion which defines a front film portion 42 and the back connector 12b comprises a second film portion which defines a back-film portion (not shown). However, it is noted that the conductive elements 18 in the third portion 18c are free from any film covering.

According to an exemplary arrangement of the solar cell assembly 10, each of the first and second portions 18a, 18b of the conductive elements 18 is attached to a surface of the respective film portions 42 that faces the solar cell. Accordingly, the "solar cell-facing" surfaces of each film portion 42 is thermally bonded to the respective surfaces 22, 24, 32, 34 of the first and second solar cells 20, 30.

In the case of the front connector 12a, the front film portion 42 is arranged to contact the front surface 22 of the solar cell in the areas in-between the conductive elements 18 and the front finger electrodes. The back-film portion is configured in the same way for the back connector 12b. Each of the films portions is configured to at least partially (e.g. completely) envelope, or surround, the respective conductive elements 18 and the respective finger electrodes.

The front and back film portions are arranged to provide adhesion between the solar cells and the conductive elements 18 so that the conductive elements are correctly arranged on the

solar cells (i.e. aligned with the finger electrodes). In an exemplary embodiment, the front and back film portions may not fully cover the respective surfaces of the solar cells.

5 Whilst the film (e.g. the front film portion 42 as shown in the drawings) comprises a substantially planar bottom and top surfaces. It will be understood that the film may be configured to conform to the structural components of solar cells and/or conductive elements. For example, the film 40 may be comprised of elongate channels recessed towards the solar cell in the regions of the back surface in-between conductive elements, and may form ridges/protuberances over the structures electrodes (e.g. finger electrodes and conductive
10 elements) where they are present.

An exemplary film handling system 60, for manufacturing the electrode assembly 12 of the solar cell assembly 10, will now be described with reference to Figs. 3 to 6. The system comprises a film handling device 62 which is configured to receive a film 40 in a first position
15 (e.g. a film-loading position). The film handling device 62 receives and holds the film 40 whilst it is being transported to a second position (e.g. a film-unloading position), whereupon the film 40 is attached to a plurality of conductive elements 18. In particular, the film handling device 62 is configured to hold and then release the film 40 at different stages of the electrode assembly manufacturing method, as will be explained in more detail below.

20 The film-loading position corresponds to where the film 40 is installed (e.g. laid) onto the film handling device 62, whereas the film-unloading position defines a location whereupon the film 40 is released from the film handling device 62. For example, the film-unloading position corresponds to the position of the second portion 18b of the plurality of conductive elements
25 to which the film 40 is attached to form the back connector 12b of the electrode assembly 12. Accordingly, the film-unloading position also defines a film attachment position.

The plurality of conductive elements 18 are supported at the film-unloading position by a conductive element handling device 80, as shown in Figs. 3 to 6. The conductive element
30 handling device 80 is attached to an actuator (not shown) which is configured move the conductive element handling device 80 up and down, relative to the conductive elements 18 (i.e., in the vertical direction shown in Figs. 3 to 6). The actuator is operated to apply a compressive force so as to bring the conductive elements 18 and the film 40 together, as will be described in more detail below.

35 The film handling device 62 is mechanically coupled to a conveying assembly 64 configured to move (e.g. translate) the film handling device 62 between the film-loading and film-

unloading positions during the construction of the electrode assembly 12. The conveying assembly 64 includes a shuttle 74 having an actuator configured to move the shuttle 74 along a rail 76 of the conveying assembly 64 to thereby translate the film handling device 62 in a horizontal direction, relative to the plurality of conductive elements 18. The shuttle 74 further includes a vertical actuator configured to translate the film handling device 62 in a vertical direction, relative to the plurality of conductive elements 18. Each of the horizontal and vertical actuators comprises an electric motor coupled to a rack and pinion mechanism configured to convert the rotational motion of the motor into a linear motion used to propel the film handling device 62.

The film handling device 62 includes a substrate having a contact surface for receiving the film 40. The contact surface is provided with a plurality of openings which are fluidly coupled to a vacuum generator (negative-pressure generator) 66 configured to apply a negative gas pressure to the film 40. The negative gas pressure holds (e.g. sucks) a second surface of the film 40 in position against the contact surface on the substrate whilst the film handling device 62 is in transit. The openings in the contact surface of the film handling device 62 are also fluidly coupled to a positive-pressure generator (e.g. a blower or compressor) 68 configured to apply a positive gas pressure (e.g. a flow of pressurised gas) to the film 40. The positive gas pressure conveniently prevents the second surface of film 40 from sticking to the film handling device 62 during, or after, bonding of a first surface of the film 40 to the conductive elements 18 when forming the electrode assembly 12. For example, the positive gas pressure pushes the second surface of the film off of the contact surface. For completeness, it is restated that the openings in the contact surface may comprise a first set of openings couplable to the positive-pressure generator (e.g. couplable only to the positive-pressure generator) and a second set of openings couplable to the negative-pressure generator (e.g. couplable only to the negative pressure-generator), or all of the openings may be couplable to both the positive-pressure generator and the negative pressure generator.

The vacuum generator 66 and the positive-pressure generator 68 are fluidly coupled to the film handling device by a series of fluid conduits 72 (e.g. hoses). A switching assembly 70 is fluidly coupled between the film handling device 62 and each of the vacuum and positive-pressure generators 66, 68. During operation of the film handling system 60, the switching assembly 70 is configured to switch the fluid connection with the film handling device 62 between the vacuum generator 66 and the positive-pressure generator 68. The switching assembly 70 includes at least one valve configured to inhibit the flow of air between the film handling device and each of the vacuum and positive-pressure generators 66, 68.

Alternatively, or in addition, the switching assembly 70 comprises a controller configured to switch each of the generators 66, 68 on and off, as required.

5 The vacuum generator 66 comprises a vacuum pump configured to provide a negative gas pressure (i.e., a vacuum, or sucking, force) used to hold the second surface of the film 40 (the lower surface of the film 40 in Fig. 3) against the film handling device 62. The vacuum generator 66 is configured to provide a negative pressure of at least 0.1 MPa and up to 0.9 MPa.

10 The positive-pressure generator 68 comprises a compressed dry air system which includes a pressure vessel containing a pressurised gas, e.g. air. The positive-pressure generator 68 is configured to provide a positive gas pressure (i.e. a blowing force) to the film handling device 62 in the form of a pressurised flow of gas, which is used to actively detach the film 40 (e.g. the second surface of the film 40) from the film handling device 62 when required.

15 The compressed dry air system may comprise a blower or compressor configured to pressurise the air within the pressure vessel, for example when the film handling system 60 is not in use. Alternatively, once the pressure vessel is depleted it may be replaced with a full vessel. The compressed dry air system includes a valve assembly (not shown) to control the release of the air from the pressure vessel. The positive-pressure generator 68 is configured to provide a positive-pressure of at least 0.1 MPa and up to 0.9 MPa.

20 An exemplary method of manufacturing the electrode assembly 12 will now be described with reference to Figs. 3 to 6, which illustrate the steps of the manufacturing method. Reference will also be made to Fig. 7 which shows a flow chart of the corresponding method steps.

30 The method commences with a first method step 102 in which a film 40 is loaded onto the film handling device 62, as shown in Fig. 3, with the film handling device 62 located at the film-loading position. The switching assembly 70 fluidly couples the vacuum generator 66 to the film handling device 62 to exert a negative gas pressure upon the film 40, which thereby holds the film 40 in position on the contact surface of the film handling device 62. During this method step 102, the positive-pressure generator is simultaneously decoupled from the film handling device 62 by the switching assembly 70 and/or is simply switched off (e.g. via the controller).

35 In a second method step 104, the conveying assembly 70 moves the film handling device 62 to the film-unloading position. The negative gas pressure exerted on the film 40 by the vacuum generator 66 means that the film 40 is held in position securely by the film handling device 62,

as the conveying assembly 64 moves the film handling device 62 to the film-loading position. As the film handling device 62 arrives at the film-loading position, the first surface of the film 40 (the upper surface in Fig. 4) is brought into contact with the underside of the plurality of conductive elements 18, as shown in Fig. 4.

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According to a third method step 106, the film 40 is thermally bonded to the plurality of conductive elements 18 to define the front connector 12a or back connector 12b of the electrode assembly 12. As an example, the film 40 is thermally bonded to the second portion 18b of the plurality of conductive elements 18 to define the back connector 12b. A compressive

10 force is exerted by the film handling device 62 and the conductive element handling device 80 in order to bond the film 40 to the conductive elements 18. The film 40 comprises a polymeric material. Heat is also applied to the film 40, as shown in Fig. 4, which causes the film's polymeric material to soften, and thereby adheres the film 40 to the conductive elements 18.

15 During the third method step 106, the negative gas pressure is applied to the film 40. This causes the film 40 to remain flat on the contact surface of the film handling device 62, which improves the contact between the film 40 and the conductive elements 18, thereby ensuring that a strong thermal bond is formed therebetween.

20 A fourth method step 108 comprises actively detaching, or releasing, the film 40 from the film handling device 62 by directing pressurised gas from the positive-pressure generator 68 through the openings in the contact surface of the film handling device 62. The positive gas pressure is applied immediately after the film 40 is bonded to the conductive elements 18. This ensures that the film 40 does not stick to the film handling device 62 as the film handling

25 device 62 is separated from the film 40 in subsequent method steps. Accordingly, the vacuum generator 66 is decoupled from the film handling device 62 during the fourth method step 108 and/or is simply switched off (e.g. via the controller).

A fifth method step 110 involves returning the film handling device 62 to the film-loading position, as shown in Fig. 6. During this method step 110, positive gas pressure continues to be applied whilst the film handling device 62 is separated from the film 40, to ensure a clean release of the second surface of the film 40 from the film handling device 62.

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The above-described bonding of the film 40 to the conductive elements 18 results in the conductive elements 18 being at least partially embedded in the film 40, such that at least a portion of each conductive element remains exposed so as to form an ohmic contact with the respective solar cells 20, 30. The film 40 is heated using an infrared lamp (not shown).

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Alternatively, the required heat may be applied by any suitable heating means, such as a convection heating element, a hot air blower or an induction heating element.

It will be understood that the first and second portions 18a, 18b, of the plurality of conductive elements 18 can be attached to the respective film portions at the same time, or during
5 separate processes. When the electrode assembly 12 is in use, the first portion 18a of the plurality of conductive elements defines a front connector 12a of the electrode assembly 12, whereas the second conductive element portions 18b defines a back connector 12a. Similarly, the first and second film portions, define front and back film portions, respectively. As can be
10 appreciated, the first film portion may be attached to the first portion 18a of the plurality of conductive elements 18 with the conductive elements 18 in the same orientation as shown in Figs. 3 – 6 by the film handling device 62 for attaching the first film portion to the plurality of conductive elements 18 being inverted compared to the orientation of the film handling device 62 in Figs. 3 – 6 and positioned above a conductive element handling device 80 for handling
15 the first portion 18a of the plurality of conductive elements 18, said conductive element handling device 80 also being inverted compared to the orientation of the conductive element handling device 80 illustrated in Figs. 3 – 6. As can be appreciated, a film handling device 62 inverted from the orientation shown in Figs. 3 – 6 is conveniently configured to allow a negative gas pressure to be provided at the contact surface thereof such that a film 40 positioned
20 against the contact surface can be held in position against gravity.

An exemplary film handling device 62 will now be described with reference to Figs. 8A and 8B which shown isometric and plan views of a film handling device 62, respectively. Reference will also be made to Fig. 8C which illustrates a transverse-sectional view of the film handling
25 device 62 taken along the dashed line A-A, as shown in Fig. 8B. The film handling device 62 comprises a substrate 82 having a contact surface 84 for contacting with the film 40.

The film handling device 62 also includes a support structure 86 for attaching the substrate 82 to the shuttle 74 of the conveying assembly 64, as described above in relation to Figs. 3 to 6.
30 The support structure 86 is formed of a rigid material, such as stainless steel, in order to provide structural support for the substrate 82 during the manufacturing of the electrode assembly 12. The support structure 86 comprises a substrate connecting end 86a, or back plate, which is mechanically coupled (e.g. bonded) to a rear surface of the substrate 82, opposite the contact surface 84. A shuttle connecting end 86b of the support structure 86 is
35 mechanically couplable by removable fastener to the conveying assembly 64.

The substrate 82 has a length (L), a width (W), and a height (H), as shown in Figs. 8B and 8C. The substrate 82 is configured such that it is wider and longer than the film 40, as shown in Fig. 8B. Accordingly, an exemplary arrangement of the substrate 82 has a length of approximately 192 mm, a width of approximately 80 mm and a height of approximately 3 mm.

- 5 It will be appreciated that the substrate 82 may be configured with a range of different dimensions without departing from the scope of the present disclosure.

The substrate 82 also comprises a plurality of openings 90 arranged on the contact surface 84. The plurality of openings 90 are fluidly coupled to a network of fluid passageways 88, as shown in Fig. 8C. The fluid passageways 88 pass through the substrate 82 and the support structure 86 and thereby connect to the fluid conduits 72 of the film handling system 60. In this way, the plurality of openings 90 fluidly connect the contact surface 84 of the substrate 82 to the vacuum generator 66 and the positive pressure generator 68.

- 15 Each of the plurality of openings 90 is fluidly connected to a distal fluid passageway section. A plurality of the primary (e.g. distal) fluid passageway sections couple to a common secondary (e.g. intermediate) fluid passageway section. A plurality of secondary fluid passageways sections each connect to a common tertiary (e.g. proximal) fluid passageway section which passes through the support structure 86 to an inlet/outlet of the film handling device 62, as is shown in Fig. 8C. Each of the primary fluid passageway sections extend in a vertical direction (i.e., parallel to the height H of the substrate) towards the connecting secondary fluid passageway section which, in turn, extends in a lengthwise direction (i.e., parallel to the length L of the substrate) along the substrate 82. The tertiary fluid passageway section extends vertically through the substrate 82 and the support structure 86, as shown in Fig. 8C.

- According to an exemplary arrangement, the substrate 82 is arranged with eighty-four openings. However, it will be appreciated that the substrate 82 may have be configured with any number of openings without departing from scope of the present disclosure. Each of the openings is circular and has radius of at least 0.3 mm and up to 0.5 mm.

- The substrate 82 is formed of polytetrafluoroethylene (PTFE), or Teflon®, which has a static coefficient of friction, with respect to polished stainless steel, determined to be within a range of between 0.05 to 0.2. Accordingly, PTFE defines an anti-adhesive material, which is configured such that the contact surface 84 of the substrate 82 does not grip the film 40, when in use. Known film grippers are configured with contact surfaces that are made from rubbery, and therefore adhesive materials e.g. exhibiting a static coefficient of friction, with respect to

polished stainless steel, of at least 0.8, such as silicone rubber. By contrast, the PTFE comprising contact surface 84 of the film handling device 62 according to present disclosure is configured to prevent the film 40 from sticking, which thereby avoids unnecessary and costly delays to the construction of the electrode assembly 12.

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At least a portion of the contact surface 84 of the substrate 82 may be formed of any number of anti-adhesive (i.e., low friction) materials, including other fluorinated polymeric materials which have static coefficients of friction of up to 0.4 (e.g. PFA). Alternatively, at least a portion of the contact surface 84 may be formed of polypropylene.

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An alternative exemplary film handling device 162 will now be described with reference to Figs. 9 to 11. The film handling device 162 is configured with a plurality of protuberances 192 (e.g. ridges) arranged on the contact surface 184 of the substrate 182, as shown in Fig. 9. Each of the protuberances 192 has an elongate form. The protuberances 192 are arranged to each extend across the substrates 182 in the transverse direction (i.e. in a direction parallel to the width W of the substrate 182, as shown in Fig. 9) and are equally spaced apart in the longitudinal direction (i.e. in a direction parallel to the length L of the substrate 182).

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The protuberances 192 are equally spaced apart in a longitudinal direction relative to the substrate contact surface 184 to define longitudinally extending spaces (e.g. valleys) between adjacent protuberances 192 (e.g. ridges). The protuberances 192 are parallel to one another, and equally spaced apart in the longitudinal direction of the substrate contact surface 184. Accordingly, the plurality of protuberances 192 forms an array of parallel, longitudinally spaced (e.g. equally longitudinally spaced) protuberances 192. It will be appreciated that the protuberances and spaces between the protuberances defines the contact surface 184 of the substrate 182. However, in use, only the distal ends of the ridges may contact the film 40, i.e. the film 40 may not contact the floors of the valleys.

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The dimensions of each protuberance 192 are substantially the same as that of every other protuberance 192. Each protuberance 192 has length L, a width W, and a height H, as shown in Fig. 10. The height and width are substantially less than the length. According to an exemplary arrangement, the height of the protuberances 192 (i.e., the maximum extension from the main body of the substrate 182) is approximately 7 mm (e.g. greater than or equal to 6 mm and less than or equal to 8 mm). The maximum width of the protuberances 192 is approximately 3 mm (e.g. greater than or equal to 2mm and less than or equal to 4 mm). The length of each protuberance 192 is equal to the width of the substrate 182 (e.g. greater than

or equal to 70 mm and less than or equal to 90 mm, approximately 80 mm), as shown in Fig. 9.

Each protuberance 192 has a cross-sectional profile which narrows as the protuberance 192 extends away from a main body of substrate 182, as shown in Fig. 10. The side walls 196 of the protuberances 192 are arranged at an angle to the main body of the substrate 182, which in some embodiments is at least 100° and/or up to 110°. The protuberances 192 comprise an end portion 198 which extends furthest from the substrate 182. This may be referred to as the distal end portion since this portion is not connected to anything. The end portion 198 defines a peak, or uppermost end, of the protuberance 192, for example when the contact surface 184 is facing in a substantially upwards direction. The base of the protuberance, i.e. that part where it meets the valley floor, may be referred to as the proximal end portion since it is connected to the substrate.

A depressed, or recessed, region 194 is formed within the end portion 198 of the protuberance 192. The depressed region 194 defines a portion of the contact surface 194 on the protuberance that forms a concavity extending away from the film when the film is positioned on the contact surface during use (e.g. forms a concavity extending towards the main portion of the substrate) to create a void between the film 40 and the protuberance 192. The depressed region 194 is configured with a depth D of at least 3 mm and/or up to 5 mm. The depressed region has a concave surface having a uniform curvature measured transversely across the width of the protuberance 192. The radius of curvature in this direction is about 3 mm.

The openings 190 are arranged in the depressed region 194, as shown in Figs. 10 and 11. The depressed region 194 extends in the longitudinal direction of the protuberance (i.e. extend in the transverse direction of the substrate contact surface 184) to define a channel, which extends substantially along the entire length of the protuberance 192. The channels of the protuberances 192 can be aligned, when in use, with respective conductive elements 18. Accordingly, the channels can be used to guide and retain the conductive elements 18 in the correct bonding alignment with the film 40 whilst they are thermally bonded together.

The plurality of openings 190 are fluidly coupled to a network of fluid passageways 188, as shown in Fig. 10. The fluid passageways 188 are configured with primary, secondary, and tertiary fluid passageway sections as is described above in relation to the film handling device 62 shown in Fig. 8C.

It will be understood that the disclosure is not limited to the embodiments above described and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to

5 and includes all combinations and sub-combinations of one or more features described herein.

CLAIMS

1. A film handling device for manufacturing an electrode assembly for a solar cell assembly, the electrode assembly comprising a film and a plurality of electrically conductive elements for arranging on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the film handling device comprises:
- 5 a substrate comprising a contact surface for contacting the film; and
- characterised in that one or more protuberances are arranged on the contact surface
- 10 of the substrate for reducing a contact area between the contact surface and the film.
2. The film handling device according to claim 1, wherein the or each protuberance comprises an end portion which is extended furthest from a main body of the substrate, and wherein a depressed region is formed in the end portion of the protuberance.
- 15 3. The film handling device according to claim 2, wherein the substrate comprises one or more openings in the contact surface, the one or more openings arranged in the depressed region.
- 20 4. The film handling device according to claim 3, wherein the or each protuberance has a substantially elongate form having a length extending at least partly across the contact surface, and wherein the depressed region extends in the longitudinal direction of the protuberance to define a channel for receiving an electrically conductive element.
- 25 5. The film handling device according to claim 4, wherein the substrate comprises an array of parallel, transversely spaced protuberances.
6. The film handling device according to any one of claims 1 to 5, wherein the or each protuberance comprises a cross-sectional profile which narrows as the protuberance extends
- 30 away from the contact surface of the substrate.
7. A film handling device for manufacturing an electrode assembly for a solar cell assembly, the electrode assembly comprising a film and a plurality of electrically conductive elements for arranging on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the film handling device comprises:
- 35 a substrate comprising a contact surface for contacting the film; and

characterised in that at least a portion of the contact surface comprises an anti-adhesion material for reducing adherence of the contact surface to the film.

8. The film handling device according to claim 7, wherein the anti-adhesion material is
5 configured with a coefficient of friction within a range of between 0.05 and 0.4, optionally between 0.05 and 0.2.

9. The film handling device according to claim 7 or claim 8, wherein the anti-adhesion
10 material comprises one or more of polytetrafluoroethylene, perfluoroalkoxy alkanes, and polypropylene.

10. The film handling device according to any one of claims 7 to 9, wherein the anti-adhesion material is a non-wetting material.

15 11. A film handling system for manufacturing an electrode assembly for a solar cell assembly, the electrode assembly comprising a film and a plurality of electrically conductive elements for arranging on a surface of a solar cell such that the electrically conductive elements are interposed, in the solar cell assembly, between the film and the surface of the solar cell, the film handling system comprises:

20 a film handling device comprising a substrate, the substrate comprising a contact surface for contacting the film and one or more openings in the contact surface; and

characterised in that the film handling system comprises a positive-pressure generator which is fluidly coupled to the one or more openings and is configurable, in use, to apply a positive fluid pressure to the film on the contact surface of the film handling device to push the
25 film away from the contact surface.

12. The film handling system according to claim 11, wherein the positive-pressure generator is configured to provide a positive pressure of at least 0.1 MPa and up to 0.9 MPa.

30 13. The film handling system according to claim 11 or claim 12, wherein the positive-pressure generator comprises a compressed dry air system.

14. The film handling system according to any one of claims 11 to 13, wherein the system comprises;

35 a negative-pressure generator, configurable, in use, to apply a negative fluid pressure to the film on the contact surface of the film handling device; and

a switching assembly configured to switch between applying a positive fluid pressure and a negative fluid pressure to the film.

15. A method of manufacturing an electrode assembly for a solar cell assembly, the
5 electrode assembly comprises a film and a plurality of electrically conductive elements for
arranging on a surface of a solar cell such that the electrically conductive elements are
interposed, in the solar cell assembly, between the film and the surface of the solar cell, the
method comprises:

loading a film onto a film handling device at a film-loading position;
10 conveying the film handling device to a film-unloading position adjacent to a plurality
of electrically conductive elements; and
depositing the film onto the plurality of electrically conductive elements at the film-
unloading position;
characterised in that depositing the film comprises applying a positive fluid pressure to
15 detach the film from the film handling device.

16. The method according to claim 15, wherein depositing the film comprises:
applying a negative fluid pressure to the film during a process of thermally bonding the
film to the plurality of electrically conductive elements; and
20 applying the positive fluid pressure to release the thermally bonded film from the film
handling device.