Embodiments of the present disclosure generally relate to seals for thin-film photovoltaic apparatuses, and more particularly to waterproof seals for the electrical conductors routed into thin-film photovoltaic apparatuses. A photovoltaic apparatus is provided including a front sheet; a back sheet having a first opening; a photovoltaic device disposed between the front sheet and the back sheet; and a first assembly sealing the first opening. The first assembly includes a first layer formed over the first opening of the back sheet; a second layer formed over the first layer; and a barrier layer formed over the second layer. The photovoltaic apparatus further includes one or more conductors extending through the first opening of the back sheet, the one or more conductors electrically coupled to the photovoltaic device.
THIN-FILM DEVICE SEAL

BACKGROUND

Field

[0001] Embodiments of the present disclosure generally relate to seals for thin-film photovoltaic apparatuses, and more particularly to waterproof seals for the electrical conductors routed into thin-film photovoltaic apparatuses.

Description of the Related Art

[0002] Photovoltaic apparatuses are often placed outside and can thus be exposed to moisture from sources, such as precipitation and humidity. The interior of photovoltaic apparatuses can be damaged by moisture. For example, moisture can cause corrosion of some of the internal components of a photovoltaic apparatus and the formation of ice can cause structural damage to a photovoltaic apparatus.

[0003] Conductors are generally routed into the photovoltaic apparatus through an opening underneath the panel. This opening generally includes a junction box that is sealed with a potting compound. Although a waterproof seal for the opening that includes the junction box can be created by using potting compound, the potting compound can be expensive and the potting process can be time consuming and can produce inconsistent results.

[0004] Therefore, there is a need for an improved seal for openings of photovoltaic apparatuses as well as a method for producing such a seal.

SUMMARY

[0005] Embodiments of the present disclosure generally relate to seals for thin-film photovoltaic apparatuses, and more particularly to waterproof seals for the electrical conductors routed into thin-film photovoltaic apparatuses.

[0006] In one embodiment, a photovoltaic apparatus is provided. The photovoltaic apparatus includes a front sheet; a back sheet having a first opening; a photovoltaic device disposed between the front sheet and the back
sheet; and a first assembly sealing the first opening. The first assembly includes a first layer formed over the first opening of the back sheet; a second layer formed over the first layer; and a barrier layer formed over the second layer. The photovoltaic apparatus further includes one or more conductors extending through the first opening of the back sheet, the one or more conductors electrically coupled to the photovoltaic device.

[0007] In another embodiment, a photovoltaic module is provided. The photovoltaic module includes a front sheet; a back sheet having a first opening; a first array of photovoltaic devices disposed between the front sheet and the back sheet. Each photovoltaic device includes an array of photovoltaic cells, the array of photovoltaic cells extending in a first direction from a first end to a second end and each photovoltaic cell extends from a first side to a second side of the array. The first array extends in a second direction. A first assembly seals the first opening. The first assembly includes a first layer formed over the first opening of the back sheet; a second layer formed over the first layer; and a barrier layer formed over the second layer. The photovoltaic module further includes one or more conductors extending through the first opening of the back sheet, the one or more conductors electrically coupled to the photovoltaic devices of the first array.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

[0009] Figure 1A is a cross sectional view a photovoltaic apparatus, according to one embodiment.

[0010] Figure 1B is a close-up sectional view of the photovoltaic apparatus of the embodiment shown in Figure 1A.
[0011] Figure 1C is a cross sectional view of a photovoltaic apparatus, according to another embodiment.

[0012] Figure 1D is a cross sectional view of a photovoltaic apparatus, according to another embodiment.

[0013] Figure 2A is a top sectional view of a photovoltaic apparatus, according to another embodiment.

[0014] Figure 2B is a top sectional view of a photovoltaic apparatus, according to another embodiment.

[0015] Figure 2C is a top sectional view of a photovoltaic apparatus, according to another embodiment.

[0016] Figure 2D is a top sectional view of a photovoltaic apparatus, according to another embodiment.

[0017] Figure 3A is a close-up sectional view of an opening through the back sheet of a photovoltaic apparatus, according to one embodiment.

[0018] Figure 3B is a close-up sectional view of a first opening and a second opening through a back sheet of a photovoltaic apparatus, according to one embodiment.

[0019] Figure 4A is a top sectional view of a photovoltaic module, according to one embodiment.

[0020] Figure 4B is a top sectional view of a photovoltaic module, according to another embodiment.

[0021] Figure 4C is a top sectional view of a photovoltaic module, according to another embodiment.

[0022] Figure 4D is a cross-sectional view of the photovoltaic module taken along a section line of Figure 4C.

[0023] Figure 5 is a process flow diagram of a method for manufacturing a photovoltaic module, according to one embodiment.

[0024] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the
figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

**DETAILED DESCRIPTION**

[0025] Embodiments of the present disclosure generally relate to seals for thin-film photovoltaic apparatuses, and more particularly to waterproof seals for the electrical conductors routed into thin-film photovoltaic apparatuses.

[0026] Figure 1A is a cross sectional view a photovoltaic apparatus 300A, according to one embodiment. The photovoltaic apparatus 300A may be encapsulated, for example with one or more thermoplastic polymer materials. The photovoltaic apparatus 300A may include multiple optoelectronic devices, such as photovoltaic devices (e.g., solar cells), diodes, and LEDs. The view in Figure 1A of the photovoltaic apparatus 300A is shown including a photovoltaic device 100 (or sub-module).

[0027] The photovoltaic device 100 is formed on a substrate 110. The substrate 110 may be a rigid substrate or a flexible substrate. The substrate 110 may also be formed from an electrically insulating material. For example, in one embodiment a polyimide substrate may be used, such as a polyimide substrate having a thickness in the Z-direction from about 5 μm to about 200 μm, such as from about 15 μm to about 100 μm.

[0028] In some embodiments, the photovoltaic device 100 can be thin-film layer deposited on the substrate 110, such as a scribed thin-film layer including a plurality of monolithically interconnected photovoltaic cells. In other embodiments, the photovoltaic device 100 can include a photovoltaic device formed on another substrate that is then positioned on the substrate 110.

[0029] The photovoltaic device 100 can be formed of, for example, a back-contact layer formed on the substrate 110, an absorber layer formed over the back-contact layer, and a front-contact layer formed over the absorber layer. The back-contact layer can be fabricated from a material having a high optical reflectance and is commonly made of molybdenum (Mo) although several other thin-film materials, such as metal chalcogenides, molybdenum chalcogenides, molybdenum selenides (such as MoSe2), sodium (Na)-doped Mo, potassium (K)-doped Mo, Na- and K-doped Mo, transition metal chalcogenides, tin-doped
indium oxide (ITO), doped or non-doped indium oxides, doped or non-doped zinc oxides, zirconium nitrides, tin oxides, titanium nitrides, titanium (Ti), tungsten (W), tantalum (Ta), gold (Au), silver (Ag), copper (Cu), and niobium (Nb) may also be used or included advantageously. In some embodiments, the back-contact layer is deposited onto the substrate 110 by use of sputtering process.

[0030] The absorber layer is typically made of an "ABC" material, wherein "A" represents elements in group 11 of the periodic table of chemical elements as defined by the International Union of Pure and Applied Chemistry including copper (Cu) or silver (Ag), "B" represents elements in group 13 of the periodic table including indium (In), gallium (Ga), or aluminum (Al), and "C" represents elements in group 16 of the periodic table including sulfur (S), selenium (Se) or tellurium (Te). An example of an ABC material is the Cu(In,Ga)Se2 semiconductor also known as CIGS. In some embodiments, the absorber layer may be a polycrystalline material. In other embodiments, the absorber layer may be a monocrystalline material. Another example of a material that may be used as the absorber layer is chalcopyrite.

[0031] The front-contact layer can be an electrically conductive and optically transparent material, such as a transparent conductive oxide (TCO) layer. For example, in some embodiments, the front-contact layer may be formed of doped or non-doped variations of materials, such as indium oxides, tin oxides, or zinc oxides.

[0032] In some embodiments, a semiconductive buffer layer can be disposed between the absorber layer and the front-contact layer. The semiconductive buffer layer ordinarily has an energy bandgap higher than 1.5 eV. The semiconductive buffer layer may be formed of materials, such as CdS, Cd(S,OH), CdZnS, indium sulfides, zinc sulfides, gallium selenides, indium selenides, compounds of (indium, gallium)-sulfur, compounds of (indium, gallium)-selenium, tin oxides, zinc oxides, Zn(Mg,0)S, Zn(O,S) material, or variations thereof.

[0033] A first busbar 170 forms an electrical connection to the photovoltaic device 100, such as to the back-contact layer through a connection region of
the front-contact layer of the photovoltaic device 100 that is coupled to the back-contact layer. The first busbar 170 may be a conductive material that forms the cathode of the photovoltaic device 100. In some embodiments, the first busbar 170 may be formed of a flexible material. The busbars and junction busbars described herein may also be referred to as conductors.

[0034] A second busbar 180 forms an electrical connection to the photovoltaic device 100, such as to the to the front-contact layer of the photovoltaic device 100. The second busbar 180 may be a conductive material that forms the anode of the photovoltaic device 100. In some embodiments, the second busbar 180 may be formed of a flexible material.

[0035] The photovoltaic device 100 may be encapsulated within the photovoltaic apparatus 300A by use of a front-side adhesive 240 and a back-side adhesive 230. In some embodiments, the front-side adhesive 240 and the back-side adhesive 230 completely surround and encapsulate the photovoltaic device 100. The front-side adhesive 240 is formed over the front-contact layer of each of the photovoltaic device 100, and also over the first and second busbars 170, 180. The front-side adhesive 240 may be formed of a flexible material, such as a flexible polymer. For example, in one embodiment the front-side adhesive 240 may be formed of a thermoplastic olefin (TPO) based polymer or a TPO blend.

[0036] The back-side adhesive 230 is disposed over the side of the substrate 110 that is opposite to the side that the photovoltaic device 100' is formed on. The back-side adhesive 230 may be formed of a flexible material, such as a flexible polymer. For example, in one embodiment the back-side adhesive 230 may be formed of a thermoplastic olefin-based polymer (TPO) or a TPO polymer blend. The back-side adhesive 230 may contact the front-side adhesive 240 at each of the ends of the photovoltaic device 100 (i.e., the ends where the first and second busbars 170, 180 are located) and also on either side of the photovoltaic device 100 (i.e., both sides in the Y-direction of Figure 1A that are not visible in the cross-section of Figure 1A), so that the front-side adhesive 240 and the back-side adhesive 230 completely surround and encapsulate the photovoltaic device 100.
A front sheet 250 can be disposed on an outer surface of the front-side adhesive 240, such as a top surface of the front-side adhesive 240. The front sheet 250 can include a first surface 251 contacting the front-side adhesive 240 and facing the photovoltaic device 100. The front sheet 250 can further include a second surface 252 disposed opposite to the first surface 251 and facing away from the photovoltaic device 100. The front sheet 250 can be formed of a transparent material, such as glass or a transparent thermoplastic polymer. In some embodiments, the front sheet 250 may be formed of a rigid material. In other embodiments, the front sheet 250 may be formed of a flexible material.

A back sheet 210 can be disposed on an outer surface of the back-side adhesive 230, such as a bottom surface of the back-side adhesive 230. The back sheet 210 can include a first surface 211 contacting the back-side adhesive 230 and facing the photovoltaic device 100. The back sheet 210 can include a second surface 212 disposed opposite to the first surface 211 and facing away from the photovoltaic device 100. The back sheet 210 may include a reflective material, such as a metal layer, a reflective polymer or a polymer with a reflective layer (e.g., metal foil) formed over the first surface 211. In some embodiments, the back sheet 210 may be formed of a rigid material. In other embodiments, the back sheet 210 may be formed of a flexible material. In some embodiments, a fiber-reinforced polymer may be used as the material for the back sheet 210. In still other embodiments, the back sheet 210 may be formed of glass material.

The photovoltaic apparatus 300A can further include an edge seal 260. The presence of the edge seal 260 at the edge of the photovoltaic apparatus 300A can help assure that photovoltaic apparatus 300A will meet electrical certification requirements and eliminate common photovoltaic apparatus manufacturing and photovoltaic device failure modes. In general, the edge seal 260 comprises a polymeric material, such as an elastomer, for example a butyl rubber that can be formed by dispensing a liquid precursor material along the edge of the photovoltaic apparatus 300A and allowing it to cure. The edge seal 260 can optionally include a first portion 260a1 disposed between the first surface 211 of the back sheet 210 and the first surface 251 of
the front sheet 250. The first portion 260a1 can contact the first surface 251 of the front sheet 250 and the first surface 211 of the back sheet 210. An inner surface of the first portion 260a1 may also contact the front-side adhesive 240 and the back-side adhesive 230. The first portion 260a1 may have a width 263 in the X-direction. The width 263 can be, for example, from about 5 mm to about 15 mm, such as about 10 mm.

[0040] The back sheet 210 includes an outer portion 213 that extends past the front sheet 250 in the X-direction for a distance 214. The distance 214 can be, for example, from about 0.5 mm to about 10 mm, such as about 4 mm. The front sheet 250 includes an outer edge 253. The outer edge 253 can extend substantially in the Z-direction to allow the edge seal 260 to form a seal thereon.

[0041] The edge seal 260 further includes a second portion 260a2. The second portion 260a2 of the edge seal 260a extends from the first surface 211 of the outer portion 213 of the back sheet 210 to the outer edge 253 of the front sheet 250. In some embodiments, the second portion 260a2 may cover all of the first surface 211 of the outer portion 213 of the back sheet 210. The second portion 260a2 may have an outer curved surface 260a3. The second portion 260a2 may cover all of the outer edge 253 of the front sheet 250. The second portion 260a2 may extend to the second surface 252 of the front sheet 250.

[0042] The photovoltaic apparatus 300A may further include an opening 320 extending through the back sheet 210. The opening 320 may be used to route one or more conductors to electrically connect the photovoltaic apparatus 300A to one or more external devices, such as electronics to charge one or more external batteries. An edge 321 of the back sheet 210 can surround the opening 320. The opening 320 can have a width 325 in the X-direction of at least 1.5 mm, such as at least 3.0 mm. A junction box 330 may be positioned over the opening 320. The junction box 330 may contact the second surface 212 of the back sheet 210. The junction box 330 may cover the opening 320 on the second surface 212 of the back sheet 210.

[0043] A first junction busbar 172 can extend from the junction box 330 through the opening 320 and to the first busbar 170 allowing for an electrical connection to be made to the first busbar 170 in the junction box 330. In some
embodiments, the first junction busbar 172 may be formed of a flexible material, such as a thin metal strip. Furthermore, in some embodiments, a conductive adhesive can be used to paste the first junction busbar 172 to the first busbar 170. In other embodiments, the first busbar 170 and the first junction busbar 170 may be welded or soldered together. In still other embodiments, the first junction busbar 172 can be a folded continuation of the first busbar 170. In some embodiments, a first junction busbar insulation 174 can be formed around the first junction busbar 172 to electrically insulate the first junction busbar 172. The first junction busbar insulation 174 can be formed of, for example, a polytetrafluoroethylene (PTFE) heat-shrink tubing or a silicon rubber coated fiberglass tube. The first junction busbar insulation 174 can extend from inside the junction box 330 to a folded segment (e.g., third segment 172c of Figure 1B) of the first junction busbar 172. In other embodiments, the first junction busbar insulation 174 can extend from the junction box 330 to the first busbar 170.

[0044] A second junction busbar 182 can extend from the junction box 330 through the opening 320 and to the second busbar 180 allowing for an electrical connection to be made to the second busbar 180 in the junction box 330. In some embodiments, the second junction busbar 182 may be formed of a flexible material, such as a thin metal strip. Furthermore, in some embodiments, a conductive adhesive can be used to paste the second junction busbar 182 to the second busbar 180. In other embodiments, the second junction busbar 182 and the second busbar 180 may be welded together. In still other embodiments, the second junction busbar 182 can be a folded continuation of the second busbar 180. In some embodiments, a second junction busbar insulation 184 can be formed around the second junction busbar 182 to electrically insulate the second junction busbar 182. In some embodiments, the second junction busbar insulation 184 can extend from inside the junction box 330 to a folded segment (e.g., third segment 182c of Figure 1B) of the second junction busbar 182. In other embodiments, the second junction busbar insulation 184 can extend from the junction box 330 to the second busbar 180. The second junction busbar insulation 184 can be formed of, for example, a polytetrafluoroethylene (PTFE) heat-shrink tubing or a silicon rubber coated fiberglass tube.
The junction box 330 may include one or more connectors for connecting the first junction busbar 172 and the second junction busbar 182 with one or more external conductors (not shown). In some embodiments, the first junction busbar 172 and the second junction busbar 182 can be welded to one or more of these external conductors in the junction box 330.

The photovoltaic apparatus 300A can further include a sealing assembly 30 (Figure 1B), which is also referred to herein as a first assembly, to seal the opening 320. The sealing assembly 30 can include a first layer 314 formed over the back sheet 210. In some embodiments, the first layer 314 can be formed on the back sheet 210. The first layer 314 can be formed of a polymeric material, such as an elastomer, for example a butyl rubber. The first layer 314 can extend for a distance 315 over the back sheet 210 on both sides of the opening 320 in the X-direction. The distance 315 (X-direction in Figure 1A) can be at least 5 mm, such as at least 10 mm. The first layer 314 can have a total width in the X-direction of the width 325 plus double the distance 315. The first layer 314 can extend over the opening 320 the Y-direction for distances similar to the distance 315.

The sealing assembly 30 can further include a second layer 312 formed over the first layer 314. In some embodiments, the second layer 312 can be formed on the first layer 314. The second layer 312 can be formed of a polymeric material, such as an elastomer, for example a butyl rubber. The second layer 312 can be sized similarly to the first layer 314. The first layer 314 and the second layer 312 can have a combined thickness 316 in the Z-direction from about 0.25 mm to about 1.5 mm, such as from about 0.45 mm to about 1 mm.

The sealing assembly 30 can further include a barrier layer 310 formed over the second layer 312. In some embodiments, the barrier layer 310 can be formed on the second layer 312. The barrier layer 310 can be formed of a foil having a low water vapor transmission rate (WVTR), such as WVTR less than about 1*10^{-4} (g/m^2·day). For example, in one embodiment the barrier layer 310 can be a metal foil, such as an aluminum foil for its reflective properties. The barrier layer 310 can have a thickness in the Z-direction from about 5 \mu m to about 100 \mu m, such as from about 10 pm to about 30 pm. The first layer 314,
the second layer 312, and the barrier layer 310 can have a combined thickness 318 in the Z-direction from about .25 mm to about 2.0 mm, such as from about 0.45 mm to about 1.5 mm.

[0049] The photovoltaic apparatus 300A can further include a third layer 309 formed over the barrier layer 310. The third layer 309 can be formed of a polymer, such as a polymer encapsulant, such as or poliyimide. The third layer 309 can be formed between the sealing assembly 30 and the substrate 110. The third layer 309 can protect the substrate 110 from the barrier layer 310. For example, the third layer 309 can protect the substrate 110 from a barrier layer 310 that is formed of aluminum that will expand and contract a significant amount with changes in temperature. The thermal expansion and contraction of a barrier layer 310 may cause cutting or abrasion of the substrate 110 by the barrier layer 310 if the barrier layer 310 is in contact with the substrate 110.

[0050] Figure 1B is a close-up sectional view of the photovoltaic apparatus 300A. In one embodiment, the first junction busbar 172 can include a first segment 172a, a second segment 172b, a third segment 172c, and a fourth segment 172d. Similarly, the second junction busbar 182 can include a first segment 182a, a second segment 182b, a third segment 182c, and a fourth segment 182d.

[0051] The first segments 172a, 182a can be connected to the respective busbars 170, 180 by using the methods described above, such as welding, soldering, or using conductive paste. The second segments 172b, 182b can extend from the respective first segments 172a, 182a through a portion of the back-side adhesive 230. In some embodiments, the second segments 172b, 182b can extend to a position located in the Z-direction where the first layer 314 and the second layer 312 contact each other.

[0052] The third segments 172c, 182c can extend from the respective second segments 172b, 182b to a location over the opening 320. In some embodiments, the third segments 172c, 182c may be substantially parallel to the first surface 211 of the back sheet 210. Furthermore, in some embodiments the third segments 172c, 182c can be disposed between the first layer 314 and the second layer 312. In one embodiment, the junction bars 172, 182 are
positioned so that the third segments 172c, 182c are disposed between the first layer 314 and the second layer 312 and then a portion of the photovoltaic apparatus 300A is laminated to have the first layer 314 and the second layer 312 surround the third segments 172c, 182c. Furthermore, in some embodiments, the third segments 172c, 182c can be insulated with the respective busbar insulations 174, 184.

[0053] The fourth segments 172d, 182d extend from the third segments 172c, 182c through the opening 320 and to a location in the junction box 330. Also, the portion of the fourth segments 172d, 182d that extends into the junction box 330 generally includes at least some length that is not covered by the busbar insulations 174, 184, so that the junction busbars 172, 182 to be electrically connected to one or more external devices.

[0054] Referring to Figures 1A and 1B, portions of the sealing assembly 30, such as the first layer 314 and the second layer 312 can be formed using different methods. For example, in one embodiment the first layer 314 and the second layer 312 can be formed of butyl strips that are placed on top of each other to cover the opening 320, and then the junction busbars 172, 182 can be pushed through one or more of the butyl strips. Afterwards, the first layer 314 and the second layer 312 as well as other components of the photovoltaic apparatus 300A can be laminated causing the first layer 314 and the second layer 312 to melt and form a seal around the junction busbars 172, 182 and the opening 320.

[0055] In another embodiment, a separate piece of sealing material (e.g., an elastomeric material) having preformed holes can be used in place of the first layer 314 and the second layer 312, and then the junction busbars 172, 182 can be routed though the preformed holes to the respective busbars 170, 180. A similar lamination process can be used for this embodiment to cause the sealing material to melt and form a seal around the junction busbars 172, 182 and the opening 320.

[0056] The junction busbar insulations 174, 184 can be formed of a material (e.g., PTFE) that does not melt or flow during the laminations described herein. By using a material that does not melt or flow during these laminations,
distances between the conductors, such as the junction busbars 172, 182, and other components of the photovoltaic apparatus 300A, such as the back-contact layer or the back sheet 210 described above, can be controlled, which can be useful for certification purposes.

[0057] In yet another embodiment, the seal created by first layer 314 and the second layer 312 can be formed instead by adding liquid sealing material, such as a thermoplastic material (e.g., a butyl rubber) into the opening 320 after the junction busbars have been positioned. This liquid sealing material can then solidify around at least portions of the third segments 172c, 182c and the fourth segments 172d, 182d.

[0058] By sealing the opening 320 by use of materials inside the photovoltaic apparatus, such as the first layer 314 and the second layer 312, potting of the junction box 330 is no longer required. The pressure of the lamination can also create a stronger and more reliable seal than, for example, potting compound(s) that are typically injected at atmospheric pressures into the opening 320. Furthermore, lamination processes are commonly used in the manufacturing of photovoltaic apparatuses, so openings, such as the opening 320, can be sealed during an existing step of an existing process using existing equipment.

[0059] Figure 1C is a cross sectional view of a photovoltaic apparatus 300C, according to another embodiment. Photovoltaic apparatus 300C is similar to photovoltaic apparatus 300A of Figure 1A except that photovoltaic apparatus 300C includes: (1) a plurality of ravings 220 positioned over the back sheet 210; (2) junction busbars 172t, 182t in place of the junction busbars 172, 182; and (3) a plurality of spacers 225 positioned between the back sheet 210 and the junction busbars 172t, 182t in the opening 320. Also, the photovoltaic apparatus 300C does not include the third layer 309 that was used to protect the substrate 110 from the barrier layer 310 to illustrate that the third layer 309 is optional.

[0060] A spacing layer can be created by using a plurality of ravings 220 or other spacing material. The plurality of ravings 220 can be positioned on the back sheet 210 in some embodiments. Each roving 220 can be formed of a bundle of organic or inorganic fibers. The fibers in the ravings 220 may be
formed of a fibrous material, such as fiberglass. In other embodiments, the ravings 220 may be formed of another fiber material, such as a carbon fiber material, or of a fabric. In other embodiments, the ravings 220 may be formed of a layer of a unidirectional glass fiber with a non-woven binder.

[0061] The ravings 220 can be embedded in the back-side adhesive 230 during a lamination process, which is used to form the photovoltaic apparatus 300C. For example, when the photovoltaic apparatus 300C is finally formed the ravings 220 may be separated by sections of back-side adhesive 230 in the X-direction. Furthermore, the ravings 220 generally extend in the Y-direction between the substrate 110 and the back sheet 210. In some embodiments, the ravings 220 can contact the substrate 110 and/or the back sheet 210. Because the ravings 220 can be formed from a rigid material that can be arranged in a desirable structural pattern or orientation, such as fiberglass, the ravings 220 can be used to maintain a spacing between an electrically active component of the photovoltaic device 100, such as the back-contact layer described above, and an external object. Furthermore, a material such as fiberglass generally does not substantially shrink or compress over time, which enables spacing between electrically active components and external objects to be maintained over time in the photovoltaic apparatus 300C. Maintaining adequate spacing between electrically active components of the photovoltaic device 100, such as the back-contact layer described above, and an external object can help to prevent occurrences of arcing and assure that the formed photovoltaic apparatus 300C will meet photovoltaic device certification standards.

[0062] The junction busbars 172t, 182t are similar to the junction busbars 172, 182 of the photovoltaic apparatus 300A except that the junction busbars 172t, 182t are connected to a top surface of the respective busbars 170, 180 instead of a bottom surface of the respective busbars 170, 180. The junction busbars 172t, 182t can be connected to the respective busbars 170, 180 using the methods described above such as welding, soldering, or using a conductive paste. The junction busbars 172t, 182t illustrated in Figure 1C may be used with any of the other photovoltaic apparatus configurations disclosed herein.

[0063] Each spacer 225 can be formed of a bundle of fibers. The fibers in the spacers 225 may be formed of a fibrous material, such as fiberglass. In
other embodiments, the spacers 225 may be formed of a polymer tube or a fiber tube. The spacers 225 can provide support for the portions of the junction busbars 172t, 182t in the opening 320 of the back sheet 210. The plurality of spacers 225 can further help ensure the photovoltaic apparatus 300C will meet photovoltaic device certification standards.

[0064] Figure 1D is a cross sectional view of a photovoltaic apparatus 300D, according to another embodiment. The photovoltaic apparatus 300D is similar to the photovoltaic apparatus 300A of Figure 1A except that a number of the layers and other components of the photovoltaic apparatus 300D includes a hump. The humps in these layers and other components can result after lamination of the photovoltaic apparatus 300D, for example, when the photovoltaic apparatus 300D includes a rigid back sheet 210 and the photovoltaic device 100 is placed over the opening 320. In some embodiments, the formation of one or more humps above the opening 320 can indicate that the lamination process has properly sealed the opening 320.

[0065] The photovoltaic apparatus 300D includes the first layer 314 and the second layer 312 described above for the photovoltaic apparatus 300A. The photovoltaic apparatus 300D further includes a barrier layer 310d that includes a hump and a third layer 309d that also includes a hump. For example, the top surface of each of the barrier layer 310d and the third layer 309d slopes upwardly from the edges of the layers 309d, 310d towards the center of the layers 309d, 310d.

[0066] The photovoltaic apparatus 300D further includes a photovoltaic device layer 111d that includes a hump 111h. The photovoltaic device layer 111d can include, for example, similar components and materials as the substrate 110 and the photovoltaic device 100 described above for the photovoltaic apparatus 300A. The hump 111h can be formed across portions of the photovoltaic device layer 111d that are positioned above the third layer 309d.

[0067] The photovoltaic apparatus 300D further includes a front-side adhesive 240d that includes a hump 240h. The hump 240h can be formed across portions of the front-side adhesive 240d that are positioned above the
third layer 309d. The photovoltaic apparatus 300D further includes a front sheet 250d that includes a hump 250h. The hump 250h can be formed across portions of the front sheet 250d that are positioned above the third layer 309d. In some embodiments, the front sheet hump 250h can have a width 256 in the X-direction that is greater than the width of the first layer 314 by about 2 mm to about 40 mm, such as by about 4 mm to about 20 mm, such as by about 6 mm to about 12 mm. Furthermore, the front sheet hump 250h can have a height 257 from about 0.1 mm to about 2 mm, such as about 0.3 mm to about 1 mm, such as about 0.4 mm to about 0.7 mm. Furthermore, the laminated structure above the back sheet 210 through and including the front sheet 250d at locations not including the hump (e.g., the hump 250h) can have a thickness 319 from about 0.1 mm to about 5 mm, such as 0.5 mm to about 3 mm, such as 1.1 mm to about 1.4 mm.

[0068] Figure 2A is a top sectional view of a photovoltaic apparatus 301A, according to another embodiment. The photovoltaic apparatus 301A can include many of the same components and layers as the photovoltaic apparatus 300A of Figure 1A. In the photovoltaic apparatus 300A of Figure 1A, the opening 320 of the back sheet 210 is positioned below the photovoltaic device 100. Conversely, here the opening 320 of the back sheet 210 is not positioned below the photovoltaic device 100. During the following descriptions, the top view of the photovoltaic apparatus 301A of Figure 2A as well as the top views of the photovoltaic apparatuses of Figures 2B to 2D are shown without the front sheet 250, the front-side adhesive 240, and the back-side adhesive 230 to give a clearer view of the arrangement of layers and components in these photovoltaic apparatuses.

[0069] The photovoltaic apparatus 301A extends from a first end 401 to a second end 402 in the X-direction. The photovoltaic apparatus 301A extends from a first side 403 to a second side 404 in the Y-direction. The photovoltaic device 100 is disposed over the back sheet 210. The photovoltaic device 100 extends from a first end 1101 to a second end 1102 in the X-direction. Individual photovoltaic cells, such as photovoltaic cell 101, extend from a first side 1103 to a second side 1104 of the photovoltaic device 100 in the Y-direction. Serial interconnects 191 (e.g., monolithic serial interconnects) divide
the solar cells to form an array of serially connected solar cells, the array extending in the X-direction.

[0070] In the photovoltaic apparatus 301A, the opening 320 is offset from the photovoltaic device 100 in the Y-direction. The junction busbars 172, 182 extend from the opening 320 to the respective busbars 170, 180 in the X-direction. Portions of the junction busbars 172, 182 can be covered by the respective busbar insulations 176, 186. Furthermore, additional insulating layers 176, 186 can be positioned between the junction busbars 172, 182 and the back sheet 210, such as between the busbar insulations 176, 186 and the back sheet 210. The insulating layers 176, 186 can be formed of, for example, an insulating tape, such as an insulating tape formed of polyimide. Furthermore, the insulating layers 176, 186 can extend in the X-direction from the location where the busbars 170, 180 connect to the respective junction busbars 172, 182 to the edges of the barrier layer 310.

[0071] Figure 2B is a top sectional view of a photovoltaic apparatus 301B, according to another embodiment. The photovoltaic apparatus 301B is similar to photovoltaic apparatus 301A of Figure 2A except that the photovoltaic apparatus 301B includes different busbars, as well as a different opening 320b for routing the busbars 170b, 180b. The photovoltaic apparatus 301B includes a back sheet 210 having an opening 320b with a circular cross-section that is positioned below the photovoltaic device 100. Furthermore, a barrier layer 310b with a corresponding circular cross-section can be provided between the opening 320b of the back sheet 210 and the photovoltaic device 100. The barrier layer 310b can have a larger diameter than the opening 320b. Moreover, the first layer and the second layer (i.e., similar to the first layer 314 and the second layer 312 described above) can also have a circular cross-section, such as the same circular cross-section of the circular barrier layer 310b. Using a barrier layer 310b having a circular cross-section allows for an improved distribution of strain during the lamination process relative to using a barrier layer having a square or rectangular cross-section, which can reduce the risk of causing damage to the substrate, such as forming wavelets in the substrate. Furthermore, using a circular opening 320b is easier and less expensive to form than a square or rectangular opening. Furthermore, there is
a lower risk of forming cracks in the back sheet 210 when using the circular opening 320b relative to using a square or rectangular opening. The circular opening 320b also allows for an improved and more uniform seal pressure distribution formed around the opening 320b relative to a seal formed around a square or rectangular opening.

[0072] The photovoltaic apparatus 301 B can include a first busbar 170b and a second busbar 180b. The busbars 170b, 180b include respective first portions 170b1, 180b1 extending from the first side 1103 of the photovoltaic device 100 to the second side 1104 of the photovoltaic device 100. The busbars 170b, 180b further include respective second portions 170b2, 180b2 that fold under the photovoltaic device 100 and extend between the back sheet 210 and the photovoltaic device 100 and into the opening 320b. Portions of busbars 170b, 180b after the folding over can be surrounded by the respective busbar insulations 174b, 184b. Having the busbars 170b, 180b fold over the photovoltaic device 100 can allow for less material parts to be used relative to the photovoltaic apparatus 301A that used separate busbars and junction busbars.

[0073] Busbar spacers 175b, 185b can be disposed between the respective busbar insulations 174b, 184b and the photovoltaic device 100. The busbar spacers 175b, 185b can be used to prevent mechanical friction between the busbars and the substrate of the photovoltaic device 100 during the lamination process. The busbar spacers 175b, 185b can be formed of a polymer, such as a PTFE encapsulant, polyimide, or a polyimide adhesive tape. Furthermore, insulating layers 176b, 186b can be positioned between the junction busbars and the back sheet 210, such as between the busbar insulations 174b, 184b and the back sheet 210. The insulating layers 176b, 186b can be formed of, for example, an insulating tape, such as an insulating tape formed of polyimide.

[0074] Figure 2C is a top sectional view of a photovoltaic apparatus 301 C, according to another embodiment. The photovoltaic apparatus 301 C is similar to photovoltaic apparatus 301 A of Figure 2A except that the photovoltaic apparatus 301 C includes different busbars, a different opening for routing conductors, and a plurality of ravings 220.
The rovings 220 are disposed between the photovoltaic device 100 and the back sheet 210. A centerline 220C of each roving 220, which extends in the Y-direction, can be substantially aligned with each serial interconnect(s) 191 that extends in the Y-direction. The serial interconnects 191 can be a source of electrical arcing. For example, an arc may form between a serial interconnect and a conductive sheet or a conductive support on which the photovoltaic device is fastened, for example by adhesive bonding. Thus, a person skilled in the art will take care to maintain spacing between the various differently biased regions within and adjacent to each of the serial interconnects 191 during operation. Therefore, having the centerline 220C of the rovings 220 aligned with each serial interconnect 191 will support this relatively flexible region of the photovoltaic device 100 so that the spacing between the various separated portions of the serial interconnects 191 and other nearby electrically conductive parts can be maintained, and thus electrical arcing within or emanating from the photovoltaic device 100 can be prevented.

One or more outer rovings 221e are disposed at a position in the X-direction between an end of the photovoltaic device 100 and the adjacent end of the photovoltaic apparatus 300C. For example, an outer roving 221e is disposed between the first end 1101 of the photovoltaic device 100 and the first end 401 of the photovoltaic apparatus 300C. The outer rovings 221e can provide additional support in the outer areas of the photovoltaic apparatus 300C.

Furthermore, the outer rovings 221e can strengthen the bonding of edge seals (e.g., the edge seal 260 of Figures 1A and 2C) to at least one of the front sheet 250, the back sheet 210, the front-side adhesive 240, and the back-side adhesive 230. The outer rovings 221e can strengthen the bonding of the edge seals by taking advantage of the fact that the thermal expansion coefficient of the rovings is lower than that of other components of the photovoltaic apparatus 300C. Furthermore, the outer rovings 221e can prevent fluid slippage, deformation, and displacement of components, for example adhesives, that may be caused, for example, by increased temperatures during operation of the photovoltaic apparatus. The outer rovings 221e can also provide similar benefits at other locations of the photovoltaic apparatus 300C.
The photovoltaic apparatus 300C further includes longitudinal rovings 2201-2203. The longitudinal rovings 2201-2203 can each extend from a location in the X-direction between the first end 401 of the photovoltaic apparatus 300C and the first end 1101 of the photovoltaic device 100 to a location in the X-direction between the second end 402 of the photovoltaic apparatus 300C and the second end of the 1102 of the photovoltaic device 100. A first longitudinal roving 2201 can be aligned with the first side 1103 of the photovoltaic device 100 and can be disposed between the first side 1103 of the photovoltaic device 100 and the back sheet 210. A second longitudinal roving 2202 can be aligned with the second side 1104 of the photovoltaic device and can be disposed between the second side 1104 of the photovoltaic device 100 and the back sheet 210. A third longitudinal roving 2203 can be disposed at an intermediate location between the first longitudinal roving 2201 and the second longitudinal roving 2202. In some embodiments, additional longitudinal rovings may be included. The longitudinal rovings 2201-2203 that extend in the X-direction may underlie or overlie in the Z-direction the rovings 220 that extend in the Y-direction. In some embodiments, one or more of the longitudinal rovings 2201-2203 may partly overlie some of the rovings 220 and underlie the remainder of the rovings 220. For example, one or more of the longitudinal rovings may alternate between being disposed above and below the rovings 220 as the longitudinal rovings 2201-2203 extend in the X-direction to create a weaving pattern between the longitudinal rovings 2201-2203 and the rovings 220.

The photovoltaic apparatus 301C further includes a first busbar 170c and a second busbar 180c. The second busbar 180c includes a first portion 180c1 extending from the first side 1103 to the second side 1104 at the second end 1102. The second busbar 180c further includes a second portion 180c2 extending into the opening 320c. The photovoltaic apparatus 301C includes a back sheet 210 having a rectangular opening 320c with rounded corners. The opening 320c can be aligned with the second busbar 180c in the X-direction allowing for the second busbar 180c to be folded over or bent and routed through the opening 320c and into the junction box (not shown). For example a central axis of the second busbar 180c extending in the Y-direction can be
aligned with a center of the opening 320c in the X-Y plane. Furthermore, a corresponding rectangular barrier layer 310c having rounded corners is provided over the opening 320c of the back sheet 210. The barrier layer 310c can have larger dimensions in the X and Y-directions than the opening 320c. Moreover, the first layer and the second layer (i.e., similar to the first layer 314 and the second layer 312 described above) can also have a rectangular shape having rounded corners, such as the same shape of the rectangular barrier layer 310c having rounded corners. Using a rectangular barrier layer 310c having rounded corners allows for an improved distribution of strain during the lamination process relative to using a square or rectangular shaped barrier layer, which can reduce the risk of causing damage to the substrate, such as forming wavelets in the substrate. Using a rectangular opening 320c having rounded corners is also easier and less expensive to form than a square or rectangular opening. Furthermore, there is a lower risk of forming cracks in the back sheet 210 when using the rectangular opening 320c having rounded corners relative to using a square or rectangular opening. The rectangular opening 320c having rounded corners also allows for an improved and more uniform seal pressure distribution formed around the opening 320c relative to a seal formed around a square or rectangular opening.

[0080] The first busbar 170c extends past the photovoltaic device 100 at the first end 1101 of the photovoltaic device 100 and then is folded over. After folding over the first busbar 170c is surrounded by a busbar insulation 174, and the first busbar 170c extends in the X-direction to the opening 320c and into the junction box (not shown). Furthermore, an insulating layer 176c can be positioned between the first busbar 170c and the back sheet 210, such as between the busbar insulation 174c and the back sheet 210. In some embodiments, the insulating layer 176c can also extend in the Y-direction between the first busbar 170c and the back sheet 210 to provide additional insulation. The insulating layer 176c can be formed of, for example, an insulating tape, such as an insulating tape formed of polyimide.

[0081] Figure 2D is a top sectional view of a photovoltaic apparatus 301 D, according to another embodiment. The photovoltaic apparatus 301 D is similar to photovoltaic apparatus 301 C of Figure 2C except that the photovoltaic
apparatus 301 D includes different busbars, and two openings through the back sheet 210 instead of one. The back sheet 210 of the photovoltaic apparatus 301 D includes a first opening 320d1 and a second opening 320d2. The photovoltaic apparatus 301 D further includes a first busbar 170d and a second busbar 180d. The openings 320d1, 320d2 have a rectangular shape with rounded corners like the opening 320c of the photovoltaic apparatus 301C described above. The photovoltaic apparatus 301 D further includes a first barrier layer 310d1 disposed over the first opening 320d1 and a second barrier layer 310d2 disposed over the second opening 320d2. The first barrier layer 310d1 and the second barrier layer 310d2 can have a rectangular shape with rounded corners similar to the barrier layer 310c of the photovoltaic apparatus 301C.

[0082] The first busbar 170d includes a first portion 170d1 extending from the first side 1103 to the second side 1104 at the first end 1101. The first busbar 170d further includes a second portion 170d2 extending into the first opening 320d1. The first opening 320d1 can be aligned in the X-direction with the first busbar 170d. For example a central axis of the first busbar 170d extending in the Y-direction can be aligned with a center of the opening 320d1 in the X-Y plane. The first busbar 170d can extend in the Y-direction over the first opening 320d1 and then extend in the Z-direction through the first opening 320d1 and directly into the junction box (not shown). A plurality of spacers 225 can be disposed between the first busbar 170d and the edges of the back sheet 210 in the opening 320d1. In some embodiments, the spacers 225 can surround the first busbar 170d in the opening 320d1.

[0083] The second busbar 180d includes a first portion 180d1 extending from the first side 1103 to the second side 1104 at the second end 1102. The second busbar 180d further includes a second portion 180d2 extending into the second opening 320d2. The second opening 320d2 can be aligned in the X-direction with the second busbar 180d. For example a central axis of the second busbar 180d extending in the Y-direction can be aligned with a center of the opening 320d2 in the X-Y plane. The second busbar 180d can extend in the Y-direction over the second opening 320d2 and then extend in the Z-direction through the second opening 320d2 and directly into the junction box.
(not shown). A plurality of spacers 225 can be disposed between the second busbar 180d and the edges of the back sheet 210 in the opening 320d2. In some embodiments, the spacers 225 can surround the second busbar 180d in the opening 320d2.

[0084] Figure 3A is a close-up sectional view of an opening 320d through the back sheet 210 of a photovoltaic apparatus, according to one embodiment. The opening 320d is a rectangular opening with rounded corners. The first junction busbar 172 and the second junction busbar 182 are disposed in the opening 320d. The busbar insulation 174 surrounds the first junction busbar 172. The busbar insulation 184 surrounds the second junction bar 182. A plurality of spacers 225 can be disposed around each junction busbar 172, 182. For example, three spacers 225 are disposed around each junction busbar 172, 182 to prevent movement of the junction busbars towards edges of the back sheet 210. In some embodiments, spacers 225 may contact the busbar insulations 174, 184. Furthermore, the spacers 225 may also contact edges of the back sheet 210.

[0085] Figure 3B is a close-up sectional view of a first opening 320e1 and a second opening 320e2 through a back sheet 210e of a photovoltaic apparatus, according to one embodiment. The first opening 320e1 and the second opening 320e2 have a circular shape. The first junction busbar 172 is disposed in the first opening 320e1. The second junction busbar 182 is disposed in the second opening 320e2. The busbar insulation 174 surrounds the first junction busbar 172. The busbar insulation 184 surrounds the second junction bar 182. A plurality of spacers 225 can be disposed around each junction busbar 172, 182 in the respective openings 320e1, 320e2. For example, each junction busbar 172, 182 is surrounded by four spacers 225 to maintain adequate spacing between the junction busbars 172, 182 and the back sheet 210 and/or other components in the photovoltaic apparatus or external to the photovoltaic apparatus.

[0086] Figure 4A is a top sectional view of a photovoltaic module 304A, according to one embodiment. During the following descriptions, the photovoltaic module 304A of Figure 4A as well as the photovoltaic modules of Figures 2B and 2C are shown without the front sheet 250, the front-side
adhesive 240, and the back-side adhesive 230 to give a clearer view of the arrangement of devices and components in these photovoltaic modules. The photovoltaic module 304A includes a one-dimensional array 40 of photovoltaic devices 100a-100c disposed over the back sheet 210. The photovoltaic module 304A is similar to the photovoltaic apparatus 301A of Figure 2A except that the photovoltaic module 304A includes two additional photovoltaic devices 100b, 100c and longer busbars. For example, the photovoltaic device 100 of Figure 2A can be the same as the photovoltaic device 100a of Figure 4A. Furthermore, the connection between busbars 170e, 180e to the opening 320 and the junction box (not shown) of Figure 4A can be the same as the connection of the busbars 170, 180 to the opening 320 and junction box 330 of Figure 2A.

The array 40 includes a first side 411 and a second 412 spaced apart in the X-direction and each side 411, 412 extends along the Y-direction. The photovoltaic devices 100a-100c are spaced apart from each other in the Y-direction. The photovoltaic module 304A further includes a first busbar 170e and a second busbar 180e. The first busbar 170e extends in the Y-direction along the first side 411 of the array 40. The second busbar 180e extends in the Y-direction along the second side 412 of the array 40.

Figure 4B is a top sectional view of a photovoltaic module 304B, according to another embodiment. The photovoltaic module 304B includes a first one-dimensional array 40b1 of photovoltaic devices 100a-100c disposed over the back sheet 210 and a second one-dimensional array 40b2 of photovoltaic devices 100d-100f disposed over the back sheet 210. The photovoltaic module 304B has a first end 421 spaced apart from a second end 422 in the Y-direction. The first array 40b1 is spaced apart from the second array 40b2 in the X-direction. The photovoltaic devices 100a-100c of the first array 40b1 are arranged along the Y-direction from the photovoltaic device 100a positioned at the first end 421 to the photovoltaic device 100c positioned at the second end 422. Similarly, the photovoltaic devices 100d-100f of the second array 40b2 are arranged along the Y-direction from the photovoltaic device 100d positioned at the first end 421 to the photovoltaic device 100f positioned at the second end 422.
The first array 40b1 has an inner edge 431 and an outer edge 432 extending in the Y-direction. The inner edge 431 is spaced apart from outer edge 432 in the X-direction. The second array 40b2 has an inner edge 441 and outer edge 442 extending in the Y-direction. The inner edge 441 is spaced apart from outer edge 442 in the X-direction. The inner edge 431 of the first array 40b1 faces the inner edge 441 of the second array 40b2.

Each array 40b1, 40b2 includes a first busbar 170e extending in the Y-direction along the respective inner edges 431, 441 of the arrays 40b1, 40b2. Furthermore, each array 40b1, 40b2 includes a second busbar 180e extending in the Y-direction along the respective outer edges 432, 442 of the arrays 40b1, 40b2. The second busbars 180e are connected to each other by a third busbar 480e. The third busbar 480e can extend between the second busbars 180e in the X-direction between an outer edge of the photovoltaic devices 100c, 100f and the second end 422 of the photovoltaic module 304B.

The two first busbars 170e can each have a same polarity during operation. Furthermore the two second busbars 180e can each have a same polarity during operation. For example, the first busbars 170e can have a positive voltage relative to the second busbars 180e during operation and the second busbars 180e can have a negative voltage relative to the first busbars 170e during operation.

The photovoltaic module 304B can include a first opening 320e1 through the back sheet 210 and a second opening 320e2 through the back sheet 210. The photovoltaic device 100a can be positioned over the first opening 320e1 and the second opening 320e2. Furthermore, a barrier layer 310d1 can be positioned between the openings 320e1, 320e2 and the photovoltaic device 100a.

The photovoltaic module 304B can further include a first junction busbar 172e and a second junction busbar 182e. The first junction busbar 172e can electrically connect the two first busbars 170e to each other. Furthermore, the first junction busbar 172e can extend from the first busbar 170e of the first array 40b1 to the first opening 320e1 and into the junction box (not shown). The second junction busbar 182e can be electrically coupled to the second
busbar 180e that extends along the outer edge 432 of the first array 40b1. The second junction busbar 182e can extend from the second busbar 180e of the first array 40b1 to the second opening 320e2 and into the junction box (not shown).

[0094] A first insulating layer 176e can be positioned between the first junction busbar 172e and the back sheet 210. A second insulating layer 186e can be positioned between the second junction busbar 182e and the back sheet 210. Furthermore, a third insulating layer 486e can be positioned between the third busbar 480e and the back sheet 210. The insulating layers 176e, 186e, 486e can be formed of the same material as the insulating layer 176 described above.

[0095] In some embodiments, the photovoltaic module can include additional arrays (not shown) of photovoltaic devices spaced apart from the arrays 40b1, 40b2 in the X-direction. Each of these additional arrays can include first busbars 170e and second busbars 180e. The third busbar 480e can extend further in the X-direction along the second end 422 to connect to these additional second busbars 180e. An additional busbar (not shown) can extend in the X-direction along the first end 421 to connect the first busbars 170e of the additional arrays to the first junction busbar 172e.

[0096] Figure 4C is a top sectional view of a photovoltaic module 304C, according to another embodiment. The photovoltaic module 304C includes a first one-dimensional array 40c1 of photovoltaic devices 100a-100c and a second one-dimensional array 40c2 of photovoltaic devices 100d-100f disposed over the back sheet 210. The photovoltaic module 304C has a first end 451 spaced apart from a second end 452 in the Y-direction. The first array 40c1 is spaced apart from the second array 40c2 in the X-direction. The photovoltaic devices 100a-100c of the first array 40c1 are arranged along the Y-direction from the photovoltaic device 100a positioned at the first end 451 to the photovoltaic device 100c positioned at the second end 452. Similarly, the photovoltaic devices 100d-100f of the second array 40c2 are arranged along the Y-direction from the photovoltaic device 100d positioned at the first end 451 to the photovoltaic device 100f positioned at the second end 452.
The first array 40c1 has an inner edge 461 and an outer edge 462 extending in the Y-direction. The inner edge 461 is spaced apart from outer edge 462 in the X-direction. The second array 40c2 has an inner edge 471 and outer edge 472 extending in the Y-direction. The inner edge 471 is spaced apart from outer edge 472 in the X-direction. The inner edge 461 of the first array 40c1 faces the inner edge 471 of the second array 40c2.

The first array 40c1 includes a first busbar 170e1 extending in the Y-direction along the outer edge 462 of the first array 40c1. The first array 40c1 further includes a second busbar 180e1 extending in the Y-direction along the inner edge 461 of the first array 40c1. The second array 40c2 includes a first busbar 170e2 extending in the Y-direction along the inner edge 471 of the second array 40c2. The second array 40c2 further includes a second busbar 180e2 extending in the Y-direction along the outer edge 472 of the second array 40c2.

The two first busbars 170e1, 170e2 are connected to each other by a third busbar 470e. The third busbar 470e can extend between the first busbars 170e1, 170e2 in the X-direction between an outer edge of the photovoltaic devices 100c, 100f and the second end 452 of the photovoltaic module 304C. A first insulating layer 476e can be positioned between the third busbar 470e and the back sheet 210. The second busbars 180e1, 180e2 are connected to each other by a fourth busbar 480e1. The fourth busbar 480e1 can extend between the second busbars 180e1, 180e2 in the X-direction between an outer edge of the photovoltaic devices 100a, 100d and the first end 451 of the photovoltaic module 304C. A second insulating layer 486e1 can be positioned between the fourth busbar 480e1 and the back sheet 210. The insulating layers 476e, 486e1 can be formed of the same material as the insulating layer 176 described above.

The two first busbars 170e1, 170e2 can each have a same polarity during operation. Furthermore the two second busbars 180e1, 180e2 can each have a same polarity during operation. For example, the first busbars 170e1, 170e2 can have a positive voltage relative to the second busbars 180e1, 180e2 during operation and the second busbars 180e1, 180e2 can have a negative voltage relative to the first busbars 170e1, 170e2 during operation.
[00101] The photovoltaic module 304C can include a first opening 320e1 through the back sheet 210 and a second opening 320e2 through the back sheet 210. The second busbar 180e1 of the first array 40c1 can be disposed over the first opening 320e1. The second busbar 180e1 of the first array 40c1 can include a first folded portion 180f1 that folds over in the Z-direction. The second busbar 180e1 of the first array 40c1 can then extend from the first folded portion 180f1 to the first opening 320e1.

[00102] The first busbar 170e2 of the second array 40c2 can be disposed over the second opening 320e2. The first busbar 170e2 of the second array 40c2 can include a folded portion 170f that folds over in the Z-direction. The first busbar 170e2 of the second array 40c2 can then extend from the folded portion 170f to the second opening 320e2. Having the busbars 180e1, 170e2 disposed over the respective openings 320e1, 320e2 can reduce the material costs relative to other designs due to the short distances between the junction box (not shown) and the busbars 180e1, 170e2.

[00103] Figure 4D is a cross-sectional view of the photovoltaic module 304C taken along section line 4D of Figure 4C. Figure 4D provides additional detail for illustrating the extension of the second busbar 180e1 of the first array 40c1 into the first opening 320e1. The second busbar 180e1 extends over and past the photovoltaic device 100a to the first folded portion 180f1. The first folded portion 180f1 folds around the fourth busbar 480e1 allowing for multiple contact points between the second busbar 180e1 and the fourth busbar 480e1. The second busbar 180e1 can contact the fourth busbar 480e1 at a first contact point 181 located on a top surface of the fourth busbar 480e1. The second busbar 180e1 can also contact the fourth busbar 480e1 at a second contact point 183 located on a bottom surface of the fourth busbar 480e1.

[00104] From the first folded portion 180f1, the second busbar 180e1 extends in the Y-direction towards the photovoltaic device 100a and to a second folded portion 180f2. The second folded portion 180f2 can be located within the backside adhesive 230. The second folded portion 180f2 can change the direction of the second busbar 180e1 from primarily extending in the Y-direction towards the photovoltaic device 100a to primarily extending in the Z-direction towards the back sheet 210. In some embodiments, the second busbar 180e1 includes
additional folds and/or curves besides the first and second folded portions 180f1, 180f2. The first and second folded portions 180f1, 180f2 allows for local extension of the second busbar 180e1 when photovoltaic module expands from heat or other stresses. From the second folded portion 180f2, the second busbar 180e1 extends into the opening 320e1 and into the junction box (not shown). The second folded portion 180f2 is positioned between the back sheet 210 and the substrate 110.

[00105] An additional layer 308 (fourth layer) can be formed over the third layer 309. In one embodiment, the additional layer 308 can be pasted onto the third layer. The additional layer 308 can extend past the third layer 309 in the Y-direction to protect the portions of the substrate 110 that extend past the third layer 309 in the Y-direction. The additional layer 308 can protect the substrate 110 from abrasion that could be caused by portions of the second busbar 180e1 along locations of the substrate 110 that extend past the third layer 309 in the Y-direction. The additional layer 308 can be formed of a polymer, such as a polymer encapsulant, such as polyimide.

[00106] Referring to Figures 4C and 4D, the first busbar 170e2 of the second array 40c2 can be extend into the second opening 320e2 in a similar way as the extension of the second busbar 180e1 into the first opening 320e1 as described above. For example, folded portion 170f of the first busbar 170e2 can have a similar shape to the folded portion 180f1 of the second busbar 180e1. Furthermore, an additional layer 308e2 can be used to protect the substrate 110 of the photovoltaic device 100d from the first busbar 170e2 in a similar way as the additional layer 308 protects the substrate 110 of the photovoltaic device 110a from the second busbar 180e1 as described above.

[00107] Figure 5 is a process flow diagram of a method 5000, according to one embodiment, for manufacturing a photovoltaic module that includes many of the components of the embodiments described above. At block 5002, the back sheet 210 is provided with one or more openings, such as the opening 320 shown in Figure 1A. At block 5004, a spacing layer is optionally placed on the back sheet 210 using a plurality of ravings, such as the ravings 220 of Figure 2C.
[00108] At block 5006, the back-side adhesive 230 is placed on the back sheet 210 and over the plurality of rovings 220 that were optionally added at block 5004. The back-side adhesive 230 is not added over the back sheet 210 around the openings, such as the opening 320 of Figure 1A, leaving a cutout so that the sealing assembly 30 can be added to seal the openings.

[00109] At block 5008, one or more insulating layers, such as the insulating layers 176, 186 of Figure 2A are optionally placed over the back-side adhesive. In some embodiments, the insulating layers are placed on the back sheet 210 before the back-side adhesive 230 is added, such as the insulating layer 486e1 shown contacting the back sheet 210 in Figure 4D.

[00110] At block 5010, the first layer 314 is added over the areas of the back sheet 210 around the one or more openings where the back-side adhesive was not added. The first layer 314 covers the one or more openings.

[00111] At block 5012, insulation is applied to the junction busbars, such as the first junction busbar insulation 174 that is formed around the first junction busbar 172 of Figure 1A. For embodiments not including junction busbars, such as the photovoltaic module 304C of Figure 4C, insulation can be applied to portions of the busbars that will be disposed in the opening or near the opening, such as portions of the busbars contacting the first layer 314.

[00112] At block 5014, junction busbar spacers, such as the busbar spacers 175b, 185b of Figure 2B, can optionally be added to prevent mechanical friction between the junction busbars and the substrate of the photovoltaic device.

[00113] At block 5016, the junction busbars can be placed through the opening in the back sheet 210. In some embodiments, the junction busbars can be pushed through the first layer 314 and into the opening. In other embodiments, the first layer 314 can be formed around junction busbars that have already been placed through the opening.

[00114] At block 5018, a plurality of spacers 225 can optionally be added to the one or more openings, so that adequate spacing can be maintained between the back sheet 210 and the junction busbars or busbars that extend through the opening.
[0015] At block 5020, the second layer 312 can be added over the first layer 314 and over portions of the junction busbars or busbars located on the first layer 314. At block 5022, the barrier layer 310 is placed over the second layer 312. At block 5023, the third layer 309 can be placed over the barrier layer 310 to protect the substrate 110 from the barrier layer 310.

[0016] At block 5024, the photovoltaic assembly is placed over the back-side adhesive 230 and the one or more sealing assemblies 30. Block 5024 can include adding one or more photovoltaic devices 100 including the substrates 110 as well as the busbars, such as the busbars 170, 180 of Figure 1A, to the structure. At block 5026, the busbars can be bonded to the junction busbars using methods, such as welding, soldering, or using a conductive paste.

[0017] At block 5028, the front-side adhesive 240 is added over the back-side adhesive 230, the one or more photovoltaic devices 100, the busbars and the junction busbars.

[0018] At block 5030, the edge seal 260 can be formed around the edges of the structure. At block 5032, the front sheet 250 is placed over the front-side adhesive 240 and portions of the edge seal 260.

[0019] At block 5034, the structure is laminated together to form the photovoltaic module. In embodiments in which the sealing assembly 30 is disposed between a photovoltaic device 100 and the back sheet 210, the lamination can cause humps to form in one or more of the layers above the one or more openings, such as the hump 250h shown in Figure 1D.

[0020] At block 5036, the junction box 330 can optionally be bonded to the photovoltaic module at the location of the one or more openings, for example, by using an adhesive. Portions of the junction busbars, such as the junction busbars 172, 182 can be positioned to extend into the junction box 330 at this time, so that electrical connections from the photovoltaic module to one or more external devices can made.

[0021] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.
What is claimed is:

1. A photovoltaic apparatus comprising:
   a front sheet;
   a back sheet having a first opening;
   a photovoltaic device disposed between the front sheet and the back sheet;
   a first assembly sealing the first opening, the first assembly comprising:
   a first layer formed over the first opening of the back sheet;
   a second layer formed over the first layer; and
   a barrier layer formed over the second layer; and
   one or more conductors extending through the first opening of the back sheet, the one or more conductors electrically coupled to the photovoltaic device.

2. The photovoltaic apparatus of claim 1, wherein each of the one or more conductors includes a segment disposed between the first layer and the second layer.

3. The photovoltaic apparatus of claim 1, wherein each of the one or more conductors includes a segment surrounded by the first layer and the second layer.

4. The photovoltaic apparatus of claim 1, wherein the photovoltaic device is disposed over the first opening.

5. The photovoltaic apparatus of claim 4, wherein the front sheet includes a hump extending away from the photovoltaic device, wherein the hump is disposed over the first opening.

6. The photovoltaic apparatus of claim 1, wherein the first layer and the second layer are formed of a polymer and the barrier layer comprises a metal.
7. The photovoltaic apparatus of claim 6, further comprising a third layer disposed between the barrier layer and the photovoltaic device, wherein the third layer comprises a polymer.

8. The photovoltaic apparatus of claim 1, wherein the first layer is formed on the back sheet.

9. The photovoltaic apparatus of claim 1, further comprising one or more ravings disposed between the one or more conductors and the back sheet, wherein the one or more ravings comprise fiberglass.

10. The photovoltaic apparatus of claim 1, further comprising a plurality of spacers disposed in the first opening between the one or more conductors and the back sheet.

11. The photovoltaic apparatus of claim 1, further comprising insulation surrounding the one or more conductors within the first assembly.

12. The photovoltaic apparatus of claim 1, further comprising an insulating layer disposed between the one or more conductors and the back sheet.

13. The photovoltaic apparatus of claim 1, wherein:
   - the photovoltaic device is disposed over the first opening;
   - the first opening has a circular cross-section; and
   - the first assembly has a circular cross-section.

14. The photovoltaic apparatus of claim 1, wherein:
   - the photovoltaic device includes an array of photovoltaic cells, the array extending in a first direction from a first end to a second end and each photovoltaic cell extends from a first side to a second side of the array; and
   - the one or more conductors includes a first conductor comprising:
     - a first portion extending from the first side to the second side at
the first end of the array; and
   a second portion extending between the photovoltaic device and
the back sheet and into the first opening.

15. The photovoltaic apparatus of claim 1, wherein:
   the first opening has a rectangular cross-section having rounded
   corners; and
   the first assembly has a rectangular cross-section having rounded
   corners.

16. The photovoltaic apparatus of claim 1, wherein:
   the photovoltaic device includes an array of photovoltaic cells, the array
   extending in a first direction from a first end to a second end and each
   photovoltaic cell extending from a first side to a second side of the array; and
   the one or more conductors includes a first conductor comprising:
      a first portion extending from the first side to the second side at
   the second end of the array; and
   a second portion extending into the first opening, wherein the first
   opening and the first portion of the first conductor are positioned at a
same location in the first direction.

17. The photovoltaic apparatus of claim 1, wherein:
   the back sheet 210 further includes a second opening;
   the photovoltaic device includes an array of photovoltaic cells, the array
   extending in a first direction from a first end to a second end and each
   photovoltaic cell extending from a first side to a second side of the array;
   the one or more conductors includes a first conductor comprising:
      a first portion extending from the first side to the second side at
   the first end of the array; and
   a second portion extending into the first opening, wherein the first
   opening and the first portion of the first conductor are positioned at a
same location in the first direction; and
   the one or more conductors includes a second conductor comprising:
18. A photovoltaic module comprising:
   a front sheet;
   a back sheet having a first opening;
   a first array of photovoltaic devices disposed between the front sheet and the back sheet, wherein
   each photovoltaic device includes an array of photovoltaic cells, the array of photovoltaic cells extending in a first direction from a first end to a second end and each photovoltaic cell extends from a first side to a second side of the array; and
   the first array extends in a second direction;
   a first assembly sealing the first opening, the first assembly comprising:
   a first layer formed over the first opening of the back sheet;
   a second layer formed over the first layer; and
   a barrier layer formed over the second layer; and
   one or more conductors extending through the first opening of the back sheet, the one or more conductors electrically coupled to the photovoltaic devices of the first array.

19. The photovoltaic module of claim 18, further comprising:
   a second array of photovoltaic devices disposed between the front sheet and the back sheet, wherein:
   the second array is spaced apart from the first array in the first direction;
   the second array extends in the second direction; and
   a first photovoltaic device of the first array is disposed over the first opening.
20. The photovoltaic module of claim 18, further comprising:
   a second array of photovoltaic devices disposed between the front
   sheet and the back sheet, wherein:
   the second array is spaced apart from the first array in the first
direction;
   the second array extends in the second direction; and
   at least a portion of the first assembly is disposed between the first
array and the second array.

21. The photovoltaic module of claim 20, wherein:
   a first photovoltaic device of the first array is disposed over the first
opening;
   a third layer is disposed between the barrier layer and the first
photovoltaic device;
   a fourth layer is disposed between the third layer and the first
photovoltaic device, wherein the fourth layer extends past the third layer in the
second direction; and
   the one or more conductors includes a first conductor and a second
conductor, wherein the first conductor:
   folds around the second conductor;
   extends between the fourth layer and the back sheet; and
   extends into the first opening.
5000

5002 PROVIDE BACK SHEET WITH OPENING(S)
5004 PLACE SPACING LAYER(S)
5006 PLACE BACK SIDE ADHESIVE WITH CUTOUT FOR SEALING ASSEMBLY
5008 PLACE INSULATING LAYER(S)
5010 ADD FIRST LAYER
5012 PLACE INSULATION ONTO JUNCTION BAR(S)
5014 ADD JUNCTION BAR SPACER
5016 PLACE JUNCTION BAR(S)
5018 ADD SPACERS
5020 ADD SECOND LAYER
5022 PLACE BARRIER LAYER
5023 ADD SUBSTRATE PROTECTOR LAYER
5024 PLACE PV MODULE ASSEMBLY BY ADDING THE PV DEVICE(S) AND BUSBARS
5026 BOND BUSBARS WITH JUNCTION BAR(S)
5028 ADD FRONT SIDE ADHESIVE
5030 FORM EDGE SEAL(S)
5032 PLACE FRONT SHEET
5034 LAMINATE
5036 BOND JUNCTION BOX
A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L31/02
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C. See patent family annex.

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Stirn, Jean-Pierre
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<tr>
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<td>EP 2535943 AI</td>
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<tr>
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Form PCT/ISA/210 (patent family annex) (April 2005)