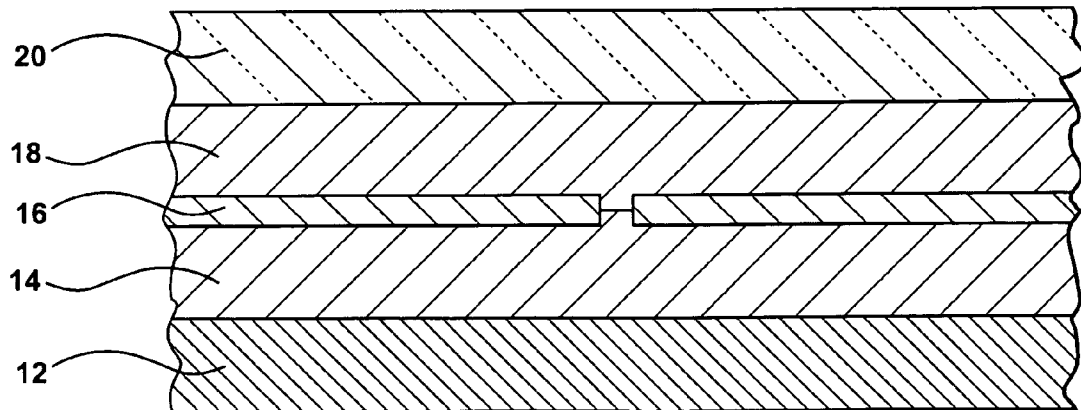




US 20110061724A1

(19) **United States**(12) **Patent Application Publication**
Houle et al.(10) **Pub. No.: US 2011/0061724 A1**(43) **Pub. Date: Mar. 17, 2011**(54) **PHOTOVOLTAIC CELL MODULE AND
METHOD OF FORMING SAME**Jan. 22, 2009 (US) 61/146551
Mar. 13, 2009 (US) PCT/US2009/001623(76) Inventors: **Kevin Houle**, Midland, MI (US);
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Midland, MI (US)**Publication Classification**(51) **Int. Cl.**
H01L 31/048 (2006.01)
C23C 14/34 (2006.01)
H01L 31/18 (2006.01)
(52) **U.S. Cl.** **136/252**; 204/192.25; 438/73;
257/E31.11(21) Appl. No.: **12/922,583**(22) PCT Filed: **Mar. 13, 2009**(86) PCT No.: **PCT/US09/01623**§ 371 (c)(1),
(2), (4) Date: **Nov. 10, 2010**(30) **Foreign Application Priority Data**Mar. 14, 2008 (US) 61/036748
Mar. 14, 2008 (US) 61/036752(57) **ABSTRACT**

A photovoltaic cell module, a photovoltaic array including at least two modules, and a method of forming the module are provided. The photovoltaic cell module includes a substrate and a tie layer disposed on the substrate. The tie layer has a depth of penetration of from 1.1 to 100 mm and a tack value of less than -0.6 g-sec. The photovoltaic cell module also includes a photovoltaic cell disposed on the tie layer. The method of forming the photovoltaic cell module includes the steps of disposing the tie layer on the substrate and disposing the photovoltaic cell on the tie layer to form the photovoltaic cell module.



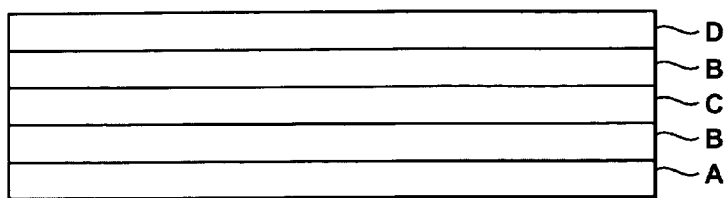


FIG - 1
PRIOR ART

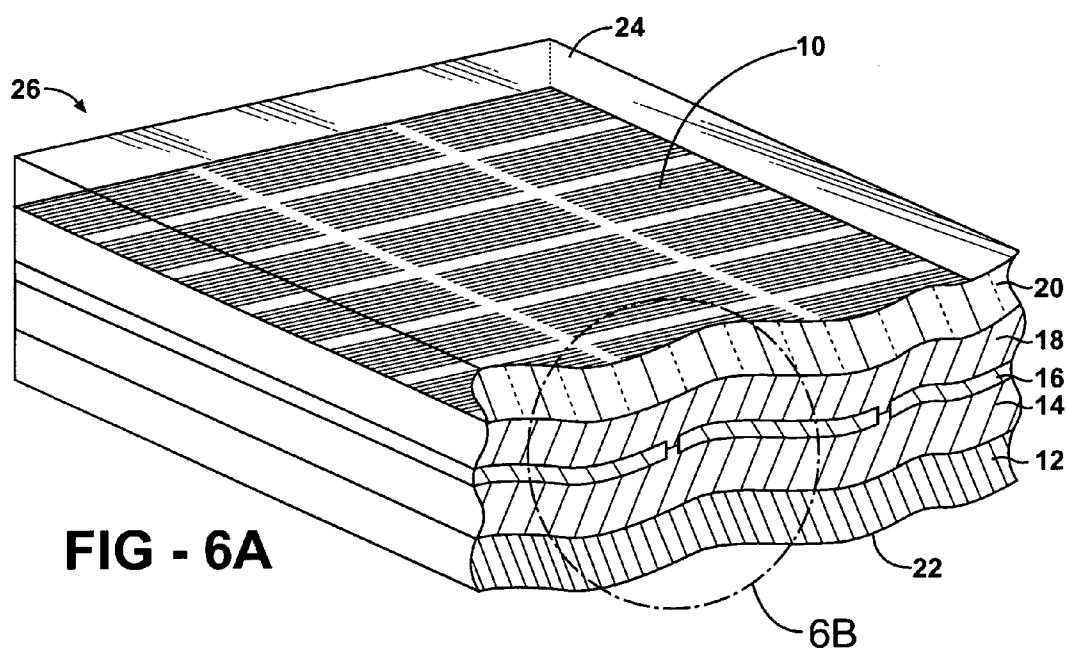
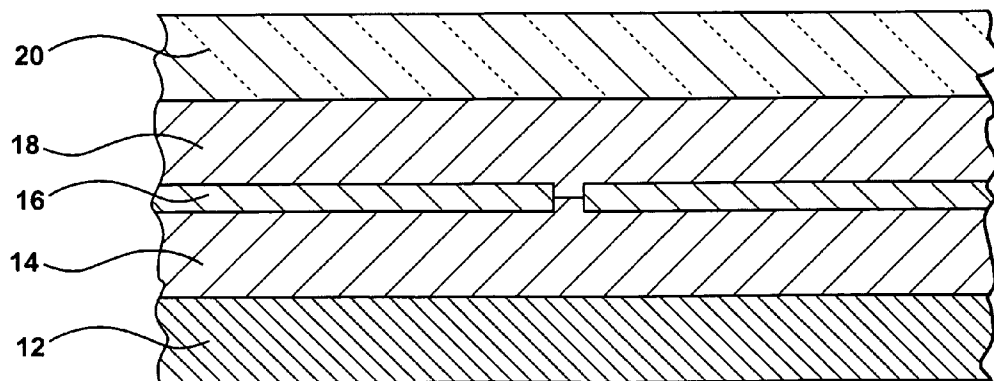
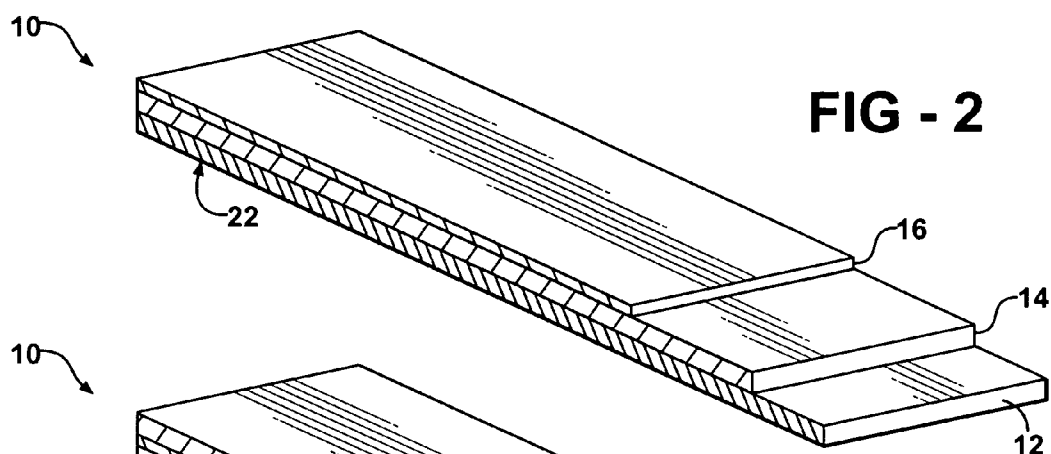
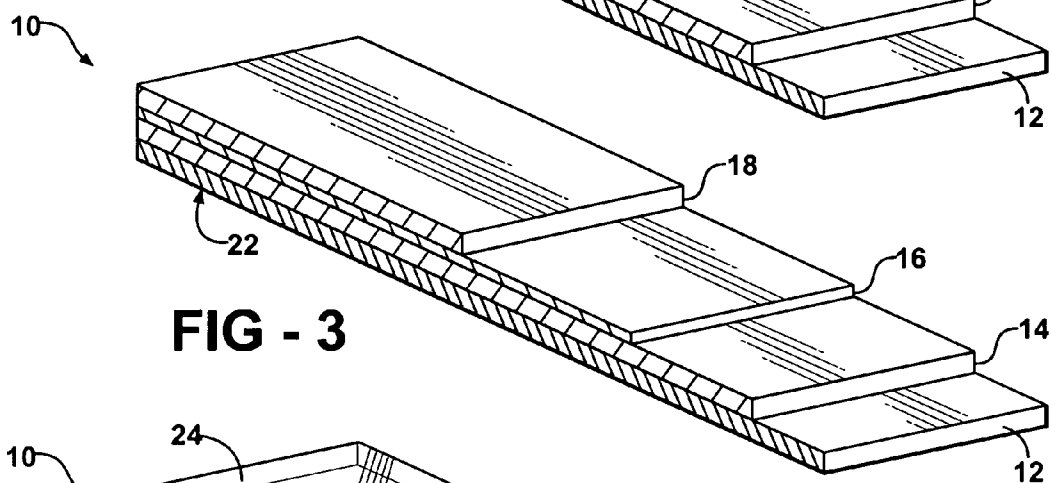
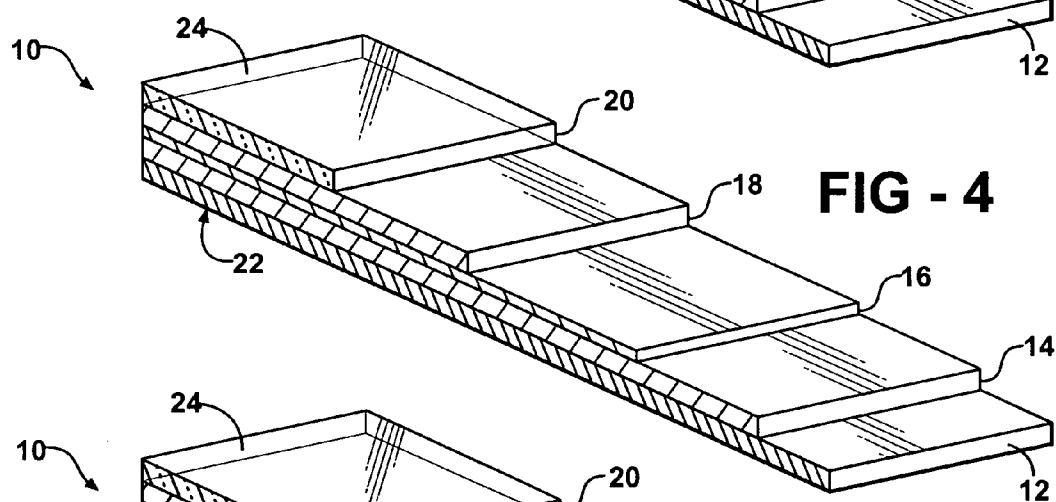
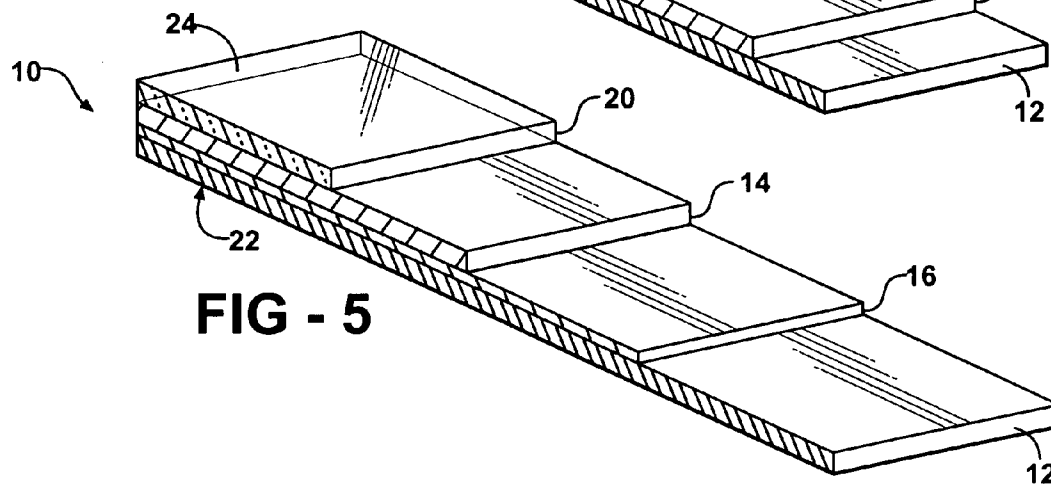


FIG - 6A

FIG - 6B





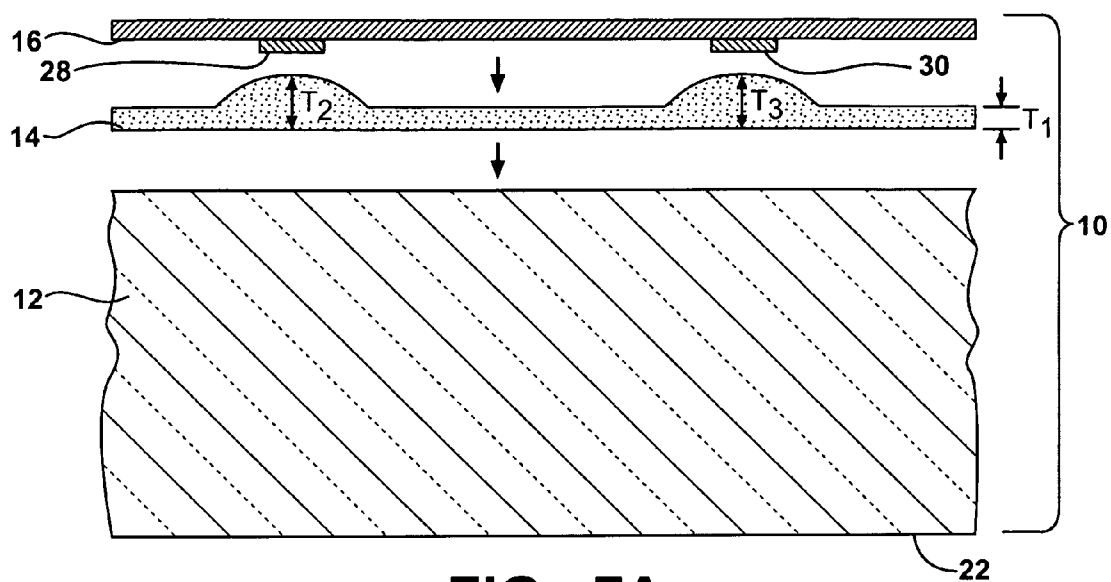


FIG - 7A

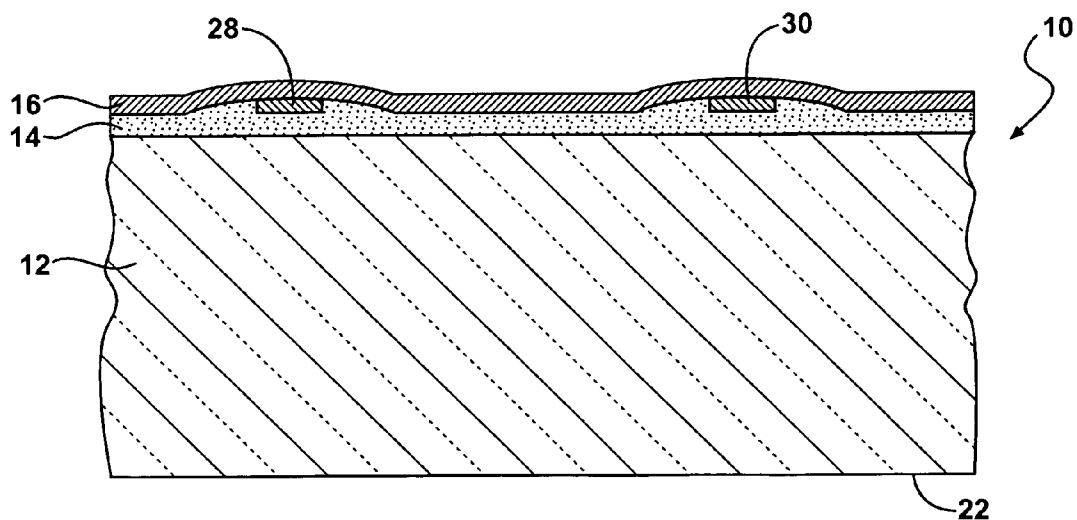


FIG - 7B

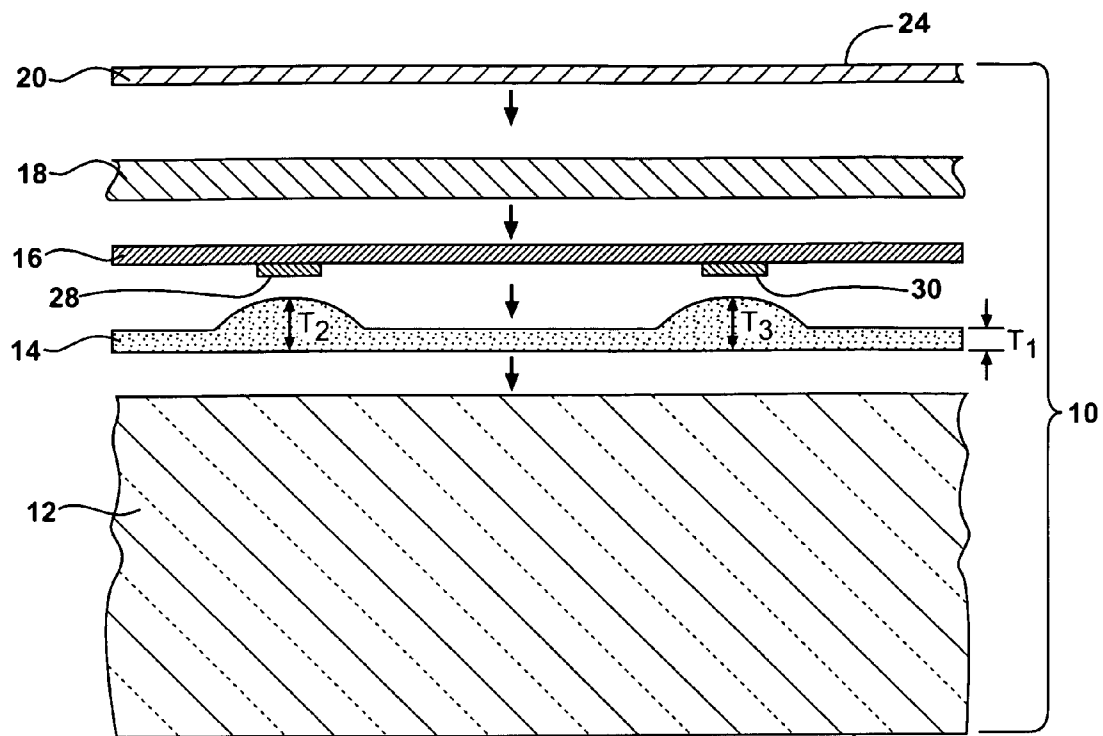


FIG - 8A

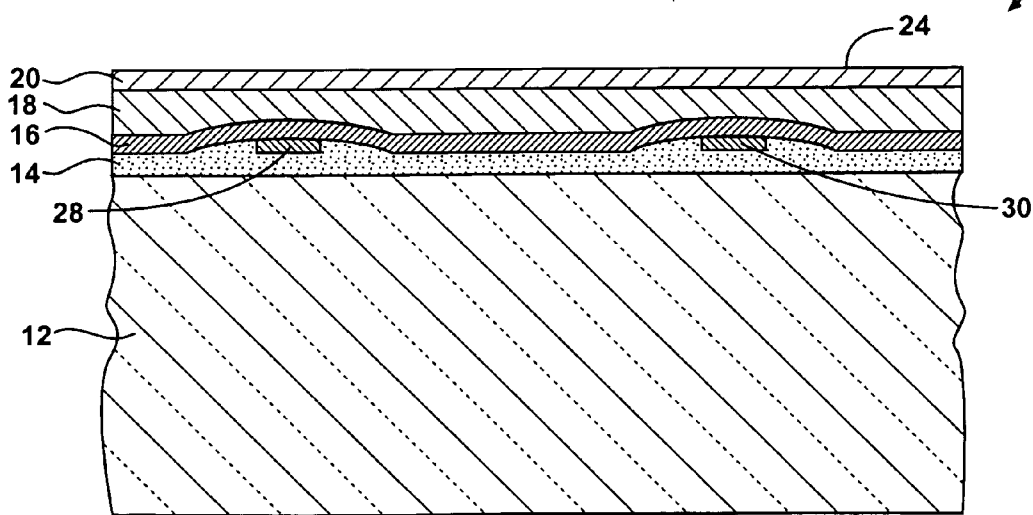


FIG - 8B

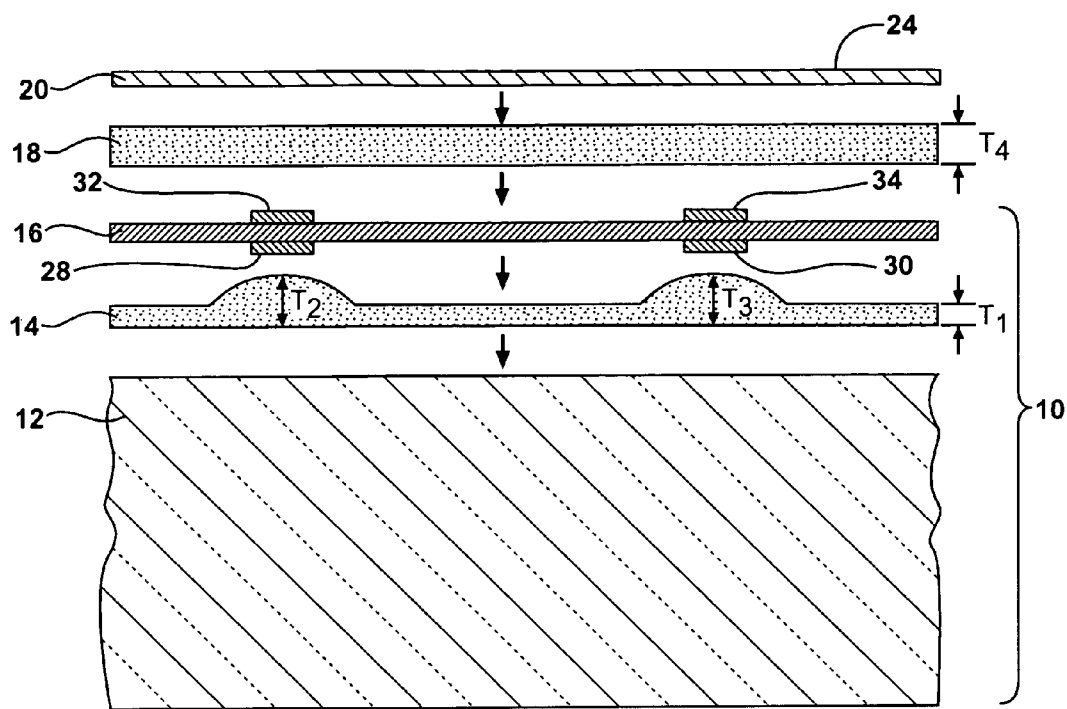


FIG - 9A

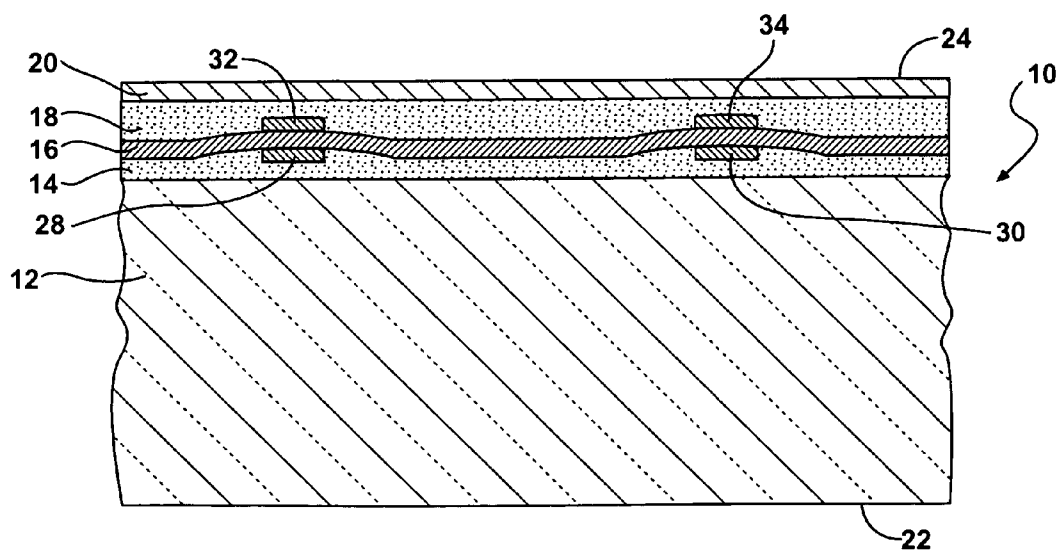


FIG - 9B

PHOTOVOLTAIC CELL MODULE AND METHOD OF FORMING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The subject patent application claims priority to, and all the benefits of, U.S. Provisional Patent Application Ser. Nos. 61/036,748 and 61/036,752, both filed on Mar. 14, 2008, and U.S. Provisional Patent Application Ser. No. 61/146,551 filed on Jan. 22, 2009. The entirety of these provisional patent applications is expressly incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention generally relates to a photovoltaic cell module and method of forming the same. More specifically, the photovoltaic cell module includes a substrate and a tie layer having particular properties that is disposed on the substrate.

DESCRIPTION OF THE RELATED ART

[0003] Solar or photovoltaic cells are semiconductor devices used to convert light into electricity. There are two general types of photovoltaic cells, wafers and thin films. Wafers are thin sheets of semiconductor material that are typically formed from casting or mechanically sawing the wafer from a single crystal or multicrystal ingot. Thin film photovoltaic cells usually include continuous layers of semiconducting materials deposited on a substrate using sputtering or chemical vapor deposition.

[0004] In many applications, the photovoltaic cells are encapsulated to provide additional protection from environmental factors such as wind and rain. However, encapsulants and encapsulation methods known in the art are expensive and time consuming and typically ineffective.

[0005] One known encapsulant is ethyl vinyl acetate (EVA). EVA is used because it is able to harvest light for the photovoltaic cells. However, EVA is degraded by wavelengths of light below 400 nm. Hence, photovoltaic cells including EVA are limited to harvesting light at wavelengths above 400 nm. More specifically, EVA has low UV resistance, has a tendency to discolor, and has a tendency to chemically and physically degrade upon exposure to light.

[0006] EVA is also known to exhibit poor adhesive properties relative to glass substrates and have a high modulus. These poor adhesive properties and high modulus tend to cause high stress conditions around the photovoltaic cells resulting in gradual delamination of the encapsulant from the substrate. This delamination leads to water accumulation in the encapsulant and photovoltaic cell corrosion.

[0007] Consequently, the industry has used increased amounts of EVA to reduce delamination and discoloring. However, this reduces a total amount of available light impinging on the photovoltaic cell, thereby reducing cell efficiency. Additionally, glass doped with cerium and antimony has been used as a substrate or superstrate to protect the EVA from UV damage. Further, UV stabilizing packages including UV absorbers and/or hindered amine light stabilizers have been added to the EVA. However, use of the doped glass or UV absorbers typically causes a 1% to 5% loss in photovoltaic cell efficiency.

[0008] Use of EVA to encapsulate photovoltaic cells is described in EP 0658943, WO 94/29106, EP 0528566 and EP

0755080. Typically, EVA is applied as one or more thermo-setting sheets sandwiched between a substrate and a superstrate and subjected to heat, vacuum and pressure. These conditions cause the EVA to flow, wet the substrate and the superstrate, and encapsulate the photovoltaic cell. Production of photovoltaic cells in this way is relatively expensive and time consuming.

[0009] Alternatively, the EVA may be cured through use of peroxides to initiate a radical cure. This method tends to promote side reactions that reduce overall durability. If peroxides are used, curing temperatures typically range from 150° C. to 160° C. These temperatures typically cause excessive stress in the photovoltaic cells and result in mechanical breakdown and/or increased production time and a number of steps needed to strengthen the photovoltaic cells.

[0010] Some photovoltaic cell modules include multiple sheets of EVA as hot melt thermoset adhesives. As set forth in FIG. 1, which represents the prior art, photovoltaic cell modules include multiple sheets of EVA (B) as hot melt thermoset adhesives to bond and encapsulate photovoltaic cells (C) to a glass superstrate (D) and a Tedlar or PET/SiOx-PET/Al substrate (A). The glass superstrate (D), whilst transparent to light, is typically doped with cerium and antimony to filter UV light thereby increasing production costs and complexities.

[0011] In addition, silicones have been investigated for use as encapsulants but are not typically used due to numerous drawbacks resulting from production methods. WO 2005/006451 describes a continuous method for the encapsulation of photovoltaic cells using heat cured liquid silicone. Whilst this method provides significant advantages over other encapsulation methods, the method tends to trap air bubbles underneath the photovoltaic cells which causes the photovoltaic cells to exhibit inferior properties. Additional drawbacks include a difficulty in controlling thickness of the encapsulant, increased expense, increased processing times, and increased processing complexity. These all result in increased cost for the end purchaser.

[0012] The prior art does not account for differing thicknesses of electrical leads that are included on photovoltaic cells in relation to detrimental exposure of such leads due to long term use of the photovoltaic cells, weathering, and general wear and tear. The exposure of the leads results in decreased performance and decreased conversion of light into electricity. Furthermore, the prior art does not account for the use of differing amounts of encapsulants to protect the electrical leads while maintaining performance and decreasing production costs.

[0013] Accordingly, there remains an opportunity to develop photovoltaic cell modules that are effective and durable. There also remains an opportunity to develop a method of forming the photovoltaic cell modules that minimizes processing complexities, trapped air underneath photovoltaic cells, and an amount of a tie layer that is used, thus maximizing production efficiency, cost savings, and repeatability.

SUMMARY OF THE INVENTION AND ADVANTAGES

[0014] The instant invention provides a photovoltaic cell module and a method of forming. The photovoltaic cell module includes a substrate and a tie layer disposed on the substrate. The tie layer has a depth of penetration of from 1.1 to 100 mm and a tack value of less than -0.6 g-sec. The photo-

voltaic cell module also includes a photovoltaic cell disposed on the tie layer. The method of forming the photovoltaic cell module includes the steps of disposing the tie layer on the substrate and disposing the photovoltaic cell on the tie layer to form the photovoltaic cell module.

[0015] The tie layer allows light to enter the photovoltaic cell and be efficiently converted to electricity. The tie layer also allows the photovoltaic cell to be secured within the photovoltaic cell module while simultaneously allowing for trapped air to be evacuated from underneath thereby leading to increased durability and weatherability. The tie layer further allows for cost effective and repeatable production of the photovoltaic cell module because of efficient evacuation of the trapped air.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0016] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0017] FIG. 1 is a cross-sectional view of a photovoltaic cell module of the prior art including EVA sheets;

[0018] FIG. 2 is a cross-sectional view of one embodiment of a photovoltaic cell module of this invention including a substrate, a tie layer disposed on the substrate, and a photovoltaic cell disposed on the tie layer;

[0019] FIG. 3 is a cross-sectional view of the photovoltaic cell module of FIG. 2 including a second tie layer disposed on the photovoltaic cell;

[0020] FIG. 4 is a cross-sectional view of the photovoltaic cell module of FIG. 3 including a second substrate disposed on the second tie layer;

[0021] FIG. 5 is a cross-sectional view of another embodiment of a photovoltaic cell module of this invention including a substrate, a photovoltaic cell disposed directly on the substrate via chemical vapor deposition or physical sputtering, a tie layer disposed directly on the photovoltaic cell, and a second substrate disposed directly on the tie layer;

[0022] FIG. 6A is a cross-sectional view of a series of photovoltaic cell modules of FIG. 4 that are electrically connected and arranged as a photovoltaic array;

[0023] FIG. 6B is a magnified cross-sectional view of the series of photovoltaic cell modules of FIG. 4 that are electrically connected and arranged as a photovoltaic array.

[0024] FIG. 7A is an exploded cross-sectional view of yet another embodiment of a photovoltaic cell module of this invention including a substrate and a tie layer disposed on the substrate and having thicknesses (T_1 , T_2 , T_3) that vary across the substrate. The photovoltaic cell module also includes a photovoltaic cell and first and second electrical leads each spaced apart from one another, disposed on a first side of the photovoltaic cell, and sandwiched between the photovoltaic cell and the tie layer;

[0025] FIG. 7B is a cross-sectional view of the photovoltaic cell module of FIG. 7A formed according to this invention;

[0026] FIG. 8A is an exploded cross-sectional view of the photovoltaic cell module of FIG. 7A further including a second tie layer that is the same or different than the tie layer and that is also disposed on the photovoltaic cell, and a second substrate disposed on the second tie layer;

[0027] FIG. 8B is a cross-sectional view of the photovoltaic cell module of FIG. 8A formed according to this invention;

[0028] FIG. 9A is an exploded cross-sectional view of the photovoltaic cell module of FIG. 8A further including third and fourth electrical leads each spaced apart from one another, disposed on a second side of the photovoltaic cell opposite the first side, and sandwiched between the photovoltaic cell and the second tie layer; and

[0029] FIG. 9B is a cross-sectional view of the photovoltaic cell module of FIG. 9A formed according to this invention.

DETAILED DESCRIPTION OF THE INVENTION

[0030] The present invention provides a photovoltaic cell module (10) (hereinafter referred to as "module") generally shown in FIGS. 2-9 and a method of forming the module (10). The module (10) includes a substrate (12), a tie layer (14) disposed on the substrate (12), and a photovoltaic cell (16) disposed on the tie layer (14), as shown in FIG. 2. The substrate (12), tie layer (14), and photovoltaic cell (16) are described in greater detail below.

[0031] Modules (10) convert light energy into electrical energy due to a photovoltaic effect and perform two primary functions. A first function is photogeneration of charge carriers such as electrons and holes in light absorbing materials. The second function is direction of the charge carriers to a conductive contact to transmit electricity.

[0032] The module (10) includes the substrate (12) which may include any suitable material known in the art. Typically, the substrate (12) provides protection to a rear surface (22) of the module (10). Similarly, the substrate (12) may provide protection to a front surface (24) of the module (10). The substrate (12) may be soft and flexible but is typically rigid and stiff. Alternatively, the substrate (12) may include rigid and stiff segments while simultaneously including soft and flexible segments. The substrate (12) is typically transparent to light, may be opaque, or may not transmit light (i.e., be impervious to light). The substrate (12) may include glass, stainless steel, metal foils, polyimides, ethylene-vinyl acetate copolymers, and/or organic fluoropolymers including, but not limited to, ethylene tetrafluoroethylene (ETFE), Tedlar® (polyvinylfluoride), polyester/Tedlar®, Tedlar®/polyester/Tedlar®, polyethylene terephthalate (PET) alone or coated with silicon and oxygen based materials (SiO_x), and combinations thereof. In one embodiment, the substrate (12) is selected from the group of polyvinylfluoride and polyethylene. The substrate (12) may alternatively be further defined as a PET/ SiO_x -PET/Al substrate, wherein x has a value of from 1 to 4. Still further, the substrate (12) may include silicone, may consist essentially of silicone and not include organic monomers or polymers, or may consist of silicone. It is to be understood that the substrate (12) is not limited to the aforementioned compounds.

[0033] The substrate (12) may be load bearing or non-load bearing and may be included in any portion of the module (10). Typically, the substrate (12) is load bearing. The substrate (12) may be a "top layer," also known as a superstrate, or a "bottom layer" of the module (10). Bottom layers are typically positioned behind the photovoltaic cells (16) and serve as mechanical support, as shown in the Figures. In various embodiments, the module (10) includes the substrate (12) and a second substrate (20), which may be the same or different from each other. In other words, the substrate (12) and the second substrate (20) may be formed from the same material or from different materials. The substrate (12) is typically the bottom layer while the second substrate (20) is typically the top layer and functions as a superstrate, as shown

in FIGS. 4-6, 8, and 9. Typically, the second substrate (20) (e.g. a second substrate functioning as a superstrate) is transparent to sunlight and is positioned on top of the substrate (12) and in front of a light source. The second substrate (20) is typically used to protect the module (10) from environmental conditions such as rain, snow, and heat. Most typically, the second substrate (20) functions as a superstrate and is a rigid glass panel that is transparent to sunlight and is used to protect the front surface of the module (10), as also shown in FIGS. 4-6, 8 and 9.

[0034] The substrate (12) and/or the second substrate (20) typically have a thickness of from 50 to 500, of from 100 to 225, or of from 175 to 225, micrometers. The substrate (12) and/or the second substrate (20) may have a length and width of 125 mm each or a length and width of 156 mm each. Of course, the instant invention is not limited to these dimensions.

[0035] In addition, the module (10) also includes the tie layer (14). The tie layer (14) is disposed on the substrate (12) and usually functions to adhere the photovoltaic cell (16) to the substrate (12). The module (10) typically includes multiple tie layers, e.g. a second (18) and/or a third tie layer. Any second (18), third, or additional tie layer may be the same or different from the tie layer (14). Thus, any second (18), third or additional tie layer may be formed from the same material or from a different material than the tie layer (14). In one embodiment, the module (10) includes the tie layer (14) and a second tie layer (18), as shown in FIGS. 3, 4, 6, 8 and 9. The second tie layer (18) may also be disposed on the substrate (12). Alternatively, the second tie layer (18) may be disposed on the first tie layer (14) and/or may be disposed on a photovoltaic cell (16) as described in greater detail below and as set forth in FIGS. 3, 4, 6, 8 and 9. Further, the tie layer (14) is typically transparent to UV and/or visible light and the second (or additional) tie layers (18) may be impermeable to light or opaque. In one embodiment, the second tie layer (18) has high transmission across visible wavelengths, long term stability to UV and provides long term protection to the photovoltaic cell (16). In this embodiment, there is no need to dope the substrate (12) with cerium due to the UV stability of the tie layer (14).

[0036] The tie layer (14) has a depth of penetration (value) of from 1.1 to 100 mm. It is understood by those of skill in the silicone arts that the terminology "depth of penetration" is also referred to as "penetration" or "penetration value." In various embodiments, the tie layer (14) has a depth of penetration of from 1.3 to 100 mm and more typically of from 2 to 55 mm. Without intending to be bound by any particular theory, it is believed that as temperature rises, the depth of penetration values also rise. It is contemplated that the tie layer (14) may have a depth of penetration of from 1.1 to 100 mm, of from 1.3 to 100 mm, or of from 2 to 55 mm, as determined at room temperature or at any other temperature. Typically, depth of penetration is determined at room temperature.

[0037] The depth of penetration is determined by first calculating hardness and then calculating depth of penetration. Thus, the tie layer (14) typically has a hardness in grams (g) of Force of from 5 to 500, more typically of from 5 to 400, and most typically of from 10 to 300. More specifically, hardness is determined using a TA-XT2 Texture Analyzer commercially available from Stable Micro Systems using a 0.5 inch (1.27 cm) diameter steel probe. Test samples of the tie layer having a mass of 12 g are heated at 100° C. for 10 minutes and

are analyzed for hardness using the following testing parameters, as known in the art: 2 mm/sec pre-test and post-test speed; 1 mm/s test speed; 4 mm target distance; 60 second hold; and a 5 g force trigger value. The maximum grams force is measured at 4 mm distance into the tie layer (14).

[0038] Depth of penetration measurements are typically calculated using the hardness (grams of force) obtained using the TA-XT2 Texture Analyzer and the following equation: Depth of penetration (mm×10)=5,350/grams force. This relationship is determined using a universal penetrometer, commercially available from Precision Scientific of Chicago, Ill., and by measuring hardness with the texture analyzer of the tie layer (14). There typically are seventy nine sample measurements taken for the tie layer (14). The 5,350 constant is determined by multiplying the depth of penetration by the grams of force from the texture analyzer for each of the seventy nine samples and then averaging the results.

[0039] The tie layer (14) also has a tack value of less than -0.6 g-sec. In various embodiments, the tie layer (14) has a tack value of from -0.7 to -300 g-sec and more typically of from -1 to -100 g-sec. In one embodiment, the tie layer (14) has a tack value of about -27 g-sec. Without intending to be bound by any particular theory, it is believed that as temperature rises, the tack value decreases. It is contemplated that the tie layer (14) may have a tack value of less than -0.6 g-sec., of from -0.7 to -300 g-sec., or of from -1 to -100 g-sec., as determined at room temperature or at any other temperature. Typically, tack value is determined at room temperature.

[0040] The tack value is determined using the TA-XT2 Texture Analyzer using a 0.5 inch (1.27 cm) diameter steel probe. The probe is inserted into the tie layer (14) to a depth of 4 mm and then withdrawn at a rate of 2 mm/sec. The tack value is calculated as a total area (Force-Time) during withdrawal of the probe from the tie layer (14). The tack value is expressed in gram-sec. wherein the time is measured as a time difference between a time when the force is equal to zero and a time when the probe separates from the tie layer (14). It is believed that the depth of penetration and the tack values do not substantially change with varying thicknesses of the tie layer (14). However, methods of determining the depth of penetration and the tack values may be modified depending on the thickness of the tie layer (14).

[0041] The tie layer (14) is typically tacky and may be a gel, gum, liquid, paste, resin, or solid. In one embodiment, the tie layer (14) is a film. In another embodiment, the tie layer (14) is a gel. In yet another embodiment, the tie layer (14) is a liquid that is cured (e.g. pre-cured) to form a gel. Alternatively, the tie layer (14) may include multiple segments, with each segment including a different composition and/or different form (e.g., gel and liquid), so long as the segments and the overall tie layer (14) have the appropriate depth of penetration and tack values, set forth above. Examples of suitable gels for use as the tie layer (14) are described in U.S. Pat. Nos. 5,145,933, 4,340,709, and 6,020,409, each of which is expressly incorporated herein by reference relative to these gels. It is to be understood that the tie layer (14) can have any form so long as the tie layer (14) has a depth of penetration of from 1.1 to 100 mm and a tack value of less than -0.6 g-sec. The tie layer (14) also typically has an elastic modulus (G' at cure) of from 7×10^2 to 6×10^5 dynes/cm².

[0042] The tie layer (14) may be formed from and/or include any suitable compound known in the art. These compounds may or may not require curing. In one embodiment, the curable composition includes at least one of an ethylene-

vinyl acetate copolymer, a polyurethane, an ethylene tetrafluoroethylene, a polyvinylfluoride, a polyethylene terephthalate, and combinations thereof. In another embodiment, the curable composition includes carbon atoms and is substantially free of compounds including silicon atoms. The terminology "substantially free," as used immediately above, refers to less than 0.1 weight percent of compounds including silicon atoms present in the curable composition. The curable composition may include organic compounds and less than 0.1 weight percent of compounds including silicon atoms.

[0043] In a further embodiment, the tie layer (14) is formed from a curable composition including silicon atoms. The tie layer may be formed completely from a curable silicone composition such as those disclosed in U.S. Pat. Nos. 6,020, 409 and 6,169,155, herein expressly incorporated by reference relative to these curable silicone compositions. In an alternative embodiment, the tie layer (14) may be formed from a cured or curable composition that includes a silicone fluid such as those commercially available from Dow Corning Corporation of Midland, Mich. One non-limiting example of a particularly suitable silicone fluid is trimethylsilyl terminated polydimethylsiloxane having a viscosity of 100 mPa-s.

[0044] In one embodiment, the curable silicone composition is further defined as hydrosilylation-curable and includes an organosilicon compound having at least one unsaturated moiety per molecule, an organohydrogensilicon compound having at least one silicon-bonded hydrogen atom per molecule, and a hydrosilylation catalyst used to accelerate a hydrosilylation reaction between the organosilicon compound and the organohydrogensilicon compound. In this embodiment, a ratio of silicon-bonded hydrogen atoms per molecule of the organohydrogensilicon compound to unsaturated moieties per molecule of the organosilicon compound is typically of from 0.05 to 100.

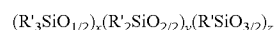
[0045] In an alternative embodiment, the organosilicon compound is further defined as an alkenyldialkylsilyl end-blocked polydialkylsiloxane which may itself be further defined as vinyl dimethylsilyl end-blocked polydimethylsiloxane. The organohydrogensilicon compound may also be further defined as a mixture of a dialkylhydrogensilyl terminated polydialkylsiloxane and a trialkylsilyl terminated polydialkylsiloxane-alkylhydrogensiloxane co-polymer. The dialkylhydrogensilyl terminated polydialkylsiloxane itself may be further defined as dimethylhydrogensilyl terminated polydimethylsiloxane while the trialkylsilyl terminated polydialkylsiloxane-alkylhydrogensiloxane co-polymer may be further defined as a trimethylsilyl terminated polydimethylsiloxane-methylhydrogensiloxane co-polymer.

[0046] Alternatively, the tie layer (14) may be formed from a curable composition including one or more of components (A)-(E) and combinations thereof. Each of components (A)-(E) is optional for use in this invention and is not required. One or more of components (A)-(E) may be silicon containing or may be organic. If the curable composition is further defined as a curable silicone composition, component (A) is typically utilized along with component (B). Component (A) may include a mixture of compounds. Similarly, each of components (B)-(E) may independently include mixtures of compounds.

[0047] Component (A) may include any organic and/or inorganic compounds known in the art and may include both carbon and silicon atoms. Typically, component (A) includes a diorganopolysiloxane containing polymer. The diorganopolysiloxane containing polymer may have high or low number

(M_n) and/or weight average (M_w) molecular weights and may be a silicone gum having at least two reactive groups per molecule that are designed to cure with component (B), described in greater detail below. Alternatively, the diorganopolysiloxane containing polymer may be a resin, a gel and/or a gum or may include a gum, a gel and/or a gum. In another embodiment, the diorganopolysiloxane containing polymer has a low molecular weight. However, the diorganopolysiloxane containing polymer is not limited to the description above and may have any number average or weight average molecular weight.

[0048] The diorganopolysiloxane containing polymer typically has a molecular structure which is substantially linear. However, this structure may be partially branched. In one embodiment, the diorganopolysiloxane containing polymer has the average unit formula:



wherein x and y are positive numbers, z is greater than or equal to zero, and each R' is independently a monovalent radical. In this formula, x+y+z is typically at least 100 and is more typically greater than 700. Also, y/(x+y+z) is typically greater than or equal to 0.8 and more typically greater than or equal to 0.95. Non-limiting examples of monovalent radicals include alkyl groups such as methyl, ethyl, propyl, isopropyl, butyl, and tertiary butyl groups, phenyl groups, alkylphenyl groups, hydrogen atoms, hydroxyl groups, alkenyl groups, oximo groups, alkoxy groups, epoxide groups, carboxyl groups, alkyl amino radicals, and combinations thereof. Typically all non-reactive R' groups are alkyl groups having from 1 to 6 carbon atoms and/or phenyl groups. Most typically, all non-reactive R' groups are methyl groups. Typically at least two R' groups per molecule are reactive groups which may be unsaturated and may be alkenyl and/or alkynyl groups. Most typically, these reactive groups are alkenyl groups such as vinyl or hexenyl groups. Suitable non-limiting examples of reactive groups include alkenyl groups that are linear or branched and have from 2 to 10 carbon atoms, such as vinyl groups, propenyl groups, butenyl groups, hexenyl groups, isopropenyl groups, tertiary butenyl groups and combinations thereof. The diorganopolysiloxane may also include reactive groups other than unsaturated groups to enhance adhesion properties of the curable composition.

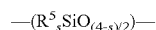
[0049] Additional suitable examples of component (A) include, but are not limited to, dimethylalkenylsiloxy-terminated dimethylpolysiloxanes, dimethylalkenylsiloxy-terminated copolymers of methylalkenylsiloxane and dimethylsiloxane, dimethylalkenylsiloxy-terminated copolymers of methylphenylsiloxane and dimethylsiloxane, dimethylalkenylsiloxy-terminated copolymers of methylphenylsiloxane, methylalkenylsiloxane, and dimethylsiloxane, dimethylalkenylsiloxy-terminated copolymers of diphenylsiloxane and dimethylsiloxane, dimethylalkenylsiloxy-terminated copolymers of diphenylsiloxane, methylalkenylsiloxane, and dimethylsiloxane, and combinations thereof.

[0050] Alternatively, component (A) may include a compound having hydroxyl or hydrolysable groups X and X¹ which may be the same or different. These groups may or may not be terminal groups and are typically not sterically hindered. For example, this compound may have the general formula:



wherein X and/or X¹ may include and/or terminate with any of the following groups: —Si(OH)₃, —(R^a)Si(OH)₂, —(R^a)₂SiOH, —R^aSi(OR^b)₂, —Si(OR^b)₃, —R^a₂SiOR^b or —R^a₂Si—R^c—SiR^d_p(OR^b)_{3-p} where each R^a may independently include a monovalent hydrocarbyl group such as an alkyl group having from 1 to 8 carbon atoms. Typically, R^a is a methyl group. Each R^b and R^d may independently be an alkyl group having up to 6 carbon atoms or alkoxy group. R^c is typically a divalent hydrocarbon group which may include one or more siloxane spacers having up to six silicon atoms. Typically, p has a value 0, 1 or 2. In one embodiment, X and/or X¹ include functional groups which are hydrolysable in the presence of moisture.

[0051] Additionally, in this formula, (A) typically includes a siloxane molecular chain. In one embodiment, (A) includes a polydiorgano-siloxane chain having siloxane units of the following formula



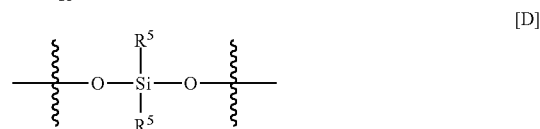
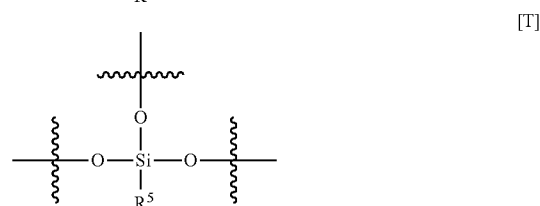
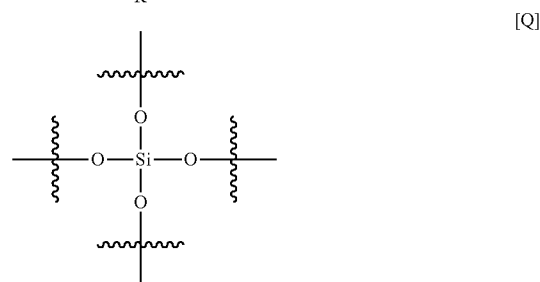
wherein each R⁵ is independently an organic group such as a hydrocarbyl group having from 1 to 10 carbon atoms that is optionally substituted with one or more halogen group such as chlorine or fluorine, and s is 0, 1 or 2. More specifically, R⁵ may include methyl, ethyl, propyl, butyl, vinyl, cyclohexyl, phenyl, and/or tolyl groups, propyl groups substituted with chlorine or fluorine such as 3,3,3-trifluoropropyl, chlorophenyl, beta-(perfluorobutyl)ethyl or chlorocyclohexyl groups, and combinations thereof. Typically at least some of the groups R⁵ are methyl groups. Most typically, all of the R⁵ groups are methyl groups. Typically there are at least approximately 700 units of the above formula per molecule.

[0052] Typically, component (A) has a viscosity of greater than 50 mPa·s. In one embodiment, component (A) has a viscosity of greater than 1,000,000 mPa·s. In another embodiment, component (A) has a viscosity of 50 to 1,000,000, more typically of from 100 to 250,000, and most typically of from 100 to 100,000, mPa·s. Each of the aforementioned viscosities are measured at 25° C. according to ASTM D4287 using a Brookfield DVIII Cone and Plate Viscometer. Component (A) is typically present in the curable composition in an amount of from 25 to 99.5 parts by weight, per 100 parts by weight of the curable composition.

[0053] In some embodiments, component (A) has a degree of polymerization (dp) of above 1500 and a Williams plasticity number, as determined using ASTM D926, of from 95 to 125. In other embodiments, component (A) has a dp of greater than 100 or even greater than 700. The plasticity number, as used herein, is defined as a thickness in millimeters×100 of a cylindrical test specimen 2 cm³ in volume and approximately 10 mm in height after the specimen has been subjected to a compressive load of 49 Newtons for three minutes at 25° C.

[0054] Referring now to component (B), this component typically includes a silicone resin (M, D, T, and/or Q) or mixture of resins. The resin(s) may or may not include functional groups that could react with component (A). Component (B) may be combined with component (A) with or without solvent. More specifically, component (B) may include an organosiloxane resin such as an MQ resin including R⁵₃SiO_{1/2} units and SiO_{4/2} units, a TD resin including R⁵₂SiO_{3/2} units and R⁵₂SiO_{2/2} units, an MT resin including R⁵₃SiO_{1/2} units and R⁵₂SiO_{3/2} units, an MTD resins including R⁵₃SiO_{1/2} units, R⁵₂SiO_{3/2} units, and R⁵₂SiO_{2/2} units, and combinations thereof. In these formulas, R⁵ is as described above.

[0055] The symbols M, D, T, and Q used above represent the functionality of structural units of polyorganosiloxanes including organosilicon fluids, rubbers (elastomers) and resins. The symbols are used in accordance with established understanding in the art. Thus, M represents the monofunctional unit R⁵₃SiO_{1/2}. D represents the difunctional unit R⁵₂SiO_{2/2}. T represents the trifunctional unit R⁵SiO_{3/2}. Q represents the tetrafunctional unit SiO_{4/2}. Generic structural formulas of these units are shown below:



Typically, the number average molecular weight of component (B) is at least 5,000 and typically greater than 10,000 g/mol. Component (B) is typically present in the curable composition in an amount of from 0.5 to 75 parts by weight per 100 parts by weight per 100 parts by weight of the curable composition.

[0056] Without intending to be bound by any particular theory, it is believed that the aforementioned silicones impart outstanding UV resistance to the curable compound and tie layer (14). Use of these silicones may reduce or eliminate a need to include a UV additive or cerium doped glass in the module (10). These silicones may also exhibit long term UV and visual light transmission thereby maximizing an efficiency of the module (10).

[0057] Referring now to component (C), this component typically includes a curing catalyst. The catalyst may be of any type known in the art and typically is selected from the group of condensation catalysts, hydrosilylation catalysts, radical catalysts, UV catalysts, thermal catalysts, and combinations thereof. Choice of this catalyst may reduce production and processing times by >20% and may eliminate certain production steps altogether, thereby leading to decreased production costs and purchasing costs for the end user.

[0058] More specifically, component (C) may include any suitable hydrosilylation catalyst, such as the hydrosilylation catalyst introduced and described above. The hydrosilylation catalyst can be any of the well known hydrosilylation catalysts including a platinum group metal, a compound containing a platinum group metal, or a microencapsulated platinum group metal or compound containing same. These metals typically include platinum, rhodium, ruthenium, palladium, osmium and iridium. More specifically, component (C) may include any suitable hydrosilylation catalyst, such as the hydrosilylation catalyst introduced and described above. The hydrosilylation catalyst can be any of the well known hydrosilylation catalysts including a platinum group metal, a compound containing a platinum group metal, or a microencapsulated platinum group metal or compound containing same. These metals typically include platinum, rhodium, ruthenium, palladium, osmium and iridium. Platinum and platinum compounds are most typically used based on their high activity level in hydrosilylation reactions. Most typically, the catalyst is a hydrosilylation catalyst and includes platinum. This catalyst may be a Karstedt based platinum catalyst and/or may include fine platinum powder, platinum black, chloroplatinic acid, an alcoholic solution of chloroplatinic acid, an olefin complex of chloroplatinic acid, a complex of chloroplatinic acid and alkenylsiloxane, a thermoplastic resin including platinum, and combinations thereof. In various embodiments, the catalyst is typically present in the curable composition in an amount of from 0.01 to 1, more typically in an amount of from 0.01 to 0.5, and most typically in an amount of from 0.01 to 0.3, parts by weight per one hundred parts by weight of the curable composition. If the catalyst includes a metal, the metal itself is typically present in the curable composition in an amount of from 1 to 500, more typically of from 1 to 100, and most typically of from 1 to 50, parts by weight per one million parts by weight of the curable composition. Resins may be used in conjunction with microencapsulated catalysts and may include, but are not limited to, organosilicon resins and organic resins derived from ethylenically unsaturated hydrocarbons and/or esters of ethylenically unsaturated carboxylic acids, such as acrylic and methacrylic acids.

[0059] In another embodiment, component (C) includes a peroxide catalyst which is used for free-radical based reactions between siloxanes including, but not limited to, =Si-CH_3 groups and other =Si-CH_3 groups or =Si-CH_3 groups and =Si-alkenyl groups (typically vinyl), or =Si-alkenyl groups and =Si-alkenyl groups. Suitable peroxide catalysts may include, but are not restricted to, 2,4-dichlorobenzoyl peroxide, benzoyl peroxide, dicumyl peroxide, tert-butyl perbenzoate, 1,1-bis(t-butylperoxy)-3,3,5-trimethylcyclohexane (TMCH) (2,5-bis(t-butylperoxy)-2,5-dimethylhexane) catalyst, 1,1-bis(tert-amylperoxy)cyclohexane, ethyl 3,3-bis(tert-amylperoxy)butyrate, 1,1-bis(tert-butylperoxy)cyclohexane, and combinations thereof. These catalysts may be utilized as a neat compound or in an inert matrix (liquid or solid).

[0060] Typically, when one or more peroxide catalysts are used, a temperature at which curing is initiated is generally determined/controlled on a basis of a half-life of the catalyst. However, a rate of cure and ultimate physical properties of the curable compound and the tie layer (14) are controlled by a level of unsaturation of compounds used to form the tie layer (14). Additionally, reaction kinetics and physical properties can be tuned by blending linear non-reactively endblocked

polymers with differing degrees of polymerization (dp) with dimethylmethylvinyl-copolymers with or without vinyl end-blocking.

[0061] In yet another embodiment, component (C) includes a condensation catalyst and may also include a combination of the condensation catalyst with one or more silanes or siloxane based cross-linking agents which include silicon bonded hydrolysable groups such as acyloxy groups (for example, acetoxo, octanoyloxy, and benzoyloxy groups), ketoximino groups (for example dimethyl ketoxime and isobutylketoximino groups), alkoxy groups (for example methoxy, ethoxy, and propoxy groups), alkenyloxy groups (for example isopropenyloxy and 1-ethyl-2-methylvinyl groups), and combinations thereof. It is also contemplated that condensation catalysts may be used in component (C) when the curable composition includes resin polymer blends that are prepared such that they form a sheeting material that, on exposure to a moist atmosphere, reacts to form a permanent network. Alternatively, condensation catalysts may be used in component (C) when the curable composition includes alkoxy-functional silicone polymers that are capable of co-reacting with the moisture triggered polymers.

[0062] Component (C) may include any suitable condensation catalyst known in the art. More specifically, the condensation catalyst may include, but is not limited to, tin, lead, antimony, iron, cadmium, barium, manganese, zinc, chromium, cobalt, nickel, aluminum, gallium, germanium, zirconium, and combinations thereof. Non-limiting particularly suitable condensation catalysts include alkyltin ester compounds such as dibutyltin dioctoate, dibutyltin diacetate, dibutyltin dimaleate, dibutyltin dilaurate, butyltin 2-ethylhexoate, 2-ethylhexoates of iron, cobalt, manganese, lead and zinc, and combinations thereof.

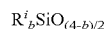
[0063] Alternatively, the condensation catalyst may include titanates and/or zirconates having the general formula Ti[OR]_4 or Zr[OR]_4 respectively, wherein each R may be the same or different and represents a monovalent, primary, secondary or tertiary aliphatic hydrocarbon group which may be linear or branched and have from 1 to 10 carbon atoms. In one embodiment, the condensation catalyst includes a titanate including partially unsaturated groups. In another embodiment, the condensation catalyst includes titanates and/or zirconates wherein R includes methyl, ethyl, propyl, isopropyl, butyl, tertiary butyl, and/or branched secondary alkyl groups such as 2,4-dimethyl-3-pentyl, and combinations thereof. Typically, when each R is the same, R is an isopropyl group, branched secondary alkyl group or a tertiary alkyl group, and, in particular, a tertiary butyl group. Alternatively, the titanate may be chelated. Chelation may be accomplished with any suitable chelating agent such as an alkyl acetylacetonate such as methyl or ethylacetylacetonate. Examples of suitable titanium and/or zirconium based catalysts are described in EP 1254192 which is expressly incorporated herein by reference relative to these catalysts. Typically, the condensation catalyst, if utilized, is present in an amount of from 0.01 to 3% by weight of the total curable composition.

[0064] Component (C) may alternatively include a cationic initiator which can be used when the curable composition includes cycloaliphatic epoxy functionality. Typically, the cationic initiators are suitable for thermal and/or UV cure and may be used when the curable composition includes iodonium or sulfonium salts that will produce a cured network upon heating. In one embodiment, the cationic initiator is used in combination with a radical initiator. This combination

can be cured by UV-visible irradiation when sensitized with suitable UV-visible radical initiators such those described above.

[0065] Referring now to component (D), this component typically includes a cross-linking agent, chain extender, or a combinations thereof. Each of the cross-linking agent and/or chain extender may independently have a linear, partially branched linear, cyclic, or a net-like structure. Component (D) may be included independently of, or in combination with, the catalyst described above. Component (D) may be any known in the art and typically includes a polyorganosiloxane having at least two silicon-bonded hydrogen atoms per molecule. Component (D) may promote a hydrosilylation or addition cure reaction between an Si—H group (typically of the cross-linking agent) and an Si-alkenyl group, e.g. a vinyl group of the diorganopolysiloxane, to form an alkylene group between adjacent silicon atoms ($\text{—Si—CH}_2\text{—CH}_2\text{—Si—}$). Typical examples of component (D) are described in U.S. Pat. Nos. 6,020,409 and 6,169,155, which are hereby expressly incorporated by reference relative to these cross-linking agents.

[0066] In various embodiments, component (D) includes a polyorganosiloxane having at least two silicon-bonded hydrogen atoms per molecule and the following average unit formula:



wherein each R' may be the same or different and may be a hydrogen atom, an alkyl group such as methyl, ethyl, propyl, and isopropyl groups, or an aryl group such as phenyl and tolyl groups, and b is from 0 to 2. Particularly suitable examples of polyorganosiloxanes include, but are not limited to, a trimethylsiloxy-terminated polymethylhydrogensiloxane, a trimethylsiloxy-terminated copolymer of methylhydrogensiloxane and dimethylsiloxane, a dimethylhydrogensiloxy-terminated copolymer of methylhydrogensiloxane and dimethylsiloxane, a cyclic polymer of methylhydrogensiloxane, a cyclic copolymer of methylhydrogensiloxane and dimethylsiloxane, an organopolysiloxane composed of siloxane units expressed by the formula $(\text{CH}_3)_3\text{SiO}_{1/2}$, siloxane units expressed by the formula $(\text{CH}_3)_2\text{HSiO}_{1/2}$, and/or siloxane units expressed by the formula $\text{SiO}_{4/2}$, an organopolysiloxane including siloxane units expressed by the formula $(\text{CH}_3)_2\text{HSiO}_{1/2}$ or siloxane units expressed by the formula $\text{CH}_3\text{SiO}_{3/2}$, an organopolysiloxane including siloxane units expressed by the formula $(\text{CH}_3)_2\text{HSiO}_{1/2}$, siloxane units expressed by the formula $(\text{CH}_3)_2\text{SiO}_{2/2}$, and/or siloxane units expressed by the formula $\text{CH}_3\text{SiO}_{3/2}$, a dimethylhydrogensiloxy-terminated polydimethylsiloxane, a dimethylhydrogensiloxy-terminated copolymer of methylphenylsiloxane and dimethylsiloxane, a dimethylhydrogensiloxy-terminated copolymer of a methyl (3,3,3-trifluoropropyl) siloxane and dimethylsiloxane, a product formed from cyclic silicic hydride cross-linkers as outlined in WO 2003/093349 or WO 2003/093369, each of which are expressly incorporated herein by reference relative to these cross-linkers, and combinations thereof. In one embodiment, component (D) is further defined as a (poly)dialkylhydrogensilyl terminated polymer such as a (poly)dimethylhydrogensilyl terminated polydimethylsiloxane. Typically, this polymer acts as a chain extender.

[0067] In another embodiment, component (D) is selected from the group of silanes, siloxanes, and combinations thereof. Suitable non-limiting examples of silanes and silox-

anes include alkyltrialkoxysilanes such as methyltrimethoxysilane (MTM) and methyltriethoxysilane, alkenyltrialkoxysilanes such as vinyltrimethoxysilane and vinyltriethoxysilane, isobutyltrimethoxysilane (iBTM), ethyltrimethoxysilane, vinyltriethoxysilane, phenyltrimethoxysilane, alkenyl alkyl dialkoxysilanes such as vinyl methyl dimethoxysilane, vinyl ethyldimethoxysilane, vinyl methyl diethoxysilane, vinyl ethyldiethoxysilane, alkenylalkyldioximosilanes such as vinyl methyl dioximosilane, vinyl ethyldioximosilane, vinyl methyl dioximosilane, vinyl ethyldioximosilane, alkoxytrioximosilane, alkenyltrioximosilane, alkenylalkyldiacetoxysilanes such as vinyl methyl diacetoxysilane, vinyl ethyldiacetoxysilane, vinyl methyl diacetoxysilane, vinyl ethyldiacetoxysilane and alkenylalkyldihydroxysilanes such as vinyl methyl dihydroxysilane, vinyl ethyldihydroxysilane, vinyl methyl dihydroxysilane, vinyl ethyldihydroxysilane, methylphenyl-dimethoxysilane, 3,3,3-trifluoropropyltrimethoxysilane, methyltriacetoxysilane, vinyltriacetoxysilane, ethyl triacetoxysilane, di-butoxy diacetoxysilane, phenyl-tripropionoxysilane, methyltris(methyl-ethylketoximo)silane, vinyl-tris-methylethylketoximo)silane, methyltris(methylethylketoximo)silane, methyltris(isopropenoxy)silane, vinyltris(isopropenoxy)silane, ethylpolysilicate, n-propylorthosilicate, ethylorthosilicate, dimethyltetraacetoxysiloxane, alkylalkenylbis(N-alkylacetamido) silanes such as methylvinyl-di-(N-methylacetamido)silane, and methylvinyl-di-(N-ethylacetamido)silane, dialkylbis(N-arylacetamido) silanes such as dimethyl-di-(N-methylacetamido)silane, dimethyl-di-(N-ethylacetamido)silane, alkylalkenylbis(N-arylacetamido) silanes such as methylvinyl-di-(N-phenylacetamido)silane, dialkylbis(N-arylacetamido) silanes such as dimethyl-di-(N-phenylacetamido)silane, and combinations thereof.

[0068] Alternatively, component (D) may have two but typically has three or more silicon-bonded hydrolysable groups per molecule. If component (D) is a silane and has three silicon-bonded hydrolysable groups per molecule, component (D) may also include a non-hydrolysable silicon-bonded organic group. These silicon-bonded organic groups are typically hydrocarbyl groups which are optionally substituted by halogen such as fluorine and chlorine. Examples of suitable groups include, but are not limited to, alkyl groups such as methyl, ethyl, propyl, and butyl groups, cycloalkyl groups such as cyclopentyl and cyclohexyl groups, alkenyl groups such as vinyl and allyl groups, aryl groups such as phenyl and tolyl groups, aralkyl groups such as 2-phenylethyl groups, and halogenated derivatives thereof. Most typically, the non-hydrolysable silicon-bonded organic group is a methyl group.

[0069] In another embodiment, component (D) includes one or more silanes including hydrolysable groups such as acyloxy groups (e.g. acetoxo, octanoyloxy, and benzoyloxy groups), ketoximino groups (e.g. dimethyl ketoximo and isobutylketoximino groups), alkoxy groups (e.g. methoxy, ethoxy, and propoxy groups), alkenyloxy groups (e.g. isopropenyloxy and 1-ethyl-2-methylvinyl groups), and combinations thereof. These siloxanes may be straight chained, branched, or cyclic.

[0070] In one embodiment, component (D) has silicon-bonded hydrogen atoms (Si—H moieties) and the diorganopolysiloxane has alkenyl groups (e.g. vinyl groups) such that a mole ratio of silicon-bonded hydrogen atoms in the cross-linking agent to alkenyl groups in the diorganopolysiloxane is less than 0.9. In another embodiment, component (D) is

added to the curable composition in an amount such that a mole number of silicon-bonded hydrogen atoms in component (D) to a mole number of alkenyl groups in the diorganopolysiloxane (Si-vinyl moieties), for example, is in the range of from 0.1:1.5 to 1:1.5, more typically of from 0.1:1 to 0.8:1, and most typically of from 0.1:1 to 0.6:1. Alternatively, the ratio may be less than 1 or 0.4. If this ratio is too low, the density of cross-linking will be too low and the tie layer (14) will be excessively fluid. Conversely, if this ratio is too high, the tie layer (14) will be excessively viscous. In one embodiment, component (D) is added in an amount such that a mole ratio of silicon-bonded hydrogen atoms in the cross-linking agent to the mole number of alkenyl groups in components (A) and (B) is in the range of from 0.8:1 to 4:1. In this embodiment, there is an excess of Si—H moieties (i.e. the ratio is >1:1) which enhances adhesion between the substrate (12) and the tie layer (14). In another embodiment, the ratio is also >1:1 which enhances adhesion between the tie layer (14) and the second tie layer (18). In a further embodiment, the ratio in the tie layer (14) is <1 while the ratio in the second tie layer (18) is >1 which increases adhesion and allows for efficient encapsulation of the photovoltaic cell (16) between the tie layer (14) and the second tie layer (18).

[0071] As described above, component (D) may be combined with the aforementioned catalyst of component (C). In one embodiment, component (D) includes oximosilanes and/or acetoxysilanes and is combined with a tin catalyst such as diorganotin dicarboxylate, dibutyltin dilaurate, dibutyltin diacetate, dimethyltin bisneodecanoate, and combinations thereof. In another embodiment, component (D) includes alkoxy silanes combined with titanate and/or zirconate catalysts such as tetrabutyl titanate, tetraisopropyl titanate, chelated titanates or zirconates such as diisopropyl bis(acetylacetonate) titanate, diisopropyl bis(ethylacetoacetate) titanate, diisopropoxytitanium bis(ethylacetoacetate), and combinations thereof. Alternatively, component (D) may include one or more silanes or siloxanes which may include silicon bonded hydrolysable groups such as acyloxy groups (for example, acetoxo, octanoyloxy, and benzoyloxy groups), ketoximino groups (for example dimethyl ketoximo and isobutylketoximino groups), alkoxy groups (for example methoxy, ethoxy, and propoxy groups) and alkenyloxy groups (for example isopropenyloxy and 1-ethyl-2-methylvinyl groups). In the case of siloxanes, the molecular structure can be straight chained, branched, or cyclic.

[0072] The curable composition may also include component (E). This component typically includes a highly functional modifier. Suitable modifiers include, but are not limited to, methyl vinyl cyclic organopolysiloxane structures ($(E^{\text{vi}})_x$) and branched structures such as $(M^{\text{vi}}E_x)_4Q$ structures, which are described in EP 1070734 which is expressly incorporated herein by reference relative to these structures. If included, component (E) may be used in amounts determined by those of skill in the art.

[0073] In addition to components (A-E), the curable composition may further include a block copolymer and/or a mixture of a block copolymer and a silicone resin. The block copolymer may be used alone but is typically cured using one of the catalysts described above. The block copolymer may include a thermoplastic elastomer having a “hard” segment (i.e., having a glass transition point $T_g \geq$ the operating temperature of the module (10)) and a “soft” segment (i.e., having a glass transition point $T_g \leq$ the operating temperature of the module (10)). Typically, the soft segment is an organopolysi-

loxane segment. It is contemplated that the block copolymer may be an AB, an ABA, or $(AB)_n$ block copolymer.

[0074] More specifically, these block co-polymers may be prepared from a hard segment polymer prepared from an organic monomer or oligomer or combination of organic monomers and/or oligomers including, but not limited to, styrene, methylmethacrylate, butylacrylate, acrylonitrile, alkenyl monomers, isocyanate monomers and combinations thereof. Typically, the hard segment polymer is combined or reacted with a soft segment polymer prepared from a compound having at least one silicon atom such as an organopolysiloxane polymer. Each of the aforementioned hard and soft segments can be linear or branched polymer networks or combination thereof.

[0075] Preferred block-copolymers for use in the present invention include silicone-urethane and silicone-urea copolymers. Silicone-urethane and silicone-urea copolymers, described in U.S. Pat. Nos. 4,840,796 and 4,686,137, expressly incorporated herein by reference relative to these copolymers, typically form materials with good mechanical properties such as being elastomeric at room temperature. Desired properties of these silicone-urea/urethane copolymers can be optimized by varying a level of polydimethylsiloxane (PDMS), a type of chain extender used, and a type of isocyanate used. If included, the block copolymers are typically present in the curable composition in an amount of from 1 to 100 parts by weight per 100 parts by weight of the curable composition.

[0076] The curable composition may also include a curing inhibitor to improve handling conditions and storage properties. The curing inhibitor may be any known in the art and may include, but is not limited to, methyl-vinyl cyclics, acetylene-type compounds, such as 2-methyl-3-buten-2-ol, 2-phenyl-3-buten-2-ol, 3,5-dimethyl-1-hexyn-3-ol, 1-ethynyl-1-cyclohexanol, 1,5-hexadiene, 1,6-heptadiene, 3,5-dimethyl-1-hexen-1-yne, 3-ethyl-3-buten-1-yne and/or 3-phenyl-3-buten-1-yne, an alkenylsiloxane oligomer such as 1,3-divinyltetramethyldisiloxane, 1,3,5,7-tetravinyltetramethylcyclotetrasiloxane, or 1,3-divinyl-1,3-diphenyldimethyldisiloxane, a silicon compound including an ethynyl group such as methyltris (3-methyl-1-buten-3-oxo) silane, a nitrogen compound such as tributylamine, tetramethylethylenediamine, benzotriazole, a phosphorus compound such as triphenylphosphine, sulphur compounds, hydroperoxy compounds, maleic-acid derivatives thereof, and combinations thereof. Alternatively, the curing inhibitor may be selected from the curing inhibitors disclosed in U.S. Pat. Nos. 6,020, 409 and 6,169,155, expressly incorporated herein by reference relative to the curing inhibitors. If included, the curing inhibitors are and is typically included in an amount of less than 3 parts by weight, more typically of from 0.001 to 3 parts by weight, and most typically of from 0.01 to 1 part by weight, per 100 parts by weight of component (A). In one embodiment, the curing inhibitor is further defined as methylvinylcyclosiloxane having a viscosity of 3 mPa·s. with an average dp of 4, an average number average molecular weight of 344 g/mol, and 31.4 weight percent of Si-Vinyl bonds.

[0077] Each of the components (A-E) may be pre-reacted (or tethered) together, also known in the art as bodying. In one embodiment, silanol functional polymers are tethered to silanol functional resins. This tethering typically involves condensation and re-organization and can be carried out using base or acid catalysis. Tethering can be further refined by the inclusion of reactive or non-reactive organo-silane species.

[0078] Still further, the curable composition may include additives such as fillers, extending fillers, reinforcing particulate fillers, pigments, adhesion promoters, corrosion inhibitors, dyes, diluents, anti-soiling additives, and combinations thereof. Inclusion of such additives may be based on shelf-life, cure kinetics and optical properties of the final tie layer (14) or second tie layer (18). More specifically, the reinforcing particulate fillers may include one or more finely divided reinforcing particulate fillers such as high surface area fumed and precipitated silicas, calcium carbonate, and/or additional extending fillers such as crushed quartz, diatomaceous earths, barium sulphate, iron oxide, titanium dioxide and carbon black, talc, wollastonite, aluminite, calcium sulphate (anhydrite), gypsum, calcium sulphate, magnesium carbonate, clays such as kaolin, aluminum trihydroxide, magnesium hydroxide (brucite), graphite, copper carbonate such as malachite, nickel carbonate such as zarachite, barium carbonate such as witherite, strontium carbonate such as strontianite, aluminum oxide, silicates including, but not limited to, olivine groups, garnet groups, aluminosilicates, ring silicates, chain silicates, and sheet silicates, and combinations thereof. The olivine groups may include, but are not limited to, forsterite, Mg_2SiO_4 , and combinations thereof. Non-limiting examples of the garnet groups may include pyrope, $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$, grossular, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{12}$, and combinations thereof. The aluminosilicates may include, but are not limited to, sillimanite, Al_2SiO_5 , mullite, $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, kyanite, Al_2SiO_5 and combinations thereof. The ring silicates may include, but are not limited to, cordierite, $\text{Al}_3(\text{MgFe})_2[\text{Si}_4\text{AlO}_{18}]$, and combinations thereof. The chain silicates may include, but are not limited to, wollastonite, $\text{Ca}[\text{SiO}_3]$, and combinations thereof. Suitable examples of the sheet silicates that are not limiting may include mica, $\text{K}_2\text{Al}_4[\text{Si}_6\text{Al}_2\text{O}_{20}](\text{OH})_4$, pyrophyllite, $\text{Al}_4[\text{Si}_8\text{O}_{20}](\text{OH})_4$, talc, $\text{Mg}_6[\text{Si}_8\text{O}_{20}](\text{OH})_4$, serpentine, asbestos, Kaolinite, $\text{Al}_4[\text{Si}_4\text{O}_{10}](\text{OH})_8$, vermiculite, and combinations thereof. Low density fillers may also be included to reduce weight and cost per volume. Typically, the fillers are transparent to light and substantially match a refractive index of the silicone. The reinforcing particulate fillers also typically include particles that are smaller than $\frac{1}{4}$ of the wavelength of light to avoid scattering. Thus, reinforcing particulate fillers such as wollastonite, silica, quartz, titanium dioxide, hollow glass spheres and clays, e.g. kaolin, are particularly preferred. In one embodiment, the curable composition is not a gel if it includes reinforcing particulate fillers.

[0079] When included in the curable composition, an amount of filler depends on properties desired in tie layer (14) and/or second tie layer (18). In one embodiment, the filler is typically included in the curable composition in an amount of from 1 to 150 parts by weight per 100 parts by weight of the curable composition. The aforementioned fillers may be surface treated with fatty acids or fatty acid esters to make the fillers easier to handle and obtain a homogeneous mixture with the other components of the curable composition. In one embodiment, the filler is further defined as a quartz filler having an average particle size of 5 μm . In another embodiment, the second tie layer (18) does not need to be transparent to light and includes a reinforcing particulate filler which provides added strength to the second tie layer (18) such that a second substrate is not required in the module (10).

[0080] The curable composition may also include co-catalysts for accelerating curing, optical brighteners, rheological modifiers, adhesion promoters, pigments, heat stabilizers,

flame retardants, UV stabilizers, chain extenders, plasticizers, extenders, fungicides and/or biocides, water scavengers, pre-cured silicone and/or organic rubber particles to improve ductility and maintain low surface tack, and combinations thereof. Each of these components may be included in amounts as determined by one of skill in the art.

[0081] Particularly preferred examples of suitable adhesion promoters may include, but are not limited to, vinyltriethoxysilane, acrylopropyltrimethoxysilane, alkylacrylopropyltrimethoxysilane, allyltriethoxysilane, glycidopropyltrimethoxysilane, allylglycidylether, hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer, a reaction product of hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer with glycidopropyltrimethoxysilane, bis-triethoxysilyl ethylene glycol, hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer, a reaction product of hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer with glycidopropyltrimethoxysilane and bis-triethoxysilyl ethylene glycol, a 0.5:1 to 1:2, and more typically a 1:1 mixture of the hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer and a methacrylopropyltrimethoxysilane, and combinations thereof.

[0082] Suitable examples of the fire retardants include alumina powder or wollastonite as described in WO 00/46817, which is expressly incorporated herein by reference relative to these fire retardants. The fire retardant may be used alone or in combination with other fire retardants or a pigment such as titanium dioxide.

[0083] In one embodiment, the curable composition is substantially free of silicone resins. In another embodiment, the curable composition is substantially free of thermoplastic resins. The terminology "substantially free," as used immediately above, refers to an amount of the silicone resins and/or thermoplastic resins in the curable composition of less than 1,000, more typically of less than 500, and most typically of less than 100, parts by weight per one million parts by weight of the curable composition. In a further embodiment, the curable composition does not have suitable physical properties such that it could be classified as a hot melt composition, i.e., as an optionally curable thermoset product that is inherently high in strength and resistant to flow (i.e. high viscosity) at room temperature.

[0084] The curable composition may be cured by any mechanism known in the art. These mechanisms include, but are not limited to, a hydrosilylation cure, a condensation cure, a radical cure, a heat cure, a UV light cure, and combinations thereof. The curable composition may be completely cured, partially cured, or "pre-cured," as described in greater detail below.

[0085] In one embodiment, the curable composition is cured at a temperature of from 25° C. to 200° C. Alternatively, the curable composition may be cured at a temperature of from 50° C. to 150° C. or at a temperature of approximately 100° C. However, other temperatures may be used, as selected by one of skill in the art. If the curable composition is cured with heat, heating may occur in any suitable oven or the like in either a batch or continuous mode. A continuous mode is most preferred. Additionally, the curable composition may be cured for a time of from 1 to 600 seconds. However, the curable composition may be cured for a longer time, as selected by one of skill in the art depending on application.

[0086] Relative to compositions including silicon atoms that are cured via hydrosilylation mechanisms, and without intending to be bound by any particular theory, it is believed that the depth of penetration and the tack values depend, at least in part, on a ratio of Si:H groups to vinyl groups in the compositions. Relative to all types of compositions (such as those including silicon atoms and those free of silicon atoms), it is also believed that the tack values, and to a lesser extent the depth of penetration, depend, at least in part, on a presence of chain extenders and/or cross-linkers which increase density and complexity of the compositions. Still further, it is believed that the presence of long chain polymers, such as those having a viscosity of 450 mPa·s at 25° C., in the compositions, contributes to the tack values and, to a lesser extent, the depth of penetration.

[0087] It is also contemplated that the curable composition may include silicone-organic compounds, also known as silicone-organic “hybrids.” Suitable, non-limiting examples of silicone-organic “hybrids” are described above and also include organosilicones, organosiloxanes, compounds that have organic backbones and pendant silicon-containing groups, and compounds that have silicone backbones and pendant organic groups.

[0088] Referring back to the tie layer (14), the tie layer (14) is disposed on the substrate (12). In one embodiment, the substrate (12) is in direct contact with the tie layer (14), as shown in FIGS. 2-4 and 6-9. However, the invention is not limited to such an embodiment, i.e., the tie layer (14) may be physically separated from the substrate (12) and remain “disposed on” the substrate (12), as set forth in FIG. 5.

[0089] In one embodiment, the tie layer (14) has a thickness that varies across the substrate (12). The thickness of the tie layer (14) may be varied to minimize an amount of the tie layer that is used, thereby reducing production costs of the module (10), and also to simultaneously minimize or prevent “bottoming out” of electrical leads (28, 30, 32, 34). The electrical leads (28, 30, 32, 34) are described in greater detail below. The terminology “bottoming-out” refers to when the electrical leads (28, 30, 32, 34) contact the substrate (12) or second substrate (20) during compression, such as during a step of compressing the photovoltaic cell (16), the tie layer (14), and the substrate (12) which is also described in greater detail below. This phenomenon is undesirable, and is preferably minimized or eliminated. The tie layer (14) typically may have a varying thickness of from 1 to 30, or alternatively of from 1 to 25, 1 to 20, 3 to 17, 5 to 10, 5 to 25, or 10 to 30, mils. In one embodiment, the tie layer (14) has a varying thickness of from 10 to 15 mils. In another embodiment, the tie layer (14) has a varying thickness of from 10 to 17 mils. In still another embodiment, the tie layer (14) has a varying thickness of from 12 to 15 mils. It is to be understood that the tie layer (14) is not limited to these varying thicknesses. In one embodiment, the tie layer (14) has a varying thickness and is thicker across some portions of the substrate (12) and thinner across other portions. In another embodiment, the tie layer (14) has a thickness of from 1 to 10 mils across some portions of the substrate (12) and has a thickness of from 10 to 30 mils across other portions. In a further embodiment, the tie layer (14) has a thickness of from 5 to 7 mils across some portions of the substrate (12) and a thickness of from 12 to 15 mils across other portions.

[0090] In one embodiment, the tie layer (14) is substantially free of entrapped air (bubbles). The terminology “substantially free of entrapped air” means that the tie layer (14) has no

visible air bubbles. In another embodiment, the tie layer (14) is totally free of entrapped air including both visible and microscopic air bubbles. The second tie layer (18), like the tie layer (14) described immediately above, can also be substantially free or totally free of entrapped air.

[0091] Referring back to the second tie layer (18), the second tie layer (18) can be the same or different from the tie layer (14), as described above. In one embodiment, the module (10) includes the second tie layer (18) but does not include the second substrate (20). In another embodiment, the second tie layer (18) is formed from the curable silicone composition that is hydrosilylation-curable. In this embodiment, the curable silicone composition includes the organosilicon compound having the at least one unsaturated moiety per molecule, the organohydrogensilicon compound having the at least one silicon-bonded hydrogen atom per molecule, and the hydrosilylation catalyst, described above. The curable composition, the organosilicon compound, and/or the organohydrogen silicon compound may be any known in the art.

[0092] When included in the module (10), the second tie layer (18) is typically the same size as the substrate (12) and the photovoltaic cell (16). However, in one embodiment, the second tie layer (18) is smaller than the photovoltaic cell (16). Of course, the instant invention is not limited to these dimensions.

[0093] In addition, the second tie layer (18) typically has a thickness of from 1 to 50, more typically of from 3 to 30, and most typically of from 4 to 15, mils. In various embodiments, the second tie layer (18) has a thickness of from 1 to 30, 1 to 25, 1 to 20, 3 to 17, 5 to 10, 5 to 25, 10 to 15, 10 to 17, 12 to 15, or 10 to 30, mils. In an additional embodiment, the second tie layer (18) has a thickness of about 9 mils. Of course, the invention is not limited to these thicknesses.

[0094] In one embodiment, the second tie layer (18) has high transmission across visible wavelengths, long term stability to UV light and provides long term protection to the photovoltaic cell (16). Thus, in this embodiment, there is no need to dope the substrate (12) with cerium due to the UV stability of the tie layer (14).

[0095] In an alternative embodiment, the second tie layer (18) may be any silicone encapsulant or any organic encapsulant, such as ethyl vinyl acetate (EVA). In another embodiment, the second tie layer (18) is further defined as an EVA film and/or a UV curable urethane. In various other embodiments, the second tie layer (18) is further defined as the silicone encapsulant that is a silicone liquid or gel and/or a hot melt silicone sheet of the type described in the applicant's co-pending application PCT/US06/043073. EVA is a thermoplastic which melts at temperatures above 80° C. However, at temperatures of from about 25° C. to less than about 80° C., the EVA can be a gel or can be gel-like. Organic encapsulants such as EVA can be reformulated to form a gel or be gel-like at any temperature including temperatures above 80° C.

[0096] In addition to the substrate (12) and the tie layer (14) disposed thereon, the module (10) also includes the photovoltaic cell (16) disposed on the tie layer (14). The photovoltaic cell (16) is typically in direct contact with the tie layer (14) but may be spaced apart from the tie layer (14). The photovoltaic cell (16) is also typically sandwiched between the tie layer (14) and the second tie layer (18), as shown in FIGS. 3, 4, 6, 8 and 9. In another embodiment, the photovoltaic cell (16) is sandwiched between the tie layer (14) and the second tie layer (18) in addition to being sandwiched between the substrate (12) and the second substrate (20), as also shown

in FIGS. 4, 6, 8 and 9. The photovoltaic cell (16) typically has a thickness of from 50 to 250, more typically of from 100 to 225, and most typically of from 175 to 225, micrometers. The photovoltaic cell (16) also typically has a length and width of from 100×100 cm to 200×200 cm. In one embodiment, the photovoltaic cell (16) has a length and width of 125 cm each. In another embodiment, the photovoltaic cell (16) has a length and width of 156 cm each. It is to be understood that the instant invention is not limited to these dimensions.

[0097] The photovoltaic cell (16) may include large-area, single-crystal, single layer p-n junction diodes. These photovoltaic cells (16) are typically made using a diffusion process with silicon wafers, also commonly referred to as sliced wafers. Alternatively, the photovoltaic cell (16) may include thin epitaxial deposits of (silicon) semiconductors on lattice-matched wafers. In this embodiment, photovoltaic cells (16) including the thin epitaxial deposits may be classified as either space or terrestrial and typically have AM0 efficiencies of from 7 to 40%. Further, the photovoltaic cell (16) may include quantum well devices such as quantum dots, quantum ropes, and the like, and also include carbon nanotubes. Without intending to be limited by any particular theory, it is believed that these types of photovoltaic cells (16) can have up to a 45% AM0 production efficiency. Still further, the photovoltaic cell (16) may include mixtures of polymers and nano particles that form a single multispectrum layer which can be stacked to make multispectrum photovoltaic cells more efficient and less expensive.

[0098] The photovoltaic cell (16) may include amorphous silicon, monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, nanocrystalline silica, cadmium telluride, copper indium/gallium selenide/sulfide, gallium arsenide, polyphenylene vinylene, copper phthalocyanine, carbon fullerenes, and combinations thereof in ingots, ribbons, thin films, and/or wafers. The photovoltaic cell (16) may also include light absorbing dyes such as ruthenium organometallic dyes. Most typically, the photovoltaic cell (16) includes monocrystalline and polycrystalline silicon.

[0099] The photovoltaic cell (16) also has a first side and a second side. Typically the first side is opposite the second side. However, the first and second sides may be adjacent each other. Typically, one or more of the electrical leads (28, 30, 32, 34) are attached to one or both of the first and second sides to connect a series of modules (10) together and form a photovoltaic array. The electrical leads (28, 30, 32, 34) may be of any size and shape and typically are rectangular-shaped and have dimensions of approximately 0.005 to 0.080 inches in length and/or width. In various embodiments, the electrical leads (28, 30, 32, 34) have a thickness of from 0.005 to 0.015, from 0.005 to 0.010, or from 0.007 to 0.010, inches. The electrical leads (28, 30, 32, 34) may be of any type known in the art and may be disposed on any portion of the module (10).

[0100] Typically, one electrical lead acts as an anode while another electrical lead typically acts as a cathode. As described in greater detail below, the module (10) of this invention may include first, second, third, and fourth electrical leads (28, 30, 32, 34) disposed on the photovoltaic cell (16). These electrical leads (28, 30, 32, 34) may be the same or may be different from each other (i.e., made from the same material or from different materials) and may include metals, conducting polymers, and combinations thereof. In one embodiment, the first, second, third, and fourth electrical leads (28, 30, 32, 34) include tin-silver solder coated copper.

In another embodiment, the first, second, third, and fourth electrical leads (28, 30, 32, 34) include tin-lead solder coated copper.

[0101] In one embodiment, as shown in FIGS. 7-9, the module (10) includes first and second electrical leads (28, 30) spaced apart from each other, disposed on the first side the photovoltaic cell (16), and sandwiched between the photovoltaic cell (16) and the tie layer (14). In this embodiment, the tie layer (14) typically has a thickness of from 1 to 30 mils between the first electrical lead (28) and the substrate (12). Also in this embodiment, the tie layer (14) also typically has a thickness of from 1 to 30 mils between the second electrical lead (30) and the substrate (12). In addition, the tie layer typically has a different thickness across a remainder of the substrate (12), e.g. of from 1 to 30 mils. In various other embodiments, the thicknesses of the tie layers described immediately above are further defined as from 1 to 30, 1 to 25, 1 to 20, 3 to 17, 5 to 10, 5 to 25, 10 to 15, 10 to 17, 12 to 15, or 10 to 30, mils. Typically, the thickness of the tie layers is related to, or a function of, the thickness of the electrical leads.

[0102] In another embodiment, the module (10) includes the second tie layer (18) and the second substrate (20), and the first and second electrical leads (28, 30) are spaced apart from one another and disposed on opposite sides of the photovoltaic cell (16). In addition, the first electrical lead (28) may be sandwiched between the photovoltaic cell (16) and the tie layer (14), the second electrical lead (30) is sandwiched between the photovoltaic cell (16) and the second tie layer (18). In this embodiment, the tie layer (14) has a thickness of from 1 to 30 mils between the first electrical lead (28) and the substrate (12). Also in this embodiment, the second tie layer (18) also has a thickness of from 1 to 30 mils between the second electrical lead (30) and the second substrate (20). In addition, the tie layer (14) and/or the second tie layer (18) typically have different thicknesses across a remainder of the substrate (12) and/or the second substrate (20), respectively, e.g. of from 1 to 30 mils. In various other embodiments, the thicknesses of the tie layers described immediately above are further defined as from 1 to 30, 1 to 25, 1 to 20, 3 to 17, 5 to 10, 5 to 25, 10 to 15, 10 to 17, 12 to 15, or from 10 to 30, mils.

[0103] In yet another embodiment, as shown in FIG. 9, the module (10) includes the second tie layer (18), the second substrate (20), and third and fourth electrical leads (32, 34) each spaced apart from one another and disposed on the second side of the photovoltaic cell opposite the first side. The third and fourth electrical leads (32, 34) may be the same or different from the first and/or second electrical leads (28, 30). In other words, the third and fourth electrical leads (32, 34) may be formed from the same material or from different materials than the first and/or second electrical leads (28, 30). In this embodiment, the third and fourth electrical leads (32, 34) are sandwiched between the photovoltaic cell (16) and the second tie layer (18). The second tie layer (18) typically has a thickness of from 1 to 3 mils between the third electrical lead (32) and the second substrate (20). The second tie layer (18) typically also has a thickness of from 1 to 30 mils between the fourth electrical lead (34) and the second substrate (20). In addition, the second tie layer (18) has a different thickness across a remainder of the second substrate (20). In various embodiments, the thicknesses of the tie layers described immediately above are further defined as from 1 to 30, 1 to 25, 1 to 20, 3 to 17, 5 to 10, 5 to 25, 10 to 15, to 17, 12 to 15, or from 10 to 30, mils. In a further embodiment, the second tie

layer (18) has a thickness at least equal to a thickness of said third and fourth electrical leads (32, 34). In still another embodiment, the module (10) includes the second substrate (20) that is the same or different than the substrate (12), as described above, and the photovoltaic cell (16) is further disposed on the second substrate (20) via chemical vapor deposition or sputtering. Typically, in this embodiment, no second tie layer (18) is required.

[0104] This embodiment is typically referred to as a “thin-film” application. Typically, after the photovoltaic cell (16) is disposed on the second substrate (20) using sputtering or chemical vapor deposition processing techniques, one or more of the electrical leads (28, 30, 32, 34) are attached to the photovoltaic cell (16). The curable composition may then be applied over the electrical leads (28, 30, 32, 34) and cured to form the tie layer (14).

[0105] As described above, the module (10) includes the substrate (12), the tie layer (14), and the photovoltaic cell (16). These may be present in the module (10) in any order. In one embodiment, as shown in FIG. 2, the module (10) includes the following, in order: the substrate (12), the tie layer (14) disposed directly on the substrate (12), and the photovoltaic cell (16) disposed directly on the tie layer (14). In another embodiment, as shown in FIG. 3, the module (10) includes the following, in order: the substrate (12), the tie layer (14) disposed directly on the substrate (12), the photovoltaic cell (16) disposed directly on the tie layer (14), and the second tie layer (18) disposed directly on the photovoltaic cell (16). In a further embodiment, as shown in FIG. 4, the module (10) includes the following, in order: the substrate (12), the tie layer (14) disposed directly on the substrate (12), the photovoltaic cell (16) disposed directly on the tie layer (14), a second tie layer (18) disposed directly on the photovoltaic cell (16), and the second substrate (20) disposed directly on the second tie layer (18).

[0106] In addition, the module (10) may include a protective seal (not shown in the Figures) disposed along each edge of the module (10) to cover the edges. The module (10) may also be partially or totally enclosed within a perimeter frame that typically includes aluminum and/or plastic (also not shown in the Figures).

[0107] The module (10) of the instant invention can be used in any industry. In one embodiment, a series of module (10) are electrically connected and form a photovoltaic array (26), as set forth in FIGS. 6A and 6B. More specifically, in FIG. 6, the photovoltaic array (26) includes a series of modules of the type shown in FIG. 4 that are electrically connected together. The photovoltaic array (26) of the instant invention may be planar or non-planar and typically functions as a single electricity producing unit wherein the modules (10) are interconnected in such a way as to generate voltage.

[0108] The present invention also provides a method of forming the module (10). The method includes the step of disposing the tie layer (14) on the substrate (12). This step may include any suitable application method known in the art. In various embodiments, the tie layer (14) is a liquid or a gel and the liquid or gel is disposed on the substrate (12) using an application method including, but not limited to, spray coating, flow coating, curtain coating, dip coating, extrusion coating, knife coating, screen coating, laminating, melting, pouring, and combinations thereof. In an alternative embodiment, the curable composition is applied to the substrate (12) by one or more of the aforementioned methods and is then cured or pre-cured on the substrate (12) to form the tie layer (14).

Typically, the tie layer (14) is formed from the curable composition and the method further includes the step of partially curing, e.g. “pre-curing,” the curable composition to form the tie layer (14). As set forth herein, the terminology “pre-curing” includes curing the curable composition such that it forms the tie layer (14) having a depth of penetration of from 1.1 to 100 mm and a tack value of less than –0.6 g-sec. It is to be understood that the terminology “pre-curing” can be used interchangeably with “curing” throughout. In another embodiment, the method further includes the steps of applying the curable composition to the photovoltaic cell (16) and curing the curable composition on the photovoltaic cell (16) to form the tie layer (14). In this embodiment, the curable composition is typically cured prior to the step of disposing the tie layer (14) on the substrate (12). In other words, the curable composition may be cured and the tie layer (14) may be formed completely independent from the substrate (12). In this embodiment, the tie layer (14) may be a pre-formed film, sheet, laminate, or the like or may be formed into a film, sheet, laminate or the like. The method may also include the step of curing the curable composition on the substrate (12) prior to the step of disposing the photovoltaic cell (16) on the tie layer (14). As set forth above, the curable composition is typically cured at a temperature of from 25 to 200° C. The curable composition is also typically cured for a time of from 1 to 600 seconds. Alternatively, the curable composition may be cured in a time of greater than 600 seconds, as determined by one of skill in the art.

[0109] In one embodiment, the curable composition is a liquid and the step(s) of applying is further defined as applying a liquid. In another embodiment, the curable composition is supplied to a user as a multi-part system. A first part may include components (A), (B), and/or (D), as described above. A second part may include components (A), (B), and/or (C), as also described above. The first and second parts are typically mixed immediately prior to the step(s) of applying. Alternatively, each component and/or a mixture of components of the curable composition may be applied individually and then react to form the tie layer (14).

[0110] In one embodiment, the method includes the step of applying a base amount of the curable composition on the substrate (12) resulting in a first thickness (T_1) of from 5 to 25 mils across the substrate (12), as set forth in FIGS. 7-9. The method also includes the step of applying a first supplemental amount of the curable composition between the first electrical lead (28) and the substrate (12) resulting in a second thickness (T_2) of from 10 to 30 mils about the first electrical lead (28), as also set forth in FIGS. 7-9. The method further includes the step of applying a second supplemental amount of the curable composition between the second electrical lead (30) and the substrate (12) resulting in a third thickness (T_3) of from 10 to 30 mils about the second electrical lead (30), as further set forth in FIGS. 7-9. Still further, the curable composition is cured after the amounts have been applied to form the tie layer (14). In other words, in this embodiment, the base amount of the curable composition is not cured before the first and second supplemental amounts are applied. In addition, the method includes the step of disposing the photovoltaic cell (16) on the tie layer (14) to form the module (10).

[0111] Typically, the first and/or second supplemental amounts are applied on the first thickness (T_1). However, the first and/or second supplemental amounts may be applied only on one portion of the substrate (12) or, in the alternative, across an entirety of the substrate (12), and may be applied

directly on the substrate as opposed to on the first thickness (T_1). The first thickness (T_1) is typically further defined as from 5 to 7 mils, while the second and/or third thicknesses (T_2 , T_3) are typically each independently be further defined as from 12 to 15 mils.

[0112] The step(s) of applying the first and/or second supplemental amounts of the curable composition may occur sequentially or simultaneously. In one embodiment, the steps of applying the first and second supplemental amounts of the curable composition occur after the step of applying the base amount. Alternatively, the steps of applying the first and second supplemental amounts of the curable composition may occur before the step of applying the base amount.

[0113] The method also includes the step of disposing the photovoltaic cell (16) on the tie layer (14) to form the module (10). Typically, the photovoltaic cell (16) is disposed on the tie layer (14) after the curable composition is cured. However, the invention is not limited to this embodiment. The photovoltaic cell (16) can be disposed (e.g. applied) by any suitable mechanisms known in the art but is typically applied using an applicator in a continuous mode. Other suitable mechanisms of application include applying a force to the photovoltaic cell (16) to more completely contact the photovoltaic cell (16) and the tie layer (14). In one embodiment, the method includes the step of compressing the photovoltaic cell (16) and the tie layer (14). Compressing the photovoltaic cell (16) and the tie layer (14) is believed to maximize contact between the two and maximize encapsulation, if desired. As set forth above, it is to be understood that even if the method includes the step of compressing, the photovoltaic cell (16) and the tie layer (14) do not need to be in direct contact. The step of compressing is typically further defined as applying a vacuum to the photovoltaic cell (16) and the tie layer (14). Alternatively, a mechanical weight, press, or roller (e.g. a pinch roller) may be used for compression. In one embodiment, the step of compressing is further defined as compressing using the cell press described in U.S. Provisional Patent Application No. 61/036,748, which is expressly incorporated herein by reference. The tie layer (14) and/or curable composition may be applied to the substrate (12) and/or to the photovoltaic cell (16) outside of the cell press or within the cell press. Similarly, the curable composition may be cured or pre-cured on or apart from the substrate (12) and/or the photovoltaic cell (16) to form the tie layer (14) either outside of the cell press or within the cell press. Further, the step of compressing may be further defined as laminating. Still further, the method may include the step of applying heat to the module (10) or any or all of the substrate (12), the tie layer (14), the photovoltaic cell (16), the second (18) (or multiple) tie layers, and/or the second substrate (20). Heat may be applied in combination with any other step or may be applied in a discrete step. The entire method may be continuous or batch-wise or may include a combination of continuous and batch-wise steps.

[0114] The step of disposing the photovoltaic cell (16) on the tie layer (14) may be further defined as encapsulating at least part of the photovoltaic cell (16) with the tie layer (14) and/or the second tie layer (18). More specifically, the tie layer (14) and/or second tie layer (18) may partially or totally encapsulate the photovoltaic cell (16). Alternatively, the photovoltaic cell (16) may simply be disposed on the tie layer (14) without any encapsulation. Without intending to be limited by any particular theory, it is believed that at least partial encapsulation encourages more efficient manufacturing and better utilization of the solar spectrum, thereby resulting in greater

efficiency. Use of the tie layer (14) of the instant invention allows for production of a module (10) with the optical and chemical advantages of silicone. Additionally, use of silicone allows for formation of UV transparent tie layers (14) and may increase cell efficiency by at least 1-5%. Use of peroxide catalysts, as described above, may also provide better transparency and increased cure speeds. Sheets of the curable composition including silicone may be used to assemble the module (10).

[0115] In an additional embodiment, the method also includes the step of applying a second base amount of the curable composition across the second substrate (20). Typically, the second base amount of the curable composition has a thickness at least equal to that of the third and fourth electrical leads (32, 34). In various embodiments, the second base amount of the curable composition has a thickness of from 1 to 30, 1 to 25, 1 to 20, 3 to 17, 5 to 10, 5 to 25, 10 to 15, 10 to 17, 12 to 15, or to 30, mils.

[0116] In yet another embodiment of the instant method, the curable composition may be further defined as a film and the step(s) of applying may be further defined as applying the film. In this embodiment, the step of applying the film may be further defined as melting the film. Alternatively, the film may be laminated. In still another embodiment, the method includes the steps of applying the protective seal and/or the frame to the module (10), as first introduced above.

[0117] In an alternative embodiment, the method includes the step of applying the photovoltaic cell (16) to the substrate (12) by chemical vapor deposition or physical sputtering. This step may be performed by any mechanisms known in the art.

[0118] The method may also include the step of applying the second tie layer (18). The second tie layer (18) may be applied to the photovoltaic cell (16), the first tie layer (14), the substrate (12), and/or the second substrate (20). The method may further include the step of applying the second substrate (20). The second substrate (20) may be applied to the photovoltaic cell (16), the first tie layer (14), the substrate (12), and/or the second tie layer (18).

[0119] This invention also provides a method of forming the module (10), wherein the module is commonly known as a "thin-film" module. In this embodiment of the method, the module (10) includes the substrate (12), the tie layer (14) disposed on the substrate (12), the photovoltaic cell (16), the first and second electrical leads (22, 24) each spaced apart from one another, disposed on the first side of the photovoltaic cell (16), and sandwiched between the photovoltaic cell (16) and the tie layer (14), and the second substrate (20) that is the same or different than the substrate (12), as described above. Typically, in this embodiment, no second tie layer (18) is required. This method typically includes the steps of applying the base amount of the curable composition on the substrate (12) resulting in the first thickness of from 5 to 25 mils on the substrate (12) and applying the first supplemental amount of the curable composition between the first electrical lead (22) and the substrate (12) resulting in the second thickness of from 10 to 30 mils about the first electrical lead (22). This method also typically includes the steps of applying the second supplemental amount of the curable composition between the second electrical lead (24) and the substrate (12) resulting in the third thickness of from 10 to 30 mils about the second electrical lead (24) and curing the curable composition after the amounts have been applied to form the tie layer

(12). Still further, this method typically includes the steps of disposing the photovoltaic cell (14) on the second substrate (20) via chemical vapor deposition or physical sputtering and then disposing the photovoltaic cell (16) on the tie layer (12) to form the module (10). In one embodiment, the method also includes the steps of disposing the first and second electrical leads (22, 24) on the first side of the photovoltaic cell (16) after the photovoltaic cell (16) is disposed on the second substrate (20) via chemical vapor deposition or physical sputtering.

EXAMPLES

[0120] Two tie layers (Layers 1 and 2) are formed according to the instant invention. In addition, two comparative tie layers (Comparative Layers 1 and 2) are also formed but not according to the instant invention. During and after formation, each of the Layers 1 and 2 and the Comparative Layers 1 and 2 are evaluated to determine viscosity, Shore 00 durometer hardness, hardness, depth of penetration, and tack value. The formulations used to form Layers 1 and 2 and the Comparative Layers 1 and 2, in addition to the measurements of viscosity, Shore 00 durometer hardness, hardness, depth of penetration, and tack value are set forth in Table 1 below wherein all parts are in parts by weight, unless otherwise indicated.

TABLE 1

	Layer 1	Layer 2	Comparative Layer 1	Comparative Layer 2
Formulation				
Polymer 1	98.98	48.81	35.1	80.49
Polymer 2	—	41.87	—	—
Polymer 3	—	—	—	11.04
Polymer 4	—	4.06	—	7.73
Polymer 5	0.9	0.13	1.44	0.49
Polymer 6	—	5.38	—	—
Cure	0.04	0.01	0.19	0.17
Inhibitor	—	—	—	—
Catalyst 1	0.08	—	0.09	—
Catalyst 2	—	0.14	—	0.08
Filler	—	—	55.38	—
Pigment	—	—	7.57	—
Adhesion	—	—	0.23	—
Promoter	—	—	—	—
Total Weight percent	100.00	100.00	100.00	100.00
SiH:SiVi Ratio	0.39	0.87	1.12	0.94
Pt Concentration (ppm)	4.7	12.5	5.4	6.6
Viscosity (mPa · s)	403	296	3750	392
Shore 00 Durometer Hardness	0	0	75	58
Hardness (grams of force)	11.5	72.4	6066	501
Depth of Penetration (mm)	46.5	7.4	0.09	1.07
Elastic Modulus G' at Cure (dynes/cm ²)	7.75×10^3	4.6×10^4	4.5×10^6	6.9×10^5

TABLE 1-continued

	Layer 1	Layer 2	Comparative Layer 1	Comparative Layer 2
Tack Value				
Area F-T 3:4 (g.sec)	-27.4	-27.8	0	-0.56
Time 1 (sec)	67.0	64.90	0	65.74
Time 2 (sec)	73.0	66.78	0	65.98
Time 2 - 1 (sec)	6.0	1.88	0	0.24

[0121] Polymer 1 is a vinyl dimethylsilyl end-blocked polydimethylsiloxane having a viscosity of 450 mPa·s at 25° C. and including 0.46 weight percent Si-Vinyl bonds.

[0122] Polymer 2 is a trimethylsilyl terminated polydimethylsiloxane that has a viscosity of 100 mPa·s and that is commercially available from Dow Corning Corporation of Midland, Mich.

[0123] Polymer 3 is a polymer/filler blend of 80% by weight of Polymer 1 and 20% by weight of (CH₃)₃SiO_{3/2} treated fumed silica, has a viscosity of 120,000 mPa·s and has 0.37 weight percent of Si-Vinyl bonds.

[0124] Polymer 4 is a dimethylhydrogensilyl terminated polydimethylsiloxane that has a viscosity of 10 mPa·s and 0.16 weight percent of Si—H bonds.

[0125] Polymer 5 is a trimethylsilyl terminated polydimethylsiloxane-methylhydrogensiloxane co-polymer having a viscosity of 5 mPa·s and including 0.76 weight percent of Si—H bonds.

[0126] Polymer 6 is a vinyl dimethylsilyl endblocked polydimethylsiloxane having a viscosity of 55,000 mPa·s. and including 0.09 weight percent of Si-Vinyl bonds.

[0127] Cure Inhibitor is methylvinylcyclosiloxane having a viscosity of 3 mPa·s. with an average dp of 4, an average number average molecular weight of 344 g/mol, and 31.4 weight percent of Si-Vinyl bonds.

[0128] Catalysts 1 and 2 are platinum catalysts including platinum complexes of 1,3-diethenyl-1,1,3,3-tetramethyldisiloxane.

[0129] Filler is a quartz filler having an average particle size of 5 μm.

[0130] Pigment is a blend of 82 weight percent of Polymer 1, 12 weight percent of ZnO powder, and 6 weight percent of carbon black powder, has a viscosity of 20,000 mPa·s., and has 0.38 weight percent of Si-Vinyl bonds.

[0131] Adhesion Promoter is a reaction product of trimethylsilyl- and dimethylvinylsilyl-treated silica and an organofunctional silane and has a viscosity of 25 mPa·s.

[0132] The viscosity measurements of the Layers 1 and 2 and the Comparative Layers 1 and 2 are taken using a Brookfield DVIII Cone and Plate Viscometer at 25° C. according to ASTM D4287. More specifically, a 0.5 g sample of each of the Layers is tested using a CPE 51 spindle and a speed of the spindle is varied to keep torque in the required range.

[0133] Durometer hardness measurements are taken by placing 12 g of each of the Layers in a 44 ml aluminum weigh dish and curing each of the Layers 100° C. for 10 minutes, according to ASTM D2240. 1 inch (2.54 cm) diameter circular discs are then punched out from each of the cured layers and analyzed using a Shore 00 Durometer.

[0134] Hardness measurements are taken using a TA-XT2 Texture Analyzer commercially available from Stable Micro Systems using a 0.5 inch (1.27 cm) diameter steel probe. Test samples of 12 g of each of the uncured layers are cured in a 2 ounce (oz) glass vial at 100° C. for 10 minutes. Samples are analyzed using the following Texture Analyzer test method: 2 mm/s pre-test and post-test probe speed; 1 mm/s test probe speed; 4 mm target distance; 60 sec hold; and a 5 g Force trigger value. The maximum grams force hardness is determined at a 4 mm distance.

[0135] Depth of Penetration measurements are calculated using the hardness measurements (grams of force) obtained using the TA-XT2 Texture Analyzer and the following equation: Depth of Penetration (mm×10)=5,350/grams force. This relationship is determined using a universal penetrometer, commercially available from Precision Scientific of Chicago, Ill., and by measuring hardness with the texture analyzer of each Layer. There are seventy nine sample measurements taken for each layer. The 5,350 constant is determined by multiplying the depth of penetration by the grams of force from the texture analyzer for each of the seventy nine samples and then averaging the results.

[0136] Tack values are determined using a Stable Micro Systems TA XT2 Texture Analyzer. A 0.5 inch diameter stainless steel probe is inserted into 12 gram samples of each of the Layers to a depth of 4 mm and then withdrawn at a rate of 2 mm/s. The tack values are determined as a total area under a Force-Time curve during probe separation from the Layers. The results in Force-Time are expressed in gram-sec. wherein the time is measured as a time difference between a time when the force is equal to zero and a time when the probe separates from the layers.

[0137] After formation, both of the Layers 1 and 2 are used to assemble modules (Modules 1-6) of the instant invention. The Comparative Layers 1 and 2 are used to form Comparative Modules 1 and 2 but not via the method of the instant invention. The terminology “front contact” and “back contact” are well known in the art and refer to a side of the photovoltaic cell (16) upon which one of the Layers 1 and 2 or Comparative Layers 1 and 2 are disposed.

Module 1:

[0138] Module 1 includes a Substrate (12) including glass; 15 mils of Layer 1 disposed on the Substrate (12), and a “front contact” polycrystalline Photovoltaic Cell (16) disposed on Layer 1.

Module 2:

[0139] Module 2 includes a Substrate (12) including glass; 15 mils of Layer 1 disposed on the Substrate (12), and a “front contact” monocrystalline Photovoltaic Cell (16) disposed on Layer 1.

Module 3:

[0140] Module 3 includes a Substrate (12) including glass; 10 mils of Layer 1 disposed on the Substrate (12), and a “back contact” monocrystalline Photovoltaic Cell (16) disposed on Layer 1.

Module 4:

[0141] Module 4 includes a Substrate (12) including glass; 15 mils of Layer 2 disposed on the Substrate (12), and a “front contact” polycrystalline Photovoltaic Cell (16) disposed on Layer 1.

Module 5:

[0142] Module 5 includes a Substrate (12) including glass; 15 mils of Layer 2 disposed on the Substrate (12), and a “front contact” monocrystalline Photovoltaic Cell (16) disposed on Layer 1.

Module 6:

[0143] Module 6 includes a Substrate (12) including glass; 10 mils of Layer 2 disposed on the Substrate (12), and a “back contact” monocrystalline Photovoltaic Cell (16) disposed on Layer 1.

Comparative Module 1:

[0144] Comparative Module 1 includes a Substrate (12) including glass; 15 mils of Comparative Layer 1 disposed on the Substrate (12), and a “front contact” monocrystalline Photovoltaic Cell (16) disposed on Layer 1.

Comparative Module 2:

[0145] Comparative Module 2 includes a Substrate (12) including glass; 15 mils of Comparative Layer 2 disposed on the Substrate (12), and a “front contact” monocrystalline Photovoltaic Cell (16) disposed on Layer 1.

[0146] After formation, each of the Modules 1-6 and the Comparative Modules 1 and 2 are evaluated to determine an amount of air entrapped in the Layers 1 or 2 or the Comparative Layers 1 or 2, respectively. The Modules are also evaluated to determine Adhesion of the Substrate (12), the Layers, and the Photovoltaic Cells (16). Both of these determinations are set forth in Table 2 below and both are based on visual evaluations.

TABLE 2

	Mod. 1	Mod. 2	Mod. 3	Mod. 4	Mod. 5	Mod. 6	Comp. Mod. 1	Comp. Mod. 2
Amount of Trapped Air	0	0	0	0	0	0	Visible	Visible
Adhesion	Yes	Yes	Yes	Yes	Yes	Yes	No	No

[0147] In addition, both of the Layers 1 and 2 are used to assemble additional modules (Modules 7 and 8) according to the method of this invention. Further, Comparative Modules 3 and 4 are formed using the Comparative Layers 1 and 2.

Module 7:

[0148] Module 7 includes a Substrate (12) including glass, Layer 1 disposed on the substrate, a monocrystalline Photovoltaic Cell (16), and First and Second Electrical Leads (28, 30) each spaced apart from one another, disposed on a first side of the Photovoltaic Cell (16) and sandwiched between the Photovoltaic Cell (16) and Layer 1. More specifically, Module 7 includes 5-10 mils of Layer 1 formed from the composition described above and disposed across the Substrate (12), 10 to 17 mils of Layer 1 between the First Electrical Lead (28) and the Substrate (12) resulting in a thickness of from 10 to 17 mils of Layer 1 about the First Electrical Lead (28) and 10 to 17 mils of Layer 1 between the Second Electrical Lead (30) and the Substrate (12) resulting in a thickness of from 10 to 17 mils of Layer 1 about the Second Electrical Lead (30).

Module 8:

[0149] Module 8 includes a Substrate (12) including glass, Layer 2 disposed on the substrate, a monocrystalline Photovoltaic Cell (16), and First and Second Electrical Leads (28, 30) each spaced apart from one another, disposed on a first side of the Photovoltaic Cell (16) and sandwiched between the Photovoltaic Cell (16) and Layer 2. More specifically, Module 8 includes 5-10 mils of Layer 2 formed from the composition described above and disposed across the Substrate (12), 10 to 17 mils of Layer 2 between the First Electrical Lead (28) and the Substrate (12) resulting in a thickness of from 10 to 17 mils of Layer 2 about the First Electrical Lead (28) and 10 to 17 mils of Layer 2 between the Second Electrical Lead (30) and the Substrate (12) resulting in a thickness of from 10 to 17 mils of Layer 2 about the Second Electrical Lead (30).

Comparative Module 3:

[0150] Comparative Module 3 includes a Substrate (12) including glass; 15 mils of Comparative Layer 1 disposed across an entirety of Substrate (12), a monocrystalline Photovoltaic Cell (16) disposed on Layer 1, and first and second electrical leads (22, 24) disposed on the photovoltaic cell (16).

Comparative Module 4:

[0151] Comparative Module 4 includes a Substrate (12) including glass; 15 mils of Comparative Layer 2 disposed across an entirety of Substrate (12), a monocrystalline Photovoltaic Cell (16) disposed on Layer 1, and first and second electrical leads (22, 24) disposed on the photovoltaic cell (16).

[0152] After formation, each of the Modules 7 and 8 and the Comparative Modules 3 and 4 are also evaluated to determine an amount of air entrapped in the Layers 1 and 2 and Comparative Layers 1 and 2 and evaluated to determine Adhesion of the Substrate (12), the Layers, and the Photovoltaic Cells (16) and whether the Photovoltaic Cell (16) is securely disposed within the Modules. These determinations are set forth in Table 3 below and are based on visual evaluations.

TABLE 3

	Module 7	Module 8	Comparative Module 3	Comparative Module 4
Amount of Trapped Air	0	0	Visible	Visible
Adhesion	Yes	Yes	No	No
Photovoltaic Cell Securely Disposed Within Module	Yes	Yes	No	No

[0153] As shown above in Tables 2 and 3 above, the Modules 1-8 of the instant invention do not include visible air bubbles trapped in the Layers. This increases adhesion and overall stability of the Modules, provides better aesthetic performance, reduces potential erosion due to condensation, and prevents degradation of efficiency due to light reflection off of air bubbles. The Modules of the instant invention also exhibit adhesion, i.e., structural stability, between the Substrate (12), the Layers, and the Photovoltaic Cell (16). Conversely, the Comparative Modules 1-4 do not exhibit adequate adhesion to form a unified and functioning module. Without intending to be limited by any particular theory, it is believed that this is due to the presence of the air bubbles and the inability of the Comparative Layers 1 and 2 to adequately “wet” the Substrates (12) and bond the Substrates (12) to the Photovoltaic Cells (16).

[0154] In addition, the Modules of the instant invention allow the Photovoltaic Cell to be securely disposed therein, while the Comparative Modules 1 and 2 do not. The determination of whether the Photovoltaic Cells are securely disposed within the Modules is determined visually on a “pass/fail” basis. Without intending to be limited by any particular theory, it is believed that the poor adhesion and the lack security of the Photovoltaic Cells in the modules is due to the presence of the air bubbles and the inability of the Comparative Layers 1 and 2 to adequately “wet” the Substrates (12) and bond the Substrates (12) to the Photovoltaic Cells (16).

[0155] Further, the minimized amount of the Layers 1 and 2 used in the Modules 7 and 8 and the strategic deposition of the Layers 1 and 2 around the first and second electrical leads, not only provide superior Modules but also allow the Modules to be produced faster and with less cost than the Comparative Modules 1-4 which are formed using excess amounts of the Comparative Layers 1 and 2. In addition, the strategic deposition of the Layers 1 and 2 around the first and second electrical leads allows the Modules to be formed with minimized deformation of the photovoltaic cell and without cracking the photovoltaic cell upon compression.

[0156] The invention has been described in an illustrative manner, and it is to be understood that the terminology which has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations of the present invention are possible in light of the above teachings, and the invention may be practiced otherwise than as specifically described.

1. A photovoltaic cell module comprising:

- a substrate;
- a tie layer disposed on said substrate having a depth of penetration of from 1.1 to 100 mm and a tack value of less than -0.6 g/sec; and
- a photovoltaic cell disposed on said tie layer.

2. A photovoltaic cell as set forth in claim 1 wherein said tie layer has a thickness that varies across said substrate from 1 to 25 mils or from 5 to 25 mils.

3. (canceled)

4. (canceled)

5. A photovoltaic cell module as set forth in claim 1 further comprising first and second electrical leads each spaced apart from one another, disposed on a first side of said photovoltaic cell, and sandwiched between said photovoltaic cell and said tie layer and wherein said tie layer has a thickness of from 10 to 30 mils between said first electrical lead and said substrate, a thickness of from 10 to 30 mils between said second electrical lead and said substrate, and a thickness of from 5 to 25 mils across a remainder of said substrate.

6. A photovoltaic cell module as set forth in claim 5 wherein said thickness across the remainder of said substrate is further defined as from 5 to 7 mils and/or said thicknesses between said first and second electrical leads and said substrate are each independently further defined as from 12 to 15 mils.

7. (canceled)

8. A photovoltaic cell module as set forth in claim 1 further comprising a second tie layer that is the same or different than said tie layer and that is disposed on said photovoltaic cell.

9. (canceled)

10. A photovoltaic cell module as set forth in claim 1 wherein said cell module further comprises third and fourth electrical leads each spaced apart from one another and disposed on a second side of said photovoltaic cell opposite said first side, wherein said third and fourth electrical leads are sandwiched between said photovoltaic cell and said second tie layer and wherein said second tie layer has a thickness of from 5 to 25 mils.

11. (canceled)

12. (canceled)

13. A photovoltaic cell module as set forth in claim 5 wherein said cell module further comprises a second substrate that is the same or different than said substrate, and the photovoltaic cell is further disposed on the second substrate via chemical vapor deposition or physical sputtering.

14. (canceled)

15. (canceled)

16. (canceled)

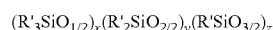
17. A photovoltaic cell module as set forth in claim 16 wherein said curable composition comprises carbon atoms and is substantially free of compounds including silicon atoms.

18. (canceled)

19. (canceled)

20. A photovoltaic cell module as set forth in claim 1 wherein said tie layer is formed from a curable composition and said curable composition comprises a cross-linking agent having silicon-bonded hydrogen atoms and a diorganopolysiloxane having alkenyl groups and a mole ratio of silicon-bonded hydrogen atoms in said cross-linking agent to alkenyl groups in said diorganopolysiloxane is less than 0.9.

21. A photovoltaic cell module as set forth in claim 15 wherein said tie layer is formed from a curable composition and said curable composition comprises a diorganopolysiloxane having the average unit formula:



wherein x and y are positive numbers, z is greater than or equal to zero, and each R' is independently a monovalent radical.

22. A photovoltaic cell module as set forth in claim 1 wherein said tie layer is formed from a curable composition and said curable composition comprises at least one of an ethylene-vinyl acetate copolymer, a polyurethane, an ethylene tetrafluoroethylene, a polyvinylfluoride, a polyethylene terephthalate, and combinations thereof.

23. A photovoltaic cell module as set forth in claim 1 wherein said tie layer is further defined as a film.

24. (canceled)

25. (canceled)

26. A method of forming a photovoltaic cell module comprising a substrate, a tie layer formed from a curable composition, and a photovoltaic cell, said method comprising the steps of:

A. disposing, on the substrate, the tie layer having a depth of penetration of from 1.1 to 100 mm and a tack value of less than -0.6 g-sec; and

B. disposing the photovoltaic cell on the tie layer to form the photovoltaic cell module.

27. (canceled)

28. A method as set forth in claim 26 wherein the photovoltaic cell module further comprises first and second electrical leads each spaced apart from one another, disposed on a first side of the photovoltaic cell, and sandwiched between the photovoltaic cell and the tie layer and wherein the step of disposing the tie layer is further defined as:

A. applying a base amount of the curable composition on the substrate resulting in a first thickness of from 5 to 25 mils on the substrate;

B. applying a first supplemental amount of the curable composition between the first electrical lead and the substrate resulting in a second thickness of from 10 to 30 mils about the first electrical lead;

C. applying a second supplemental amount of the curable composition between the second electrical lead and the substrate resulting in a third thickness of from 10 to 30 mils about the second electrical lead; and

D. curing the curable composition after the amounts have been applied to form the tie layer.

29. A method as set forth in claim 28 wherein the first thickness is further defined as across an entirety of the substrate, the step of applying the first supplemental amount is further defined as applying the first supplemental amount on the first thickness, and the step of applying the second supplemental amount is further defined as applying the second supplemental amount on the first thickness.

30. A method as set forth in claim 29 wherein the first thickness is further defined as from 5 to 7 mils.

31. A method as set forth in claim 30 wherein the second and third thicknesses are each independently further defined as from 12 to 15 mils.

32. A method as set forth in claim 28 wherein said steps of applying the first and second supplemental amounts of the curable composition occur sequentially.

33. A method as set forth in claim 28 wherein said steps of applying the first and second supplemental amounts of the curable composition occur simultaneously.

34. A method as set forth in claim 28 wherein said steps of applying the first and second supplemental amounts of the curable composition occur after the step of applying the base amount of the curable composition.

35. A method as set forth in claim **28** wherein said steps of applying the first and second supplemental amounts of the curable composition occur before the step of applying the base amount of the curable composition.

36. A method as set forth in claim **28** wherein the cell module further comprises a second tie layer that is the same or different than the tie layer and that is disposed on the photovoltaic cell, a second substrate disposed on the second tie layer, and third and fourth electrical leads each spaced apart from one another and disposed on a second side of the photovoltaic cell opposite the first side, wherein the third and fourth electrical leads are sandwiched between the photovoltaic cell and the second tie layer, and wherein the method further comprises the step of applying a second base amount of the curable composition across the second substrate wherein the second base amount of the curable composition has a thickness of from 5 to 25 mils.

37. (canceled)

38. A method as set forth in claim **36** wherein the second base amount of the curable composition has a thickness of from 5 to 25 mils.

39. (canceled)

40. (canceled)

41. A method as set forth in claim **26** wherein the step of disposing the tie layer on the substrate is further defined as disposing the curable composition on the substrate and curing the curable composition on the substrate to form the tie layer.

42. (canceled)

43. A method as set forth in claim **26** wherein the method further comprises the step of curing the curable composition to form the tie layer prior to the step of disposing the tie layer on the substrate.

44. A method as set forth in claim **26** wherein the method further comprises the steps of applying the curable composition to the photovoltaic cell and curing the curable composition on the photovoltaic cell to form the tie layer prior to the step of disposing the tie layer on the substrate.

45. A method as set forth in claim **26** wherein the tie layer is further defined as a film and the step of disposing the tie layer is further defined as melting the film on the substrate.

46. (canceled)

47. A method as set forth in claim **41** further comprising the step of applying the photovoltaic cell to the substrate by chemical vapor deposition or physical sputtering.

48. (canceled)

49. (canceled)

50. (canceled)

51. (canceled)

52. A method as set forth in claim **26** wherein the curable composition comprises a cross-linking agent having silicon-bonded hydrogen atoms and a diorganopolysiloxane having alkenyl groups and a mole ratio of silicon-bonded hydrogen atoms in the cross-linking agent to alkenyl groups in the diorganopolysiloxane is less than 0.9.

53. (canceled)

54. A method as set forth in claim **26** wherein the curable composition comprises carbon atoms and is substantially free of compounds including silicon atoms.

55. (canceled)

56. (canceled)

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