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(54) Title: METHODS OF REDUCING AND/OR ELIMINATING POTENTIAL INDUCED DEGRADATION OF PHOTOVOLTAIC CELL MODULES

(57) Abstract: Methods of reducing and/or eliminating Potential Induced Degradation (PID) of a negatively-grounded photovoltaic cell module are disclosed. The negatively- grounded photovoltaic cell module comprises at least one photovoltaic cell, a first encapsulant layer formed from a silicone composition disposed on the photovoltaic cell, and a cover sheet disposed on the first encapsulant layer. The methods comprise exposing the negatively-grounded photovoltaic cell module to ultraviolet light, thereby reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module.

METHODS OF REDUCING AND/OR ELIMINATING POTENTIAL INDUCED DEGRADATION OF PHOTOVOLTAIC CELL MODULES

BACKGROUND OF THE DISCLOSURE

[0001] The disclosure relates to methods of reducing and/or eliminating potential induced degradation (PID) of a negatively-grounded photovoltaic cell module which comprises at least one photovoltaic cell.

[0002] Photovoltaic cell modules are well known in the art and are generally utilized for converting solar radiation to electrical energy. However, over time, photovoltaic cell modules generally suffer from Potential Induced Degradation (PID) wherein the photovoltaic cell modules have a decreased efficiency and output over time during their use. PID is theorized to result from the build up of a charge within the photovoltaic cell modules, which restricts and may even prevent electron flow from the photovoltaic cell modules, thereby undesirably decreasing output and efficiency of the photovoltaic cell modules.

[0003] One conventional method of minimizing PID of photovoltaic cell modules includes reversing a direction in which electrons flow within photovoltaic cell modules. However, such methods only temporarily address PID of the photovoltaic cell modules, and such methods require continued adjustment and monitoring of photovoltaic cell modules. Other methods include adjustments to photovoltaic cell modules themselves, such as providing conductive paths for bleeding a charge from photovoltaic cells of the photovoltaic cell modules to a wafer separate from the photovoltaic cells. Yet further methods involve reversing a bias of the photovoltaic cell modules, e.g. positively grounding the photovoltaic cell modules, instead of negatively grounding the photovoltaic cell modules. An alternative method requires the inclusion of an organic encapsulant layer having a certain volume specific resistivity in photovoltaic cell modules. However, these methods require additional processing steps and components when manufacturing the photovoltaic cells, which increases cost and processing steps associated with the manufacture of photovoltaic cell modules.

SUMMARY OF THE DISCLOSURE

[0004] The disclosure provides methods of reducing and/or eliminating Potential Induced Degradation (PID) of a negatively-grounded photovoltaic cell module. The negatively-grounded photovoltaic cell module comprises at least one photovoltaic

cell, a first encapsulant layer formed from a silicone composition disposed on the photovoltaic cell, and a cover sheet disposed on the first encapsulant layer. The methods comprise exposing the negatively-grounded photovoltaic cell module to ultraviolet light, thereby reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module. As the negatively-grounded photovoltaic cell module is exposed to ultraviolet light, the ultraviolet light substantially passes through the cover sheet and the first encapsulant layer of the negatively-grounded photovoltaic cell module such that the ultraviolet light contacts the at least one photovoltaic cell.

[0005] In a first method, the first encapsulant layer, which is formed from the silicone composition, is characterized by a volume specific resistance of at least $5x10^{13}$ Ohm-centimeter (Ωcm) in the temperature range -40 to 90 °C. In a second method, the first encapsulant layer, which is formed from the silicone composition, need not have the volume specific resistance of the first method while still reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0006] The disclosure provides methods of reducing and/or eliminating Potential Induced Degradation (PID) of a negatively-grounded photovoltaic cell module. PID may alternatively be referred to as polarization. The methods of the disclosure may be utilized for various negatively-grounded photovoltaic cell modules that suffer from PID during their use.

[0007] The negatively-grounded photovoltaic cell module is referred to herein merely as the "module" or "modules" in plural form because the instant methods of the disclosure may be utilized in a plurality of modules. The module can be of various shapes, sizes, and configurations. In certain embodiments, the module has a length of from about 1.2 to about 2.0 and a width of from about 0.7 to about 1.1, meters (m). The module is not limited to any particular shape, length or width.

[0008] The instant method may be utilized for a single module or for a plurality of modules, which is generally referred to as an array. In the array, the modules are typically interconnected with one another in a geometric configuration. The array may be planar or non-planar. The module and/or the array, as well as the instant method, may be used for various applications, such as for structures, buildings, vehicles, devices, etc.

[0009] In certain embodiments, the negatively-grounded photovoltaic cell module is a negatively-grounded selective emitter cell module. Such negatively-grounded selective emitter cell modules are generally more susceptible to PID than conventional negatively-grounded photovoltaic cell modules such that the instant method is particularly advantageous for negatively-grounded selective emitter cell modules.

[0010] Modules suitable for the instant methods comprise at least one photovoltaic cell, a first encapsulant layer formed from a silicone composition disposed on the at least one photovoltaic cell, and a cover sheet disposed on the first encapsulant layer. The modules typically also include additional components. The at least one photovoltaic cell, the first encapsulant layer, and the cover sheet are described in detail below along with the additional components that are optionally but typically utilized in the modules. The module also includes components for negatively-grounding the module, which are well known in the art.

[0011] The module typically further comprises a substrate. The substrate has a front face and a rear face spaced from the front face. The substrate may be substantially planar or non-planar. The substrate may also be referred to in the art as a backsheet. The substrate is useful for providing support, protection, and/or an interface for the module.

[0012] The substrate can be formed from various materials. Examples of suitable materials include glass, polymeric materials, composite materials, etc. For example, the substrate can be formed from glass, polyethylene terephthalate (PET), thermoplastic elastomer (TPE), polyvinyl fluoride (PVF), silicone, etc. The substrate may be formed from a combination of different materials, e.g. a polymeric material and a fibrous material. The substrate may have portions formed from one material, e.g. glass, and other portions formed from another material, e.g. a polymeric material. The substrate can be of various thicknesses, such as from about 0.05 to about 5, about 0.1 to about 4, or about 0.125 to about 3.2, millimeters (mm) on average. Thickness of the substrate may be uniform or may vary.

[0013] Further examples of suitable substrates include those described in U.S. App. Pub. Nos. 2008/0276983, 2011/0005066, and 2011/0061724, and in WO Pub. Nos. 2010/051355 and 2010/141697, the disclosures of which are incorporated herein by reference in their entirety to the extent they do not conflict with the general scope of

the disclosure. The aforementioned disclosures are hereinafter referred to as the "incorporated references."

[0014] The cover sheet also has a front face and a rear face spaced from the front face. The cover sheet may be substantially planar or non-planar. The cover sheet is useful for protecting the module from environmental conditions such as rain, snow, dirt, heat, etc. Typically, the cover sheet is optically transparent, as described below with reference to the instant methods. The cover sheet is generally the sun side or front side of the module.

[0015] The cover sheet can be formed from various materials understood in the art. Examples of suitable materials include those described above with description of the substrate. Further examples of suitable cover sheets include those described in the incorporated references. In certain embodiments, the cover sheet is formed from glass. Various types of glass can be utilized such as silica glass, polymeric glass, etc. The cover sheet may be formed from a combination of different materials. The cover sheet may have portions formed from one material, e.g. glass, and other portions formed from another material, e.g. a polymeric material. The cover sheet may be the same as or different from the substrate. For example, both the cover sheet and the substrate may be formed from glass with equal or differing thicknesses. Further, the cover sheet and/or the substrate may optionally include an anti-soiling layer disposed thereon for preventing smudging and/or soiling of the cover sheet and/or the substrate.

[0016] The cover sheet can be of various thicknesses, such as from about 0.5 to about 10, about 1 to about 7.5, about 2.5 to about 5, or about 3, millimeters (mm), on average. Thickness of the cover sheet may be uniform or may vary.

[0017] The at least one photovoltaic cell is disposed between the substrate and the cover sheet. The module may include one photovoltaic cell or a plurality of photovoltaic cells. Typically, the module includes a plurality of photovoltaic cells. When the module includes the plurality of the photovoltaic cells, the photovoltaic cells may be substantially coplanar with one another. Alternatively, the photovoltaic cells may be offset from one another, such as in non-planar module configurations. Regardless of whether the photovoltaic cells are planar or non-planar with one another, the photovoltaic cells may be arranged in various patterns, such as in a grid-like pattern.

[0018] The photovoltaic cells may independently have various dimensions, be of various types, and be formed from various materials. Examples of suitable photovoltaic cells include those described in the incorporated references. The photovoltaic cells may have various thicknesses, such as from about 50 to about 250, alternatively from about 100 to about 225, alternatively from about 175 to about 225, alternatively about 180, micrometers (μm) on average. The photovoltaic cells may have various widths and lengths. In certain embodiments, the photovoltaic cells are crystalline silicon, and may independently be monocrystalline silicon, polycrystalline silicon, or combinations thereof.

[0019] When the module includes more than one photovoltaic cell, a tabbing ribbon is disposed between the photovoltaic cells for establishing a circuit in the module. Various aspects of the tabbing ribbon, such as its dimensions and composition, are disclosed in co-pending U.S. Appln. Ser. No. 61/591,005, which is herein incorporated by reference in its entirety.

[0020] Although the module may include just one photovoltaic cell, the at least one photovoltaic cell of the module is referred to herein merely as "the photovoltaic cells," which encompasses embodiments in which the module includes a single photovoltaic cell or a plurality of photovoltaic cells, for purposes of clarity and consistency.

[0021] The first encapsulant layer is disposed on the photovoltaic cells and serves to protect the photovoltaic cells. Further, the first encapsulant layer is utilized to bond the module together by being sandwiched between the substrate (along with the photovoltaic cells) and the cover sheet. In particular, the first encapsulant layer is generally utilized for coupling the rear face of the cover sheet to the front face of the substrate.

[0022] The silicone composition is typically disposed on the substrate (along with the photovoltaic cells) to form a first layer. The cover sheet is then disposed on the first layer, and the first layer, i.e., the silicone composition, is cured to form the first encapsulant layer. To this end, the silicone composition is typically a curable silicone composition, which is distinguished from non-curable silicone compositions, such as trimethylsiloxy-endblocked polydimethylsiloxane. In certain embodiments, the first encapsulant layer is free from any layers other than that which is formed from the

silicone composition. In these embodiments, the first encapsulant layer is the only layer present in the module between the photovoltaic cell and the cover sheet.

[0023] In various embodiments, the module further includes a second encapsulant layer disposed between the substrate and the photovoltaic cells. In particular, the second encapsulant layer is for coupling the rear faces photovoltaic cells to the front face of the substrate. The second encapsulant layer generally protects the photovoltaic cells from the substrate because the second encapsulant layer is sandwiched between the photovoltaic cells and the substrate. The second encapsulant layer may be uniformly disposed across the substrate, or merely disposed between the photovoltaic cells and the substrate, in which case the second encapsulant layer is not a continuous layer across the substrate, but rather is a patterned layer.

[0024] The second encapsulant layer may be the same as or different from the first encapsulant layer. When the first and second encapsulant layers are the same, the first and second encapsulant layers typically form a continuous encapsulant layer that encapsulates the photovoltaic cells between the substrate and the cover sheet. When the second encapsulant layer is different from the first encapsulant layer, the second encapsulant layer may only be present between the photovoltaic cells and the substrate, in which case the second encapsulant layer is not a continuous layer across the substrate. In such embodiments, the first encapsulant layer generally contacts both the substrate and the cover sheet in locations in the module other than where the photovoltaic cells are disposed.

[0025] Most typically, both the first and the second encapsulant layers are independently formed from silicone compositions. In such embodiments, the silicone composition utilized to form the second encapsulant layer is uniformly applied on the substrate to form a second layer, which may optionally be partially or fully cured prior to disposing the photovoltaic cells on the second layer. The silicone composition utilized to form the first encapsulant layer is then applied on the second layer and the photovoltaic cells to form the first layer. The cover sheet is applied on the first layer to form a package, and the first and second layers of the package are cured to form the first and second encapsulant layers and the module.

[0026] Although the first encapsulant layer is typically sandwiched between the substrate (along with the photovoltaic cells) and the cover sheet, there may be at least

one intervening layer between the first encapsulant layer and the cover sheet and/or between the first encapsulant layer and the photovoltaic cells.

[0027] The first encapsulant layer is formed form a silicone composition. Examples of silicone compositions suitable for forming the first encapsulant layer include hydrosilylation-reaction curable silicone compositions, condensation-reaction curable silicone compositions, and hydrosilylation/condensation-reaction curable silicone compositions. As noted above, in certain embodiments, the second encapsulant layer, when present in the module, also is formed from a silicone composition. The silicone composition utilized to form the second encapsulant layer may independently be selected from any of these compositions. However, only the silicone composition utilized to form the first encapsulant layer is described below, although this description may be equally applicable to the silicone composition utilized to form the second encapsulant layer.

[0028] In certain embodiments, the silicone composition utilized to form the first encapsulant layer comprises a one component silicone composition. In other embodiments, to prevent premature curing of the silicone composition, the silicone composition comprises a two component silicone composition.

[0029] In certain embodiments, the silicone composition is a hydrosilylation-reaction curable silicone composition. In such embodiments, the silicone composition typically comprises an organopolysiloxane having silicon-bonded alkenyl groups (e.g. vinyl groups), an organosilicon hydride having silicon-bonded hydrogen atoms reactive with the silicon-bonded alkenyl groups of the organopolysiloxane, and optionally a hydrosilylation-reaction catalyst. In various embodiments, the silicone composition further comprises a non-reactive organopolysiloxane. By "non-reactive," it is meant that the non-reactive organopolysiloxane does not react with the organopolysiloxane or the organosilicon hydride, i.e., the non-reactive organopolysiloxane does not include silicon-bonded alkenyl groups or hydrogen atoms. However, the non-reactive organopolysiloxane may include other functional groups so long as the other functional groups are not reactive with the hydrosilylation reaction between the silicon-bonded alkenyl groups of the organopolysiloxane or the silicon-bonded hydrogen atoms of the organosilicon hydride. Examples of suitable organopolysiloxanes, organosilicon hydrides, and non-reactive organopolysiloxanes include those described in the incorporated references. Each of the

organopolysiloxane and the organosilicon hydride may independently be an oligomer, polymer or a silicone resin comprising various combinations of M, D, T, and/or Q units. The silicon-bonded alkenyl groups may be terminal, pendent, or both in the organopolysiloxane. Similarly, the silicon-bonded hydrogen atoms may be terminal, pendent, or both in the organosilicon hydride. Alternatively, the organosilicon hydride may monomeric and may not include siloxane (Si-O-Si) bonds. The organopolysiloxane and the organosilicon hydride may be linear, branched, or may have a three-dimensional network.

[0030] When the silicone composition is the hydrosilylation-reaction curable silicone composition described above, the organopolysiloxane and the organosilicon hydride may independently include various substituents, such as substituted or unsubstituted hydrocarbyl groups, as well as halogen atoms, e.g. fluorine, chlorine, bromine, and/or iodine. Most typically, the substituents are lower alkyl groups or halogen atoms. Such lower alkyl groups typically have from one to ten, alternatively one to five, alternatively one to three, carbon atoms. These lower alkyl groups may optionally be substituted or unsubstituted, but are typically unsubstituted.

[0031] The components of the silicone composition may be included in various amounts. In certain embodiments, the silicone composition comprises greater than about 45, alternatively greater than about 50, alternatively greater than about 55, alternatively greater than about 60, alternatively greater than about 65, parts by weight of the organopolysiloxane, based on 100 parts by weight of the silicone composition. Typically, in these embodiments, the silicone composition comprises from about 2.5 to about 7.5, alternatively from about 3 to about 7, or alternatively from about 3.5 to about 6.5, parts by weight of the organosilicon hydride, based on 100 parts by weight of the silicone composition. Finally, in these embodiments, the silicone composition comprises from about 25 to about 65, alternatively from about 30 to about 60, parts by weight of the non-reactive organopolysiloxane, based on 100 parts by weight of the silicone composition.

[0032] In other embodiments, the silicone composition comprises greater than about 55, alternatively greater than about 60, alternatively greater than about 65, parts by weight of the organopolysiloxane, based on 100 parts by weight of the silicone composition. In these embodiments, the silicone composition comprises from about 5 to about 25, alternatively from about 5 to about 20, alternatively from about 8 to about

22.5, parts by weight of the organosilicon hydride, based on 100 parts by weight of the silicone composition.

[0033] In yet other embodiments, the silicone composition comprises greater than about 80, alternatively greater than about 85, alternatively greater than about 90, alternatively greater than 95, parts by weight of the organopolysiloxane, based on 100 parts by weight of the silicone composition. In these embodiments, the silicone composition comprises from about greater than 0 to about 20, alternatively from greater than 0 to about 15, alternatively from greater than 0 to about 10, alternatively from greater than 0 to about 5, parts by weight of the organosilicon hydride, based on 100 parts by weight of the silicone composition.

[0034] Regardless of the silicone composition utilized to form the first encapsulant layer, the silicone composition may also include additional components, such as silanes, siloxanes, adhesion promoters, inhibitors, and catalysts. Such components can be included in various amounts. In certain embodiments, the silicone composition further comprises an organosilane and/or a dimethyl methylhydrogen siloxane. Such components can be included in various amounts, such as less than about 5 parts by weight, alternatively from about 0.1 to about 2.5 parts by weight, based on 100 parts by weight of the silicone composition. The catalyst is typically present in the silicone composition in a catalytic amount, as described in the incorporated references.

[0035] The organopolysiloxane and the organosilicon hydride generally react in the presence of the non-reactive organopolysiloxane and the catalyst to form the first encapsulant layer. The non-reactive organopolysiloxane is useful for adjusting physical properties of the first encapsulant layer formed from the silicone composition. Examples of suitable additive components, such as catalysts, include those described in the incorporated references.

[0036] In specific embodiments applicable to the embodiments described above with different amounts of the components of the silicone composition, the organopolysiloxane is a dimethylvinyl-terminated dimethyl siloxane, the organosilicon hydride is a hydrogen-terminated dimethyl siloxane, and the non-reactive organopolysiloxane is a polydimethylsiloxane (PDMS).

[0037] When the silicone composition comprises the two component silicone composition and the components described above, the organopolysiloxane may be present in one component and the organosilicon hydride may be present in the other

component. The catalyst is typically present along with the organopolysiloxane. Most typically, the organopolysiloxane is present in both components. In such embodiments, h the organosilicon hydride is present in one component and the catalyst is present in the other component to prevent premature reaction between the organopolysiloxane and the organosilicon hydride.

[0038] Alternatively, the first encapsulant layer may be formed from other silicone compositions which impart the first encapsulant layer formed therefrom with the physical properties described below. For example, the silicone composition may comprise a halogenated organopolysiloxane, e.g. a fluorinated organopolysiloxane. In such embodiments, the silicone composition is typically still a hydrosilylation-reaction curable silicone composition. As such, the halogenated organopolysiloxane typically includes halogen substitution on various carbon substituents of the halogenated organopolysiloxane, e.g. CF_3 groups instead of or in addition to CH_3 groups.

[0039] The silicone layer, which comprises the silicone composition and which cures to form the first encapsulant layer, can be of various thicknesses, such as from about 0.125 to about 0.75, alternatively from about 0.2 to about 0.5, alternatively from about 0.25 to about 0.45, millimeter (mm) on average. Typically, the thickness of the first encapsulant layer is varied to minimize the amount of the silicone composition that is used, thereby reducing production costs of the module, and also to simultaneously minimize or prevent bottoming out of the photovoltaic cells and/or the tabbing ribbon. In this context, "bottoming out" refers to a situation in which the photovoltaic cells and/or the tabbing ribbon contact the cover sheet, which is undesirable. Such a situation can arise during manufacture and/or use of the module.

[0040] In a first embodiment, the first encapsulant layer is characterized by a volume specific resistance of at least $5x10^{13}$ Ohm-centimeter (Ωcm) in the temperature range of from -40 to 90 °C, alternatively from -40 to 80 °C, alternatively from -40 to 70 °C, alternatively from -40 to 60 °C, alternatively from -40 to 50 °C, alternatively from -40 to 40 °C, alternatively from -40 to 30 °C, alternatively from -40 to 20 °C. In this embodiment, the first encapsulant layer need not be operated throughout this entire temperature range (or even within this temperature range), and PID can be reduced and/or eliminated via the method of the first embodiment at any operating temperature within this range (or even outside of this temperature range, although such

temperatures are unlikely in typical geographic locations in which modules are utilized). In a second embodiment, the first encapsulant layer need be characterized by the particular volume specific resistance recited above, i.e., the first encapsulant layer may have a volume specific resistance that is outside the specifically recited ranges or values set forth immediately above while still reducing and/or eliminating PID because ultraviolet light substantially passes therethrough independent of volume specific resistance. For example, in this second embodiment, the first encapsulant layer may have a volume specific resistance that is at least $5x10^{13}$ Ωcm at one particular temperature, e.g. at 25 °C, but not throughout the entire range recited above. The volume specific resistance of the first encapsulant layer can be measured in accordance with ASTM D257.

[0041] The methods comprise exposing the negatively-grounded photovoltaic cell module to ultraviolet light, thereby reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module. The reduction and/or elimination of PID of the module may also be referred to as prevention of PID. The terminology "reduction and/or elimination of PID" refers to the output and efficiency of the module during use relative to conventional modules, which, as described below, suffer from PID.

[0042] Exposing the negatively-grounded photovoltaic cell module to ultraviolet light comprises exposing the negatively-grounded photovoltaic cell module to any light spectrum including ultraviolet light. Typically, exposing the negatively-grounded photovoltaic cell module to ultraviolet light comprises exposing the negatively-grounded photovoltaic cell module to sunlight, which includes light in the ultraviolet spectrum. For example, sunlight includes light in the ultraviolet C range of from 100 to 280 nanometers (nm), in the ultraviolet B range of from 280 to 315 nanometers (nm), and in the ultraviolet A range of from 315 to 400 nanometers (nm), in addition to other frequency ranges, e.g. visible and infrared. Generally, ultraviolet C radiation does not pass through the atmosphere, and only a minimal portion of ultraviolet B radiation may pass through the atmosphere such that ultraviolet A radiation is relied upon for reducing and/or eliminating PID. The method typically comprises exposing the negatively-grounded photovoltaic cell module to ultraviolet light having a wavelength of from 280 to 400, alternatively from 300 to 400, nanometers (nm). The ultraviolet light of the methods is employed at an areal intensity (illuminance) that is effective for reducing and/or eliminating PID of the negatively-grounded photovoltaic

cell module. Sunlight generally provides sufficient illuminance of ultraviolet light, although artificial sources of ultraviolet light may alternatively be utilized, e.g. LED, fluorescent, compact fluorescent, metal halide, and/or halogen light sources. Generally, geographic location, weather, and time of day all impact the illuminance of the ultraviolet light in sunlight, although typical geographic locations and operational times of modules is sufficient for the instant methods.

[0043] It has been surprisingly found that the first encapsulant layer formed from the silicone composition allows ultraviolet light to substantially pass therethrough and that such ultraviolet light reduces and/or eliminates PID of negatively-grounded photovoltaic cell modules. "Substantially," as used herein with reference to the first encapsulant layer allowing ultraviolet light to substantially pass therethrough, means that the first encapsulant layer allows at least 80%, alternatively at least 85%, alternatively at least 90%, alternatively at least 95%, alternatively at least 98%, alternatively at least 99%, of ultraviolet light in the spectrum of from 300 to 400 nanometers (nm) to pass therethrough. Practical limitations on transparency of materials generally means that typically there is less than 100.00% of ultraviolet light in the spectrum of from 315 to 400 nm passing therethrough.

[0044] In contrast, conventional encapsulant layers, such as those formed from organic compositions, e.g. ethyl vinyl acetate (EVA), substantially prevent ultraviolet light in the spectrum above from passing therethrough. Unlike conventional encapsulant layers, when ultraviolet light in the range above substantially passes through the first encapsulant layer, the ultraviolet light contacts the photovoltaic cells, thereby reducing and/or eliminating PID of the module while in use.

[0045] To allow for the ultraviolet light to contact the photovoltaic cells of the module, the cover sheet also allows ultraviolet let to substantially pass therethrough. "Substantially," as used herein with reference to the cover sheet allowing ultraviolet light to substantially pass therethrough, means that the cover sheet allows at least 80%, alternatively at least 85%, alternatively at least 90%, alternatively at least 95%, alternatively at least 98%, alternatively at least 99%, of ultraviolet light in the spectrum of from 300 to 400 nanometers (nm) to pass therethrough. Practical limitations on transparency of materials generally means that typically there is less than 100.00% of ultraviolet light in the spectrum of from 315 to 400 nm passing therethrough.

[0046] As such, in certain embodiments, at least 80%, alternatively at least 85%, alternatively at least 90%, alternatively at least 95%, alternatively at least 98%, alternatively at least 99%, of ultraviolet light in the spectrum of from 300 to 400 nanometers (nm) passes through the cover sheet and the first encapsulant layer. Practical limitations on transparency of materials generally means that typically there is less than 100.00% of ultraviolet light in the spectrum of from 315 to 400 nm passing therethrough.

[0047] Because ultraviolet light need not pass through the second encapsulant layer, when present in the module, to allow for the ultraviolet light to contact the photovoltaic cells, these physical properties described above relative to the physical properties of the first encapsulant layer are not required of the second encapsulant layer. In some embodiments, the physical properties of the first encapsulant layer independently also characterize the second encapsulant layer, whereas in other embodiments, they do not.

[0048] Relative to conventional modules including an encapsulant layer comprising EVA, modules comprising the first encapsulant layer have substantially better long term photovoltaic output and efficiency due to the reduction and/or elimination of PID of the modules comprising the first encapsulant layer. For example, modules including the first encapsulant layer typically have an output at least 2, alternatively at least 4, alternatively at least 6, alternatively at least 8, alternatively at least 10, percent higher than a corresponding module including an EVA encapsulant layer instead of the first encapsulant material formed from the silicone composition after six months, all other things being equal. Said differently, conventional modules including an encapsulant layer comprising EVA have a lesser output than modules comprising the first encapsulant layer. Output may relate to efficiency, voltage, or combinations thereof. As but one example relative to efficiency, a 10 percent increase of an efficiency of 15 percent results in an efficiency of 16.5 percent.

[0049] The methods of the instant disclosure obviate concerns associated with conventional modules including encapsulant layers other than those formed from the silicone composition having a volume specific resistance that is effective for reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module. For example, one method of minimizing PID of such conventional modules is to reverse a bias of the conventional modules such that the conventional modules are positively

grounded. However, positively grounding conventional modules requires specifically made equipment, which increases associated costs of product and installation, because traditionally electronic components that require grounding are negatively grounded.

[0050] One or more of the values described above may vary by ± 5%, ± 10%, ± 15%, ± 20%, ± 25%, etc. so long as the variance remains within the scope of the disclosure. Unexpected results may be obtained from each member of a Markush group independent from all other members. Each member may be relied upon individually and or in combination and provides adequate support for specific embodiments within the scope of the appended claims. The subject matter of all combinations of independent and dependent claims, both singly and multiply dependent, is herein expressly contemplated. The disclosure is illustrative including words of description rather than of limitation. Many modifications and variations of the present disclosure are possible in light of the above teachings, and the disclosure may be practiced otherwise than as specifically described herein.

[0051] The following examples are intended to illustrate embodiments of the disclosure and are not to be viewed in any way as limiting to the scope of the disclosure.

EXAMPLES

[0052] Encapsulant layers formed from silicone layers are prepared and physical properties of the encapsulant layers are measured.

[0053] Preparation Example 1:

[0054] A hydrosilylation-curable silicone composition comprises greater than about 55 parts by weight of a diorganopolysiloxane having silicon-bonded alkenyl groups, from about 5 to about 25 parts by weight of a cross-linking agent having silicon-bonded hydrogen atoms, each based on 100 parts by weight of the silicone composition, and a catalytic amount of a hydrosilylation catalyst comprising platinum. The silicone composition is utilized to form two different slabs of a cured product, which emulate an encapsulant layer. Each of the slabs has a thickness of about 2 millimeters (mm).

[0055] Volume resistivity and surface resistivity of each of the slabs is measured at room temperature with an Agilent 4339 High Resistance Meter with a 16008B

Resistivity Cell at 500 volts for 60 seconds. The results are set forth below in Table 1.

[0056] Table 1:

Physical Property:	Slab 1	Slab 2
Volume Resistivity (Ω·cm)	1.6407E+14	1.6820E+14
Surface Resistivity (Ω)	2.1843E+17	1.7373E+15

[0057] Preparation Example 2:

[0058] A hydrosilylation-curable silicone composition comprises greater than about 45 parts by weight of an organopolysiloxane having silicon-bonded alkenyl groups, from about 2.5 to about 7.5 parts by weight of an organosilicon hydride having silicon-bonded hydrogen atoms, from about 25 to about 65 parts by weight of a non-reactive organopolysiloxane, each based on 100 parts by weight of the silicone composition, and a catalytic amount of a hydrosilylation catalyst comprising platinum. The silicone composition is utilized to form two different slabs of a cured product, which emulate an encapsulant layer. Each of the slabs has a thickness of about 2 millimeters (mm).

[0059] Volume resistivity and surface resistivity of each of the slabs is measured at room temperature with an Agilent 4339 High Resistance Meter with a 16008B Resistivity Cell at 500 volts for 60 seconds. The results are set forth below in Table 2.

[0060] Table 2:

Physical Property:	Slab 1	Slab 2
Volume Resistivity (Ω·cm)	1.2590E+15	2.1940E+15
Surface Resistivity (Ω)	5.1054E+15	2.3878E+15

[0061] Preparation Example 3:

[0062] A hydrosilylation-curable silicone composition comprises greater than about 95 parts by weight of an organopolysiloxane having silicon-bonded groups, from greater than 0 to about 5 parts by weight of a cross-linking agent having silicon-bonded hydrogen atoms, each based on 100 parts by weight of the silicone composition, and a catalytic amount of a hydrosilylation catalyst comprising platinum. The silicone composition is utilized to form a slab of a cured product, which emulates an encapsulant layer. The slab has a thickness of about 2 millimeters (mm).

[0063] Volume resistivity and surface resistivity of the slab is measured at various temperatures with an Agilent 4339 High Resistance Meter with a 16008B Resistivity Cell at 500 volts for 60 seconds. The results are set forth below in Table 3.

[0064] Table 3:

Temperature (°C)	Volume Resistivity (Ω·cm)	Surface Resistivity (Ω)
-37.3	1.5023E+16	3.3139E+16
-20.1	3.9886E+16	9.3209E+15
0	1.3363E+15	3.5043E+15
20.3	5.7120E+14	1.3185E+15
40	8.7020E+13	2.2241E+14
60	5.2879E+13	1.0017E+14
80	2.9909E+13	6.7643E+13
100	1.6297E+13	6.3990E+13

[0065] Practical Example 1 and Comparative Example 1:

[0066] Practical Example 1:

[0067] A photovoltaic cell module is prepared which includes an encapsulant layer formed from the silicone composition of Preparation Example 1.

[0068] Comparative Example 1:

[0069] A photovoltaic cell module is prepared in a manner identical to the photovoltaic cell module of Practical Example 1 but for the encapsulant layer, which is formed from ethylene-vinyl acetate (EVA) instead of a silicone composition.

[0070] Each of the photovoltaic cell modules of Practical and Comparative Example 1 is negatively grounded and subsequently disconnected for about 4 months. Once the respective photovoltaic cell modules were once again connected, the photovoltaic cell module of Comparative Example 1 had polarized, whereas the photovoltaic cell module of Practical Example 1 had not. Such PID of the photovoltaic cell module of Comparative Example 1 resulted in a voltage output of about 10% less than the voltage output of the photovoltaic cell module of Practical Example 1, which did not suffer from PID due to the inclusion of the encapsulant layer formed form a silicone composition.

[0071] Each of the photovoltaic cell modules is then positively-grounded. The PID of the photovoltaic cell module of Comparative Example 1 was minimized after about a week of the photovoltaic cell modules being positively grounded. As noted above, positive grounding is a conventional method of reversing PID of conventional

photovoltaic cell modules, but such positive grounding is nontraditional from an electricity perspective and is generally more expensive than negative grounding.

[0072] Table 4 below illustrates the output of the photovoltaic cell modules of Practical Example 1 and Comparative Example 1. Notably, the first values reported in Table 3 are recorded once the photovoltaic cell modules were positively-grounded such that the photovoltaic cell module of Comparative Example 1 was suffering from PID.

[0073] Table 4:

Example:	Initial Output (W)	Final Output (W)
Practical Example 1	1989.37	2066.1
Comparative Example 1	2031.15	2057.48

[0074] Ambient conditions are largely equivalent during the initial output measurement and the final output measurement. For example, the ambient temperature was 34 °F during the initial output reading and 27 °F during the final output reading. The temperature of the encapsulant layer of Practical Example 1 was 11 °C during the initial output reading and 12 °C during the final output reading, and the temperature of the encapsulant layer of Comparative Example 1 was 10 °C during the initial output reading and 11 °C during the final output reading.

[0075] Table 4 above illustrates the decreased output associated with PID of conventional photovoltaic cell modules, such as those which utilize encapsulant layers formed from EVA. Moreover, the initial output reading of Table 4 was taken after the photovoltaic cell module of Comparative Example 1 had been positively grounded for a period of time such that the data of Comparative Example 1 does not even fully account for the decreased output at the peak of PID of this photovoltaic cell module.

CLAIMS

What is claimed is:

1. A method of reducing and/or eliminating Potential Induced Degradation (PID) of a negatively-grounded photovoltaic cell module which comprises at least one photovoltaic cell, a first encapsulant layer formed from a silicone composition disposed on the photovoltaic cell, and a cover sheet disposed on the first encapsulant layer, said method comprising exposing the negatively-grounded photovoltaic cell module to ultraviolet light, thereby reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module;

wherein the ultraviolet light substantially passes through the cover sheet and the first encapsulant layer of the negatively-grounded photovoltaic cell module such that the ultraviolet light contacts the at least one photovoltaic cell; and

wherein the first encapsulant layer is characterized by a volume specific resistance of at least $5x10^{13}$ Ohm-centimeter (Ωcm) in the temperature range -40 to 90 °C.

2. A method of reducing and/or eliminating Potential Induced Degradation (PID) of a negatively-grounded photovoltaic cell module which comprises at least one photovoltaic cell, a first encapsulant layer formed from a silicone composition disposed on the photovoltaic cell, and a cover sheet disposed on the first encapsulant layer, said method comprising exposing the negatively-grounded photovoltaic cell module to ultraviolet light, thereby reducing and/or eliminating PID of the negatively-grounded photovoltaic cell module;

wherein the ultraviolet light substantially passes through the cover sheet and the first encapsulant layer of the negatively-grounded photovoltaic cell module such that the ultraviolet light contacts the at least one photovoltaic cell.

3. A method as set forth in claim 2 wherein the first encapsulant layer has a volume specific resistance of at least $5x10^{13}$ Ohm-centimeter (Ωcm) at 25 °C.

4. A method as set forth in any preceding wherein the negatively-grounded photovoltaic cell module is a negatively-grounded selective emitter cell module.

5. A method as set forth in any preceding claim wherein exposing the negatively-grounded photovoltaic cell module to ultraviolet light comprises exposing the negatively-grounded photovoltaic cell module to sunlight.

6. A method as set forth in any preceding claim wherein (a) at least 90% of the ultraviolet light having a wavelength of from 300 to 400 nm passes through the cover sheet and the first encapsulant layer; (b) at least 95% of the ultraviolet light having a wavelength of from 300 to 400 nm passes through the cover sheet and the first encapsulant layer; (c) the cover sheet comprises glass; (d) the negatively-grounded photovoltaic cell module further comprises a second encapsulant layer disposed on the at least one photovoltaic cell opposite the first encapsulant layer; (e) the negatively-grounded photovoltaic cell module further comprises a second encapsulant layer disposed on the at least one photovoltaic cell opposite the first encapsulant layer and a substrate disposed on the second encapsulant layer; or (f) any combination of (a)-(e).

7. A method as set forth in any preceding claim wherein (a) the silicone composition comprises a one component silicone composition; or (b) the silicone composition comprises a two component silicone composition.

8. A method as set forth in any preceding claim wherein the silicone composition comprises: (a) a hydrosilylation-curable silicone composition; or (b) a condensation-curable silicone composition.

9. A method as set forth in any one of claims 1-7 wherein the silicone composition comprises a hydrosilylation-curable silicone composition which comprises greater than about 45 parts by weight of an organopolysiloxane having silicon-bonded alkenyl groups, from about 2.5 to about 7.5 parts by weight of an organosilicon hydride having silicon-bonded hydrogen atoms, and from about 25 to about 65 parts by weight of a non-reactive organopolysiloxane, each based on 100 parts by weight of the silicone composition.

10. A method as set forth in any one of claims 1-7 wherein the silicone composition comprises a hydrosilylation-curable silicone composition which comprises greater than about 55 parts by weight of an organopolysiloxane having silicon-bonded alkenyl groups and from about 5 to about 25 parts by weight of an organosilicon hydride having silicon-bonded hydrogen atoms, each based on 100 parts by weight of the silicone composition.

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
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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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/207646 A1 (TERREAU CHRISTINE [BE] ET AL) 21 September 2006 (2006-09-21) abstract; figures 3-5 paragraph [0023] - paragraph [0028] paragraph [0132] paragraph [0074] paragraph [0053] - paragraph [0054] -----	1-10
X	US 2008/276983 A1 (DRAKE ROBERT ANDREW [GB] ET AL) 13 November 2008 (2008-11-13) cited in the application abstract; figures 2,3 paragraph [0047] - paragraph [0049] paragraph [0155] - paragraph [0156] ----- -/--	1-10

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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INTERNATIONAL SEARCH REPORT

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2011/061724 A1 (HOULE KEVIN [US] ET AL) 17 March 2011 (2011-03-17) cited in the application abstract paragraph [0047] - paragraph [0071] -----	1-10
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