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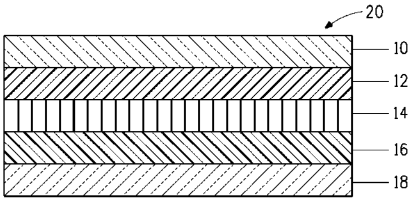
(54) **Title**: SOLAR CELL MODULES COMPRISING AN ENCAPSULANT SHEET OF AN ETHYLENE COPOLYMER

FIG. 1



(57) **Abstract**: Disclosed is a solar cell module comprising a polymeric encapsulant sheet, wherein the polymeric encapsulant sheet comprises an ethylene copolymer composition, wherein the ethylene copolymer comprises copolymerized units of ethylene and about 5 to about 20 wt % of an ester of a C_4-C_8 unsaturated acid having two carboxylic acid groups.

SOLAR CELL MODULES COMPRISING AN ENCAPSULANT SHEET OF AN ETHYLENE COPOLYMER

FIELD OF THE INVENTION

The present invention is directed to solar cell modules comprising a polymeric encapsulant sheet formed of an ethylene copolymer.

BACKGROUND OF THE INVENTION

Because they provide a sustainable energy resource, the use of solar cells is rapidly expanding. Solar cells can typically be categorized into two types based on the light absorbing material used, i.e., bulk or wafer-based solar cells and thin film solar cells.

Monocrystalline silicon (c-Si), poly- or multi-crystalline silicon (poly-Si or mc-Si) and ribbon silicon are the materials used most commonly in forming the more traditional wafer-based solar cells. Solar cell modules derived from wafer-based solar cells often comprise a series of self-supporting wafers (or cells) that are soldered together. The wafers generally have a thickness of between about 180 and about 240 µm. Such a panel of solar cells is called a solar cell layer and it may further comprise electrical wirings such as cross ribbons connecting the individual cell units and bus bars having one end connected to the cells and the other exiting the module. The solar cell layer is then further laminated to encapsulant layer(s) and protective layer(s) to form a weather resistant module that may be used for at least 20 years. In general, a solar cell module derived from wafer-based solar cell(s) comprises, in order of position from the front sun-facing side to the back non-sun-facing side: (1) an incident layer (or front sheet), (2) a front encapsulant layer, (3) a solar cell layer, (4) a back encapsulant layer, and (5) a backing layer (or backsheet). In such modules, it is essential that the materials positioned to the sun-facing side of the solar cell layer (i.e., the incident layer and the front encapsulant layer) have good transparency to allow sufficient sunlight to reach the solar cells. In addition, some modules may comprise bi-facial solar cells, where the solar cells are able to generate electrical power by receiving sunlight directly reaching the sun-facing side thereof and by receiving sunlight is are reflected back to the non-sun-facing side thereof. In such modules it is essential that all the materials surrounding the solar cells layer be sufficiently transparent.

The increasingly important alternative thin film solar cells are commonly formed from materials that include amorphous silicon (a-Si), microcrystalline silicon (μc-Si), cadmium telluride (CdTe), copper indium selenide ($CuInSe_2$ or CIS), copper indium/gallium diselenide ($CuIn_xGa_{(1-x)}Se_2$ or CIGS), light absorbing dyes, and organic semiconductors. By way of example, thin film solar cells are disclosed in e.g., U.S. Patent Nos. 5,507,881; 5,512,107; 5,948,176; 5,994,163; 6,040,521; 6,137,048; and 6,258,620 and U.S. Patent Publication Nos. 2007/0298590; 2007/0281090; 2007/0240759; 2007/0232057; 2007/0238285; 2007/0227578; 2007/0209699; and 2007/0079866. Thin film solar cells with a typical thickness of less than 2 μm are produced by depositing the semiconductor layers onto a superstrate or substrate formed of glass or a flexible film. During manufacture, it is common to include a laser scribing sequence that enables the adjacent cells to be directly interconnected in series, with no need for further solder connections between cells. As with wafer cells, the solar cell layer may further comprise electrical wirings such as cross ribbons and bus bars. Similarly, the thin film solar cells are further laminated to other encapsulant and protective layers to produce a weather resistant and environmentally robust module. Depending on the sequence in which the multi-layer deposition is carried out, the thin film solar cells may be deposited on a superstrate that ultimately serves as the incident layer in the final module, or the cells may be deposited on a substrate that ends up serving as the backing layer in the final module. Therefore, a solar cell module derived from thin film solar cells may have one of two types of construction. The first type includes, in order of position from the front sun-facing side to the back non-sun-facing side, (1) a solar cell layer comprising a superstrate and a layer of thin film solar cell(s) deposited thereon at the non-sun-facing side, (2) a (back) encapsulant layer, and (3) a backing layer. The second type may include, in order of position from the front sun-facing side to the back non-sun-facing side, (1) an incident layer, (2) a (front) encapsulant layer, (3) a solar cell layer comprising a layer of thin film solar cell(s) deposited on a substrate at the sun-facing side thereof.

The encapsulant layers used in solar cell modules are designed to encapsulate and protect the fragile solar cells. Suitable polymer materials for solar cell encapsulant layers typically possess a combination of characteristics such as high impact resistance, high penetration resistance, good ultraviolet (UV) light resistance, good long term thermal stability, adequate adhesion strength to glass and other rigid polymeric sheets, high moisture resistance, and good long term weatherability. Currently, ethylene/vinyl acetate copolymers remain the most widely used encapsulant material in the industry.

When solar cell modules are used in the field, it is found that if the encapsulant sheet and its adjacent layer(s) are not tightly sealed, moisture tends to enter the modules and cause de-lamination. There is still a need to develop an encapsulant material having superior adhesion to its adjacent layer(s) and therefore improve the weatherability of the solar cell module. This is especially true in the thin film solar cell industry where the provision of extra edge seals around the peripheral edges of the modules introduces cost and process concerns.

SUMMARY OF THE INVENTION

Disclosed herein is a solar cell module comprising a solar cell layer and a sheet comprising at least one layer of an ethylene copolymer composition, wherein (A) the solar cell layer comprises a single solar cell or a plurality of electrically interconnected solar cells; and (B) the ethylene copolymer composition comprises an ethylene copolymer comprising copolymerized units of ethylene and about 5 to about 20 wt%, or about 6 to about 15 wt%, of an ester of a C_4-C_8 unsaturated acid having two carboxylic acid groups, based on the total weight of the ethylene copolymer. The ester of the C_4-C_8 unsaturated acid having two carboxylic acid groups may be selected from the group consisting of monoesters of C_4-C_8 unsaturated acids having two carboxylic acid groups, diesters of C_4-C_8 unsaturated acids having two carboxylic acid groups, and mixtures of any two or more thereof.

In one embodiment, the sheet comprising the ethylene copolymer composition is in the form of a monolayer that consists essentially of the ethylene copolymer composition or in the form of a multilayer sheet and has two or more sub-layers, wherein at least one of the sub-layers consists essentially of the ethylene composition and each of the other sub-layers present in the multilayer sheet comprises at least one polymer selected from the group consisting of acid copolymers, ionomers of acid copolymers, ethylene/vinyl acetate copolymers, poly(vinyl acetals), polyurethanes, polyvinylchlorides, polyethylenes, polyolefin block copolymer elastomers, copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, silicone elastomers, epoxy resins, and combinations of two or more thereof.

In a further embodiment, the solar cell layer has front sun-facing side and a back non-sun-facing side. In such an embodiment, the solar cell module may comprise a front encapsulant layer laminated to the front sun-facing side of the solar cell layer and a back encapsulant layer laminated to the back non-sun-facing side of the solar cell layer, wherein one of the front and back encapsulant layers is the sheet comprising the blend composition and the other of the front and back encapsulant layers comprises a polymeric material selected from the group consisting of copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, ionomers of copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, ethylene/vinyl acetate copolymers, poly(vinyl acetals), polyurethanes, polyvinylchlorides, polyethylenes, polyolefin block copolymer elastomers, copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, silicone elastomers, epoxy resins, and combinations thereof. Further the solar cell module may further comprise an incident layer, wherein the incident layer is an outermost surface layer of the module and is positioned on the front sun-facing side of the solar cell layer, and wherein the incident layer is selected from the group consisting of (i) glass sheets, (ii) polymeric sheets comprising a polymer selected from the group consisting of polycarbonates, acrylics, polyacrylates, cyclic polyolefins, polystyrenes, polyamides, polyesters, fluoropolymers, and combinations of two or more thereof, and (iii) polymeric films comprising a polymer selected from the group consisting of polyesters, polycarbonate, polyolefins, norbornene polymers, polystyrene, styrene-acrylate copolymers, acrylonitrile-styrene copolymers, polysulfones, nylons, polyurethanes, acrylics, cellulose acetates, cellophane, poly(vinyl chlorides), fluoropolymers, and combinations of two or more thereof. Yet further, the solar cell module may further comprise a backing layer, wherein the backing layer is an outermost surface layer of the module and is positioned on the back non-sun-facing side of the solar cell layer, and wherein the backing layer is selected from the group consisting of (i) glass sheets, (ii) polymeric sheets,

(iii) polymeric films, (iv) metal sheets, and (v) ceramic plates, and wherein the polymeric sheets comprise a polymer selected from the group consisting of polycarbonates, acrylics, polyacrylates, cyclic polyolefins, polystyrenes, polyamides, polyesters, fluoropolymers, and combinations or two or more thereof; and the polymeric films comprise a polymer selected from the group consisting of polyesters, polycarbonates, polyolefins, norbornene polymers, polystyrenes, styrene-acrylate copolymers, acrylonitrile-styrene copolymers, polysulfones, nylons, polyurethanes, acrylics, cellulose acetates, cellophanes, poly(vinyl chlorides), fluoropolymers, and combinations of two or more thereof.

In a yet further embodiment, the solar cells may be wafer-based solar cells selected from the group consisting of crystalline silicon (c-Si) and multi-crystalline silicone (mc-Si) based solar cells and the solar cell module may consist essentially of, in order of position, (i) an incident layer, (ii) front encapsulant layer laminated to the front sun-facing side of the solar cell layer, (iii) the solar cell layer, (iv) a back encapsulant layer laminated to the back non-sun-facing side of the solar cell layer, and (v) a backing layer, wherein one or both of the front and back encapsulant layers comprise the ethylene copolymer composition.

In a yet further embodiment, the solar cells may be thin film solar cells selected from the group consisting of amorphous silicon (a-Si), microcrystalline silicon (μc-Si), cadmium telluride (CdTe), copper indium selenide (CIS), copper indium/gallium diselenide (CIGS), light absorbing dyes, and organic semiconductor based solar cells, and the solar cell module may (a) in one embodiment, consist essentially of, in order of position, (i) an incident layer, (ii) a front encapsulant layer comprising the sheet comprising the ethylene copolymer composition, and (iii) the solar cell layer, wherein the solar cell layer further comprises a substrate upon which the thin film solar cells are deposited and the substrate is positioned such that the substrate is an outermost surface of the module and is positioned on the back non-sun-facing side of the solar cell layer, or (b) in another embodiment, consists of amorphous silicon (a-Si), microcrystalline silicon (μc-Si), cadmium telluride (CdTe), copper indium selenide (CIS), copper indium/gallium diselenide (CIGS), light absorbing dyes, and organic semiconductor based solar cells, and wherein the solar cell module consists essentially of, in order of position (i) the solar cell layer, (ii) a back encapsulant layer comprising the sheet comprising ethylene copolymer composition, and (iii) a backing layer, wherein the solar cell layer further comprises a superstrate upon which the thin film solar cells are deposited and the superstrate is positioned such that the superstrate is an outermost surface of the module on the front sun-facing side of the solar cell layer.

Further disclosed herein is a process for preparing a solar cell module, comprising: (i) providing an assembly comprising all the component layers recited above and (ii) laminating the assembly to form the solar cell module. The laminating step may be conducted by subjecting the assembly to heat and optionally vacuum or pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view, not-to-scale, of a wafer-based solar cell module disclosed herein.

Figure 2 is a cross-sectional view, not-to-scale, of one particular thin film solar cell module disclosed herein.

Figure 3 is a cross-sectional view, not-to-scale, of another thin film solar cell module disclosed herein.

DETAILED DESCRIPTION OF THE INVENTION

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. In case of conflict, the specification, including definitions, will control.

Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the invention, suitable methods and materials are described herein.

Unless stated otherwise, all percentages, parts, ratios, etc., are by weight.

When an amount, concentration, or other value or parameter is given as either a range, preferred range or a list of upper preferable values and lower preferable values, this is to be understood as specifically disclosing all ranges formed from any pair of any upper range limit or preferred value and any lower range limit or preferred value, regardless of whether ranges are separately disclosed. Where a range of numerical values is recited herein, unless otherwise stated, the range is intended to include the endpoints thereof, and all integers and fractions within the range. It is not intended that the scope of the invention be limited to the specific values recited when defining a range.

When the term “about” is used in describing a value or an end-point of a range, the disclosure should be understood to include the specific value or end-point referred to.

As used herein, the terms “comprises,” “comprising,” “includes,” “including,” "containing," "characterized by," “has,” “having” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or.

The transitional phrase "consisting essentially of" limits the scope of a claim to the specified materials or steps and those that do not materially affect the basic and novel characteristic(s) of the claimed invention.

Where applicants have defined an invention or a portion thereof with an open-ended term such as “comprising,” it should be readily understood that unless otherwise stated the description should be interpreted to also describe such an invention using the term “consisting essentially of”.

Use of “a” or “an” are employed to describe elements and components of the invention. This is merely for convenience and to give a general sense of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

In describing certain polymers it should be understood that sometimes applicants are referring to the polymers by the monomers used to produce them or the amounts of the monomers used to produce the polymers. While such a description may not include the specific nomenclature used to describe the final polymer or may not contain product-by-process terminology, any such reference to monomers and amounts should be interpreted to mean that the polymer comprises those monomers (i.e. copolymerized units of those monomers) or that amount of the monomers, and the corresponding polymers and compositions thereof.

In describing and/or claiming this invention, the term "copolymer" is used to refer to polymers formed by copolymerization of two or more monomers. Such copolymers include dipolymers, terpolymers or higher order copolymers.

Disclosed herein is solar cell module comprising a) at least one sheet layer (i.e., an encapsulant (sheet) layer) comprising an ethylene copolymer composition, wherein the ethylene copolymer comprises copolymerized units of ethylene and about 5 to about 20 wt%, or about 6 to about 15 wt%, or about 8 to about 15 wt% of copolymerized units of an ester of a C_4-C_8 unsaturated acid having two carboxylic acid groups, based on the total weight of the ethylene copolymer.

The ethylene copolymer comprised in the encapsulant sheet may be obtained by copolymerization of ethylene and a comonomer selected from the group consisting of monoesters of C_4-C_8 unsaturated acids having two carboxylic acid groups, diesters of C_4-C_8 unsaturated acids having two carboxylic acid groups, and mixtures of any two or more thereof. The suitable comonomers may include C_1-C_{20} alkyl monoesters of butenedioc acids (e.g. maleic acid, fumaric acid, itaconic acid and citraconic acid) such as methyl hydrogen maleate, ethyl hydrogen maleate, propyl hydrogen fumarate, and 2-ethylhexyl hydrogen fumarate, and C_1-C_{20} alkyl diesters of butenedioic acids such as dimethylmaleate, diethylmaleate, dibutylcitraconate, dioctylmaleate, and di-2-ethylhexylfumarate. In one embodiment, the ethylene copolymer is obtained by copolymerization of ethylene and methyl hydrogen maleate or ethyl hydrogen maleate. In a further embodiment, the ethylene copolymer A is obtained by copolymerization of ethylene and ethyl hydrogen maleate.

The ethylene copolymer comprised in the encapsulant sheet may be a dipolymer or a higher order copolymer, such as a terpolymer. For example, when in the form of a terpolymer, the ethylene copolymer may further comprise up to about 15 wt%, or up to about 10 wt%, or up to about 5 wt% of copolymerized units of a third comonomer, based on the total weight of the ethylene copolymer, provided that the optical and adhesion properties of the copolymer are not substantially affected by the additional comonomer(s).

Specific examples of the ethylene copolymer used in the encapsulant sheet include, but are not limited to, ethylene/maleic acid monoester dipolymers (such as ethylene/ethyl hydrogen maleate dipolymer), ethylene/maleic acid monoester/*n*-butyl methacrylate terpolymers, ethylene/maleic acid monoester/methyl acrylate terpolymers, ethylene/maleic acid monoester/methyl methacrylate terpolymers, ethylene/maleic acid monoester/ethyl methacrylate terpolymers and ethylene/maleic acid monoester/ethyl acrylate terpolymers.

The ethylene copolymer used in the encapsulant sheet may be synthesized by random copolymerization of ethylene and the particular comonomer(s) in a high-pressure free radical process, generally an autoclave process. Such processes are described in U.S. Patent No. 4,351,931. Some exemplary ethylene copolymers that may be used as the encapsulant sheet are described in U.S. Patent Application Publication No. 2005/0187315.

The ethylene copolymer composition comprised in the encapsulant sheet may also contain other additives known within the art. The additives may include, but are not limited to, processing aids, flow enhancing additives, lubricants, pigments, dyes, flame retardants, impact modifiers, nucleating agents, anti-blocking agents such as silica, thermal stabilizers, UV absorbers, UV stabilizers, dispersants, surfactants, chelating agents, coupling agents, reinforcement additives, such as glass fiber, fillers and the like. Generally, additives that may reduce the optical clarity of the composition, such as reinforcement additives and fillers, are reserved for those compositions that are used in the back encapsulants in solar cell modules.

Thermal stabilizers can be used and have been widely disclosed within the art. Any known thermal stabilizer may find utility within the ethylene copolymer compositions useful in the invention. Preferable general classes of thermal stabilizers include, but are not limited to, phenolic antioxidants, alkylated monophenols, alkylthiomethylphenols, hydroquinones, alkylated hydroquinones, tocopherols, hydroxylated thiodiphenyl ethers, alkylidenebisphenols, O-, N- and S-benzyl compounds, hydroxybenzylated malonates, aromatic hydroxybenzyl compounds, triazine compounds, aminic antioxidants, aryl amines, diaryl amines, polyaryl amines, acylaminophenols, oxamides, metal deactivators, phosphites, phosphonites, benzylphosphonates, ascorbic acid (vitamin C), compounds that destroy peroxide, hydroxylamines, nitrones, thiosynergists, benzofuranones, indolinones, and the like and mixtures thereof. The ethylene copolymer composition may contain any effective amount of thermal stabilizers. Use of a thermal stabilizer is optional and in some instances is not preferred. When thermal stabilizers are used, the ethylene copolymer composition may contain at least about 0.05 wt%, and up to about 10 wt%, or up to about 5 wt%, or up to about 1 wt%, of thermal stabilizers, based on the total weight of the ethylene copolymer composition.

UV absorbers can be used and have also been widely disclosed within the art. Any known UV absorber may find utility within the present invention. Preferable general classes of UV absorbers include, but are not limited to, benzotriazoles, hydroxybenzophenones, hydroxyphenyl triazines, esters of substituted and unsubstituted benzoic acids, and the like and mixtures thereof. The ethylene copolymer composition may contain any effective amount of UV absorbers. Use of a UV absorber is optional and in some instances is not preferred. When UV absorbers are utilized, the ethylene composition may contain at least about 0.05 wt%, and up to about 10 wt%, or up to about 5 wt%, or up to about 1 wt%, of UV absorbers, based on the total weight of the ethylene copolymer composition.

Hindered amine light stabilizers (HALS) can be used and have also been widely disclosed within the art. Generally, hindered amine light stabilizers are disclosed to be secondary, tertiary, acetylated, N-hydrocarbyloxy substituted, hydroxy substituted, or other substituted cyclic amines which are characterized by a substantial amount of steric hindrance, generally derived from aliphatic substitution on the carbon atoms adjacent to the amine function. The ethylene copolymer composition may contain any effective amount of hindered amine light stabilizers. Use of hindered amine light stabilizers is optional and in some instances is not preferred. When hindered amine light stabilizers are used, the ethylene copolymer composition contains at least about 0.05 wt%, and up to about 10 wt%, or up to about 5 wt%, or up to about 1 wt%, of hindered amine light stabilizers, based on the total weight of the ethylene copolymer composition.

Silane coupling agents may be added to the ethylene copolymer composition to improve its adhesive strength. Exemplary silane coupling agents that are useful in the ethylene compositions of the invention include, but are not limited to, γ-chloropropylmethoxysilane, vinyltrimethoxysilane, vinyltriethoxysilane, vinyltris(β-methoxyethoxy)silane,γ-vinylbenzylpropyltrimethoxysilane, N-β-(N-vinylbenzylaminoethyl)-γ-aminopropyltrimethoxysilane, γ-methacryloxypropyltrimethoxysilane, vinyltriacetoxysilane, γ-glycidoxypropyltrimethoxysilane, γ-glycidoxypropyltriethoxysilane, β-(3,4-epoxycyclohexyl)ethyltrimethoxysilane, vinyltrichlorosilane, γ-mercaptopropylmethoxysilane, γ-aminopropyltriethoxysilane, N-β-(aminoethyl)-γ-aminopropyltrimethoxysilane, and mixtures of two or more thereof. The silane coupling agents are preferably incorporated in the ethylene copolymer composition at a level of about 0.01 to about 5 wt%, or about 0.05 to about 1 wt%, based on the total weight of the ethylene copolymer composition.

The encapsulant sheet used in the solar cell module may be in a single layer or multilayer form. By “single layer”, it is meant that the sheet is made of or consists essentially of the ethylene copolymer composition disclosed herein and described above. When in a multilayer form, it comprises sub-layers and at least one of the sub-layers is made of or consists essentially of the ethylene copolymer composition disclosed herein, while the other sub-layer(s) may be made of or consist essentially of any other suitable polymeric material(s), such as, for example, copolymers of α-olefins and α,β-ethylenically unsaturated carboxylic acids (i.e., acid copolymers), partially neutralized ionic acid copolymers (i.e., ionomers), ethylene/vinyl acetate copolymers, poly(vinyl acetals) (including acoustic grade poly(vinyl acetals)), polyurethanes, polyvinylchlorides, polyethylenes (e.g., linear low density polyethylenes), polyolefin block copolymer elastomers, copolymers of α-olefins and α,β-ethylenically unsaturated carboxylic acid esters (e.g., ethylene methyl acrylate copolymers and ethylene butyl acrylate copolymers), silicone elastomers, epoxy resins, and combinations of two or more thereof.

The encapsulant sheet comprising the ethylene copolymer composition may have a smooth or rough surface on one or both sides. Preferably, the sheet has rough surfaces on both sides to facilitate deaeration during the lamination process. Rough surfaces can be created by mechanically embossing or by melt fracture during extrusion of the sheets followed by quenching so that surface roughness is retained during handling. The surface pattern can be applied to the sheet through well-known, common art processes. For example, the extruded sheet may be passed over a specially prepared surface of a die roll positioned in close proximity to the exit of the extruder die. This imparts the desired surface characteristics to one side of the molten polymer exiting the die. Thus, when the surface of such a die roll has minute peaks and valleys, it will impart a rough surface to the side of the polymer sheet that passes over the roll, and the rough surface will generally conform respectively to the valleys and peaks of the roll surface. Such die rolls are disclosed in, e.g., U.S. Patent No. 4,035,549 and U.S. Patent Publication No. 2003/0124296.

The encapsulant sheets comprising the ethylene copolymer composition may be produced by any suitable process. For example, the sheets may be formed through dipcoating, solution casting, compression molding, injection molding, lamination, melt extrusion casting, blown film processes, extrusion coating, tandem extrusion coating, or by any other procedures that are known to those of skill in the art. Or, the sheets may be formed by melt extrusion casting, melt coextrusion casting, melt extrusion coating, blown film processes, or tandem melt extrusion coating processes.

The term “solar cell” is meant to include any article which can convert light into electrical energy. Solar cells useful in the invention include, but are not limited to, wafer-based solar cells (e.g., c-Si or mc-Si based solar cells, as described above in the background section) and thin film solar cells (e.g., a-Si, µc-Si, CdTe, CIS, CIGS, light absorbing dyes, or organic semiconductor based solar cells, as described above in the background section). Within the solar cell layer, it is preferred that the solar cells are electrically interconnected and/or arranged in a flat plane. In addition, the solar cell layer may further comprise electrical wirings, such as cross ribbons and bus bars.

The solar cell layer may be bifacial. In such an embodiment, all the laminating materials positioned on either side of the solar cell layer should be sufficiently transparent to allow sunlight or reflected sunlight to reach the solar cells. Or, the solar cell layer may have a sun-facing side (which is also referred to as a front side and, when in actual use conditions, would generally face toward the sun) and a non-sun-facing side (which is also referred to as a back side and, when in actual use conditions, would generally face away from the sun). In such an embodiment, all the materials that are present in the laminate layers and sub-layers positioned to the sun-facing side of the solar cell layer should have sufficient transparency to allow the sunlight to reach the solar cells. The laminating materials present in the laminate layers and sub-layers positioned to the non-sun-facing side of the solar cell layer need not be transparent.

The solar cell module typically comprises at least one layer of an encapsulant sheet comprising the ethylene copolymer composition, which is laminated to the solar cell layer. By “laminated”, it is meant that, within a laminated structure, the two layers are bonded either directly (i.e., without any additional material between the two layers) or indirectly (i.e., with additional material, such as interlayer or adhesive materials, between the two layers). In certain embodiments, the encapsulant sheet layer comprising the ethylene copolymer composition is directly bonded to the solar cell layer.

The solar cell module may further comprise additional encapsulant layers comprising other polymeric materials, such as acid copolymers, ionomers of acid copolymers, ethylene/vinyl acetate copolymers, poly(vinyl acetals) (including acoustic grade poly(vinyl acetals)), polyurethanes, poly(vinyl chlorides), polyethylenes (e.g., linear low density polyethylenes), polyolefin block copolymer elastomers, copolymers of α-olefins and α,β-ethylenically unsaturated carboxylic acid esters) (e.g., ethylene methyl acrylate copolymers and ethylene butyl acrylate copolymers), silicone elastomers, epoxy resins, and combinations of two or more thereof.

The thickness of each of the encapsulant layers comprising the ethylene copolymer composition or other polymeric encapsulant layers may independently range from about 1 to about 120 mils (about 0.025 to about 3 mm), or about 5 to about 100 mils (about 0.127 to about 2.54 mm), or about 5 to about 30 mils (about 0.127 to about 0.76 mm), or about 10 to about 30 mils (about 0.25 to about 0.76 mm), or about 10 to about 20 mils (about 0.25 to about 0.51 mm). Any or all of the encapsulant layer(s) comprised in the solar cell modules may have smooth or rough surfaces. Preferably, the encapsulant layer(s) have rough surfaces to facilitate deaeration during the lamination process.

In certain embodiments, the encapsulant layer comprising the ethylene copolymer composition is in the form of a bi-layer sheet having a first sub-layer that consists essentially of the ethylene copolymer composition and a second sub-layer facing toward the solar cell layer and comprising any suitable encapsulant material, as disclosed above. In such an embodiment, the sub-layer comprising the ethylene copolymer composition may have a thickness of about 0.5 to about 15 mils (about 13 to about 381 μm).

In a further embodiment, the encapsulant layer comprising the ethylene copolymer composition is in the form of a tri-layer sheet having two surface sub-layers and one inner sub-layer, wherein each of the two surface sub-layers consists essentially of the ethylene copolymer composition and the inner sub-layer comprises any suitable encapsulant material as disclosed above. Further, each of the surface sub-layers, which consist essentially of the ethylene copolymer composition, may have a thickness of about 0.5 to about 15 mils (about 13 to about 381 μm).

The solar cell module may further comprise an incident layer and/or a backing layer serving as the outermost layer or layers of the module at the sun-facing side and the non-sun-facing side of the solar cell module, respectively.

The outer layers of the solar cell modules, i.e., the incident layer and the backing layer, may comprise any suitable sheets or films. Suitable sheets may be glass or plastic sheets, such as polycarbonates, acrylics, polyacrylates, cyclic polyolefins (e.g., ethylene norbornene polymers), polystyrenes (preferably polystyrenes prepared in the presence of metallocene catalysts), polyamides, polyesters, fluoropolymers, or combinations of two or more thereof. In addition, metal sheets, such as aluminum, steel, galvanized steel, or ceramic plates may be utilized in forming the backing layer.

The term “glass” includes not only window glass, plate glass, silicate glass, sheet glass, low iron glass, tempered glass, tempered CeO-free glass, and float glass, but also colored glass, specialty glass (such as those containing ingredients to control solar heating), coated glass (such as those sputtered with metals (e.g., silver or indium tin oxide) for solar control purposes), low E-glass, Toroglas® glass (Saint-Gobain N.A. Inc., Trumbauersville, PA), Solexia™ glass (PPG Industries, Pittsburgh, PA) and Starphire® glass (PPG Industries). Such specialty glasses are disclosed in, e.g., U.S. Patent Nos. 4,615,989; 5,173,212; 5,264,286; 6,150,028; 6,340,646; 6,461,736; and 6,468,934. It is understood, however, that the type of glass to be selected for a particular module depends on the intended use.

Suitable film layers comprise polymers that include but are not limited to, polyesters (e.g., poly(ethylene terephthalate) and poly(ethylene naphthalate)), polycarbonate, polyolefins (e.g., polypropylene, polyethylene, and cyclic polyolefins), norbornene polymers, polystyrene (e.g., syndiotactic polystyrene),

styrene-acrylate copolymers, acrylonitrile-styrene copolymers, polysulfones (e.g., polyethersulfone, polysulfone, etc.), nylons, poly(urethanes), acrylics, cellulose acetates (e.g., cellulose acetate, cellulose triacetates, etc.), cellophane, silicones, poly(vinyl chlorides) (e.g., poly(vinylidene chloride)), fluoropolymers (e.g., polyvinyl fluoride, polyvinylidene fluoride, polytetrafluoroethylene, and ethylene-tetrafluoroethylene copolymers, and combinations of two or more thereof. The polymeric film may be non-oriented, or uniaxially oriented, or biaxially oriented. Some specific exemplary films that may be used in the solar cell module outer layers (e.g., the incident layer or the backing layer) include, but are not limited to, polyester films (e.g., poly(ethylene terephthalate) films), fluoropolymer films (e.g., Tedlar®, Tefzel®, and Teflon® films available from E. I. du Pont de Nemours and Company (DuPont), Wilmington, DE). Metal films, such as aluminum foil, may also be used as the backing layers. Further the films used in the solar cell module outer layers may be in the form of multi-layer films, such a fluoropolymer/polyester/fluoropolymer multilayer film (e.g., Tedlar®/PET/Tedlar® or TPT laminate film available from Isovolta AG., Austria or Madico, Woburn, MA).

The solar cell module may further comprise other functional film or sheet layers (e.g., dielectric layers or barrier layers) embedded within the module. Such functional layers may comprise any of the above mentioned polymeric films or those that are coated with additional functional coatings. For example, poly(ethylene terephthalate) (PET) films coated with a metal oxide coating, such as those disclosed within U.S. Patent Nos. 6,521,825 and 6,818,819 and European Patent No. EP1182710, may function as oxygen and moisture barrier layers in the laminates.

If desired, a layer of nonwoven glass fiber (scrim) may also be included between the solar cell layers and the encapsulant layers to facilitate deaeration during the lamination process and/or to serve as reinforcement for the encapsulants. The use of such scrim layers is disclosed within, e.g., U.S. Patent Nos. 5,583,057; 6,075,202; 6,204,443; 6,320,115; and 6,323,416 and European Patent No. EP0769818.

A special film or sheet may be included to serve both the function of an encapsulant layer and an outer layer. It is also conceivable that any of the film or sheet layers included in the module may be in the form of a pre-formed single-layer or multilayer film or sheet.

If desired, one or both surfaces of the incident layer films and sheets, the backing layer films and sheets, the encapsulant layers and other layers incorporated within the solar cell module may undergo any suitable adhesion enhancing treatment. This adhesion enhancing treatment may take any form known within the art and includes flame treatments (see, e.g., U.S. Patent Nos. 2,632,921; 2,648,097; 2,683,894; and 2,704,382), plasma treatments (see e.g., U.S. Patent No. 4,732,814), electron beam treatments, oxidation treatments, corona discharge treatments, chemical treatments, chromic acid treatments, hot air treatments, ozone treatments, ultraviolet light treatments, sand blast treatments, solvent treatments, and combinations of two or more thereof. Also, the adhesion strength may be further improved by further applying an adhesive or primer coating on the surface of the laminate layer(s). For example, U.S. Patent No. 4,865,711 discloses a film or sheet with improved bondability, which has a thin layer of carbon deposited on one or both surfaces. Other exemplary adhesives or primers may include silanes, poly(allyl amine) based primers (see e.g., U.S. Patent Nos. 5,411,845; 5,770,312; 5,690,994; and 5,698,329), and acrylic based primers (see e.g., U.S. Patent No. 5,415,942). The adhesive or primer coating may take the form of a monolayer of the adhesive or primer and have a thickness of about 0.0004 to about 1 mil (about 0.00001 to about 0.03 mm), or preferably, about 0.004 to about 0.5 mil (about 0.0001 to about 0.013 mm), or more preferably, about 0.004 to about 0.1 mil (about 0.0001 to about 0.003 mm).

In one particular embodiment (now referring to Figure 1), where the solar cells are derived from wafer-based self supporting solar cell units, the solar cell module (20) may comprise, in order of position from the front sun-facing side to the back non-sun-facing side, (a) an incident layer (10), (b) a front encapsulant layer (12), (c) a solar cell layer (14) comprised of one or more electrically interconnected solar cells, (d) a back encapsulant layer (16), and (e) a backing layer (18), wherein at least one or both of the front and back encapsulant layers (12 and 16) is formed of the sheet comprising the ethylene copolymer composition.

In a further embodiment, the solar cell modules are derived from thin film solar cells and may (i) in one embodiment (30 in Figure 2), comprise, in order of position from the front sun-facing side to the back non-sun-facing side, (a) a solar cell layer (14a) comprising a superstrate (24) and a layer of thin film solar cell(s) (22) deposited thereon at the non-sun-facing side, (b) a (back) encapsulant layer (16) formed of the sheet comprising the ethylene copolymer composition, and (c) a backing layer (18) or (ii) in another embodiment (40 in Figure 3), comprise, (a) a transparent incident layer (10), (b) a (front) encapsulant layer (12) formed of the sheet comprising the ethylene copolymer composition, and (c) a solar cell layer (14b) comprising a layer of thin film solar cell(s) (22) deposited on a substrate (26) at the sun-facing side thereof.

Moreover, a series of the solar cell modules described above may be further linked to form a solar cell array, which can produce a desired voltage and current.

Any lamination process known within the art (such as an autoclave or a non-autoclave process) may be used to prepare the solar cell modules.

In an exemplary process, the component layers of the solar cell module are stacked in the desired order to form a pre-lamination assembly. The assembly is then placed into a bag capable of sustaining a vacuum ("a vacuum bag"), the air is drawn out of the bag by a vacuum line or other means, the bag is sealed while the vacuum is maintained (e.g., at least about 27-28 in. Hg (689-711 mm Hg)), and the sealed bag is placed in an autoclave and the pressure is raised to about 150 to about 250 psi (about 11.3 to about 18.8 bar), and a temperature of about 130°C to about 180°C, or about 120°C to about 160°C, or about 135°C to about 155°C, or about 145°C to about 155°C, for about 10 to about 50 min, or about 20 to about 45 min, or about 20 to about 40 min, or about 25 to about 35 min. A vacuum ring may be substituted for the vacuum bag. One type of suitable vacuum bag is disclosed within U.S. Patent No. 3,311,517. Following the heat and pressure cycle, the air in the autoclave is cooled without adding additional air to maintain pressure in the autoclave. After about 20 min of cooling, the excess air pressure is vented and the laminates are removed from the autoclave.

Alternatively, the pre-lamination assembly may be heated in an oven at about 80°C to about 120°C, or about 90°C to about 100°C, for about 20 to about

40 min, and thereafter, the heated assembly is passed through a set of nip rolls so that the air in the void spaces between the individual layers may be squeezed out, and the edge of the assembly sealed. The assembly at this stage is referred to as a pre-press.

The pre-press may then be placed in an air autoclave where the temperature is raised to about 120°C to about 160°C, or about 135°C to about 160°C, at a pressure of about 100 to about 300 psi (about 6.9 to about 20.7 bar), or preferably about 200 psi (13.8 bar). These conditions are maintained for about 15 to about 60 min, or about 20 to about 50 min, after which the air is cooled while no further air is introduced to the autoclave. After about 20 to about 40 min of cooling, the excess air pressure is vented and the laminated products are removed from the autoclave.

The solar cell modules may also be produced through non-autoclave processes. Such non-autoclave processes are disclosed, e.g., in U.S. Patent Nos. 3,234,062; 3,852,136; 4,341,576; 4,385,951; 4,398,979; 5,536,347; 5,853,516; 6,342,116; and 5,415,909, U.S. Patent Publication No. 2004/0182493, European Patent No. EP1235683 B1, and PCT Patent Publication Nos. WO91/01880 and WO03/057478. Generally, the non-autoclave processes include heating the pre-lamination assembly and the application of vacuum, pressure or both. For example, the assembly may be successively passed through heating ovens and nip rolls.

These examples of lamination processes are not intended to be limiting. Essentially any lamination process may be used.

If desired, the edges of the solar cell module may be sealed to reduce moisture and air intrusion that lead to potential reduction of the efficiency and lifetime of the solar cell(s). The edges may be sealed by any means disclosed within the art. Suitable edge seal materials include, but are not limited to, butyl rubber, polysulfide, silicone, polyurethane, polypropylene elastomers, polystyrene elastomers, block copolymer elastomers (such as styrene-ethylene-butylene-styrene (SEBS)), and the like.

The invention is further illustrated by the following examples of certain embodiments.

EXAMPLES

Examples E1-E2 and Comparative Examples CE1-CE2

The following polymer materials were used in the examples:

- E/MAME-1 – an ethylene/monoethyl maleate copolymer comprising 9 wt% of copolymerized units of monoethyl ester of maleic acid, based on the total weight of the copolymer;
- E/MAME-2 – an ethylene/monoethyl maleate/methacrylic acid terpolymer comprising 6 wt% of copolymerized units of monoethyl ester of maleic acid and 11 wt% of copolymerized units of methacrylic acid, based on the total weight of the copolymer;
- LLDPE – a metallocene linear low density polyethylene available from ExxonMobil (Irving, Texas) under the tradename Exceed® 3519GA;
- EVA – an ethylene/vinyl acetate copolymer available from DuPont under the tradename Elvax® 3175LG.

In each of the following examples, a 20 mil (0.51 mm) thick polymer interlayer sheet formed of one of the above listed polymers and having a dimension of 4x7 in (10.2x17.8 cm) was laminated between a 1/8 in (3.2 mm) thick Krystal Klear® glass sheet (available from AGC Flat Glass North America, Inc., Alpharetta, GA and having a dimension of 4x4 inch (10.2x10.2 cm)) and a Tedlar®/polyethylene terephthalate (PET)/Tedlar® tri-layer film ("TPT") (4x7 in (10.2x17.8 cm)) to form a glass/interlayer/TPT laminate structure. During the lamination process, a polyester slip sheet (1x4 in (2.54x10.2 cm)) was placed between the glass sheet and the polymer interlayer sheet to provide peel initiation. The final laminates were obtained using a Meier ICOLAM 10/ 08 laminator (Meier Vakuumtechnik GmbH, Bocholt, Germany) with the lamination cycle including an evacuation step (vacuum of 3 in Hg) for 6 minutes and a pressing stage (pressure of 1000 mb) for 6.5 minutes at a temperature of 150°C.

The interlayer/TPT bilayer of the final laminates were cut into 1 in (2.54 cm) wide strips and then subjected to peel testing using an Instron tester (Instron Tensile Tester Model 1122), where the interlayer/ TPT bilayers were peeled away from the glass sheet at a 180° angle and a 3.9 in/min (9.9 cm/min) rate, before and after the laminates were subjected a damp/heat condition (85°C and 85% relative humidity (RH)) for 1000 hours. The peel initiation load for each sample is reported in Table 1.

The results in Table 1 demonstrate that the ethylene copolymer disclosed herein (exemplified in E1 and E2) has much better adhesion to glass both before and after the laminates were subjected to damp/heat condition for 1000 hours, compared to linear low density polyethylene (CE1) or poly(ethylene vinyl acetate) (CE2).

TABLE 1

Sample No.	Interlayer Material	180° Peel Load (lbs/in)	
		Prior to Damp/Heat	After Damp/Heat
E1	E/MAME-1	13.8	18.4
E2	E/MAME-2	20	12.1
CE1	LLDPE	0	-
CE2	EVA	0.3	0.9

WHAT IS CLAIMED IS:

1. A solar cell module comprising a solar cell layer and a sheet comprising at least one layer of an ethylene copolymer composition, wherein (A) the solar cell layer comprises a single solar cell or a plurality of electrically interconnected solar cells; and (B) the ethylene copolymer composition comprises an ethylene copolymer comprising copolymerized units of ethylene and about 5 to about 20 wt% of an ester of a C_4-C_8 unsaturated acid having two carboxylic acid groups, based on the total weight of the ethylene copolymer.

2. The solar cell module of Claim 1, wherein the ethylene copolymer comprises about 6 to about 15 wt% copolymerized units of the ester of the C_4-C_8 unsaturated acid having two carboxylic acid groups, based on the total weight of the ethylene copolymer.

3. The solar cell module of Claim 1, wherein the ester of the C_4-C_8 unsaturated acid having two carboxylic acid groups is selected from the group consisting of monoesters of C_4-C_8 unsaturated acids having two carboxylic acid groups, diesters of C_4-C_8 unsaturated acids having two carboxylic acid groups, and mixtures of any two or more thereof.

4. The solar cell module of Claim 1, wherein the ethylene copolymer comprises about 6 to about 15 wt% of copolymerized units of a monoester of a C_4-C_8 unsaturated acid having at least two carboxylic acid groups.

5. The solar cell module of Claim 4, wherein the monoester is ethyl hydrogen maleate.

6. The solar cell module of Claim 1, wherein the sheet comprising the ethylene copolymer composition is in the form of a monolayer that consists essentially of the ethylene copolymer composition.

7. The solar cell module of claim 1, wherein the sheet comprising the ethylene copolymer composition is in the form of a multilayer sheet and has two or more sub-layers, and wherein at least one of the sub-layers consists essentially of the ethylene composition and each of the other sub-layers present in the multilayer sheet comprises at least one polymer selected from the group consisting of acid copolymers, ionomers of acid copolymers, ethylene/vinyl acetate copolymers, poly(vinyl acetals), polyurethanes, polyvinylchlorides, polyethylenes, polyolefin block copolymer elastomers, copolymers of an α-olefin

and an α,β-ethylenically unsaturated carboxylic acid, silicone elastomers, epoxy resins, and combinations of two or more thereof.

8. The solar cell module of Claim 7, wherein the sheet comprising the ethylene copolymer composition is in the form of a bi-layer sheet having two sub-layers and one of the two sub-layer consists essentially of the ethylene composition and has a thickness of about 0.5 to about 15 mils (about 13 to about 381 μm).

9. The solar cell module of Claim 7, wherein the sheet comprising the ethylene copolymer composition is in the form of a tri-layer sheet having an inner sub-layer sandwiched between two surface sub-layers, and wherein the one or both of the two surface sub-layers each consists essentially of the ethylene copolymer composition and has a thickness of 0.5 to about 15 mils (about 13 to about 381 μm).

10. The solar cell module of Claim 1, wherein the sheet comprising the ethylene copolymer composition is directly laminated to the solar cell layer.

11. The solar cell module of Claim 1, wherein the solar cell layer has front sun-facing side and a back non-sun-facing side.

12. The solar cell module of Claim 11, which comprises a front encapsulant layer laminated to the sun-facing side of the solar cell layer and a back encapsulant layer laminated to the non-sun-facing side of the solar cell layer, wherein one of the front and back encapsulant layers is the sheet comprising the blend composition and the other of the front and back encapsulant layers comprises a polymeric material selected from the group consisting of copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, ionomers of copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, ethylene/vinyl acetate copolymers, poly(vinyl acetals), polyurethanes, polyvinylchlorides, polyethylenes, polyolefin block copolymer elastomers, copolymers of an α-olefin and an α,β-ethylenically unsaturated carboxylic acid, silicone elastomers, epoxy resins, and combinations thereof.

13. The solar cell module of Claim 12, which comprises two sheets comprising the blend composition, wherein one of the two sheets is the front encapsulant layer and the other of the two sheets is the back encapsulant layer.

14. The solar cell module of Claim 11, further comprising an incident layer, wherein the incident layer is an outermost surface layer of the module and is

positioned on the front sun-facing side of the solar cell layer, and wherein the incident layer is selected from the group consisting of (i) glass sheets, (ii) polymeric sheets comprising a polymer selected from the group consisting of polycarbonates, acrylics, polyacrylates, cyclic polyolefins, polystyrenes, polyamides, polyesters, fluoropolymers, and combinations of two or more thereof, and (iii) polymeric films comprising a polymer selected from the group consisting of polyesters, polycarbonate, polyolefins, norbornene polymers, polystyrene, styrene-acrylate copolymers, acrylonitrile-styrene copolymers, polysulfones, nylons, polyurethanes, acrylics, cellulose acetates, cellophane, poly(vinyl chlorides), fluoropolymers, and combinations of two or more thereof.

15. The solar cell module of Claim 11, further comprising a backing layer, wherein the backing layer is an outermost surface layer of the module and is positioned on the back non-sun-facing side of the solar cell layer, and wherein the backing layer is selected from the group consisting of (i) glass sheets, (ii) polymeric sheets, (iii) polymeric films, (iv) metal sheets, and (v) ceramic plates, and wherein the polymeric sheets comprise a polymer selected from the group consisting of polycarbonates, acrylics, polyacrylates, cyclic polyolefins, polystyrenes, polyamides, polyesters, fluoropolymers, and combinations or two or more thereof; and the polymeric films comprise a polymer selected from the group consisting of polyesters, polycarbonates, polyolefins, norbornene polymers, polystyrenes, styrene-acrylate copolymers, acrylonitrile-styrene copolymers, polysulfones, nylons, polyurethanes, acrylics, cellulose acetates, cellophanes, poly(vinyl chlorides), fluoropolymers, and combinations of two or more thereof.

16. The solar cell module of Claim 11, wherein the solar cells are wafer-based solar cells selected from the group consisting of crystalline silicon (c-Si) and multi-crystalline silicone (mc-Si) based solar cells and the module consists essentially of, in order of position, (i) an incident layer, (ii) front encapsulant layer laminated to the front sun-facing side of the solar cell layer, (iii) the solar cell layer, (iv) a back encapsulant layer laminated to the back non-sun-facing side of the solar cell layer, and (v) a backing layer, wherein one or both of the front and back encapsulant layers comprise the ethylene copolymer composition.

17. The solar cell module of Claim 11, wherein the solar cells are thin film solar cells selected from the group consisting of amorphous silicon (a-Si),

microcrystalline silicon (μc-Si), cadmium telluride (CdTe), copper indium selenide (CIS), copper indium/gallium diselenide (CIGS), light absorbing dyes, and organic semiconductor based solar cells, and wherein the solar cell module consists essentially of, in order of position, (i) an incident layer, (ii) a front encapsulant layer comprising the sheet comprising the ethylene copolymer composition, and (iii) the solar cell layer, wherein the solar cell layer further comprises a substrate upon which the thin film solar cells are deposited and the substrate is positioned such that the substrate is an outermost surface of the module and is positioned on the back non-sun-facing side of the solar cell layer.

18. The solar cell module of Claim 11, wherein the solar cells are thin film solar cells selected from the group consisting of amorphous silicon (a-Si), microcrystalline silicon (μc-Si), cadmium telluride (CdTe), copper indium selenide (CIS), copper indium/gallium diselenide (CIGS), light absorbing dyes, and organic semiconductor based solar cells, and wherein the solar cell module consists essentially of, in order of position (i) the solar cell layer, (ii) a back encapsulant layer comprising the sheet comprising ethylene copolymer composition, and (iii) a backing layer, wherein the solar cell layer further comprises a superstrate upon which the thin film solar cells are deposited and the superstrate is positioned such that the superstrate is an outermost surface of the module on the front sun-facing side of the solar cell layer.

19. A process for preparing a solar cell module, comprising: (i) providing an assembly comprising all the component layers recited in Claim 1 and (ii) laminating the assembly to form the solar cell module.

20. The process of Claim 19, wherein the laminating step is conducted by subjecting the assembly to heat and optionally vacuum or pressure.

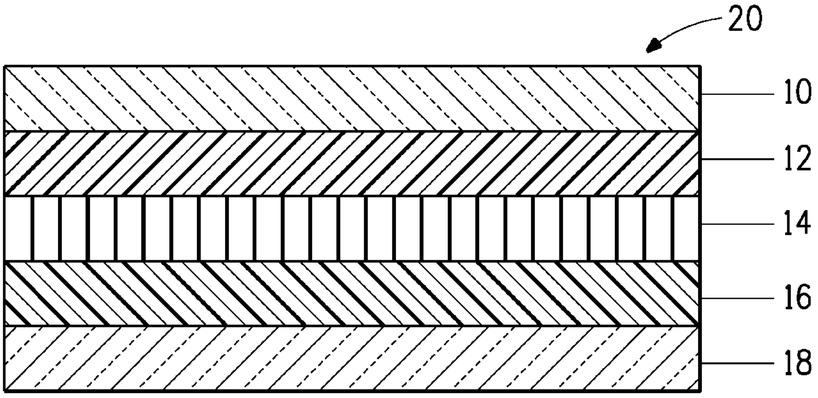


FIG. 1

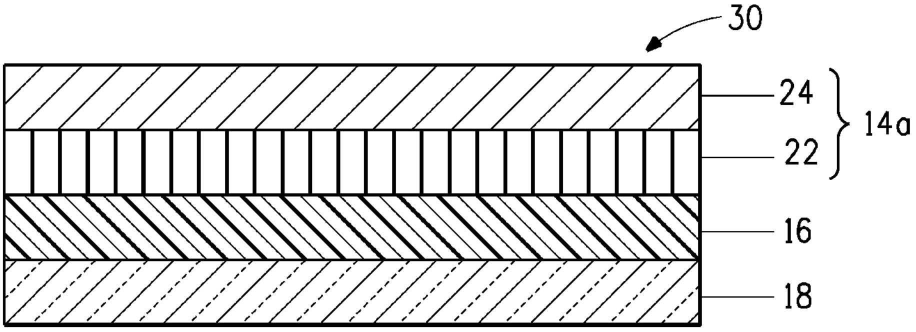


FIG. 2

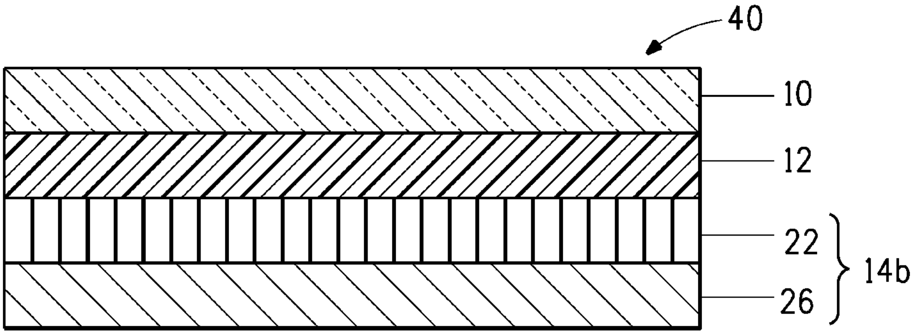


FIG. 3