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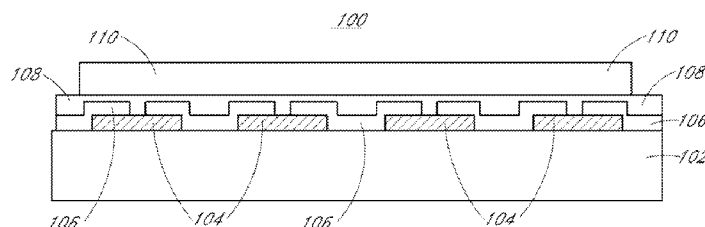


FIG. 1

(57) Abstract: Thermocompression bonding approaches for foil-based metallization of non-metal surfaces of solar cells, and the resulting solar cells, are described. For example, a solar cell includes a substrate and a plurality of alternating N-type and P-type semiconductor regions disposed in or above the substrate. A plurality of conductive contact structures is electrically connected to the plurality of alternating N-type and P-type semiconductor regions. Each conductive contact structure includes a metal foil portion disposed in direct contact with a corresponding one of the alternating N-type and P-type semiconductor regions.



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THERMOCOMPRESSION BONDING APPROACHES FOR FOIL-BASED METALLIZATION OF NON-METAL SURFACES OF SOLAR CELLS

TECHNICAL FIELD

[0001] Embodiments of the present disclosure are in the field of renewable energy and, in particular, include approaches for foil-based metallization of non-metal surfaces of solar cells.

BACKGROUND

[0002] Photovoltaic cells, commonly known as solar cells, are well known devices for direct conversion of solar radiation into electrical energy. Generally, solar cells are fabricated on a semiconductor wafer or substrate using semiconductor processing techniques to form a p-n junction near a surface of the substrate. Solar radiation impinging on the surface of, and entering into, the substrate creates electron and hole pairs in the bulk of the substrate. The electron and hole pairs migrate to p-doped and n-doped regions in the substrate, thereby generating a voltage differential between the doped regions. The doped regions are connected to conductive regions on the solar cell to direct an electrical current from the cell to an external circuit coupled thereto.

[0003] Efficiency is an important characteristic of a solar cell as it is directly related to the capability of the solar cell to generate power. Likewise, efficiency in producing solar cells is directly related to the cost effectiveness of such solar cells. Accordingly, techniques for increasing the efficiency of solar cells, or techniques for increasing the efficiency in the manufacture of solar cells, are generally desirable. Some embodiments of the present disclosure allow for increased solar cell manufacture efficiency by providing novel processes for fabricating solar cell structures. Some embodiments of the present disclosure allow for increased solar cell efficiency by providing novel solar cell structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1 illustrates a cross-sectional view of a solar cell including a metal seed layer.

[0005] Figure 2 illustrates a cross-sectional view of a solar cell omitting an intervening metal seed layer, in accordance with an embodiment of the present disclosure.

[0006] Figure 3A illustrates a cross-sectional and magnified view of an initial interface between a texturized metal foil and a BARC layer of a solar cell, in accordance with an embodiment of the present disclosure.

[0007] Figure 3B illustrates a cross-sectional and magnified view of bonding interface between a texturized metal foil and a BARC layer of a solar cell where the bonding is performed using a roller, in accordance with an embodiment of the present disclosure.

[0008] Figure 3C illustrates a cross-sectional and magnified view of bonding interface between a texturized metal foil and a BARC layer of a solar cell where the bonding is performed using a pressure plate, in accordance with an embodiment of the present disclosure.

[0009] Figure 4 is a magnified optical image of a texturized aluminum metal foil in accordance with an embodiment of the present disclosure.

[0010] Figure 5 is a flowchart representing various operations in a method of fabricating a solar cell, in accordance with an embodiment of the present disclosure.

[0011] Figures 6A and 6B illustrate angled views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with an embodiment of the present disclosure.

[0012] Figures 7A-7C illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0013] The following detailed description is merely illustrative in nature and is not intended to limit the embodiments of the subject matter or the application and uses of such embodiments. As used herein, the word “exemplary” means “serving as an example, instance, or illustration.” Any implementation described herein as exemplary is not necessarily to be construed as preferred or advantageous over other implementations. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

[0014] This specification includes references to “one embodiment” or “an embodiment.” The appearances of the phrases “in one embodiment” or “in an embodiment” do not necessarily refer to the same embodiment. Particular features, structures, or characteristics may be combined in any suitable manner consistent with this disclosure.

[0015] Terminology. The following paragraphs provide definitions and/or context for terms found in this disclosure (including the appended claims):

[0016] “Comprising.” This term is open-ended. As used in the appended claims, this term does not foreclose additional structure or steps.

[0017] “Configured To.” Various units or components may be described or claimed as “configured to” perform a task or tasks. In such contexts, “configured to” is used to connote structure by indicating that the units/components include structure that performs those task or tasks during operation. As such, the unit/component can be said to be configured to perform the task even when the specified unit/component is not currently operational (e.g., is not on/active).

Reciting that a unit/circuit/component is “configured to” perform one or more tasks is expressly intended not to invoke 35 U.S.C. §112, sixth paragraph, for that unit/component.

[0018] “First,” “Second,” etc. As used herein, these terms are used as labels for nouns that they precede, and do not imply any type of ordering (e.g., spatial, temporal, logical, etc.). For example, reference to a “first” solar cell does not necessarily imply that this solar cell is the first solar cell in a sequence; instead the term “first” is used to differentiate this solar cell from another solar cell (e.g., a “second” solar cell).

[0019] “Coupled” – The following description refers to elements or nodes or features being “coupled” together. As used herein, unless expressly stated otherwise, “coupled” means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically.

[0020] In addition, certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as “upper”, “lower”, “above”, and “below” refer to directions in the drawings to which reference is made. Terms such as “front”, “back”, “rear”, “side”, “outboard”, and “inboard” describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import.

[0021] “Inhibit” – As used herein, inhibit is used to describe a reducing or minimizing effect. When a component or feature is described as inhibiting an action, motion, or condition it may completely prevent the result or outcome or future state completely. Additionally, “inhibit” can also refer to a reduction or lessening of the outcome, performance, and/or effect which might otherwise occur. Accordingly, when a component, element, or feature is referred to as inhibiting a result or state, it need not completely prevent or eliminate the result or state.

[0022] Thermocompression bonding approaches for foil-based metallization of non-metal surfaces of solar cells, and the resulting solar cells, are described herein. In the following description, numerous specific details are set forth, such as specific process flow operations, in order to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to one skilled in the art that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known fabrication techniques, such as emitter region fabrication techniques, are not described in detail in order to not unnecessarily obscure embodiments of the present disclosure. Furthermore, it is to be understood that the various embodiments shown in the figures are illustrative representations and are not necessarily drawn to scale.

[0023] Disclosed herein are solar cells. In one embodiment, a solar cell includes a substrate and a plurality of alternating N-type and P-type semiconductor regions disposed in or above the substrate. A plurality of conductive contact structures is electrically connected to the plurality of alternating N-type and P-type semiconductor regions. Each conductive contact structure includes a metal foil portion disposed in direct contact with a corresponding one of the alternating N-type and P-type semiconductor regions.

[0024] In another embodiment, a solar cell includes a substrate and a plurality of alternating N-type and P-type semiconductor regions disposed in or above the substrate. A plurality of conductive contact structures is electrically connected to the plurality of alternating N-type and P-type semiconductor regions. Each conductive contact structure includes a metal foil portion disposed above and in alignment with a corresponding one of the alternating N-type and P-type semiconductor regions. The metal foil portion has a texturized surface proximate to the corresponding one of the alternating N-type and P-type semiconductor regions.

[0025] Also disclosed herein are methods of fabricating solar cells. In one embodiment, a method of fabricating a solar cell includes texturizing a surface of a metal foil. The method also includes locating the texturized surface of the metal foil over a non-metalized surface of a wafer of the solar cell. The method also includes, subsequent to the locating, electrically connecting the metal foil with the non-metalized surface of the wafer by thermocompression bonding.

[0026] One or more embodiments described herein provides a technique for thermocompression bonding of a metal foil (such as an aluminum foil) to a solar cell. In an embodiment, bonding of an aluminum foil is performed directly to polycrystalline silicon regions of the solar cell and a bottom anti-reflective coating (BARC) layer exposing portions of the polycrystalline silicon regions. The resulting structure may be described as a seed-free thermocompression bonded solar cell, where a seed layer is an otherwise intervening metal layer. Specific embodiments described herein involve thermocompression bonding of an aluminum foil to non-metal surfaces together with foil texturing for implemented for improved thermocompression bonding.

[0027] To provide context, process approaches described herein may be motivated by a need for cost and operation reduction in a cell metallization process. Earlier attempts at reducing cost associated with use of an intervening metal seed layer included the use of a printed seed layer, which was limited by compatibility with plating and series resistance. On the other hand, thermocompression bonding of an aluminum foil has previously also required the use of a sputtered metal “seed” layer that is deposited on the cell to enable bonding of the metal foil to semiconductor and insulating materials. By contrast, embodiments described herein do not involve use of a plating process or use of an intervening metal seed layer.

[0028] Addressing one or more of the above issues, in accordance with an embodiment of the present disclosure, electrical contact is made directly from a metal foil to a silicon wafer through the contact openings without the need for a metal seed layer. The aluminum foil can be sufficiently adhered to a BARC layer enabling direct contact between the metal foil and exposed semiconductor regions on or in the substrate. Particular embodiments that may be implemented to enhance such direct bonding may include one or more of use of a roller tool for bonding, foil cleaning before bonding, higher temperature and pressure for bonding, etc. Regardless, in at least some of the embodiments described below, use of an intervening metal seed layer is omitted.

[0029] To exemplify the concepts at hand, Figure 1 illustrates a cross-sectional view of a solar cell including a metal seed layer. Referring to Figure 1, a solar cell 100 includes a substrate 102. A plurality of alternating N-type and P-type semiconductor regions 104 is disposed in or above the substrate 102. A bottom-anti-reflective coating (BARC) layer 106 is disposed over and exposes portions of the plurality of alternating N-type and P-type semiconductor regions 104. A metal seed layer 108 is disposed on the BARC layer 106 and on the exposed portions of the plurality of alternating N-type and P-type semiconductor regions 104. A metal foil 110 is disposed on the metal seed layer 108.

[0030] In contrast to Figure 1, Figure 2 illustrates a cross-sectional view of a solar cell omitting an intervening metal seed layer, in accordance with an embodiment of the present disclosure. Referring to Figure 2, a solar cell 200 includes a substrate 202. A plurality of alternating N-type and P-type semiconductor regions 204 is disposed in or above the substrate 202. A bottom-anti-reflective coating (BARC) layer 206 is disposed over and exposes portions of the plurality of alternating N-type and P-type semiconductor regions 204. A metal foil 210 is disposed on the BARC layer 206 and on the exposed portions of the plurality of alternating N-type and P-type semiconductor regions 204. The metal foil 210 is in direct contact with the exposed portions of the plurality of alternating N-type and P-type semiconductor regions 204. In an embodiment, the metal foil 210 is bonded to the alternating N-type and P-type semiconductor regions 204 by thermocompression bonding. It is to be appreciated that Figure 2 may represent a partially completed solar cell, as further processing may include patterning of the metal foil 210, exemplary embodiments of which are described in greater detail below. It is to be appreciated that reference to a BARC layer throughout may be used to more generally refer to a dielectric layer, where the dielectric layer may be anti-reflective or reflective depending on specific implementations. Nonetheless, use of the term “BARC layer” is consistent with general usage of such a dielectric layer in the art.

[0031] It is to be appreciated that openings in the BARC layer 206 that accommodate direct contact of the metal foil 210 to the plurality of alternating N-type and P-type semiconductor regions 204 may be formed prior to metallization or during metallization. For example in one embodiment, openings are formed in the BARC layer 206 prior to metallization, e.g., by patterning with laser ablation of a lithography and etch process. In another embodiment, metallization to form a direct contact of the metal foil 210 to the plurality of alternating N-type and P-type semiconductor regions 204 may be performed through the BARC layer 206, e.g., by laser or other spot welding, to effectively create openings in the BARC layer 206 that surround such spot welds.

[0032] In accordance with another embodiment of the present disclosure, to enable successful bonding of a metal foil directly to semiconductor regions of a solar cell, texturized foil is used or a foil texturizing operation is performed. As an example, Figure 3A illustrates a cross-sectional and magnified view of an initial interface between a texturized metal foil and a BARC layer of a solar cell, in accordance with an embodiment of the present disclosure. Referring to Figure 3A, a metal foil 300 has a texturized surface 302 in contact with a BARC layer 304 of a solar cell. The BARC layer may be used to partially cover an underlying semiconductor region (not shown). In one embodiment, the texturized surface 302 is described as including valleys 306.

[0033] Not to be bound by theory, it is understood that the valleys 306 may provide a place for metal to flow to during a bonding process. As a first example, Figure 3B illustrates a cross-sectional and magnified view of bonding interface between a texturized metal foil and a BARC layer of a solar cell where the bonding is performed using a roller, in accordance with an embodiment of the present disclosure. Referring to Figure 3B, a roller 320 is rolled in the direction 322 across the surface of metal foil 300. A metal flow region 324 is formed between the texturized surface 302 and the BARC layer 304. In one embodiment, the metal flow region 324 fills in and at least partially closes the valleys 306, providing a strong bond between the metal foil 300 and the BARC layer 304.

[0034] In a second example, Figure 3C illustrates a cross-sectional and magnified view of bonding interface between a texturized metal foil and a BARC layer of a solar cell where the bonding is performed using a pressure plate, in accordance with an embodiment of the present disclosure. Referring to Figure 3C, a pressure plate 340 is pressed down on the surface of metal foil 300. A metal flow region 344 is formed between the texturized surface 302 and the BARC layer 304. In one embodiment, the metal flow region 344 fills in and at least partially closes the valleys 306, providing a strong bond between the metal foil 300 and the BARC layer 304.

[0035] Figure 4 is a magnified optical image 400 of a texturized aluminum metal foil in accordance with an embodiment of the present disclosure. Referring to Figure 4, a surface 402 of a metal foil has texture 404 therein. In one embodiment, the texture 404 is created by a wire brush 406, such as is depicted in the inset of the image 400. In one such embodiment, the brushed foil texture 404 is created by first cleaning and then texturizing with a wire brush in two directions. The process may provide a fresh oxide surface and higher bond pressure on raised portions of the metal foil. In other embodiments, embossing or etching is used to texturize the metal foil.

[0036] As described above, inclusion of a foil texturizing process for solar cell manufacture can enable adhesion of a metal foil to a solar cell. Figure 5 is a flowchart 500 representing various operations in a method of fabricating a solar cell, in accordance with an embodiment of the present disclosure.

[0037] Referring to operation 502 of Figure 5, a method of fabricating a solar cell includes texturizing a surface of a metal foil, examples of which were described in association with Figures 3A and 4. In one embodiment, texturizing the surface of the metal foil includes using a technique selected from the group consisting of brushing, embossing and etching.

[0038] Referring to operation 504 of Figure 5, the method also includes locating the texturized surface of metal foil over a non-metalized surface of a wafer of the solar cell, e.g., by foil and cell alignment. In one embodiment, locating the metal foil with the non-metalized surface of the wafer includes performing a tacking process. In a specific such embodiment, the tacking process involves first forming an array of point or spot welds. The array of point or spot welds may be formed by thermocompression bonding, e.g., using spikes, a spiked roller, a porcupine roller, or a bed of nails. Alternatively the locating may be performed using a laser welding process.

[0039] Not to be bound by theory, it is understood that a tacking process may involve breaking through portions of one or more metal oxide layers at an interface between a metal foil and a non-metalized surface of a solar cell to effectively form a plurality of spot welds. In an embodiment, the plurality of spot welds provides channels between the metal foil and the non-metalized surface for subsequent removal of air from between the metal foil and the non-metalized surface.

[0040] Referring to operation 506 of Figure 5, the method also includes, subsequent to the locating, bonding the metal foil with the non-metalized surface of the wafer by thermocompression bonding, examples of which were described in association with Figures 3B and 3C. In an embodiment, a portion of the non-metallized surface of the solar cell is a semiconductor region exposed by a BARC layer, and the thermocompression bonding

electrically connects the metal foil to the semiconductor region. In an embodiment, a relatively high bonding force is used for the thermocompression bonding, e.g., an approximately 50kg force may be applied using an approximately on 9.5mm diameter roller. In an embodiment, a relatively high bonding temperature is used, e.g., bonding temperature of approximately 440 degrees Celsius. In one specific embodiment, the thermocompression bonding involves applying a shear force to the metal foil, an example of which is the roller process of Figure 3B. In another specific embodiment, the thermocompression bonding involves applying a normal force to the metal foil, an example of which is the pressure plate process of Figure 3C.

[0041] As exemplified in Figure 3B above, in an embodiment, a shear thermocompression process is used to bond the metal foil to the wafer of the solar cell. Other approaches for generating such a shear force may include pressing a graphite puck into the metal foil over the center of the wafer and moving it toward the outside of the wafer in a spiral motion so as to expel the air from between the foil and the wafer, while still pressing the puck downwards on the metal foil. In another approach, a set of graphite paddles or squeegees are used to bond down the metal foil. One possible sequence is to use two paddles to swipe left and right from the center to bond a center strip, followed by up and down motions from the center strip to complete the bonding. It is to be appreciated that other swipe sequences may also be suitable. In one embodiment, a vacuum fixture is implemented to evacuate the air from between the metal foil and the wafer during thermocompression bonding.

[0042] A metal foil and solar cell pairing approach involving thermocompression bonding may be implemented using a non-metallized surface of a wafer of the solar cell. As an example, Figures 6A and 6B illustrate angled views of various stages in the fabrication of a solar cell using foil-based metallization. Referring to Figure 6A, a metal foil 608 is placed over a wafer 602 having a plurality of emitter regions 604 (which may include non-metallized polycrystalline silicon regions) disposed on or above a substrate 606. In Figure 6B, the metal foil is fit-up with the substrate 606, which may include a tacking process.

[0043] Upon fitting up of the metal foil 608 and the substrate 606, the metal foil is thermocompression bonded to the plurality of emitter regions 604. In an embodiment, a shear force is applied during the thermocompression bonding. In another embodiment, a normal force is applied during the thermocompression bonding. The thermocompression bonding may electrically connect a substantial portion of the metal foil 608 with a non-metalized plurality of emitter regions 604.

[0044] In an embodiment, at the time of joining the metal foil 608 and the substrate 602, the metal foil 608 has a surface area substantially larger than a surface area of the wafer 602 of the solar cell. In one such embodiment, subsequent to electrically contacting the metal foil 608 to

the non-metalized plurality of emitter regions 604, the metal foil is cut to provide the metal foil 608 having a surface area substantially the same as the surface area of the wafer 602 of the solar cell. In another embodiment, however, prior to placing the metal foil 608 over the non-metalized plurality of emitter regions 604 of the solar cell, a large sheet of foil is cut to provide the metal foil 608 having a surface area substantially the same as a surface area of the wafer 602 of the solar cell, as is depicted in Figure 6A.

[0045] In an embodiment, the resulting structures from the process described above in association with Figures 6A and 6B are subjected to a contact patterning process. As an example, Figures 7A-7C illustrate cross-sectional views of various stages in the fabrication of a solar cell using foil-based metallization, in accordance with an embodiment of the present disclosure.

[0046] Referring to Figure 7A, a plurality of alternating N-type and P-type semiconductor regions are disposed above a substrate. In particular, a substrate 700 has disposed there above N-type semiconductor regions 704 and P-type semiconductor regions 706 disposed on a thin dielectric material 702 as an intervening material between the N-type semiconductor regions 704 or P-type semiconductor regions 706, respectively, and the substrate 700. The substrate 700 has a light-receiving surface 701 opposite a back surface above which the N-type semiconductor regions 704 and P-type semiconductor regions 706 are formed.

[0047] In an embodiment, the substrate 700 is a monocrystalline silicon substrate, such as a bulk single crystalline N-type doped silicon substrate. It is to be appreciated, however, that substrate 700 may be a layer, such as a multi-crystalline silicon layer, disposed on a global solar cell substrate. In an embodiment, the thin dielectric layer 702 is a tunneling silicon oxide layer having a thickness of approximately 2 nanometers or less. In one such embodiment, the term “tunneling dielectric layer” refers to a very thin dielectric layer, through which electrical conduction can be achieved. The conduction may be due to quantum tunneling and/or the presence of small regions of direct physical connection through thin spots in the dielectric layer. In one embodiment, the tunneling dielectric layer is or includes a thin silicon oxide layer.

[0048] In an embodiment, the alternating N-type and P-type semiconductor regions 704 and 706, respectively, are formed from polycrystalline silicon formed by, e.g., using a plasma-enhanced chemical vapor deposition (PECVD) process. In one such embodiment, the N-type polycrystalline silicon emitter regions 704 are doped with an N-type impurity, such as phosphorus. The P-type polycrystalline silicon emitter regions 706 are doped with a P-type impurity, such as boron. As is depicted in Figure 7A, the alternating N-type and P-type semiconductor regions 704 and 706 may have trenches 708 formed there between, the trenches 708 extending partially into the substrate 700. Additionally, in one embodiment, a bottom anti-

reflective coating (BARC) material 710 or other protective layer (such as a layer amorphous silicon) is formed on the alternating N-type and P-type semiconductor regions 704 and 706, exposing only portions of the N-type and P-type semiconductor regions 704 and 706, as is depicted in Figure 7A. In one such embodiment, the metal foil is in direct contact with, and possibly thermocompression bonded to, the BARC material layer 710. In an embodiment, BARC layer includes a silicon-rich silicon nitride layer. It is to be appreciated that reference to a BARC layer throughout may be used to more generally refer to a dielectric layer, where the dielectric layer may be anti-reflective or reflective depending on specific implementations. Nonetheless, use of the term “BARC layer” is consistent with general usage of such a dielectric layer in the art.

[0049] In an embodiment, the light receiving surface 701 is a texturized light-receiving surface, as is depicted in Figure 7A. In one embodiment, a hydroxide-based wet etchant is employed to texturize the light receiving surface 701 of the substrate 700 and, possibly, the trench 708 surfaces as is also depicted in Figure 7A. It is to be appreciated that the timing of the texturizing of the light receiving surface may vary. For example, the texturizing may be performed before or after the formation of the thin dielectric layer 702. In an embodiment, a texturized surface may be one which has a regular or an irregular shaped surface for scattering incoming light, decreasing the amount of light reflected off of the light receiving surface 701 of the solar cell. Referring again to Figure 7A, additional embodiments can include formation of a passivation and/or anti-reflective coating (ARC) layers (shown collectively as layer 712) on the light-receiving surface 701. It is to be appreciated that the timing of the formation of passivation and/or ARC layers may also vary. It is also to be appreciated that while N-type and P-type semiconductor regions 704 and 706 are depicted and described as regions discrete from substrate 700, in another embodiment, semiconductor regions are fabricated using diffusion regions formed in the substrate 700.

[0050] Referring again to Figure 7A, a metal foil 718 is adhered to the alternating N-type and P-type semiconductor regions 704 and 706 by directly coupling portions of the metal foil 718 with a corresponding portion of each of the alternating N-type and P-type semiconductor regions 704 and 706. In one such embodiment, the direct coupling of portions of the metal foil 718 with a corresponding portion of each of the alternating N-type and P-type semiconductor regions 704 and 706 involves thermocompression bonding that may involve formation of a metal flow region 714 at each of such locations, as is depicted in Figure 7A. In relation to embodiments described herein, such a metal flow region 714 is considered part of the metal foil 718.

[0051] In an embodiment, the metal foil 718 is an aluminum (Al) foil having a thickness approximately in the range of 5-100 microns. In one embodiment, the Al foil is an aluminum

alloy foil including aluminum and second element such as, but not limited to, copper, manganese, silicon, magnesium, zinc, tin, lithium, or combinations thereof. In one embodiment, the Al foil is a temper grade foil such as, but not limited to, F-grade (as fabricated), O-grade (full soft), H-grade (strain hardened) or T-grade (heat treated). In one embodiment, the aluminum foil is an anodized aluminum foil.

[0052] Figure 7B illustrates the structure of Figure 7A following formation of laser grooves in the metal foil. Referring to Figure 7B, the metal foil 718 is laser ablated through only a portion of the metal foil 718 at regions corresponding to locations between the alternating N-type and P-type semiconductor regions 704 and 706, e.g., above trench 708 locations as is depicted in Figure 7B. The laser ablating forms grooves 730 that extend partially into, but not entirely through, the metal foil 718. In an embodiment, forming laser grooves 730 involves laser ablating a thickness of the metal foil 718 approximately in the range of 80-99% of an entire thickness of the metal foil 718. That is, in one embodiment, it is critical that the lower portion of the metal foil 718 is not penetrated, such that metal foil 718 protects the underlying emitter structures. In an alternative embodiment, an indentation approach may be used in place of a laser ablation approach.

[0053] The grooves 730 of Figure 7B may then be used to isolate conductive regions 740 as metallization structures for the underlying emitter regions. For example, referring to Figure 7C, the grooves 730 are extended to provide gaps 732 between conductive regions 740. In an embodiment, the patterned metal foil 718 is etched to isolate portions 740 of the metal foil 718. In one such embodiment, the structure of Figure 7B is exposed to a wet etchant. Although the wet etchant etches all exposed portions of the metal foil 718, a carefully timed etch process is used to break through the bottoms of the laser grooves 730 without significantly reducing the thickness of the non-grooved regions 740 of the metal foil 718, as is depicted in Figure 7C. In a particular embodiment, a hydroxide based etchant is used, such as, but not limited to, potassium hydroxide (KOH) or tetramethylammonium hydroxide (TMAH).

[0054] In another embodiment (not shown), the remaining metal foil 718 of Figure 7B is subsequently anodized at exposed surfaces thereof to isolate regions 740 of the remaining metal foil 718 corresponding to the alternating N-type and P-type semiconductor regions 704 and 706. In particular, the exposed surfaces of the metal foil 718, including the surfaces of the grooves 730, are anodized to form an oxide coating. At locations corresponding to the alternating N-type and P-type semiconductor regions 704 and 706, e.g., in the grooves 730 at locations above the trenches 708, the entire remaining thickness of the metal foil 718 is anodized there through to isolate regions 740 of metal foil 718 remaining above each of the N-type and P-type semiconductor regions 704 and 706.

[0055] Referring again to Figure 7C, a solar cell 750 includes a substrate 700 and a plurality of alternating N-type and P-type semiconductor regions 704 and 706 disposed in or above the substrate 700. A plurality of conductive contact structures 740 is electrically connected to the plurality of alternating N-type and P-type semiconductor regions 704 and 706. Each conductive contact structure includes a metal foil portion 740 disposed in direct contact with a corresponding one of the alternating N-type and P-type semiconductor regions 704 and 706.

[0056] In accordance with an embodiment of the present disclosure, the metal foil portions 740 each have a texturized surface proximate to the corresponding one of the alternating N-type and P-type semiconductor regions 704 and 706. Examples of such a texturized surface are described in association with Figure 3A-3C and 4. In one such embodiment, the texturized surface of the metal foil portion is in direct contact with the corresponding one of the alternating N-type and P-type semiconductor regions 704 and 706. However, although embodiments described herein are largely directed to seedless arrangements, a texturized surface for a metal foil may enhance arrangements where a seed layer is still used. Accordingly, in an alternative embodiment, although not depicted, the texturized surface of the metal foil portions 740 is disposed on a metal seed layer disposed on the corresponding one of the alternating N-type and P-type semiconductor regions 704 and 706.

[0057] Although certain materials are described specifically with reference to above described embodiments, some materials may be readily substituted with others with such embodiments remaining within the spirit and scope of embodiments of the present disclosure. For example, in an embodiment, a different material substrate, such as a group III-V material substrate, can be used instead of a silicon substrate. Additionally, although reference is made significantly to back contact solar cell arrangements, it is to be appreciated that approaches described herein may have application to front contact solar cells as well. In other embodiments, the above described approaches can be applicable to manufacturing of other than solar cells. For example, manufacturing of light emitting diode (LEDs) may benefit from approaches described herein.

[0058] Thus, thermocompression bonding approaches for foil-based metallization of non-metal surfaces of solar cells, and the resulting solar cells, have been disclosed.

[0059] Although specific embodiments have been described above, these embodiments are not intended to limit the scope of the present disclosure, even where only a single embodiment is described with respect to a particular feature. Examples of features provided in the disclosure are intended to be illustrative rather than restrictive unless stated otherwise. The above description is intended to cover such alternatives, modifications, and equivalents as would be apparent to a person skilled in the art having the benefit of this disclosure.

[0060] The scope of the present disclosure includes any feature or combination of features disclosed herein (either explicitly or implicitly), or any generalization thereof, whether or not it mitigates any or all of the problems addressed herein. Accordingly, new claims may be formulated during prosecution of this application (or an application claiming priority thereto) to any such combination of features. In particular, with reference to the appended claims, features from dependent claims may be combined with those of the independent claims and features from respective independent claims may be combined in any appropriate manner and not merely in the specific combinations enumerated in the appended claims.

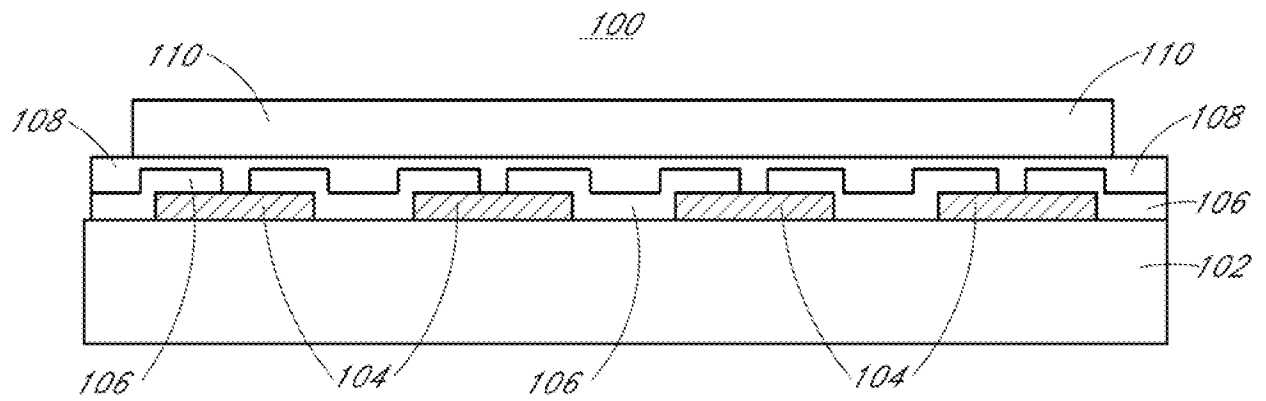
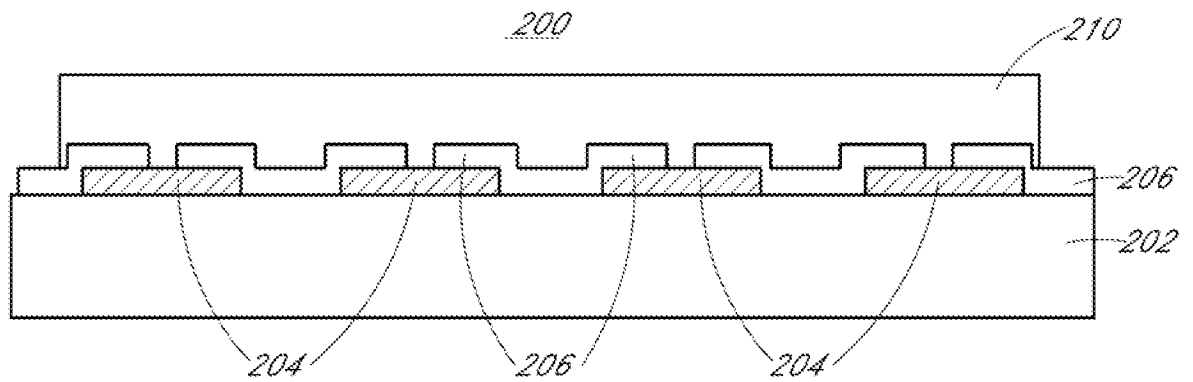
CLAIMS

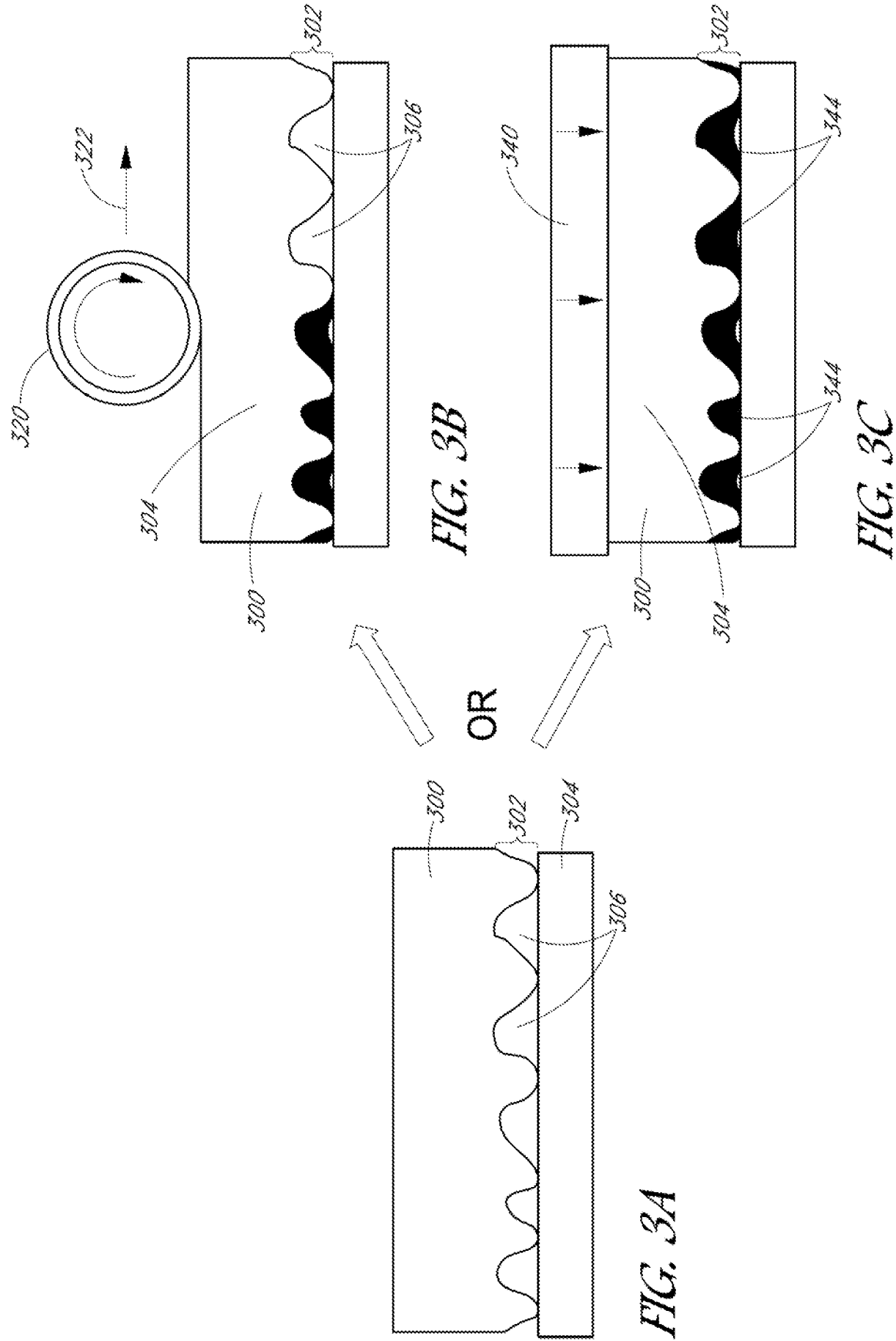
What is claimed is:

1. A solar cell, comprising:
 - a substrate;
 - a plurality of alternating N-type and P-type semiconductor regions disposed in or above the substrate; and
 - a plurality of conductive contact structures electrically connected to the plurality of alternating N-type and P-type semiconductor regions, each conductive contact structure comprising a metal foil portion disposed in direct contact with a corresponding one of the alternating N-type and P-type semiconductor regions.
2. The solar cell of claim 1, wherein each of the metal foil portions is an aluminum metal foil portion.
3. The solar cell of claim 1, wherein the plurality of alternating N-type and P-type semiconductor regions is a plurality of alternating N-type and P-type polycrystalline silicon regions disposed above the substrate.
4. The solar cell of claim 1, wherein the plurality of alternating N-type and P-type semiconductor regions is a plurality of alternating N-type and P-type diffusion regions disposed in the substrate.
5. The solar cell of claim 1, further comprising:
 - an anti-reflective coating layer disposed on and exposing portions of the plurality of alternating N-type and P-type semiconductor regions, wherein portions of the anti-reflective coating layer are in direct contact with regions of the metal foil portions of the conductive contact structures.
6. The solar cell of claim 5, wherein the anti-reflective coating layer comprises a silicon-rich silicon nitride layer.
7. A solar cell, comprising:
 - a substrate;

- a plurality of alternating N-type and P-type semiconductor regions disposed in or above the substrate; and
- a plurality of conductive contact structures electrically connected to the plurality of alternating N-type and P-type semiconductor regions, each conductive contact structure comprising a metal foil portion disposed above and in alignment with a corresponding one of the alternating N-type and P-type semiconductor regions, wherein the metal foil portion has a texturized surface proximate to the corresponding one of the alternating N-type and P-type semiconductor regions.
8. The solar cell of claim 7, wherein the texturized surface of the metal foil portion is in direct contact with the corresponding one of the alternating N-type and P-type semiconductor regions.
9. The solar cell of claim 7, wherein the texturized surface of the metal foil portion is disposed on a metal seed layer disposed on the corresponding one of the alternating N-type and P-type semiconductor regions.
10. The solar cell of claim 7, wherein each of the metal foil portions is an aluminum metal foil portion.
11. The solar cell of claim 7, wherein the plurality of alternating N-type and P-type semiconductor regions is a plurality of alternating N-type and P-type polycrystalline silicon regions disposed above the substrate.
12. The solar cell of claim 7, wherein the plurality of alternating N-type and P-type semiconductor regions is a plurality of alternating N-type and P-type diffusion regions disposed in the substrate.
13. The solar cell of claim 7, further comprising:
- an anti-reflective coating layer disposed on and exposing portions of the plurality of alternating N-type and P-type semiconductor regions, wherein portions of the anti-reflective coating layer are in direct contact with regions of the metal foil portions of the conductive contact structures.
14. The solar cell of claim 13, wherein the anti-reflective coating layer comprises a silicon-rich silicon nitride layer.

15. A method of fabricating a solar cell, the method comprising:
texturizing a surface of a metal foil;
locating the texturized surface of the metal foil over a non-metalized surface of a wafer of the solar cell; and
subsequent to the locating, electrically connecting the metal foil with the non-metalized surface of the wafer by thermocompression bonding.
16. The method of claim 15, wherein texturizing the surface of the metal foil comprises using a technique selected from the group consisting of brushing, embossing and etching.
17. The method of claim 15, wherein the thermocompression bonding comprises applying a shear force to the metal foil.
18. The method of claim 15, wherein the thermocompression bonding comprises applying a normal force to the metal foil.
19. The method of claim 15, wherein locating the metal foil with the non-metalized surface of the wafer comprises performing a tacking process.
20. The method of claim 15, wherein the metal foil has a surface area substantially larger than a surface area of the wafer of the solar cell, the method further comprising:
subsequent to electrically connecting the metal foil with the non-metalized surface of the wafer, cutting to the metal foil to provide the metal foil having a surface area substantially the same as the surface area of the wafer of the solar cell.

*FIG. 1**FIG. 2*



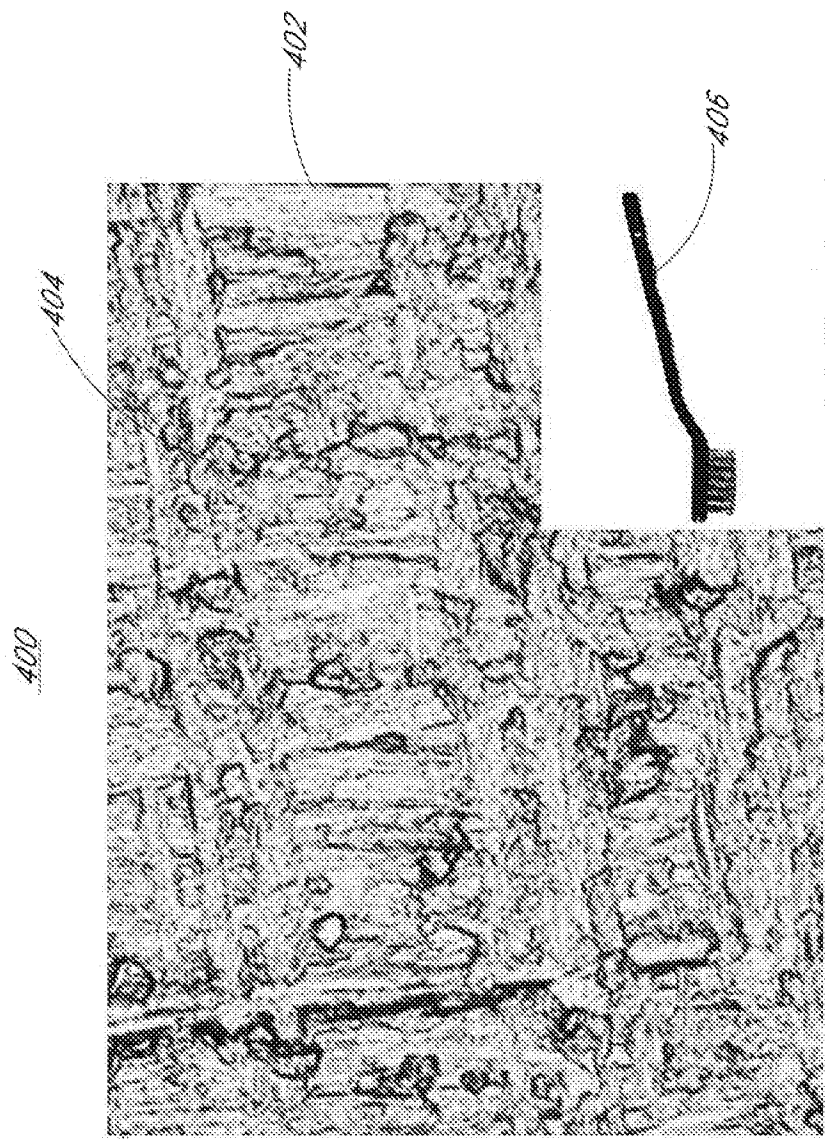
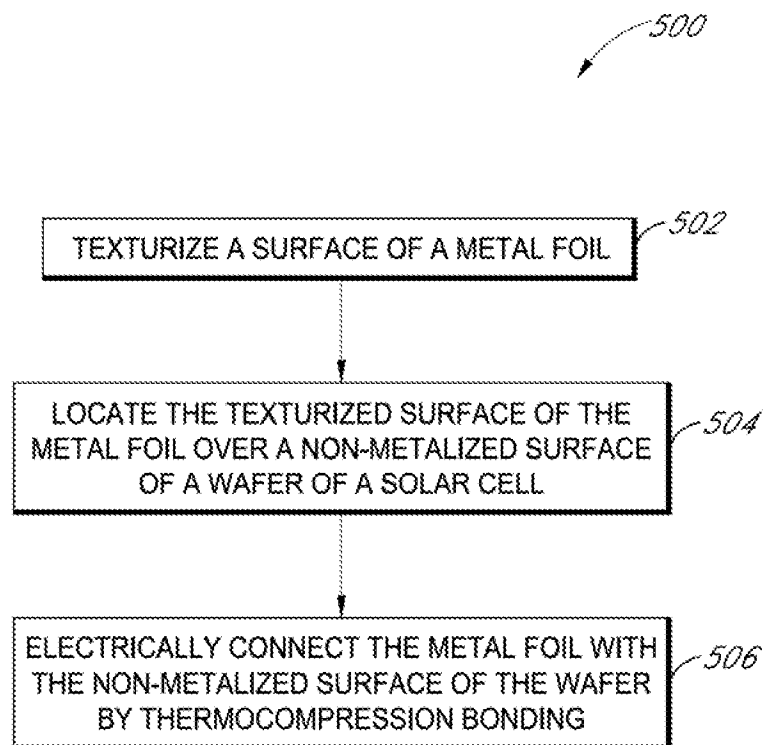
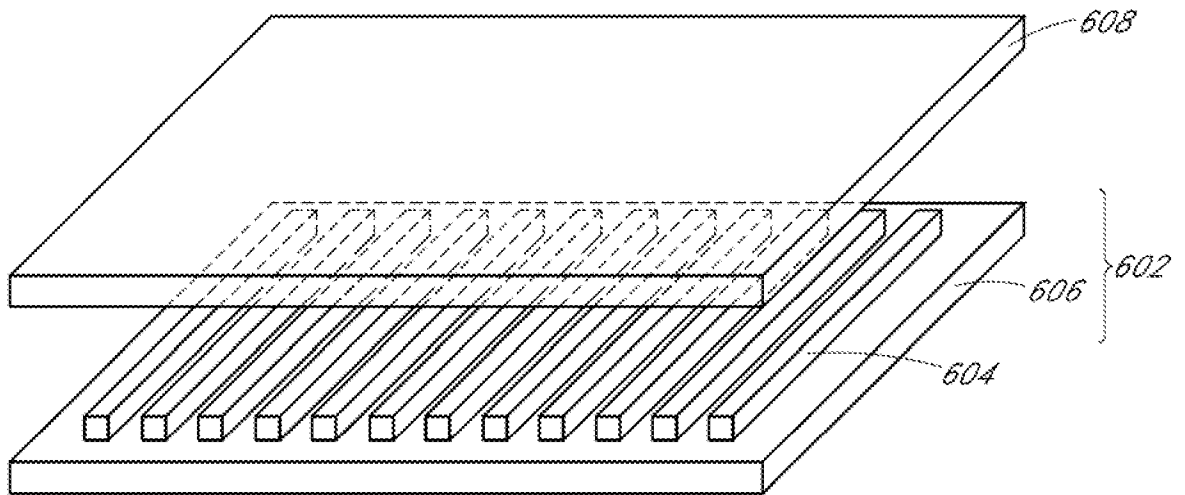
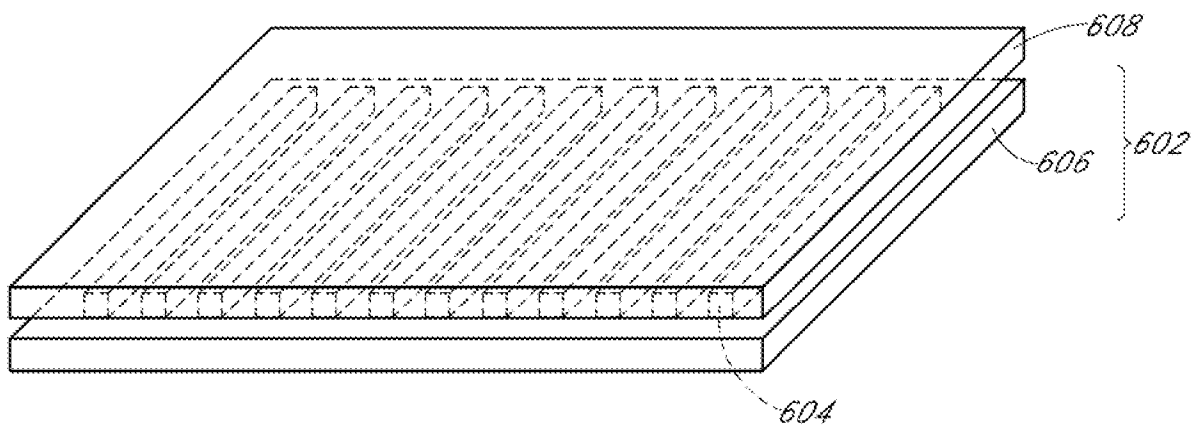
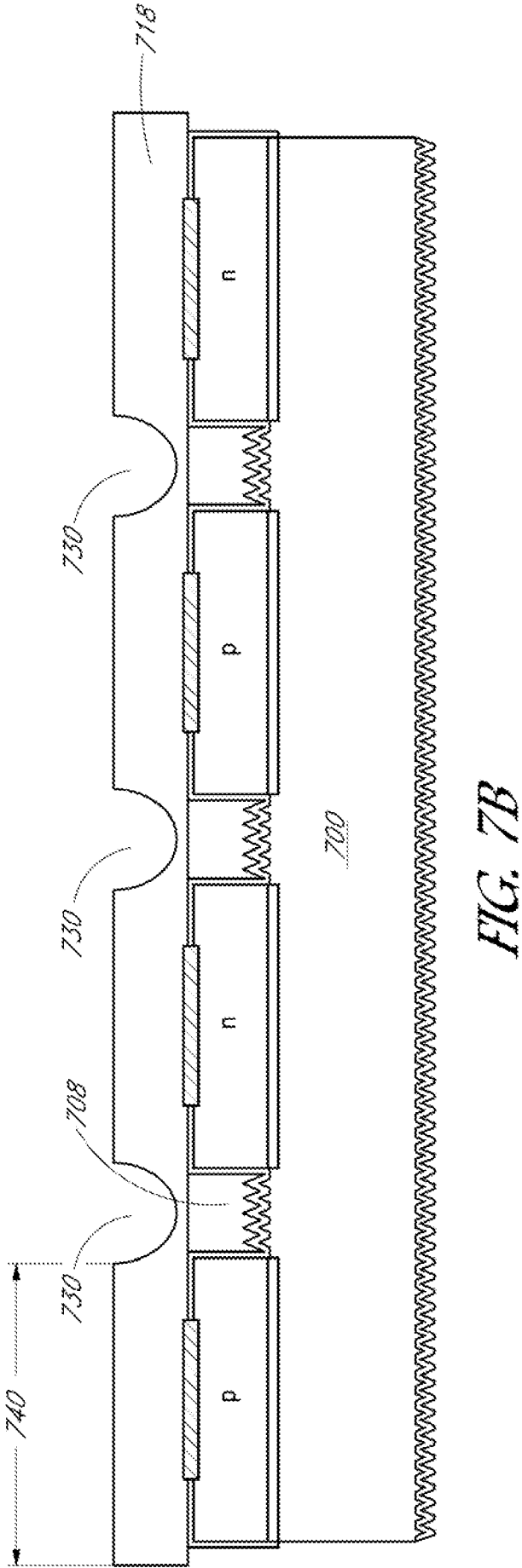
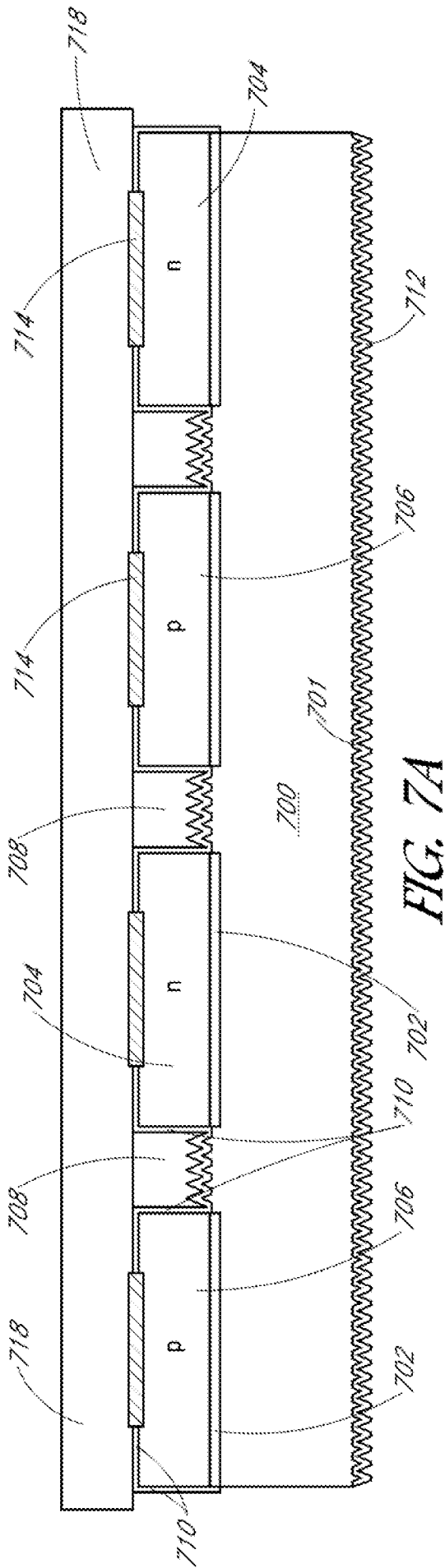


FIG. 4

*FIG. 5*

*FIG. 6A**FIG. 6B*



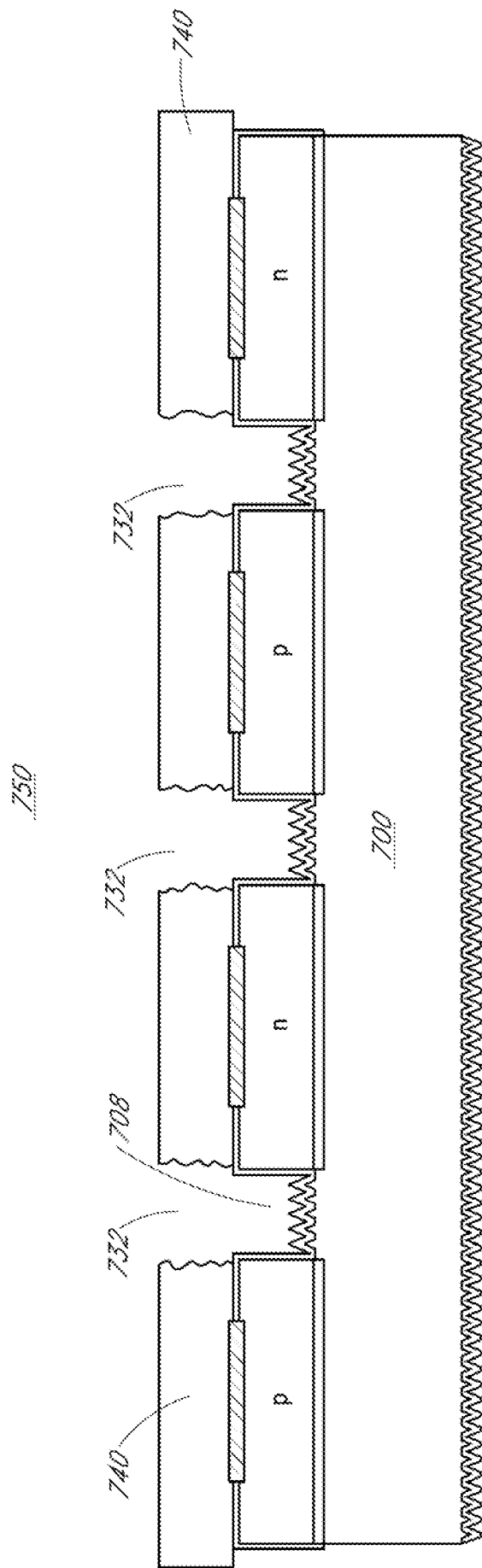


FIG. 7C

A. CLASSIFICATION OF SUBJECT MATTER**H01L 31/05(2006.01)i, H01L 31/0368(2006.01)i, H01L 31/0216(2006.01)i, H01L 31/0236(2006.01)i, H01L 31/18(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01L 31/05; H01L 31/0475; H01L 31/0264; H01L 31/0224; B32B 37/06; H01L 31/18; H01L 31/00; H01L 31/0368; H01L 31/0216; H01L 31/0236

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: solar cell, semiconductor regions, conductive contact structures, metal foil

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0318420 A1 (RICHARD HAMILTON SEWELL et al.) 05 November 2015 See paragraphs [0029]-[0046], [0070], [0071], [0088]; claim 8; and figures 1A-2A.	1-20
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A	US 2015-0090329 A1 (SUNPOWER CORPORATION) 02 April 2015 See paragraphs [0016]-[0028]; and figures 1-7.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

29 June 2017 (29.06.2017)

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

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189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/024625

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