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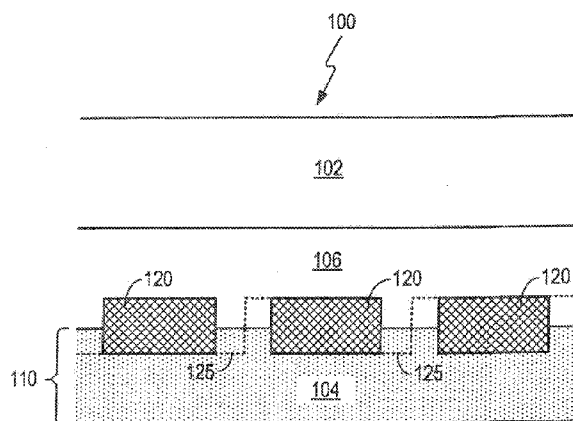


FIG. 1

(57) **Abstract:** Photovoltaic modules are disclosed. The photovoltaic module comprises a front transparency, a potting material deposited on at least a portion of the front transparency, electrically interconnected photovoltaic cells applied to the potting material and a topcoat deposited on at least a portion of the electrically interconnected photovoltaic cells. Methods of making photovoltaic modules are also disclosed.



COATING-ENCAPSULATED PHOTOVOLTAIC MODULES AND METHODS OF MAKING SAME

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0001] This invention was made with Government support under DE-EE-0000585 awarded by the United States Department of Energy. The United States Government may have certain rights in this invention.

TECHNICAL FIELD

[0002] The present invention relates to photovoltaic modules and, more particularly, coatings useful for encapsulating such cells, and methods for making the same.

BACKGROUND

[0003] Photovoltaic modules produce electricity by converting electromagnetic energy of the photovoltaic module into electrical energy. To survive in harsh operating environments, photovoltaic modules rely on encapsulant materials to provide durability and module life. A traditional bulk photovoltaic module comprises a front transparency, such as a glass sheet or a pre-formed transparent polymer sheet, for example, a polyimide sheet; an encapsulant or potting material, such as ethylene vinyl acetate ("EVA"); a photovoltaic cell or cells, comprising separate wafers (*i.e.*, a cut ingot) of photovoltaic semiconducting material, such as a crystalline silicon ("c-Si"), coated on both sides with conducting material that generate an electrical voltage in accordance with the photovoltaic effect; and a back sheet, such as a pre-formed polymeric sheet or film, for example, a sheet or film or multilayer composite of glass, aluminum, sheet metal (*i.e.*, steel or stainless steel), polyvinyl fluoride, polyvinylidene fluoride, polytetrafluoroethylene, and/or polyethylene terephthalate. "Encapsulant," "encapsulated" and like terms refer to the covering of a component such as a photovoltaic cell with a layer or layers of material such that the surface of the component is not exposed and/or to protect the photovoltaic cell from the environment. The "backing layer," "backsheet," or like terms as used herein refers to an encapsulant that is on the side of the photovoltaic cell opposite the front transparency.

[0004] Photovoltaic modules are typically produced in a batch or semi-batch vacuum lamination process in which the module components are preassembled into a module preassembly. The preassembly comprises applying the potting material to the front transparency, positioning the photovoltaic cells and electrical interconnections onto the potting material, applying additional potting material onto the photovoltaic cell assembly, and applying the back sheet onto the back side potting material to complete the module

preassembly. The module preassembly is placed in a specialized vacuum lamination apparatus that uses a compliant diaphragm to compress the module assembly and cure the potting material under reduced pressure and elevated temperature conditions to produce the laminated photovoltaic module. The process effectively laminates the photovoltaic cells between the front transparency and a back sheet with potting material.

[0005] While this laminated encapsulant module performs acceptably, there can be processing and handling issues. The attachment of the back sheet to the cell requires a vacuum lamination curing process which can be very labor intensive and time consuming. In addition, the cells may shift during the lamination process that could generate a defect. Such laminated photovoltaic modules can also suffer premature failures from moisture ingress into the module, mainly through the edges or through the back sheet, and/or from corrosion in contact layers.

[0006] Accordingly, the need exists to replace the heavy, labor intensive and/or time consuming EVA/glass encapsulation process with a lightweight protective system that has suitable cell lifetimes by minimizing moisture ingress and/or corrosion.

SUMMARY

[0007] In a non-limiting embodiment, a photovoltaic module is described. The photovoltaic module comprises a front transparency, a potting material deposited on at least a portion of the front transparency, electrically interconnected photovoltaic cells applied to the potting material and a topcoat deposited on at least a portion of the electrically interconnected photovoltaic cells.

[0008] The present invention is also directed to a method for preparing a photovoltaic module comprising applying potting material on at least a portion of a front transparency, applying photovoltaic cells onto the potting material so that the cells are electrically interconnected, laminating the potting material and electrically interconnected photovoltaic cells, applying a topcoat on at least a portion of the electrically interconnected photovoltaic cells, and curing the topcoat. The invention is further directed to photovoltaic modules produced in accordance with this method.

[0009] It is understood that the invention disclosed and described in this specification is not limited to the embodiments summarized in this Summary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various features and characteristics of the non-limiting and non-exhaustive embodiments disclosed and described in this specification may be better understood by reference to the accompanying figures, in which:

[0011] Figures 1 and 2 are schematic diagrams illustrating photovoltaic modules comprising protective coating systems;

[0012] Figure 3 is a flowchart diagram illustrating a process for producing a photovoltaic module;

[0013] Figures 4A through 4F are schematic diagrams collectively illustrating the production of a photovoltaic module comprising the application of a two-layer protective coating system comprising a primer coating and a top coating;

[0014] Figure 5 is a plot of maximum power output over time for test photovoltaic modules evaluated in accordance with International Standard IEC 61215 – 10.13; and

[0015] Figures 6A and 6B are bar charts showing the measured permeance values of various coating films.

[0016] The reader will appreciate the foregoing details, as well as others, upon considering the following detailed description of various non-limiting and non-exhaustive embodiments according to this specification.

DESCRIPTION

[0017] The present invention is directed to photovoltaic modules and methods of making photovoltaic modules. Figure 1 illustrates a non-limiting and non-exhaustive embodiment of a photovoltaic module 100 that comprises a front transparency 102, a potting material 106 deposited on at least a portion of the front transparency 102, photovoltaic cells 120 and electrical interconnections 125 that link or connect the cells applied to the potting material 106 and a top coating or topcoat 104 deposited on at least a portion of the electrically interconnected photovoltaic cells 120. As used herein “front transparency” means a material that is transparent to electromagnetic radiation in a wavelength range that is absorbed by a photovoltaic cell and used to generate electricity. In embodiments, the front transparency comprises a planar sheet of transparent material comprising the outward-facing surface of a photovoltaic module. Any suitable transparent material can be used for the front transparency including, but not limited to, glasses such as, for example, silicate glasses, and polymers such as, for example, polyimide, polycarbonate, and the like, or other planar sheet material that is transparent to electromagnetic radiation in a wavelength range that may be absorbed by a photovoltaic cell and used to generate electricity in a photovoltaic module. The term “transparent” refers to the property of a material in which at least a portion of incident electromagnetic radiation in the visible spectrum (*i.e.*, approximately 350 to 750 nanometer wavelength) passes through the material with negligible attenuation.

[0018] Potting material may be applied or deposited on at least a portion of the front transparency. As used herein "potting material" refers to polymeric materials used to adhere photovoltaic cells to front transparencies and/or back sheets in photovoltaic modules, and/or encapsulate photovoltaic cells within a covering of polymeric material. In various non-limiting embodiments, potting material may be formed from a solid sheet of potting material, such as, for example, EVA. In various other non-limiting embodiments, potting material comprises a transparent fluid potting material or encapsulant, such as, for example, a clear liquid encapsulant, onto one side of the front transparency. As used herein to describe a fluid encapsulant the term "fluid" includes liquids, powders and/or other materials that are able to flow into or fill the shape of a space such as a front sheet. In various non-limiting embodiments, fluid potting material may comprise inorganic particles, such as, for example, mica. In embodiments the mica can be dispersed in the cured coat.

[0019] Photovoltaic cells 120 and electrical interconnections 125 may be positioned on the potting material 106 so that each photovoltaic cell is electrically connected to at least one other cell. Photovoltaic cells include constructs comprising a photovoltaic semiconducting material positioned in between two electrical conductor layers, at least one of which comprises a transparent conducting material. In various non-limiting embodiments, photovoltaic cells 120 comprise bulk photovoltaic cells (*e.g.*, ITO- and aluminum-coated crystalline silicon wafers). An assembly of photovoltaic cells 120 and electrical interconnections 125 can be used. In various other non-limiting embodiments, photovoltaic cells comprise thin-film photovoltaic cells deposited onto the potting material. Thin-film photovoltaic cells typically comprise a layer of transparent conducting material (*e.g.*, indium tin oxide) deposited onto a front transparency, a layer of photovoltaic semiconducting material (*e.g.*, amorphous silicon, cadmium telluride, or copper indium diselenide) deposited onto the transparent conducting material layer, and a second layer of conducting material (*e.g.*, aluminum) deposited onto the photovoltaic semiconducting material layer.

[0020] The photovoltaic modules of the present invention further comprise a protective coating 110. A "protective coating" as used herein refers to a coating that imparts at least some degree of durability, moisture barrier and/or abrasion resistance to the photovoltaic layer. The present "protective coating" can comprise one or more coating layers. The protective coating can be derived from any number of known coatings, including powder coatings, liquid coatings and/or electrodeposited coatings. It is believed that use of durable, moisture resistant and/or abrasion resistant protective coating can be used as a

backing layer encapsulant material to minimize if not eliminate corrosion associated with photovoltaic cell failure.

[0021] In certain embodiments the protective coating 110 comprises a topcoat 104 applied or deposited on all or at least a portion of the photovoltaic cells 120. The term "topcoat" as used in the context of the present invention refers to a coating layer (or series of coating layers, for instance a "base/clear" system may be collectively referred to as a "topcoat") that has an outer surface which is exposed to the environment and an inner surface that is in contact with another coating layer or the substrate (if there is no other coating layer). The topcoat can provide an overcoat or protective and/or durable coating. In embodiments the topcoat comprises the outermost backing layer of a photovoltaic module in accordance with various embodiments described in this specification. The topcoat may comprise one or more coats, wherein any coat or coats may individually comprise the same or different coating compositions. In various non-limiting embodiments, a photovoltaic module may comprise a topcoat as the outermost backing layer of the photovoltaic module, unlike the traditional photovoltaic module designs that rely on a film that is laminated and/or a back sheet (such as glass, metal, etc.). In certain embodiments the topcoat comprises an anhydride/hydroxyl, melamine/hydroxyl and/or latex. In certain examples the topcoat comprises a polyepoxide and polyamine composition. In other examples, the topcoat comprises a fluorine-containing polymer, such as a polyamine epoxy fluoropolymer.

[0022] In certain suitable embodiments, the topcoat can be formed from Coraflon® DS-2508, PITTHANE Ultra, and/or DURANAR UC43350 extrusion coating (all of which are commercially available from PPG Industries, Inc., Pittsburgh, Pennsylvania, USA). In certain suitable embodiments when the topcoat is used alone and is a monocoat, the topcoat can be formed from PCH-90101 powder coating and/or DURANAR PD-90001 powder coating (both commercially available from PPG Industries, Inc., Pittsburgh, Pennsylvania, USA).

[0023] In various non-limiting embodiments, the photovoltaic modules, and all aspects thereof, as described above, can further include a primer. Shown for an example in Figure 2, protective coating 220 of photovoltaic module 200 further comprises a primer 208 positioned in between topcoat 204 and photovoltaic cells 225. As used herein, the term "primer" or "primer coating composition" refers to coating compositions from which an undercoating may be deposited onto a substrate in order to prepare the surface for application of a protective or decorative coating system. The primer may provide for anti-corrosion protection. For example, the primer may be formed from any suitable protective coating

compositions such as, for example, an anhydride/hydroxyl, melamine/hydroxyl, latex, anionic or cationic electyrocoat, zinc rich primer, and/or an combination thereof. In embodiments the primer comprises a thermoset polyepoxide-polyamine composition. In certain embodiments the primer may be formed from coating compositions comprising, for example, any one or a combination of the following: DP40LF refinish primer, DURAPRIME, POWERCRON 6000, POWERCRON 150, HP-77-225 GM primer surface, SPR67868A, DURANAR UC51742 duranar sprayable aluminum extrusion coating system, Aerospace primer CA7502 (all of which are commercially available from PPG Industries, Inc., Pittsburgh, Pennsylvania, USA).

[0024] In embodiments a primer is used in combination with a topcoat comprising a polyepoxide and polyamine comprising a fluorine-containing polymer. In certain such embodiments, the primer comprises an epoxy amine.

[0025] The topcoat alone or in combination with a primer and/or other coatings can comprise a protective coating system 110 or 210 that may be applied to encapsulate the photovoltaic cells and electrical interconnections between the potting material and the protective coating system. In various non-limiting embodiments, the protective coating system comprises one, two, or more coats, wherein any coat or coats may individually comprise the same or a different coating composition. In various non-limiting embodiments, the coatings used to produce the one or more coats (e.g., primer, tie coat, topcoat, monocoat, and the like) comprising a protective coating system for a photovoltaic module may comprise inorganic particles in the coating composition and the resultant cured coating film. As used herein, tie coat refers to an intermediate coating intended to facilitate or enhance adhesion between an underlying coating (such as a primer or an old coating) and an overlying topcoat. For example, particulate mineral materials, such as, for example, mica, may be added to coating compositions used to produce a protective coating system 110 or 210 for photovoltaic module 100 or 200. In embodiments, the inorganic particles comprise aluminum, silica, clays, pigments and/or glass flake or any combination thereof. Inorganic particles may be added to one or more of a primer, tie coat, topcoat and/or monocoat applied on to photovoltaic cells and electrical interconnections to encapsulate these components.

[0026] Protective coating systems comprising inorganic particles in the cured coats may exhibit improved barrier properties such as, for example, lower moisture vapor transmission rates and/or lower permeance values. Inorganic particles such as, for example, mica and other mineral particulates, may improve the moisture barrier properties of polymeric films and coats by increasing the tortuosity of transport paths for water molecules

contacting the films or coats. These improvements may be attributed to the relatively flat platelet-like structure of various inorganic particles. In various non-limiting embodiments, inorganic particles may comprise a platelet shape. In various non-limiting embodiments, inorganic particles may comprise a platelet shape and have an aspect ratio, defined as the ratio of the average width dimension of the particles to the average thickness dimension of the particles, ranging from 5 to 100 microns, or any sub-range subsumed therein. In embodiments the inorganic particles have an average particle size ranging from 10 to 40 microns.

[0027] In embodiments, inorganic particles, such as, for example, mica, are dispersed in the cured coating layer. In embodiments the inorganic particles are mechanically stirred and/or mixed into the coatings, or added following creation of a slurry. A surfactant may or may not be needed to assist the mixing. In embodiments inorganic particles can be mixed until fully distributed without settling. Any suitable method may be used to prepare an appropriate dispersion.

[0028] In various non-limiting embodiments, a photovoltaic module may comprise a topcoat, a monocoat, and/or a primer formed from the coating compositions described in U.S. Patent Application Publication No. 2004/0244829 to Rearick et al., which is incorporated by reference into this specification in its entirety.

[0029] The coating at the outermost backing layer of a photovoltaic module in accordance with various embodiments described in this specification may comprise inorganic particles at a loading level ranging from greater than zero to 40 percent by weight of coatings solids, or any sub-range subsumed therein, such as, for example, 8 to 12 percent or about 10 percent. A primer in between a topcoat and photovoltaic cells and electrical interconnections may comprise inorganic particles at a loading level ranging from greater than zero to 40 percent by weight of coatings solids, or any sub-range subsumed therein, such as, for example, 8 to 12 percent or about 10 percent.

[0030] A coating layer comprising the outermost backing layer of a photovoltaic module in accordance with various embodiments described in this specification may have a maximum permeance value ranging from 0.1 to 1,000 g*mil/m²*day, or any sub-range subsumed therein, such as, for example, 1 to 500 g*mil/m²*day. A primer in between a topcoat and photovoltaic cells and electrical interconnections may have a maximum permeance value ranging from 0.1 to 1,000 g*mil/m²*day, or any sub-range subsumed therein, such as, for example, 1 to 500 g*mil/m²*day. In embodiments the permeance for the primer is less than that of the topcoat. A two- or more-layer protective coating system

comprising at least a topcoat and a primer may together have a maximum permeance value ranging from 0.1 to 1,000 g*mil/m²*day, or any sub-range subsumed therein, such as, for example, 1 to 500 g*mil/m²*day. A liquid potting material applied or otherwise adjacent to a front transparency may have a maximum permeance value ranging from 0.1 to 1,000 g*mil/m²*day.

[0031] Figure 3 illustrates a non-limiting and non-exhaustive embodiment of a process 300 for producing a photovoltaic module 390. Application of potting material at 340 to the front transparency 320 may comprise positioning a solid sheet of potting material, such as, for example, EVA, onto one side of the front transparency. In various other non-limiting embodiments, application of transparent potting material to the front transparency may comprise depositing a transparent liquid potting material or fluid encapsulant, such as, for example, a clear liquid encapsulant, onto one side of the front transparency.

[0032] Photovoltaic cells and electrical interconnections may be positioned or applied onto the potting material at 360. In various non-limiting embodiments, application of photovoltaic cells and electrical interconnections may comprise positioning bulk photovoltaic cells and electrical interconnections on the previously-applied potting material and pressing the positioned bulk photovoltaic cells and electrical interconnections into the potting material. Application can also include electrically connecting the cells and/or an assembly of cells. In embodiments the potting material is cured to secure the bulk photovoltaic cells and electrical interconnections in place and to the front transparency. In certain embodiments, electrically-interconnected bulk photovoltaic cells may be positioned and pressed into a layer of transparent liquid potting material applied to one side of a front transparency. The transparent liquid potting material can be cured to solidify the composition and secure the bulk photovoltaic cells and electrical interconnections in place and to the front transparency. In embodiments photovoltaic cells are positioned but not cured until after application of a protective coating system. In various other non-limiting embodiments, application of photovoltaic cells and electrical interconnections at 56 may comprise depositing layers of a thin-film photovoltaic cell onto the potting material.

[0033] A protective coating is applied or deposited on at least a portion of the photovoltaic cells at 380. In embodiments applying the protective coating comprises applying a topcoat. In embodiments the process of applying the protective coating further includes applying primer on all or a portion of the photovoltaic cells before applying the topcoat.

[0034] In various non-limiting embodiments, the one or more coats comprising a protective coating can be applied or deposited onto all or a portion of the photovoltaic cells and electrical interconnections and cured to form a coat or layer thereon (*e.g.*, topcoat, primer coat, tie coat, clearcoat, or the like) using any suitable coating application technique in any manner known to those of ordinary skill in the art. For example, the coatings of the present invention can be applied by electrocoating, spraying, electrostatic spraying, dipping, rolling, brushing, roller coating, curtain coated, flow coating, slot die coating process, extrusion, and the like. As used herein, the phrase “deposited on” or “deposited over” or “applied” to a front transparency, photovoltaic cell, or another coating, means deposited or provided above or over but not necessarily adjacent to the surface thereof. For example, a coating can be deposited directly upon the photovoltaic cells or one or more other coatings can be applied there between. A layer of coating can be typically formed when a coating that is deposited onto a photovoltaic cell or one or more other coatings is substantially cured or dried. In addition, in embodiments wherein a potting material comprises a liquid encapsulant applied to one side of a front transparency, the liquid encapsulant may be applied using any of the above-described coating application techniques.

[0035] The one or more applied coats may then form a coating system over all or at least a portion of a substrate and cured which, individually, as a single coat, or collectively, as more than one coat, comprise a protective barrier over at least a portion of the substrate. One such coat may be formed from a fluid encapsulant which cures to form a transparent partial or solid coat on at least a portion of a substrate (*i.e.*, a liquid potting material or clearcoat). In this regard, the term “cured,” as used herein, refers to the condition of a liquid coating composition in which a film or layer formed from the liquid coating composition is at least set-to-touch. As used herein, the terms “cure” and “curing” refer to the progression of a liquid coating composition from the liquid state to a cured state and encompass physical drying of coating compositions through solvent or carrier evaporation (*e.g.*, thermoplastic coating compositions) and/or chemical crosslinking of components in the coating compositions (*e.g.*, thermosetting coating compositions).

[0036] In certain embodiments, the application of a protective coat at 380 encapsulates the photovoltaic cells and electrical interconnections between the underlying potting material and the overlying protective coat, thereby producing a photovoltaic module at 390. In various non-limiting embodiments, one or more protective coats may be applied to encapsulate the photovoltaic cells and electrical interconnections between underlying potting material and the one or more protective coats. The topcoat may be cured to solidify the

topcoat and adhere the topcoat to the underlying components and material, thereby producing a protective coat over the photovoltaic cells and electrical interconnections. In various non-limiting embodiments, the two or more coatings comprising the protective coating system may be cured sequentially or, in some embodiments, the two or more coatings comprising the protective coating system may be applied wet-on-wet and cured simultaneously. Thereafter an overlying constituent coating composition can optionally be applied.

[0037] It is understood that in embodiments wherein the potting material 106 or 206 comprises a liquid composition applied to one side of the front transparency 102 or 202, the one or more protective coats (for example, coats 104 or 204 and/or 208) comprising the protective coating system 110 or 210 may be applied to encapsulate the photovoltaic cells 120 or 220 and the electrical interconnections (not shown) before curing the underlying potting material 106 or 206. In such embodiments, the underlying potting material and the overlying coats comprising the protective coating system may be cured simultaneously to secure and adhere the photovoltaic cells and electrical interconnections (not shown) to the front transparency. In addition, the photovoltaic cells and electrical interconnections (not shown) may be encapsulated between the underlying potting material and the overlying coats and comprising the protective coating system. In this manner, the potting material, the primer, and the topcoat may be applied wet-on-wet and then cured simultaneously. Alternatively, the coats 106, 108, and 104, for example, may be partially or fully cured sequentially before application of an overlying constituent coat or, in some embodiments, the potting material may be partially or fully cured before application of the protective coating system, and topcoat may be applied wet-on-wet to primer and the protective coating system may be cured simultaneously.

[0038] In embodiments the topcoat or a monocoat comprises a dry (cured) film thickness ranging from 0.2 to 25 mils, or any sub-range subsumed therein, such as, for example, 1 to 10 mils, or 5 to 8 mils. A primer in between a topcoat and photovoltaic cells, electrical interconnects, and exposed potting material may have a dry (cured) film thickness ranging from 0.2 to 10 mils, or any sub-range subsumed therein, such as, for example, 1 to 2 mils. A two- or more-layer protective coating system comprising at least a topcoat and a primer may together have a dry (cured) film thickness ranging from 0.5 to 25 mils, or any sub-range subsumed therein, such as, for example, 1 to 10 mils, or 5 to 8 mils. A liquid potting material applied to a front transparency may have a dry (cured) film thickness ranging from 0.2 to 25 mils, or any sub-range subsumed therein, such as, for example, 5 to 15 mils, or 8 to 10 mils.

[0039] Figures 4A through 4F schematically illustrate the production of a photovoltaic module comprising the application of a two-coat protective coating system comprising a primer and a topcoat. A front transparency 202 (*e.g.*, a glass or polyimide sheet) is provided in Figure 4A. Figure 4B shows a potting material 206 (*e.g.*, a positioned EVA sheet or a spray-coated fluid encapsulant) applied onto one side of the front transparency 202. In Figure 4C, photovoltaic cells 220 (*e.g.*, comprising crystalline silicon wafers) are shown being applied onto the potting material 206 (electrical interconnections are not shown for clarity). The photovoltaic cells 220 (and electrical interconnections, not shown) may be positioned on the potting material 206 and may be pressed into the potting material 206. The potting material 206 may be cured to secure the assembly of photovoltaic cells 220 (and electrical interconnections, not shown) in place and to the front transparency 202, as shown in Figure 4D. Figure 4E shows a primer 208 applied onto and coating the photovoltaic cells 220 and electrical interconnections (not shown). Figure 4F shows a topcoat 204 applied onto the primer 208, in which the topcoat 204 and the primer 208 together comprise a protective coating system 210.

[0040] Various non-limiting embodiments described in this specification may address certain disadvantages of the vacuum lamination processes in the production of photovoltaic modules. For example, it will be appreciated that the processes described in this specification may eliminate the lamination of preformed backsheets and back side potting material sheets to photovoltaic cells and front transparencies. In embodiments of the present disclosure, the preformed backsheets and back side potting materials may be replaced with protective coating systems comprising one or more applied coatings that provide comparable or superior encapsulation of the photovoltaic cells and electrical interconnections. In addition, the protective coating systems described in the present disclosure may provide one or more advantages to photovoltaic modules, such as good durability, moisture barrier, abrasion resistance, and the like. In embodiments of the present disclosure, traditional potting material encapsulant, such as EVA film, can be replaced with fluid encapsulant. In embodiments, traditional potting material can be replaced with fluid encapsulant, and the backsheets and back side potting materials may be replaced with protective coating systems comprising one or more applied coatings that provide comparable or superior encapsulation of the photovoltaic cells and electrical interconnections. In embodiments replacement of traditional potting material can eliminate the need for vacuum lamination.

[0041] Various embodiments are described and illustrated in this specification to provide an overall understanding of the structure, function, properties, and use of the

disclosed modules and processes. It is understood that the various embodiments described and illustrated in this specification are non-limiting and non-exhaustive. Thus, the invention is not limited by the description of the various non-limiting and non-exhaustive embodiments disclosed in this specification. The features and characteristics described in connection with various embodiments may be combined with the features and characteristics of other embodiments. Such modifications and variations are intended to be included within the scope of this specification. As such, the claims may be amended to recite any features or characteristics expressly or inherently described in, or otherwise expressly or inherently supported by, this specification. Further, Applicants reserve the right to amend the claims to affirmatively disclaim features or characteristics that may be present in the prior art. Therefore, any such amendments comply with written description support requirements. The various embodiments disclosed and described in this specification can comprise, consist of, or consist essentially of the features and characteristics as variously described herein.

[0042] In this specification, other than where otherwise indicated, all numerical parameters are to be understood as being prefaced and modified in all instances by the term "about", in which the numerical parameters possess the inherent variability characteristic of the underlying measurement techniques used to determine the numerical value of the parameter. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter described in this specification should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

[0043] Also, any numerical range recited in this specification is intended to include all sub-ranges of the same numerical precision subsumed within the recited range. For example, a range of "1.0 to 10.0" is intended to include all sub-ranges between (and including) the recited minimum value of 1.0 and the recited maximum value of 10.0, that is, having a minimum value equal to or greater than 1.0 and a maximum value equal to or less than 10.0, such as, for example, 2.4 to 7.6. Any maximum numerical limitation recited in this specification is intended to include all lower numerical limitations subsumed therein and any minimum numerical limitation recited in this specification is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicants reserve the right to amend this specification, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein. All such ranges are intended to be inherently described in this specification such that amending to expressly recite any such sub-ranges would comply with written description support requirements.

[0044] The grammatical articles "one", "a", "an", and "the", as used in this specification, are intended to include "at least one" or "one or more", unless otherwise indicated. Thus, the articles are used in this specification to refer to one or more than one (*i.e.*, to "at least one") of the grammatical objects of the article. By way of example, "a photovoltaic cell" means one or more photovoltaic cells, and thus, possibly, more than one photovoltaic cell is contemplated and may be employed or used in an implementation of the described embodiments. Further, the use of a singular noun includes the plural, and the use of a plural noun includes the singular, unless the context of the usage requires otherwise.

[0045] It should be understood that in certain embodiments described herein certain components and/or coats may be referred to as being "adjacent" to one another. In this regard, it is contemplated that adjacent is used as a relative term and to describe the relative positioning of layers, coats, photovoltaic cells, and the like comprising a photovoltaic module. It is contemplated that one coat or component may be either directly positioned or indirectly positioned beside another adjacent component or coat. In embodiments where one component or coat is indirectly positioned beside another component or coat, it is contemplated that additional intervening layers, coats, photovoltaic cells, and the like may be positioned in between adjacent components. Accordingly, and by way of example, where a first coat is said to be positioned adjacent to a second coat, it is contemplated that the first coat may be, but is not necessarily, directly beside and adhered to the second coat.

[0046] Any patent, publication, or other disclosure material identified herein is incorporated by reference into this specification in its entirety unless otherwise indicated, but only to the extent that the incorporated material does not conflict with existing definitions, statements, or other disclosure material expressly set forth in this specification. As such, and to the extent necessary, the express disclosure as set forth in this specification supersedes any conflicting material incorporated by reference herein. Any material, or portion thereof, that is said to be incorporated by reference into this specification, but which conflicts with existing definitions, statements, or other disclosure material set forth herein, is only incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material. Applicant(s) reserve the right to amend this specification to expressly recite any subject matter, or portion thereof, incorporated by reference herein.

[0047] The non-limiting and non-exhaustive examples that follow are intended to further describe various non-limiting and non-exhaustive embodiments without restricting the scope of the embodiments described in this specification.

EXAMPLES

Example-1

[0048] Photovoltaic modules comprising a protective coating system comprising a primer and a topcoat were evaluated under International standard IEC 61215, second edition, 2004-2005, "Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval." The photovoltaic modules comprising the protective coating system were compared to photovoltaic modules comprising an EVA copolymer back potting material and a polyvinyl fluoride backsheet (Tedlar® film, E. I. du Pont de Nemours and Company, Wilmington, Delaware, USA). All tested photovoltaic modules were obtained from Spire Corporation (Bedford, Massachusetts, USA) and comprised crystalline silicon photovoltaic cells and electrical interconnects (tabs and bus-bars) adhered to glass front transparencies with a sheet of laminated EVA copolymer front potting material.

[0049] The primary control modules were produced by vacuum laminating crystalline silicon solar cells in between a glass front transparency, a single sheet of EVA copolymer front potting material, a single sheet of EVA copolymer back potting material, and a polyvinyl fluoride backsheet, thereby encapsulating the crystalline silicon photovoltaic cells and electrical interconnects in EVA copolymer sandwiched between the glass and the backsheet. The experimental modules were produced by spray coating and curing a primer coat on the photovoltaic cells, electrical interconnecting components, and exposed EVA potting material, and then spray coating and curing a topcoat on the primer coat. The primer coats were applied using CA7502 epoxy primer (PRC-DeSoto International, Inc., Sylmar, California, USA). The topcoats were applied using Coraflon® DS-2508 polyamide epoxy fluoropolymer coating composition (PPG Industries, Inc., Pittsburgh, Pennsylvania, USA).

a. Visual Inspection - Test Procedure IEC 61215 - 10.1

[0050] Each experimental and control photovoltaic (*i.e.*, test) module was inspected for visual defects as described in IEC 61215 - 10.1.2. No cracked or broken cells were observed. The surfaces of the test modules were not tacky and no bonding or adhesion failures were found at potting material or coating interfaces. There was no delamination or bubbles. No faulty interconnections or electrical termination were found. In general, there were no observable conditions that would be expected to negatively affect performance.

b. Maximum Power Determination - Test Procedure IEC 61215 - 10.2

[0051] The maximum power (P_m) and the fill factor (FF) for each test module was measured using a solar simulator according to the standard procedures described in IEC 61215 - 10.2.3 and using simulated solar irradiance of 1 sun. Each test module was measured

before and after durability testing. P_m and FF were also measured at various time intervals during each test to monitor the performance progression.

c. Insulation Test – Test Procedure IEC 61215 - 10.3

[0052] Dry current leakage was determined for each test module according to the standard test procedures described in IEC 61215 - 10.3.4. Since the test modules contained only one photovoltaic cell and had a maximum system voltage that did not exceed 50 V, an applied voltage of 500 V was used for this test as described in IEC 61215 - 10.3.3c. All of the test modules passed the test requirements specified in IEC 61215 - 10.3.5, *i.e.*, insulation resistance not exceeding 400 M Ω , and 40 M Ω per m². This insulation test was performed before and after durability testing and at various time intervals during durability testing to monitor performance progression.

d. Damp Heat Test – Test Procedure IEC 61215 - 10.13

[0053] Durability to high temperature and high humidity exposure was determined by subjecting the test modules to the damp heat test procedure described in IEC 61215 - 10.13.2. The test modules were exposed to 85°C and 85% relative humidity for a period of 1000 hours. Test modules were withdrawn from the damp heat chamber for evaluation at time intervals of 330 hours and 660 hours to evaluate how module performance was affected over time throughout the duration of the test. The withdrawn modules were then returned to the damp heat chamber to continue exposure. Each of the test modules was tested in triplicate.

[0054] One experimental CA7502/Coraflon-coated test module and one primary control EVA/Tedlar® vacuum laminated test module were exposed to ambient, room temperature conditions for 1000 hours to provide secondary controls. Maximum power performance for these secondary control test modules was also measured at 330 hours and 660 hours to evaluate how much P_m performance measurement drifts due to random effects over time. The results of the testing are reported in Table 1 and shown in Figure 6.

Table 1 – P_M (mW)

<i>Test module</i>	<i>Test Conditions</i>	<i>Baseline</i>	<i>0 hours</i>	<i>330 hours</i>	<i>660 hours</i>	<i>1000 hours</i>
EVA / Tedlar laminated	ambient	1136	1142	1124	1093	1073
CA7502 / Coraflon coated	ambient	1130	1134	1119	1123	1100
EVA / Tedlar laminated	85°C 85% RH	1142	1142	1124	1093	1073
EVA / Tedlar laminated	85°C 85% RH	1134	1134	1119	1123	1100
EVA / Tedlar laminated	85°C 85% RH	1108	1108	1081	1079	1072
CA7502 / Coraflon coated	85°C 85% RH	1129	1120	1111	1107	1081
CA7502 / Coraflon coated	85°C 85% RH	1126	1121	1105	1109	1083
CA7502 / Coraflon coated	85°C 85% RH	1141	1122	1129	1129	1113

[0055] A slight downward drift in P_m performance over the 1000 hour test period was observed for test modules that were subjected to ambient conditions and not subjected to the damp heat conditions. In general, all test modules showed about 1100 mW of power at P_m . Experimental coated test modules showed approximately the same P_m output as the control EVA/Tedlar® laminated test modules (Table 1). Similar results were observed for fill factor measurements.

[0056] The control EVA/Tedlar® laminated test modules showed less than a 5% loss in maximum power output over the entire 1000 hour duration of the damp heat test. Similar results were observed for fill factor measurements. As shown in Figure 5, which plots the average of the triplicate P_m measurements for the experimental and primary control modules, as well as the ambient secondary controls, these changes appear to be within the random drift of the module performance as measured with the secondary control test modules that were not exposed to the damp heat conditions.

[0057] Experimental coated test modules exhibited stable maximum power output after 1000 exposure hours in the damp heat test. Comparison of both power output performance and fill factor of the experimental coated test modules and the control laminated test modules showed that the CA7502/Coraflon® coating system exhibited stable damp heat test durability, which was generally similar to the performance of the control EVA/Tedlar® vacuum laminated test modules.

[0058] Visual inspection of the primary control laminated test modules showed significant levels of corrosion along the metal tabbing and bus-bars. This corrosion was evident from dark brown and yellow spots and marking along the metal electrical

interconnecting materials. In contrast, visual inspection of the experimental coated test modules showed no bus-bar corrosion. These results indicate that protective coating systems can reduce metal corrosion in photovoltaic modules as compared to conventional vacuum laminated systems while maintaining similar maximum power output performance.

e. Thermal Cycling Test – Test Procedure IEC 61215 - 10.11

[0059] The durability of the test modules to thermal cycling between -40°C and 85°C was evaluated by subjecting the test modules to the thermal cycling test procedure described in IEC 61215 - 10.11.3. An additional set of experimental coated test modules comprising a DP40LF epoxy primer coat (PPG Industries, Inc., Pittsburgh, Pennsylvania, USA) and a Coraflon® DS-2508 polyamide epoxy fluoropolymer topcoat were also tested. The thermal cycling was repeated for 50 cycles. Test modules were analyzed after all 50 cycles were completed; no analysis was performed at intermediate cycling intervals. Each of the test modules was tested in triplicate. The results of the testing are reported in Table 2.

Table 2 – P_M (mW)

<i>Test module</i>	<i>Test Conditions</i>	<i>Baseline</i>	<i>After 50 cycles</i>
EVA / Tedlar laminated	50 cycles @ -40°C/+85°C	1119	1090
EVA / Tedlar laminated	50 cycles @ -40°C/+85°C	1095	1080
EVA / Tedlar laminated	50 cycles @ -40°C/+85°C	1142	1120
CA7502 / Coraflon coated	50 cycles @ -40°C/+85°C	1125	1111
CA7502 / Coraflon coated	50 cycles @ -40°C/+85°C	1137	912
CA7502 / Coraflon coated	50 cycles @ -40°C/+85°C	1091	989
DP40LF / Coraflon coated	50 cycles @ -40°C/+85°C	1075	1030
DP40LF / Coraflon coated	50 cycles @ -40°C/+85°C	1125	1106
DP40LF / Coraflon coated	50 cycles @ -40°C/+85°C	1078	1062

[0060] The control laminated test modules showed good durability in the thermal cycling test. The mean output power from the three control test modules decreased by less than 2% after 50 thermal cycles. Similarly, the experimental coated test modules comprising the DP40LF primer coat / Coraflon® topcoat system showed about a 2% reduction in mean output power after 50 thermal cycles. Fill factor data showed similar results.

[0061] The experimental coated test modules comprising the CA7502 primer coat / Coraflon® topcoat system showed mixed results after 50 cycles with variation between the triplicate test modules. Like the laminated control and DP40LF/Coraflon® test modules, one

CA7502/Coraflon®-coated test module retained over 98% of its initial power output. Another CA7502/Coraflon®-coated test module retained about 91% of its initial power output. A third CA7502/Coraflon®-coated test module retained about 80% of its initial power output.

f. Humidity Freeze Test – Test Procedure IEC 61215 - 10.12

[0062] The durability of the test modules to thermal cycling between -40°C and 85°C with 85% relative humidity was evaluated by subjecting the test modules to the thermal cycling test procedure described in IEC 61215 - 10.12.3. An additional set of experimental coated test modules comprising a DP40LF epoxy primer coat and a Coraflon® DS-2508 polyamide epoxy fluoropolymer topcoat were also tested. The thermal cycling was repeated for 10 cycles. Test modules were analyzed after all 10 cycles were completed; no analysis was performed at intermediate cycling intervals. Each of the test modules was tested in triplicate. The results of the testing are reported in Table 3.

Table 3 – P_M (mW)

<i>Test module</i>	<i>Test Conditions</i>	<i>Baseline</i>	<i>After 10 cycles</i>
EVA / Tedlar laminated	50 cycles @ -40°C/+85°C; 85% RH	1119	1067
EVA / Tedlar laminated	50 cycles @ -40°C/+85°C; 85% RH	1095	1087
EVA / Tedlar laminated	50 cycles @ -40°C/+85°C; 85% RH	1142	1118
CA7502 / Coraflon coated	50 cycles @ -40°C/+85°C; 85% RH	1125	1102
CA7502 / Coraflon coated	50 cycles @ -40°C/+85°C; 85% RH	1137	842
CA7502 / Coraflon coated	50 cycles @ -40°C/+85°C; 85% RH	1091	938
DP40LF / Coraflon coated	50 cycles @ -40°C/+85°C; 85% RH	1075	954
DP40LF / Coraflon coated	50 cycles @ -40°C/+85°C; 85% RH	1125	1041
DP40LF / Coraflon coated	50 cycles @ -40°C/+85°C; 85% RH	1078	986

[0063] The control laminated test modules exhibited good durability with over 99% of mean output power retained for the three control modules after 10 cycles. Experimental test modules coated with the DP40LF/Coraflon® system retained 97% of mean output power. Experimental test modules coated with the CA7502/Coraflon® system exhibited mixed results after 10 cycles with variation between the three triplicate test modules. One test module retained over 99% of its initial power output. Another test module retained about 92% of its initial power output. A third test module retained about 95% of its initial power output.

Example-2

[0064] The moisture barrier properties of three primer coating compositions, two top coating compositions; and various two-layer systems of the primer coating and top coating compositions were measured and compared against the moisture barrier properties of EVA copolymer potting material films and polyvinyl fluoride backsheets. The tested materials are listed in Table 4. The as-received EVA copolymer film had a measured permeance of 458 g*mil/m²*day, and EVA copolymer material that had undergone a vacuum lamination process had a measured permeance of 399 g*mil/m²*day. The as-received Tedlar® backsheet material had a measured permeance of 30 g*mil/m²*day. The coating compositions were cast and cured to form freestanding films (single-layer films or two-layer films). The results for the various cast coating films are reported in Table 5.

Table 4 – Tested Materials

<i>Material</i>	<i>Description</i>	<i>Supplier</i>
EVA co-polymer	potting material film	Spire, Massachusetts, USA
Tedlar®	polyvinyl fluoride backsheet material	E. I. du Pont de Nemours and Company, Wilmington, Delaware, USA
DP40LF	epoxy primer coating	PPG Industries, Inc., Pittsburgh, Pennsylvania, USA
CA7502	epoxy primer coating	PRC-DeSoto International, Inc., Sylmar, California, USA
CA7755	epoxy primer coating	PRC-DeSoto International, Inc., Sylmar, California, USA
Coraflon® DS-2508	polyamide epoxy fluoropolymer top coating	PPG Industries, Inc., Pittsburgh, Pennsylvania, USA
Pitthane® Ultra	acrylic aliphatic urethane top coating	PPG Industries, Inc., Pittsburgh, Pennsylvania, USA

Table 5
Moisture Vapor Transfer Rate (MVTR, g/m²*day);
Dry Film Thickness (DFT, mils);
Permeance (g*mil/m²*day)

Primer coat	Cure Time (hr)	Cure Temp (°F)	Topcoat								
			none			Corafalon			Pitthane		
			MVTR	DFT	Permeance	MVTR	DFT	Permeance	MVTR	DFT	Permeance
none	168	r.t.	--	--	--	35	1.9	68	82	1.9	162
none	0.5	140	--	--	--	25	2.0	49	91	1.8	166
none	0.5	250	--	--	--	24	1.8	44	71	2.0	141
DP50LF	168	r.t.	35	1.3	45	11	4.0	46	21	3.2	67
DP50LF	0.5	140	34	1.2	39	10	3.8	38	16	3.3	52
DP50LF	0.5	250	19	1.2	23	7.3	3.7	27	14	3.0	42
CA7502	168	r.t.	16	1.9	29	10	3.1	30	--	--	--
CA7502	0.5	140	12	1.9	23	7	3.1	21	--	--	--
CA7502	0.5	250	7	2.0	14	7	3.0	21	--	--	--
CA7755	168	r.t.	20	1.9	26	10	2.9	31	--	--	--
CA7755	0.5	140	12	1.9	23	8	3.1	25	--	--	--
CA7755	0.5	250	13	1.2	15	7	2.8	20	--	--	--

[0065] Permeance values of freestanding films for each individual coating, as well as each two-layer primer/topcoat configuration, were lower than the permeance values for EVA copolymer film, and in most cases, the coating permeance values were an order of magnitude lower than EVA copolymer film. Most of the coatings and coating systems that were evaluated exhibited permeance values similar to that of Tedlar® backsheet material.

[0066] Lower permeance values were achieved using higher cure temperatures and shorter cure times. This is consistent with the concept that higher crosslink density is achieved at higher cure temperatures, and that higher crosslink density increases film resistance to moisture permeation. Permeance values for primer/topcoat two-layer films were similar to permeance values for the corresponding primer single-layer film. This appears to indicate that the primer may be the major contributor to barrier properties in an encapsulating coating system for photovoltaic modules, which is unique given that EVA copolymer potting films used in conventional photovoltaic modules exhibit very poor barrier properties and, therefore, both exterior durability and barrier properties are provided by the backsheet. A primer/topcoat photovoltaic module encapsulating system, in accordance with various embodiments described in this specification, positions a corrosion inhibiting coating with

good barrier properties directly into a photovoltaic cell matrix, which may improve corrosion resistance and durability.

Example-3

[0067] The moisture barrier properties of two primer coating compositions, one top coating composition; and a two-layer system of a primer coating and a top coating composition were measured with and without the addition of mica at various loading levels. The tested materials are listed in Table 6. The coating compositions (with and without mica additions) were cast and cured to form freestanding films (single-layer films or two-layer films) and the moisture vapor transmission rates and permeance values of the films were measured. Two types of mica were utilized: as-received and after surface treatment with a coupling agent. (The coating/surface treatment was performed by a third party, Aculon, Inc.). The results for the various cast coating films are reported in Tables 7 and 8 and shown in Figures 6A and 6B.

Table 6 – Tested Materials

<i>Material</i>	<i>Description</i>	<i>Supplier</i>
DP40LF	epoxy primer coating	PPG Industries, Inc., Pittsburgh, Pennsylvania, USA
CA7502	epoxy primer coating	PRC-DeSoto International, Inc., Sylmar, California, USA
Coraflon® DS-2508	polyamide epoxy fluoropolymer top coating	PPG Industries, Inc., Pittsburgh, Pennsylvania, USA
Sun Mica	particulate mica	Sun Chemical, USA

Table 7 – Permeance (g*mil/m²*day)

		<i>Mica level (weight percent in coating solids)</i>	
<i>Coating Film</i>	<i>Mica</i>	<i>0 %</i>	<i>10 %</i>
DP40LF mono-layer	Untreated	27	23
DP40LF mono-layer	Treated	27	19
CA7502 mono-layer	Untreated	14	10
CA7502 mono-layer	Treated	14	12
Coraflon mono-layer	Untreated	52	53
Coraflon mono-layer	Treated	52	28
DP40LF/Coraflon two-layer	Untreated	29	22
DP40LF/Coraflon two-layer	Treated	29	21

Table 8 – Permeance (g*mil/m²*day)

		<i>Mica level (weight percent in coating solids)</i>			
<i>Coating Film</i>	<i>Mica</i>	<i>0 %</i>	<i>10 %</i>	<i>15 %</i>	<i>20 %</i>
Coraflon mono-layer	Untreated	52	53	34	25
Coraflon mono-layer	Treated	52	28	25	26
DP40LF/Coraflon two-layer	Untreated	29	22	23	23
DP40LF/Coraflon two-layer	Treated	29	21	28	17

[0068] The effectiveness of both treated and untreated mica as an additive was evaluated in both topcoats and primer coats. Mica loading in Coraflon® freestanding films was varied from 0 to 20 weight percent (Table 7 and Figure 6B). Results show that adding mica can reduce permeance by as much as 50% at higher loading levels. Surface-treated mica appears to decrease permeance by 45% at 10 wt% loading based on coating solids, while untreated mica required 20 wt% loading to achieve similar moisture vapor barrier performance. The moisture vapor permeance of a DP40LF/Coraflon® two-layer film without added mica equaled the best results for a Coraflon® mono-layer film with added mica. The addition of mica to Coraflon® in the primer/topcoat system reduced permeance by about 25%. The addition of 20 wt% treated mica resulted in permeance values for the primer/topcoat system that were nearly half the permeance values of Tedlar® backsheets, *i.e.*, 17 g*mil/m²*day compared to 30 g*mil/m²*day.

[0069] The benefit of adding mica to primer coats is somewhat different than that observed with Coraflon® topcoats. For DP40LF primer coat, adding 10% untreated mica by

weight of coating solids content reduced permeance by 15% (Table 6 and Figure 6A). The addition of treated mica to DP40LF primer coat reduced permeance by over 30%. The addition of 10 weight percent untreated mica produced a 32% reduction in moisture vapor permeance for CA7502 primer film. The addition of 10 weight percent treated mica reduced the permeance of CA7502 primer film by 18%.

[0070] These results show that the addition of inorganic particulate materials, such as, for example, mica, to coating compositions produces protective coating systems that provide improved barrier properties for photovoltaic module encapsulation.

[0071] As described in the present disclosure, certain embodiments presented herein may address one or more disadvantages associated with the use of a vacuum lamination processes for the production of photovoltaic modules possess. For example, as set forth herein, the present processes may allow for continuous processing and improved production efficiency with the elimination of one or more vacuum lamination steps, as these latter processes are batch or semi-batch and labor-intensive. In addition, certain processes described herein may allow for the reduction or elimination of vacuum lamination apparatus required to perform the vacuum lamination process, thereby reducing or eliminating capital-intensive equipment that significantly increases production time and costs. Furthermore, the application of vacuum pressure and compression pressure to laminate the photovoltaic cells in between the front transparency and the backsheet induces large mechanical stresses on the photovoltaic semiconducting material wafers comprising bulk photovoltaic cells. The semiconducting materials (*e.g.*, crystalline silicon) are generally brittle and the constituent wafers can break under the induced mechanical stresses during the vacuum lamination process. This breakage problem is exacerbated when attempting to produce photovoltaic modules comprising relatively thin wafers, which more easily break under the mechanical stresses inherent in the vacuum lamination process. Elimination of vacuum lamination may reduce the mechanical stresses involved in the production process. Furthermore, elimination of the lamination of pre-formed backsheets and back side potting material sheets to a photovoltaic cell/front glass may decrease the mass and volume of the resultant photovoltaic module. In addition, the coating compositions and their related coating systems or configurations of the present disclosure may provide one or more advantages, such as good durability, moisture barrier, abrasion resistance, and the like.

[0072] This specification has been written with reference to various non-limiting and non-exhaustive embodiments. However, it will be recognized by persons having ordinary skill in the art that various substitutions, modifications, or combinations of any of the

disclosed embodiments (or portions thereof) may be made within the scope of this specification. Thus, it is contemplated and understood that this specification supports additional embodiments not expressly set forth herein. Such embodiments may be obtained, for example, by combining, modifying, or reorganizing any of the disclosed steps, step sequences, components, elements, features, aspects, characteristics, limitations, and the like, of the various non-limiting embodiments described in this specification. In this manner, Applicant(s) reserve the right to amend the claims during prosecution to add features as variously described in this specification, and such amendments comply with written description support requirements.

What is claimed is:

1. A photovoltaic module comprising:
a front transparency;
a potting material deposited on at least a portion of the front transparency;
electrically interconnected photovoltaic cells applied to the potting material; and
a topcoat deposited on at least a portion of the electrically interconnected photovoltaic cells.
2. The photovoltaic module of claim 1, wherein the topcoat comprises inorganic particles.
3. The photovoltaic module of claim 2, wherein the inorganic particles comprise a particulate mineral composition.
4. The photovoltaic module of claim 2, wherein the inorganic particles comprise mica.
5. The photovoltaic module of claim 2, wherein the inorganic particles have an average particle size ranging from 1 to 100 microns.
6. The photovoltaic module of claim 1, wherein the potting material comprises ethylene vinyl acetate copolymer film positioned between the front transparency and the electrically interconnected photovoltaic cells.
7. The photovoltaic module of claim 1, wherein the potting material is laminated to the front transparency and electrically interconnected photovoltaic cells.
8. The photovoltaic module of claim 1, wherein the potting material comprises a fluid encapsulant.
9. The photovoltaic module of claim 1, wherein the photovoltaic cells comprise crystalline silicon wafers.

10. The photovoltaic module of claim 1, wherein the topcoat comprises a polyepoxide and polyamine.
11. The photovoltaic module of claim 1, wherein the topcoat comprises a fluorine-containing polymer.
12. The photovoltaic module of claim 1, further comprising a primer positioned between the topcoat and the electrically interconnected photovoltaic cells.
13. The photovoltaic module of claim 12, wherein the primer comprises a polyepoxide and polyamine.
14. The photovoltaic module of claim 12, wherein the topcoat comprises a polyepoxide and polyamine comprising a fluorine-containing polymer.
15. The photovoltaic module of claim 12, wherein the primer coat comprises inorganic particles.
16. The photovoltaic module of claim 15, wherein the inorganic particles comprise mica.
17. A method for preparing a photovoltaic module comprising:
 - applying potting material on at least a portion of a front transparency;
 - applying photovoltaic cells onto the potting material wherein the cells are electrically interconnected;
 - laminating the potting material and the photovoltaic cells;
 - applying a topcoat on at least a portion of the photovoltaic cells; and
 - curing the topcoat.
18. The method of claim 17, further comprising applying a primer on at least a portion of the photovoltaic cells and electrical interconnections, and applying the topcoat onto the primer.
19. The method of claim 17, further comprising curing the primer before applying the topcoat.

20. The method of claim 17, comprising applying the topcoat onto the primer wet-on-wet, and simultaneously curing the primer and the topcoat.
21. A method for preparing a photovoltaic module comprising:
applying clear liquid encapsulant on at least a portion of a front transparency;
applying photovoltaic cells and electrical interconnections onto the potting material, wherein the cells are electrically interconnected;
applying a topcoat on at least a portion of the photovoltaic cells and electrical interconnections; and
curing the topcoat.
22. The method of claim 21, further comprising curing the clear liquid encapsulant after applying the photovoltaic cells and electrical interconnections and before applying the topcoat.
23. The method of claim 21, further comprising simultaneously curing the clear liquid encapsulant and the topcoat.
24. The method of claim 21, further comprising applying a primer on at least a portion of the photovoltaic cells and electrical interconnections, and applying the topcoat onto the primer.
25. The method of claim 21, wherein production of the photovoltaic module is free of vacuum lamination operations.
26. A photovoltaic module prepared in accordance with the method of claim 21.

1/7

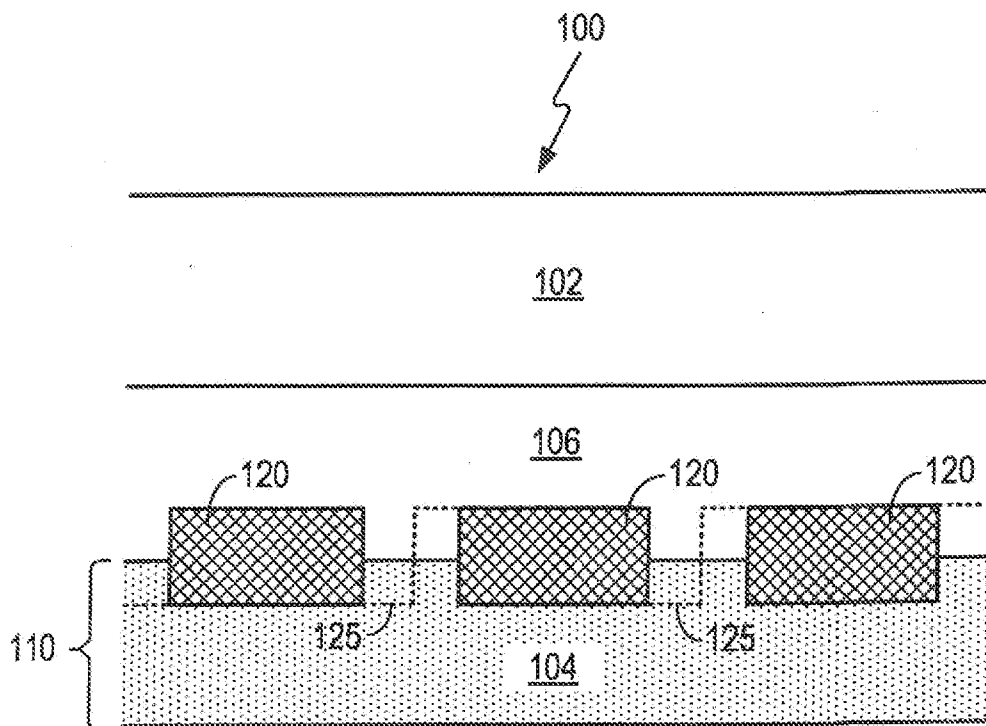


FIG. 1

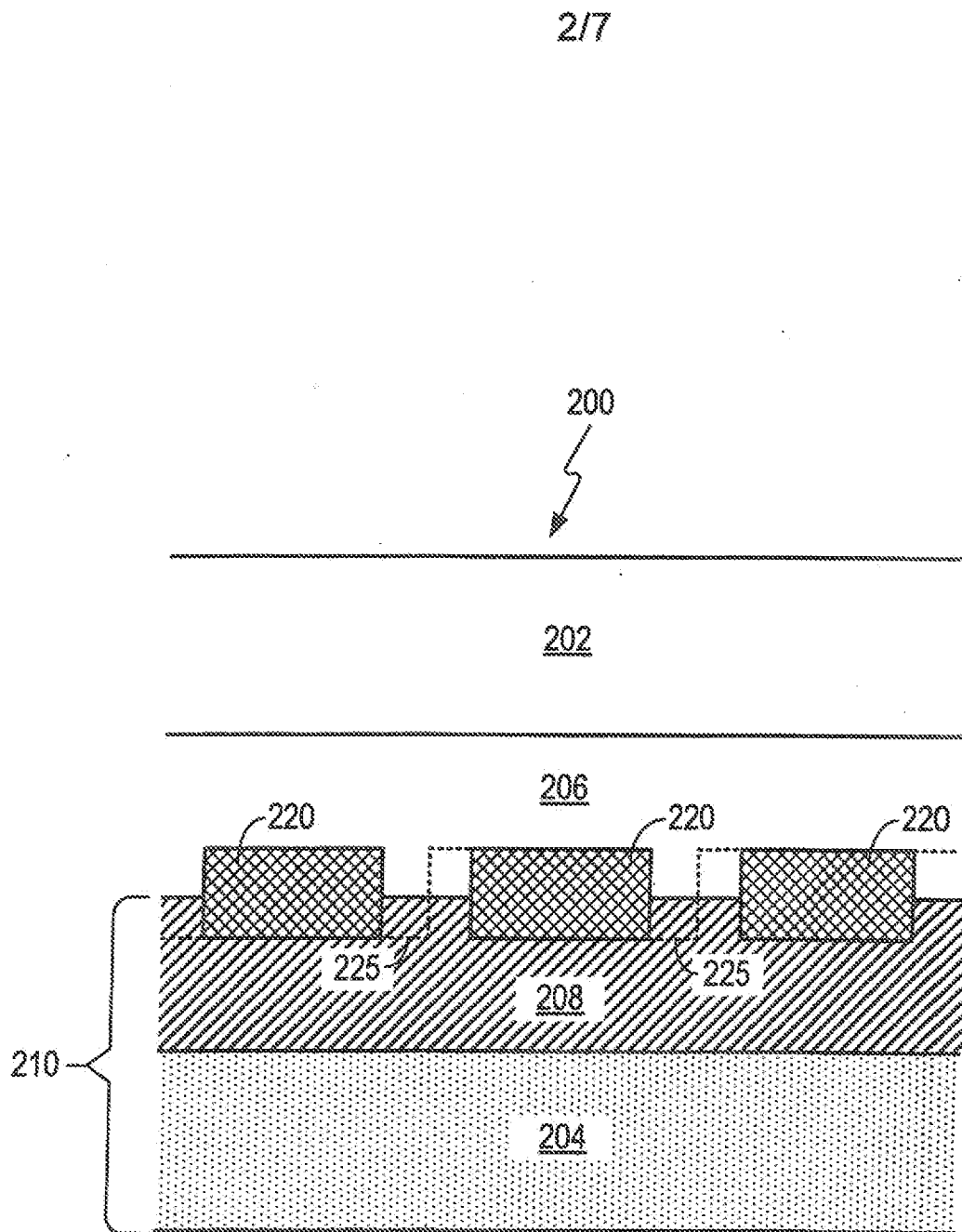


FIG. 2

3/7

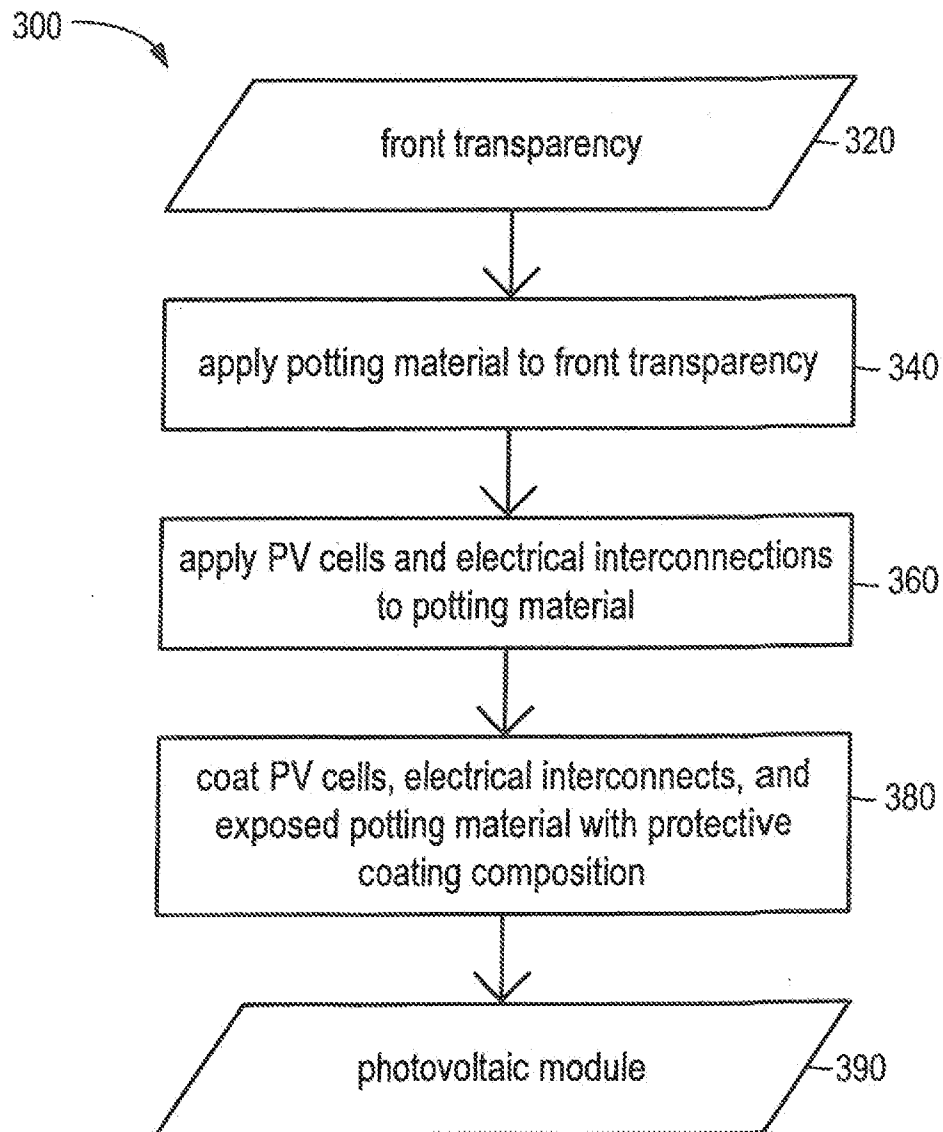


FIG. 3

FIG. 4A



FIG. 4B

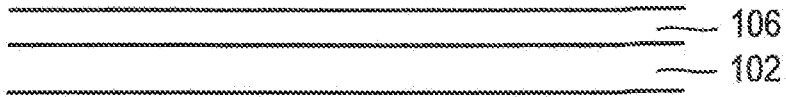


FIG. 4C

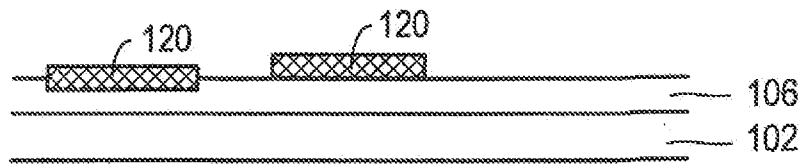


FIG. 4D

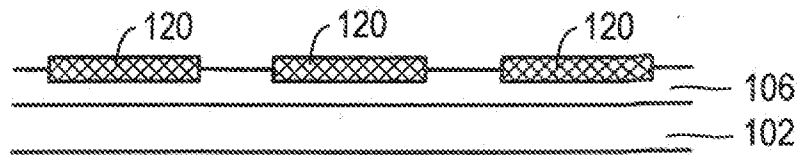


FIG. 4E

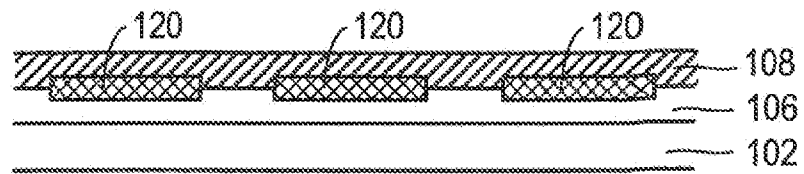
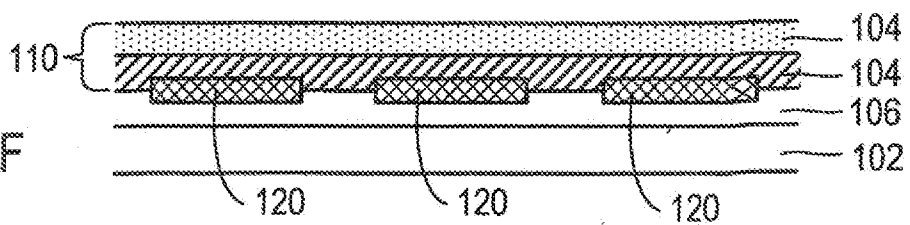


FIG. 4F



5/7

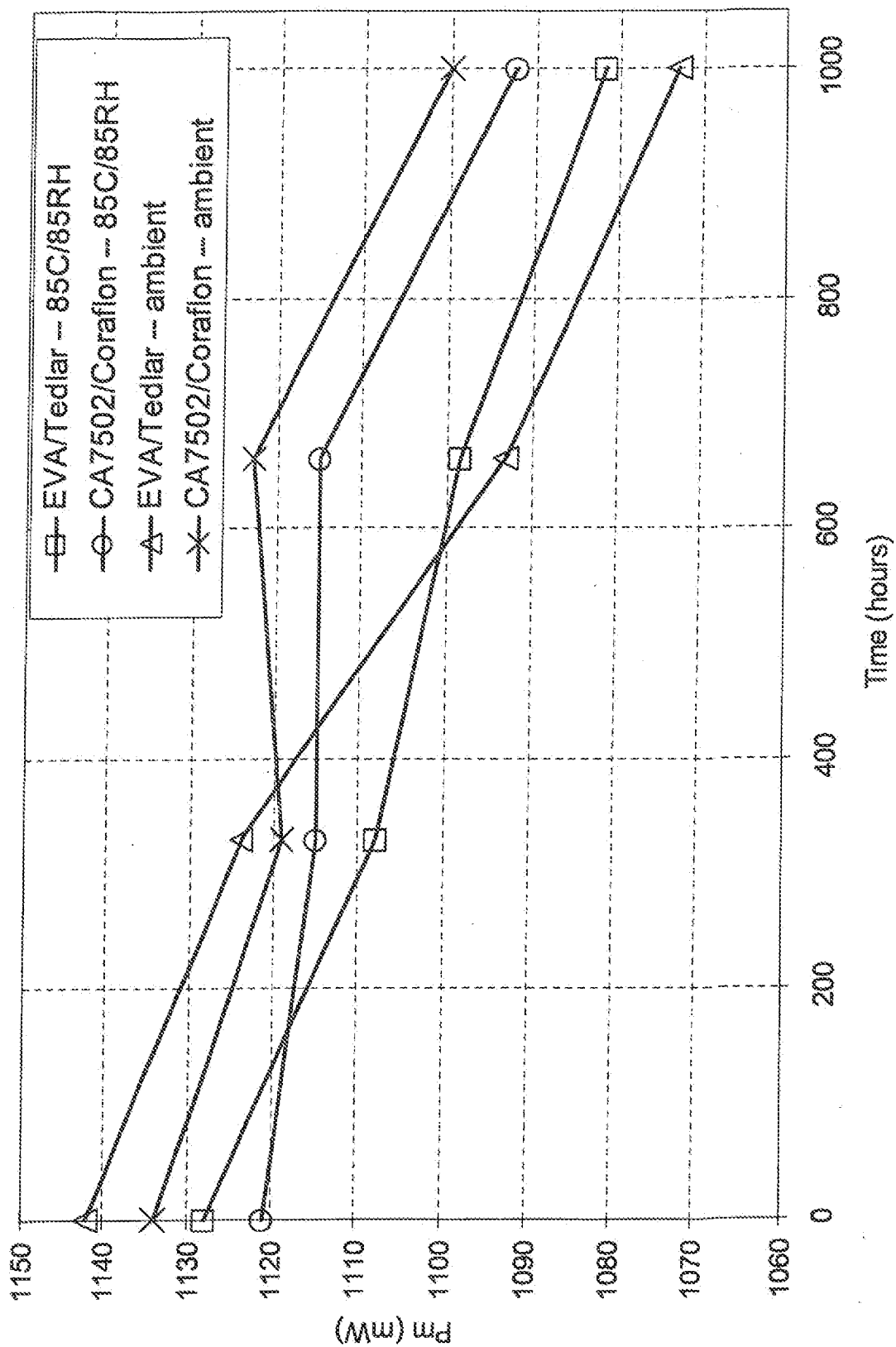


FIG. 5

6/7

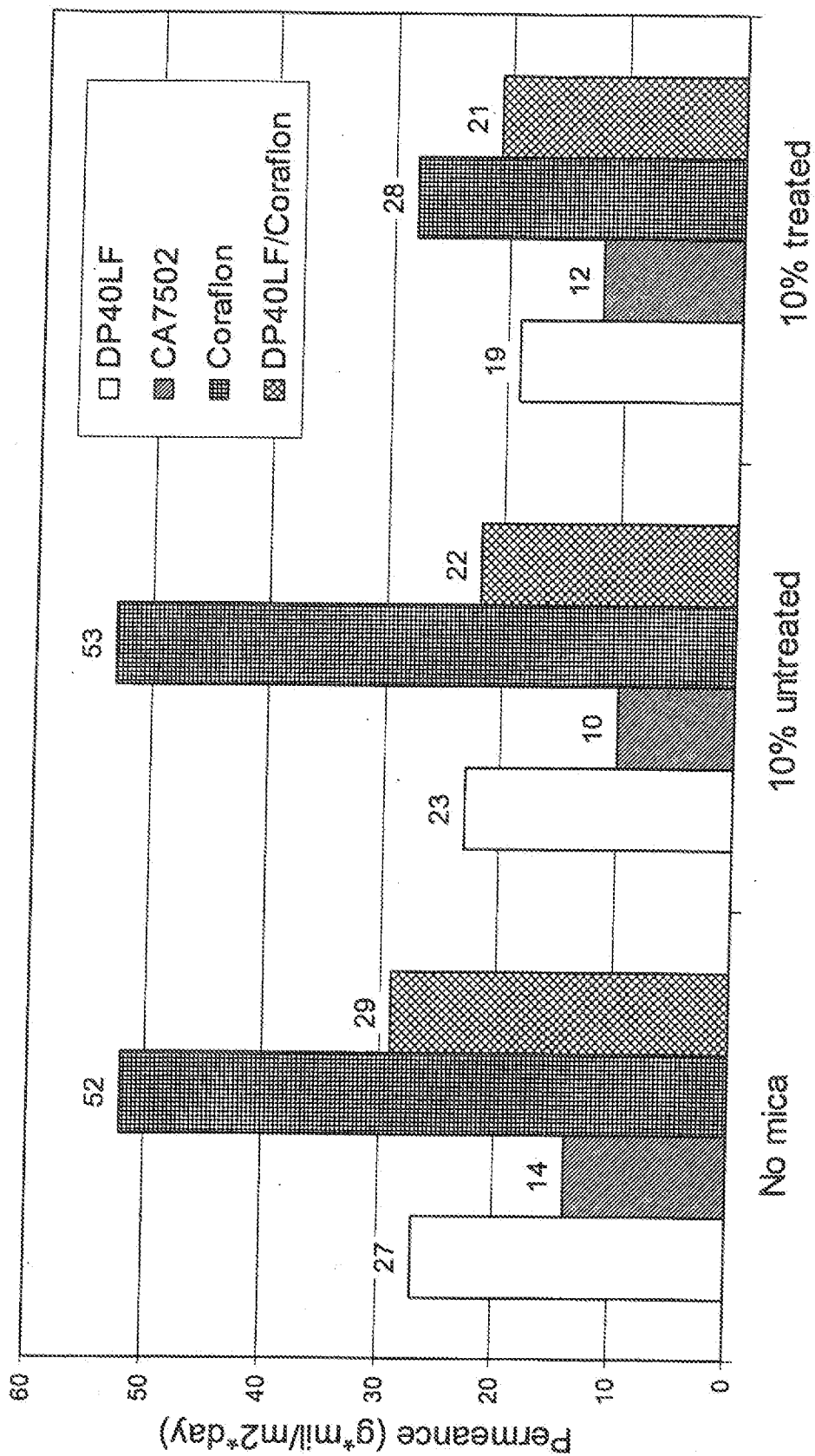


FIG. 6A

7/7

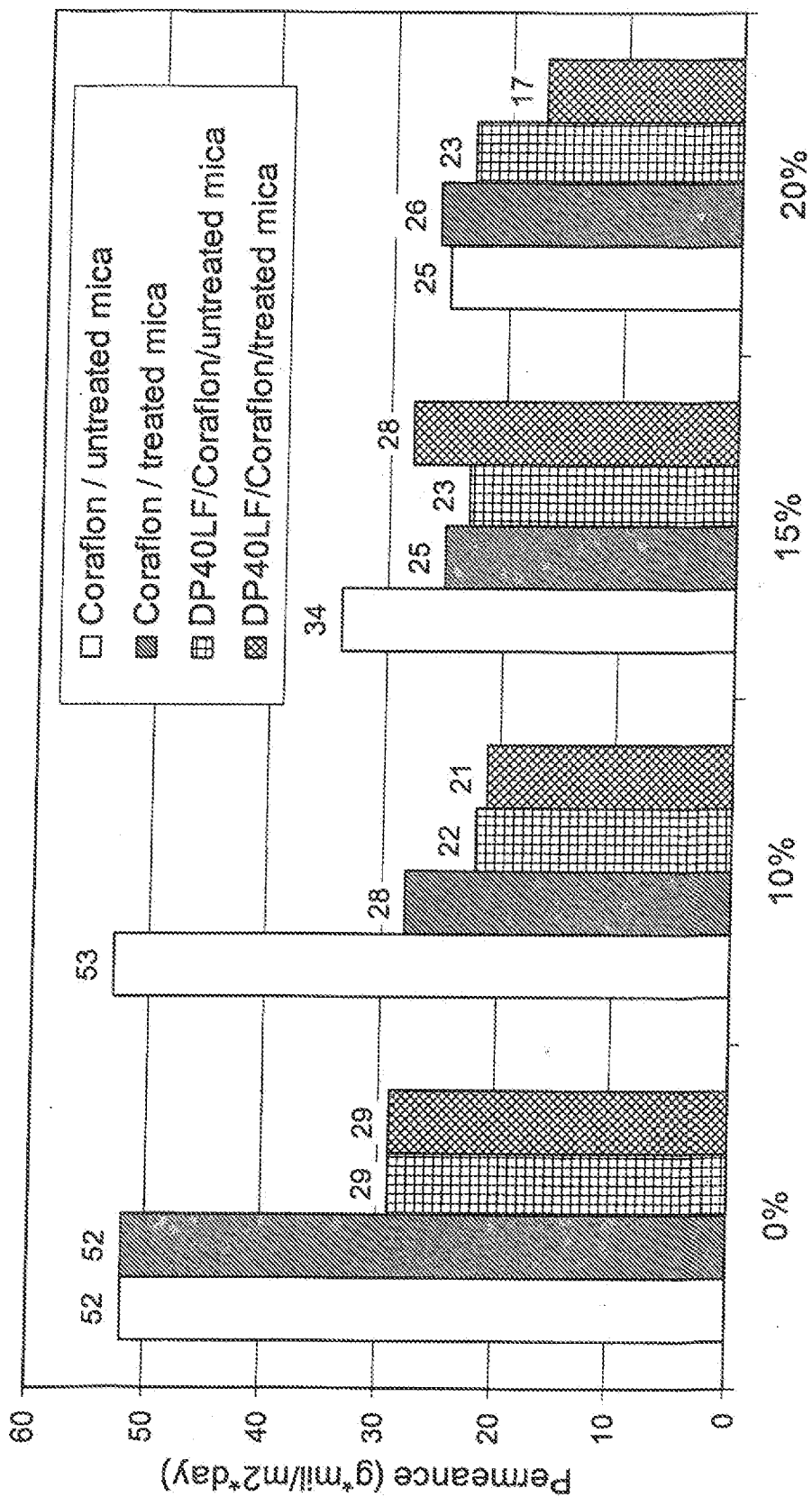


FIG. 6B