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(71) Applicant (for all designated States except US): **SUN-POWER CORPORATION** [US/US]; 3939 North First Street, San Jose, CA 95134 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **LUAN, Andy** [—/US]; 3802 Quail Drive, Palo Alto, CA 94303 (US). **SMITH, David** [US/US]; 426 N. Milton Avenue, Camp-

bell, CA 95008 (US). **COUSINS, Peter** [AU/US]; 6 Fredrick Court, Menlo Park, CA 94025 (US). **SUN, Sheng** [US/US]; 707 Cayman Lane, Foster City, CA 94404 (US).

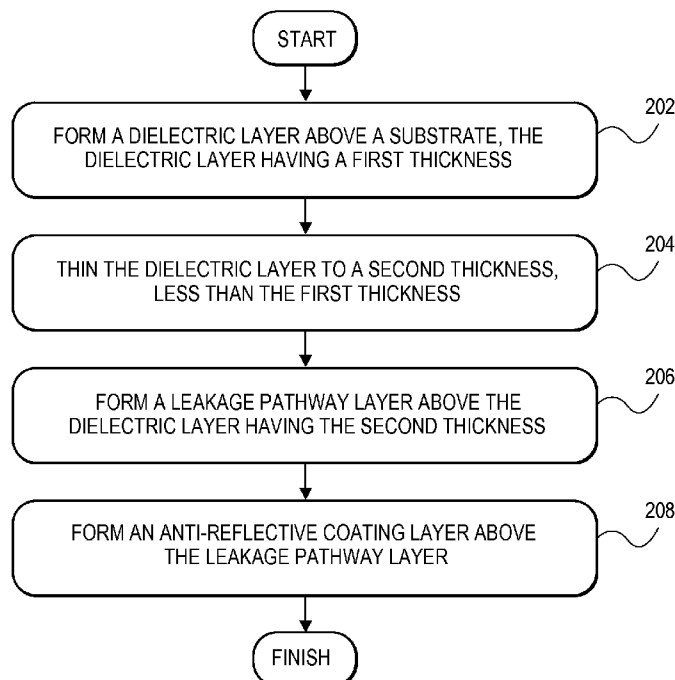
(74) Agents: **VINCENT, Lester, J.** et al.; Blakely, Sokoloff, Taylor & Zafman LLP, 1279 Oakmead Parkway, Sunnyvale, CA 94085-4040 (US).

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(54) Title: LEAKAGE PATHWAY LAYER FOR SOLAR CELL



(57) Abstract: Leakage pathway layers for solar cells and methods of forming leakage pathway layers for solar cells are described.

FIG. 2



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Leakage Pathway Layer for Solar Cell

[0001] The invention described herein was made with Governmental support under contract number DE-FC36-07GO17043 awarded by the United States Department of Energy. The Government may have certain rights in the invention.

TECHNICAL FIELD

[0002] Embodiments of the present invention are in the field of renewable energy and, in particular, leakage pathway layers for solar cells and methods of forming leakage pathway layers for solar cells.

BACKGROUND

[0003] 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 the substrate creates electron and hole pairs in the bulk of the substrate, which 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 metal contacts on the solar cell to direct an electrical current from the cell to an external circuit coupled thereto.

[0004] Efficiency is an important characteristic of a solar cell as it is directly related to the solar cell's capability to generate power. Accordingly, techniques for increasing the efficiency of solar cells are generally desirable. Embodiments of the present invention allow for increased solar cell efficiency by providing processes for fabricating novel solar cell structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Figure 1 illustrates a cross-sectional view of a back-contact solar cell including a leakage pathway layer, in accordance with an embodiment of the present invention.

[0006] Figure 2 illustrates a flowchart representing operations in a method of fabricating a solar cell including a leakage pathway layer, in accordance with an embodiment of the present invention.

[0007] Figure 3A illustrates a cross-sectional view of a stage in the fabrication of a solar cell including a leakage pathway layer, corresponding to operation 202 of the flowchart of Figure 2, in accordance with an embodiment of the present invention.

[0008] Figure 3B illustrates a cross-sectional view of a stage in the fabrication of a solar cell including a leakage pathway layer, corresponding to operation 204 of the flowchart of Figure 2, in accordance with an embodiment of the present invention.

[0009] Figure 3C illustrates a cross-sectional view of a stage in the fabrication of a solar cell including a leakage pathway layer, corresponding to operation 206 of the flowchart of Figure 2, in accordance with an embodiment of the present invention.

[0010] Figure 3D illustrates a cross-sectional view of a stage in the fabrication of a solar cell including a leakage pathway layer, corresponding to operation 208 of the flowchart of Figure 2, in accordance with an embodiment of the present invention.

[0011] Figure 4 illustrates a flowchart representing operations in a method of fabricating a solar cell including a thin dielectric layer but not a leakage pathway layer, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0012] Leakage pathway layers for solar cells and methods of forming leakage pathway layers for 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 invention. It will be apparent to one skilled in the art that embodiments of the present invention may be practiced without these specific details. In other instances, well-known fabrication techniques, such as lithographic techniques, are not described in detail in order to not unnecessarily obscure embodiments of the present invention.

Furthermore, it is to be understood that the various embodiments shown in the figures are illustrative representations and are not necessarily drawn to scale.

[0013] Disclosed herein are methods of forming leakage pathway layers for solar cells. In one embodiment, a method of fabricating a solar cell includes forming a dielectric layer above a substrate, the dielectric layer having a first thickness. The dielectric layer is thinned to a second thickness, less than the first thickness. A leakage pathway layer is formed above the dielectric layer having the second thickness. An anti-reflective coating layer is formed above the leakage pathway layer. In one embodiment, a method of fabricating a solar cell includes forming a dielectric

layer above a substrate, the dielectric layer having a first thickness. The dielectric layer is thinned to a second thickness, less than the first thickness. An anti-reflective coating layer is formed above the dielectric layer having the second thickness.

[0014] Also disclosed herein are leakage pathway layers for solar cells and solar cells including leakage pathway layers. In one embodiment, a solar cell includes a dielectric layer disposed above a substrate. A leakage pathway layer is disposed above the dielectric layer, the leakage pathway layer including a layer of phosphorus- or boron-doped silicon with a morphology such as, but not limited to, amorphous, nano-crystalline, and fine-grained. An anti-reflective coating layer is disposed above the leakage pathway layer.

[0015] In accordance with at least some embodiments of the present invention, solar cell efficiency is improved by including a leakage pathway layer in the solar cell itself. For example, front surface passivation may be key to high efficiency in back contact, and even in concentrating back-contact, solar cells based on silicon substrates. However, in one embodiment, the accumulation of charges in the front surface passivation results in degradation of cell efficiency. In accordance with an embodiment of the present invention, an approach to prevent the accumulation of such charges includes providing a layer of a conductive pathway film, or a leakage pathway layer, at or near an anti-reflective coating layer on the passivation side of the solar cell. In a specific embodiment, the conductive film is a layer of phosphorus- or boron-doped silicon.

[0016] The layer of phosphorus- or boron-doped silicon may improve the reliability of cells by providing a pathway for charges to leak away from the heart of the solar cell. In an embodiment, such a layer is applied to the back of a solar cell in cases where a similar passivation layer or stack of layers is also included on the back side of the solar cell. In accordance with an embodiment of the present invention, leakage pathway layers described herein reduce efficiency loss in solar cells by reducing effects of polarization and/or by increasing stability of the cell against ultra-violet radiation damage. It is noted that although many of the embodiments described herein are in association with back-contact solar cells, other solar cells (e.g., bifacial solar cells) are also contemplated within the scope of at least some embodiments of the present invention.

[0017] In an aspect of the present invention, a back-contact solar cell may include a leakage pathway layer. For example, Figure 1 illustrates a cross-sectional

view of a back-contact solar cell including a leakage pathway layer, in accordance with an embodiment of the present invention.

[0018] Referring to Figure 1, a solar cell 100 includes a dielectric layer 108 disposed above a substrate 102. A leakage pathway layer 110 is disposed above dielectric layer 108. An anti-reflective coating layer 112 is disposed above leakage pathway layer 110. In an embodiment, dielectric layer 108 is disposed directly on substrate 102, leakage pathway layer 110 is disposed directly on dielectric layer 108, and anti-reflective coating layer 112 is disposed directly on leakage pathway layer 110. In one embodiment, dielectric layer 108 has a thickness approximately in the range of 35 – 45 Angstroms. In one embodiment, anti-reflective coating layer 112 has a thickness approximately in the range of 70 – 80 nanometers.

[0019] In accordance with an embodiment of the present invention, leakage pathway layer 110 includes a layer of phosphorus- or boron-doped silicon with a morphology such as, but not limited to, amorphous, nano-crystalline, or fine-grained. In one embodiment, the layer of phosphorus- or boron-doped silicon has a thickness less than 10 nanometers. In a specific embodiment, the layer of phosphorus- or boron-doped silicon has a thickness of approximately 5 nanometers.

[0020] In accordance with an embodiment of the present invention, substrate 102 is composed of a bulk silicon substrate. In one embodiment, the bulk silicon substrate is doped with N-type dopants. In an embodiment, substrate 102 includes a concentrated doped region 106, as depicted in Figure 1, to accommodate field effects. In an embodiment, substrate 102 has a textured surface 104, as is also depicted in Figure 1.

[0021] In accordance with an embodiment of the present invention, solar cell 100 is a back-contact solar cell, and dielectric layer 108 is disposed on a light-receiving surface of substrate 102. Referring again to Figure 1, the back contact solar cell includes P-type and N-type active regions 114. Conductive contacts 116, such as metal contacts, are connected to active regions 114 and are separated from one another by isolation regions, which may be composed of a dielectric material.

[0022] A solar cell may be fabricated to include a leakage pathway layer. For example, Figure 2 illustrates a flowchart 200 representing operations in a method of fabricating a solar cell including a leakage pathway layer, in accordance with an embodiment of the present invention. Figures 3A-3D illustrate cross-sectional views of various stages in the fabrication of a solar cell including a leakage pathway layer,

corresponding to operations of flowchart 200, in accordance with an embodiment of the present invention.

[0023] Referring to operation 202 of flowchart 200, and corresponding Figure 3A, a method of fabricating a solar cell includes forming a dielectric layer 302A above a substrate 300. Dielectric layer 302A has a first thickness 304. In accordance with an embodiment of the present invention, the solar cell is a back-contact solar cell, and forming dielectric layer 302A above substrate 300 includes forming dielectric layer 302A on a light-receiving surface of substrate 300.

[0024] Referring to operation 204 of flowchart 200, and corresponding Figure 3B, the method of fabricating a solar cell further includes thinning dielectric layer 302A to a second thickness 306. Second thickness is less than first thickness 304, providing dielectric layer 302B.

[0025] In accordance with an embodiment of the present invention, dielectric layer 302A is composed of silicon dioxide, and thinning dielectric layer 302A to second thickness 306 (to provide dielectric layer 302B) includes etching dielectric layer 302A with an etchant such as, but not limited to, an aqueous solution of hydrofluoric acid or a CF_4 , NF_3 , CxFy or SF_6 -based plasma. In one embodiment, thinning dielectric layer 302A to second thickness 306, less than first thickness 304, includes thinning dielectric layer 302A from first thickness 304 approximately in the range of 65 – 75 Angstroms to second thickness 306 approximately in the range of 35 – 45 Angstroms. In one embodiment, a CF_4 , NF_3 , CxFy or SF_6 -based plasma is used, and thinning dielectric layer 302A to second thickness 306 includes etching dielectric layer 302A in the same process chamber in which dielectric layer 302A is formed, without removing substrate 300 between the forming and the thinning of dielectric layer 302A. 10. In an embodiment, thinning dielectric layer 302A to second thickness 306 includes reducing or eliminating a number of surface defects in dielectric layer 302A. For example, in a specific embodiment, dielectric layer 302A is hygroscopic and picks up unwanted moisture during or after the deposition of dielectric layer 302A. Upon thinning dielectric layer 302A to provide dielectric layer 302B, defects or contaminants may be removed from during the thinning process. In accordance with an embodiment of the present invention, thinning the dielectric layer 302A to the second thickness 306 enables an electric field effect on a solar-receiving surface of the solar cell, the electric field effect comprising a band-bending into substrate 300.

[0026] Referring to operation 206 of flowchart 200, and corresponding Figure 3C, the method of fabricating a solar cell further includes forming a leakage pathway layer 308 above dielectric layer 302B having second thickness 306.

[0027] In accordance with an embodiment of the present invention, forming leakage pathway layer 308 includes forming a layer of phosphorus- or boron-doped silicon with a morphology such as, but not limited to, amorphous, nano-crystalline, or fine-grained. In one embodiment, forming the layer of phosphorus- or boron-doped silicon includes depositing the layer to have a thickness less than 10 nanometers in a plasma-enhanced chemical vapor deposition chamber. In a specific embodiment, depositing the layer to have a thickness less than 10 nanometers includes depositing to a thickness of approximately 5 nanometers.

[0028] Referring to operation 208 of flowchart 200, and corresponding Figure 3D, the method of fabricating a solar cell further includes forming an anti-reflective coating layer 310 above leakage pathway layer 308.

[0029] In accordance with an embodiment of the present invention, forming anti-reflective coating layer 310 above leakage pathway layer 308 includes forming a layer of silicon nitride with a thickness approximately in the range of 70 – 80 nanometers. In an embodiment, forming dielectric layer 302A above substrate 300 includes forming dielectric layer 302A directly on substrate 300, forming leakage pathway layer 308 above dielectric layer 302B includes forming leakage pathway layer 308 directly on dielectric layer 302B, and forming anti-reflective coating layer 310 above leakage pathway layer 308 includes forming anti-reflective coating layer 310 directly on leakage pathway layer 308.

[0030] In another aspect of the present invention, a solar cell may be fabricated by thinning a dielectric layer, but need not necessarily include a leakage pathway layer. For example, Figure 4 illustrates a flowchart 400 representing operations in a method of fabricating a solar cell including a thin dielectric layer but not a leakage pathway layer, in accordance with an embodiment of the present invention.

[0031] Referring to operation 402 of flowchart 400, a method of fabricating a solar cell includes forming a dielectric layer above a substrate, the dielectric layer having a first thickness. Referring to operation 404 of flowchart 400, the method of fabricating a solar cell also includes thinning the dielectric layer to a second thickness, less than the first thickness. Referring to operation 406 of flowchart 400, the method

of fabricating a solar cell also includes forming an anti-reflective coating layer above the dielectric layer having the second thickness.

[0032] In accordance with an embodiment of the present invention, the anti-reflective coating layer is formed directly on the dielectric layer having the second thickness. In an embodiment, thinning the dielectric layer to the second thickness, less than the first thickness, includes thinning the dielectric layer to a thickness suitable to force direct tunneling from the anti-reflective coating layer, through the dielectric layer, to the substrate. In an embodiment, forming the dielectric layer above the substrate includes forming a doped dielectric layer above the substrate, and the method further includes driving dopants from the doped dielectric layer into the substrate to provide a depleted dielectric layer, wherein thinning the dielectric layer to the second thickness includes thinning the depleted dielectric layer. In one embodiment, thinning the dielectric layer to the second thickness enables an electric field effect on a solar-receiving surface of the solar cell, the electric field effect comprising a band-bending into the substrate.

[0033] Thus, leakage pathway layers for solar cells and methods of forming leakage pathway layers for solar cells have been disclosed. In accordance with an embodiment of the present invention, a method of fabricating a solar cell includes forming a dielectric layer above a substrate, the dielectric layer having a first thickness. The method also includes thinning the dielectric layer to a second thickness, less than the first thickness. The method also includes forming a leakage pathway layer above the dielectric layer having the second thickness. The method also includes forming an anti-reflective coating layer above the leakage pathway layer. In one embodiment, forming the leakage pathway layer includes forming a layer of phosphorus- or boron-doped silicon with a morphology such as, but not limited to, amorphous, nano-crystalline, or fine-grained.

CLAIMS

What is claimed is:

1. A method of fabricating a solar cell, the method comprising:
forming a dielectric layer above a substrate, the dielectric layer having a first thickness;
thinning the dielectric layer to a second thickness, less than the first thickness;
forming a leakage pathway layer above the dielectric layer having the second thickness; and
forming an anti-reflective coating layer above the leakage pathway layer.
2. The method of claim 1, wherein forming the leakage pathway layer comprises forming a layer of phosphorus- or boron-doped silicon with a morphology selected from the group consisting of amorphous, nano-crystalline, and fine-grained.
3. The method of claim 2, wherein forming the layer of phosphorus- or boron-doped silicon comprises depositing the layer to have a thickness less than 10 nanometers in a plasma-enhanced chemical vapor deposition chamber.
4. The method of claim 3, wherein depositing the layer to have a thickness less than 10 nanometers comprises depositing to a thickness of approximately 5 nanometers.
5. The method of claim 1, wherein the solar cell is a back-contact solar cell, and wherein forming the dielectric layer above the substrate comprises forming the dielectric layer on a light-receiving surface of the substrate.
6. The method of claim 1, wherein forming the dielectric layer above the substrate comprises forming the dielectric layer directly on the substrate, wherein forming the leakage pathway layer above the dielectric layer comprises forming the leakage pathway layer directly on the dielectric layer, and wherein forming the anti-reflective coating layer above the leakage pathway layer comprises forming the anti-reflective coating layer directly on the leakage pathway layer.

7. The method of claim 1, wherein the dielectric layer comprises silicon dioxide, and thinning the dielectric layer to the second thickness comprises etching the dielectric layer with an etchant selected from the group consisting of an aqueous solution of hydrofluoric acid or a CF₄, NF₃, CxF_y or SF₆-based plasma.
8. The method of claim 7, wherein thinning the dielectric layer to the second thickness, less than the first thickness, comprises thinning the dielectric layer from the first thickness approximately in the range of 65 – 75 Angstroms to the second thickness approximately in the range of 35 – 45 Angstroms.
9. The method of claim 7, wherein a CF₄, NF₃, CxF_y or SF₆-based plasma is used, and thinning the dielectric layer to the second thickness comprises etching the dielectric layer in the same process chamber in which the dielectric layer is formed, without removing the substrate between the forming and the thinning of the dielectric layer.
10. The method of claim 1, wherein thinning the dielectric layer to the second thickness comprises reducing or eliminating a number of surface defects in the dielectric layer.
11. The method of claim 1, wherein forming the anti-reflective coating layer above the leakage pathway layer comprises forming a layer of silicon nitride with a thickness approximately in the range of 70 – 80 nanometers.
12. The method of claim 1, wherein thinning the dielectric layer to the second thickness enables an electric field effect on a solar-receiving surface of the solar cell, the electric field effect comprising a band-bending into the substrate.
13. A solar cell, comprising:
 - a dielectric layer disposed above a substrate;
 - a leakage pathway layer disposed above the dielectric layer, the leakage pathway layer comprising a layer of phosphorus- or boron-doped silicon with a morphology selected from the group consisting of amorphous, nano-crystalline, and fine-grained; and

an anti-reflective coating layer disposed above the leakage pathway layer.

14. The solar cell of claim 13, wherein the layer of phosphorus- or boron-doped silicon has a thickness less than 10 nanometers.

15. The solar cell of claim 14, wherein the layer of phosphorus- or boron-doped silicon has a thickness of approximately 5 nanometers.

16. The solar cell of claim 13, wherein the solar cell is a back-contact solar cell, and the dielectric layer is disposed on a light-receiving surface of the substrate.

17. The solar cell of claim 13, wherein the dielectric layer is disposed directly on the substrate, wherein the leakage pathway layer is disposed directly on the dielectric layer, and wherein the anti-reflective coating layer is disposed directly on the leakage pathway layer.

18. The solar cell of claim 13, wherein the dielectric layer has a thickness approximately in the range of 35 – 45 Angstroms.

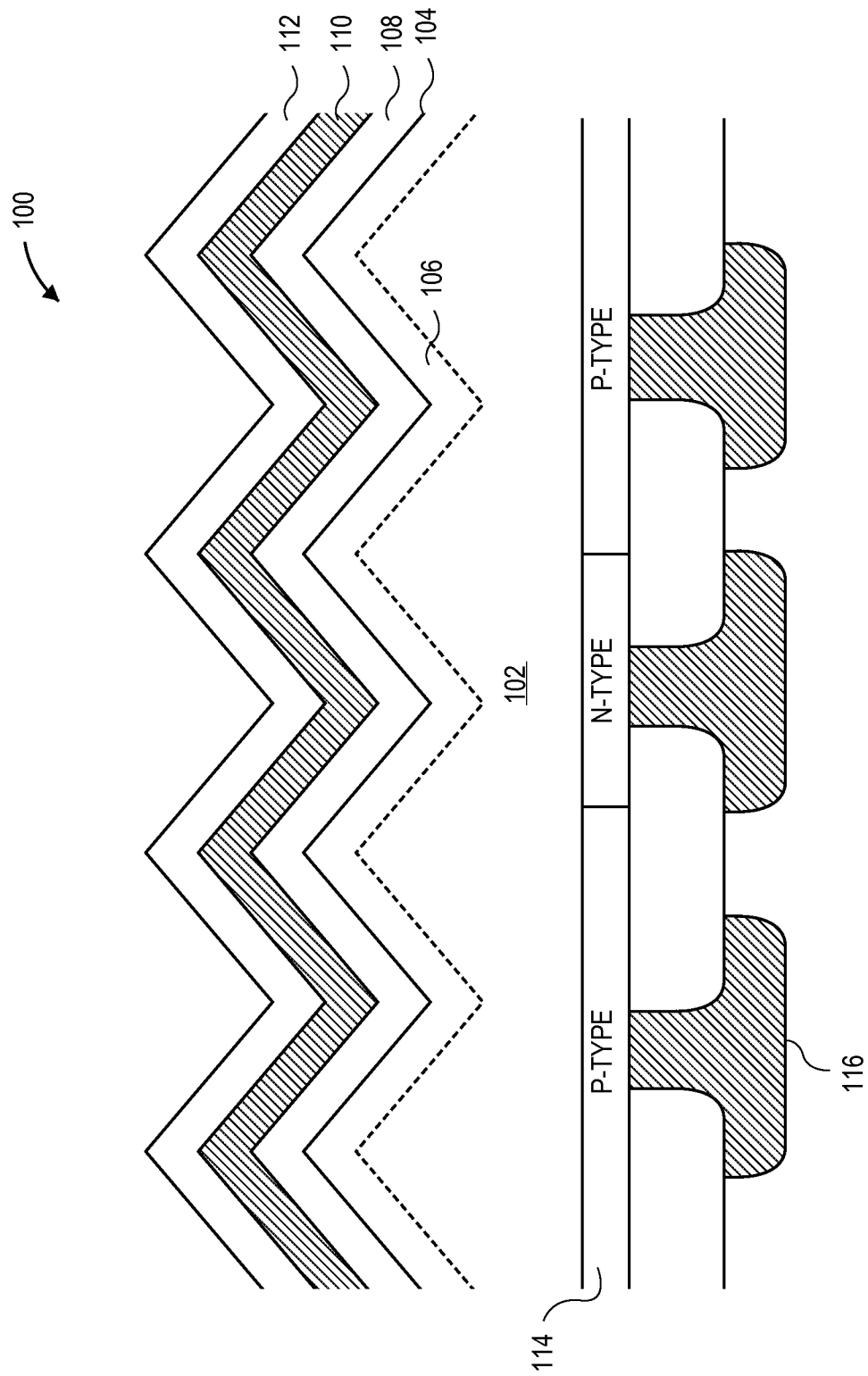
19. The solar cell of claim 13, wherein the anti-reflective coating layer has a thickness approximately in the range of 70 – 80 nanometers.

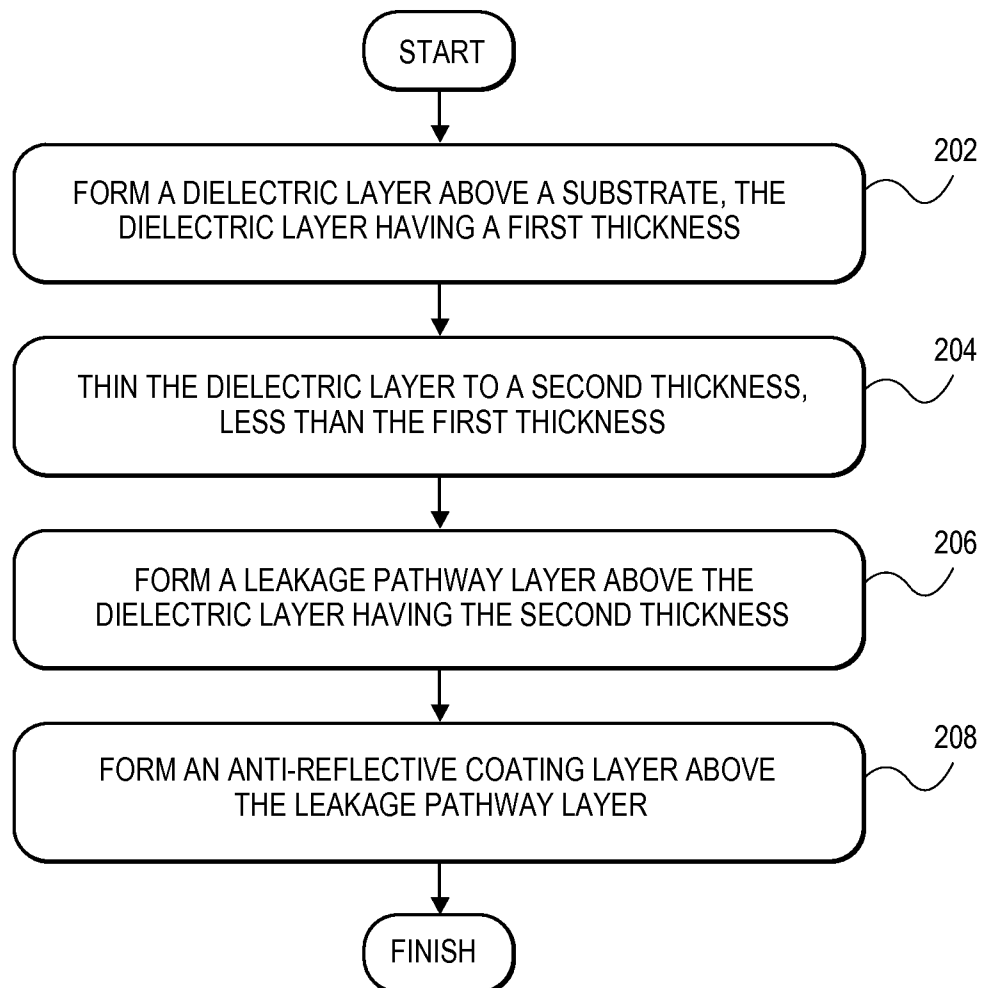
20. A method of fabricating a solar cell, the method comprising:
forming a dielectric layer above a substrate, the dielectric layer having a first thickness;
thinning the dielectric layer to a second thickness, less than the first thickness; and
forming an anti-reflective coating layer above the dielectric layer having the second thickness.

21. The method of claim 20, wherein thinning the dielectric layer to the second thickness, less than the first thickness, comprises thinning the dielectric layer to a thickness suitable to force direct tunneling from the anti-reflective coating layer, through the dielectric layer, to the substrate.

22. The method of claim 20, wherein forming the dielectric layer above the substrate comprises forming a doped dielectric layer above the substrate, wherein the method further comprises driving dopants from the doped dielectric layer into the substrate to provide a depleted dielectric layer, and wherein thinning the dielectric layer to the second thickness comprises thinning the depleted dielectric layer.

23. The method of claim 22, wherein thinning the dielectric layer to the second thickness enables an electric field effect on a solar-receiving surface of the solar cell, the electric field effect comprising a band-bending into the substrate.

**FIG. 1**

**FIG. 2**

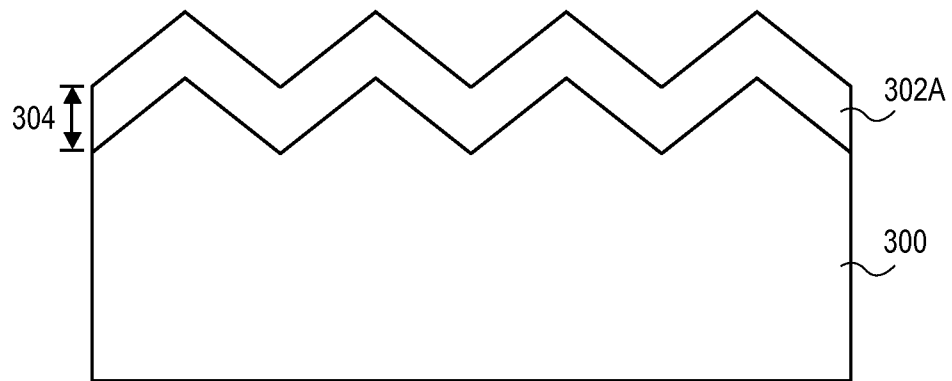


FIG. 3A

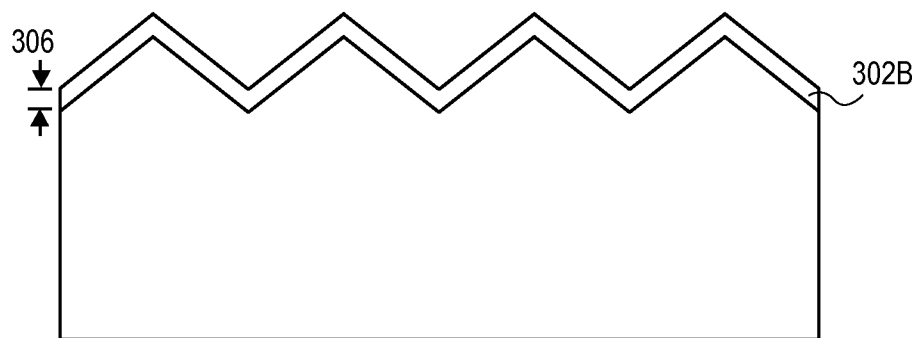


FIG. 3B

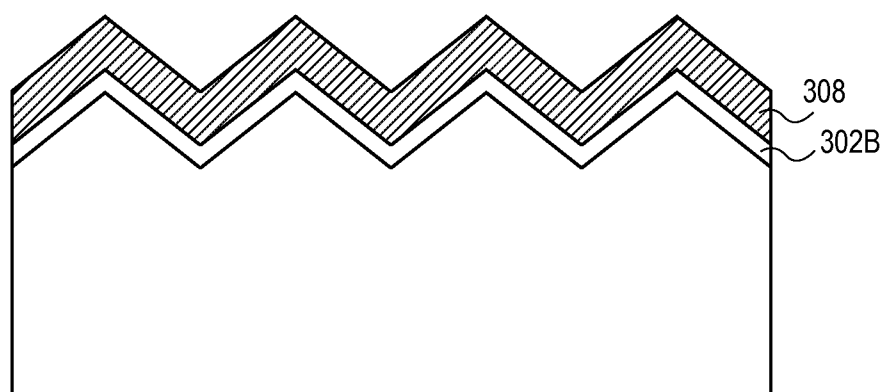
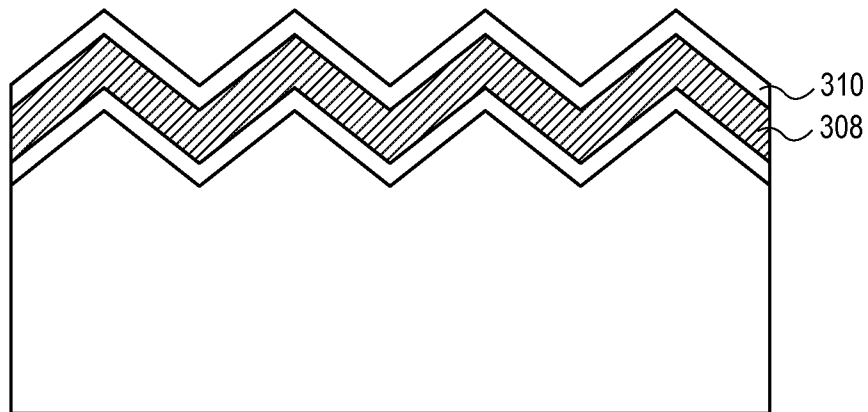
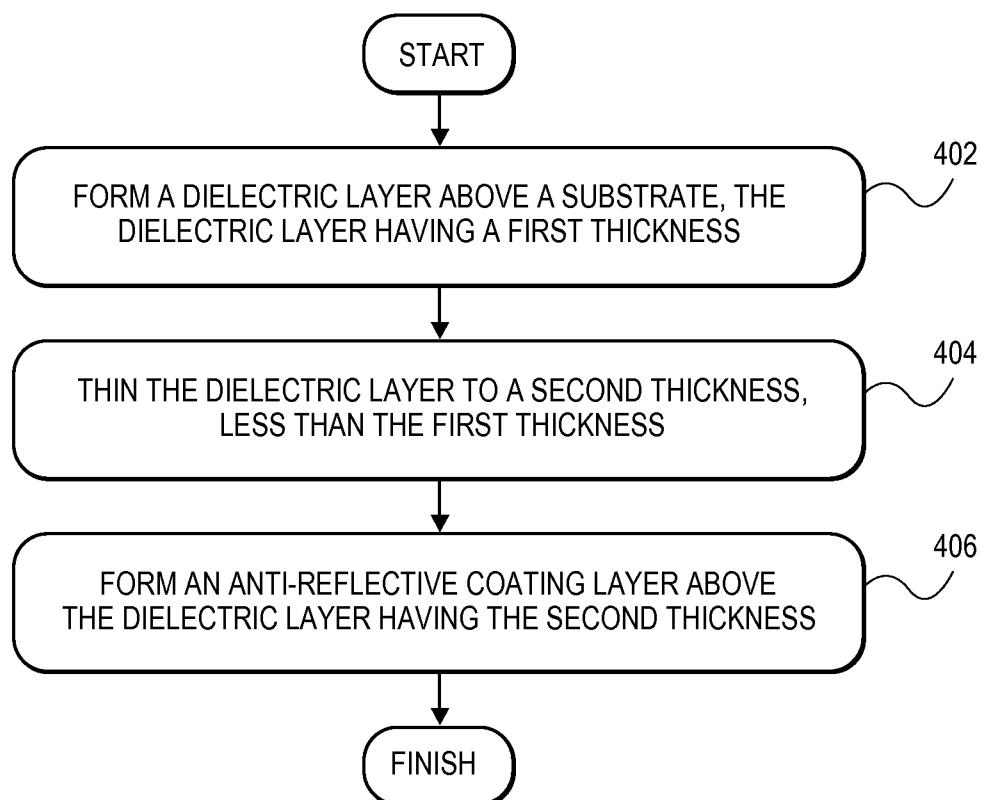


FIG. 3C

**FIG. 3D****FIG. 4**

A. CLASSIFICATION OF SUBJECT MATTER***H01L 31/042(2006.01)i, H01L 31/18(2006.01)i, H01L 31/0216(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 31/042; H01L 31/119; H01L 31/00; H01L 31/111; H01L 25/00; H01L 21/00

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: leakage pathway layer, dielectric layer, thinning, band bending

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003-0234417 A1 (IVO RAAIJMAKERS et al.) 25 December 2003 See abstract, paragraphs [0012]-[0016], figures 1 and 2, claim 1.	1-23
A	US 2002-0070416 A1 (JEFFREY D. MORSE et al.) 13 June 2002 See abstract, paragraphs [0016]-[0020], figure 1, claims 1 and 9.	1-23
A	US 2003-0010375 A1 (THOMAS L. DINWOODIE) 16 January 2003 See abstract, paragraphs [0002]-[0010], claims 1 and 43-45.	1-23



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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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