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Cousins

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(54) **FRONT CONTACT SOLAR CELL WITH FORMED ELECTRICALLY CONDUCTING LAYERS ON THE FRONT SIDE AND BACKSIDE**

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(51) **Int. Cl.**
H01L 31/0368 (2006.01)
H01L 331/028 (2006.01)

(52) **U.S. Cl.** **136/258**; 136/252; 136/256; 136/261; 438/97

(58) **Field of Classification Search** 136/243–265
See application file for complete search history.

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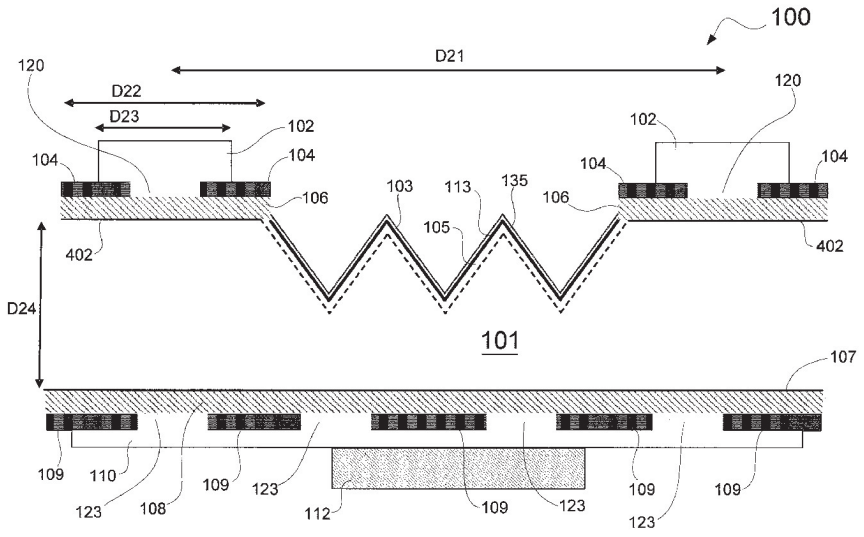
(57) **ABSTRACT**

A bipolar solar cell includes a backside junction formed by a silicon substrate and a first doped layer of a first dopant type on the backside of the solar cell. A second doped layer of a second dopant type makes an electrical connection to the substrate from the front side of the solar cell. A first metal contact of a first electrical polarity electrically connects to the first doped layer on the backside of the solar cell, and a second metal contact of a second electrical polarity electrically connects to the second doped layer on the front side of the solar cell. An external electrical circuit may be electrically connected to the first and second metal contacts to be powered by the solar cell.

11 Claims, 10 Drawing Sheets



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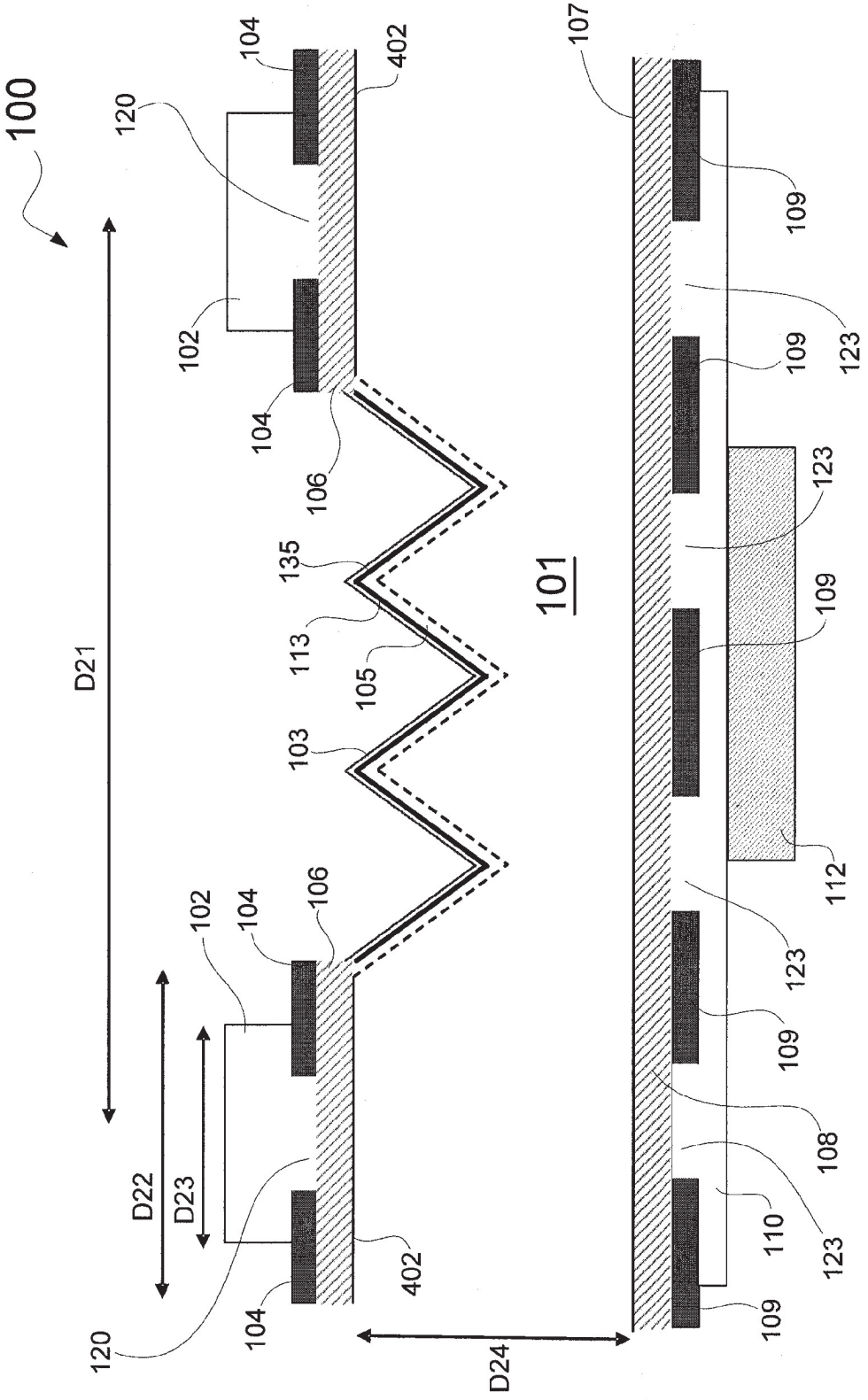
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FIG. 1

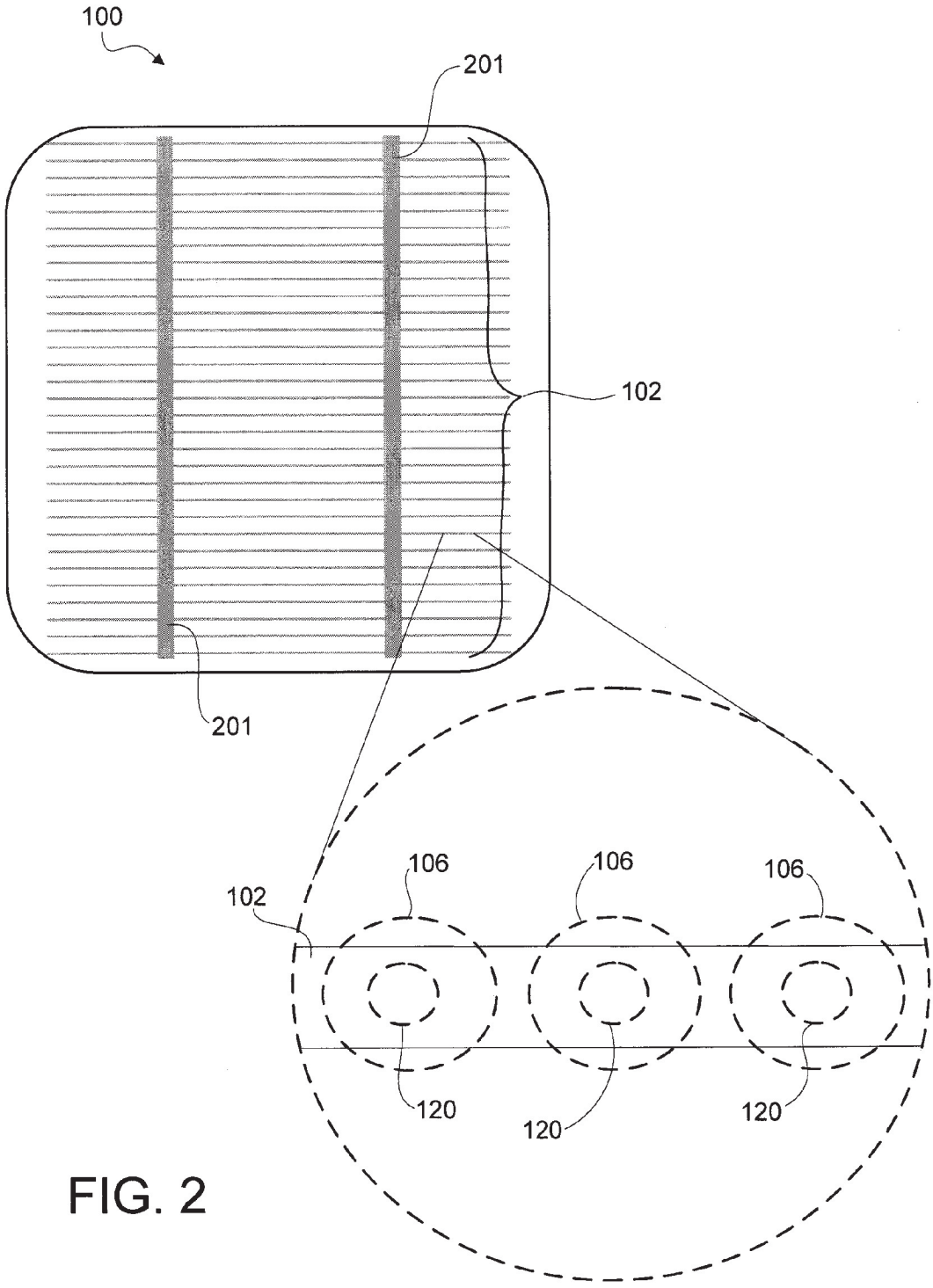


FIG. 2

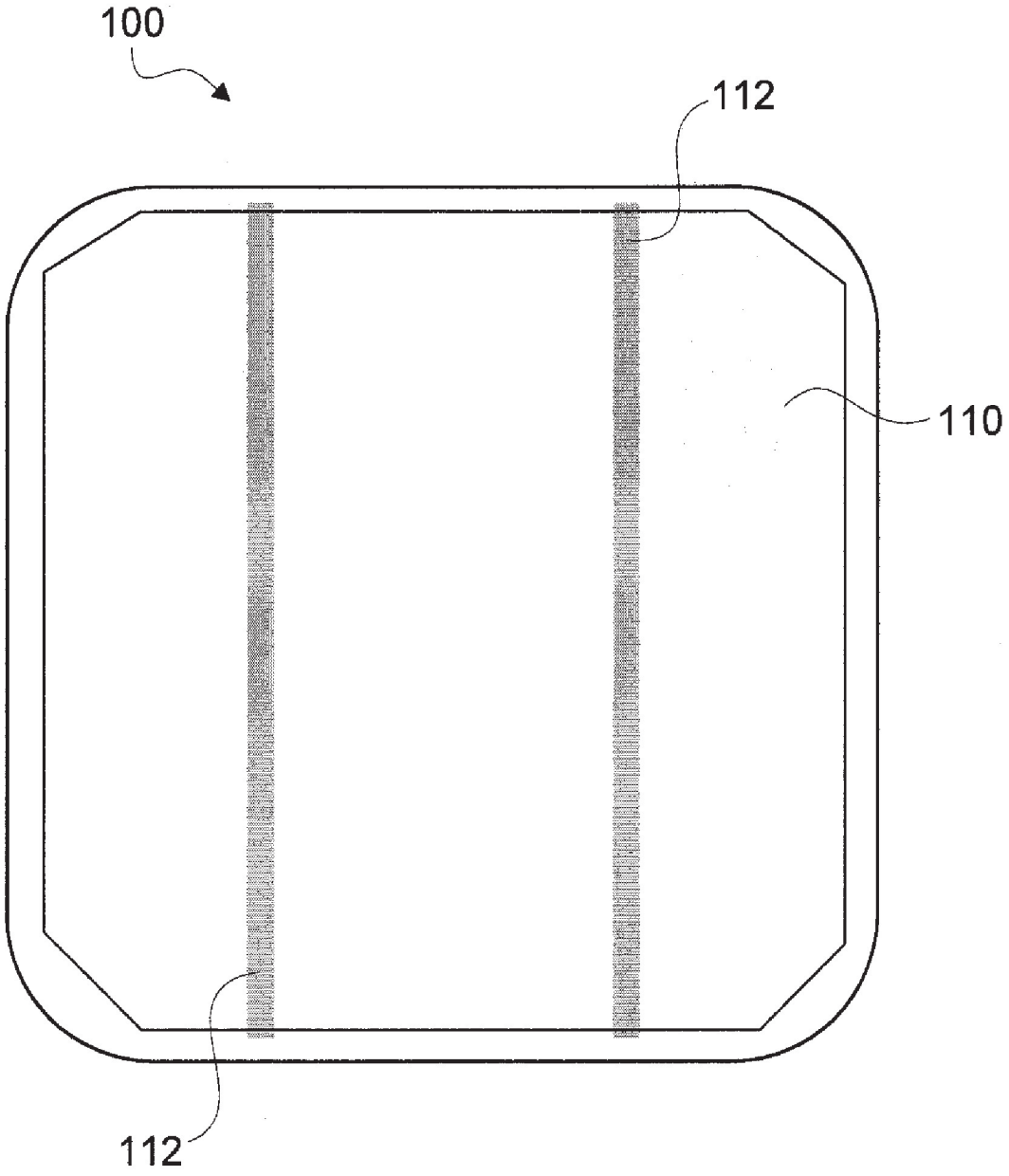
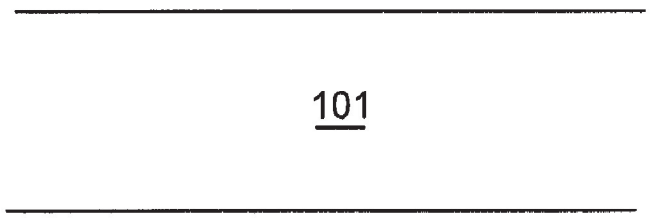


FIG. 3



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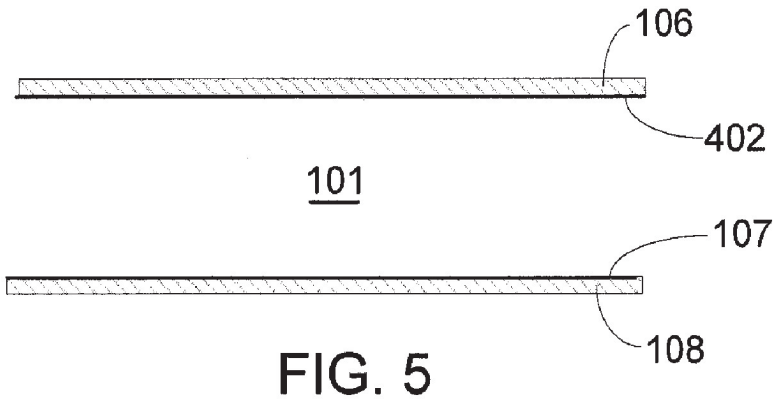


FIG. 5

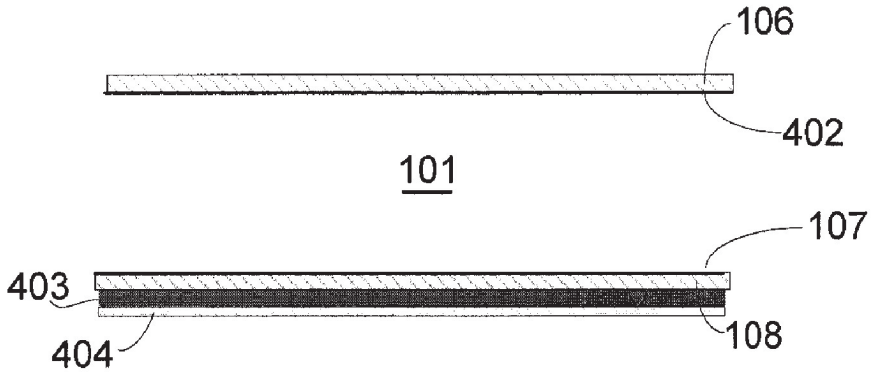
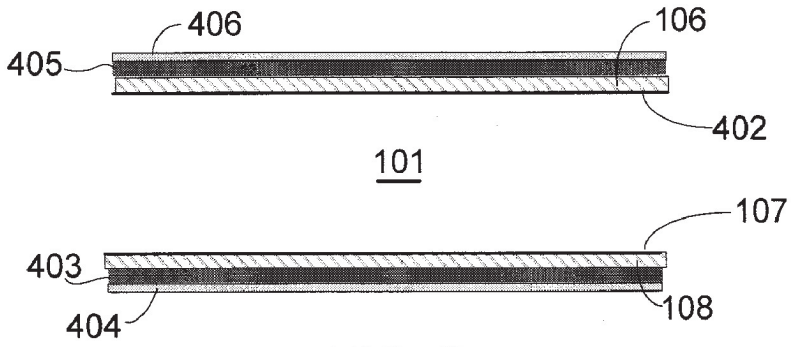


FIG. 6



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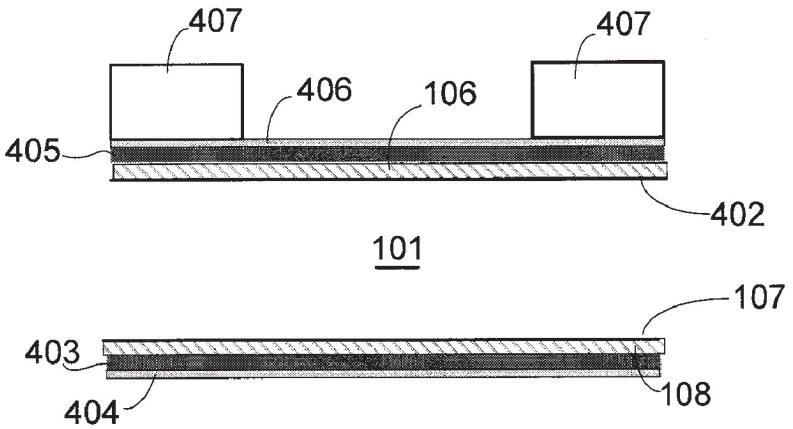

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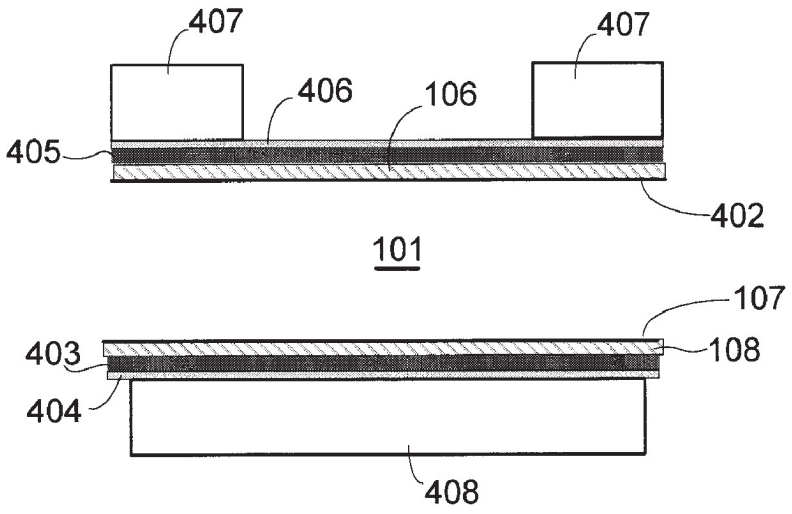
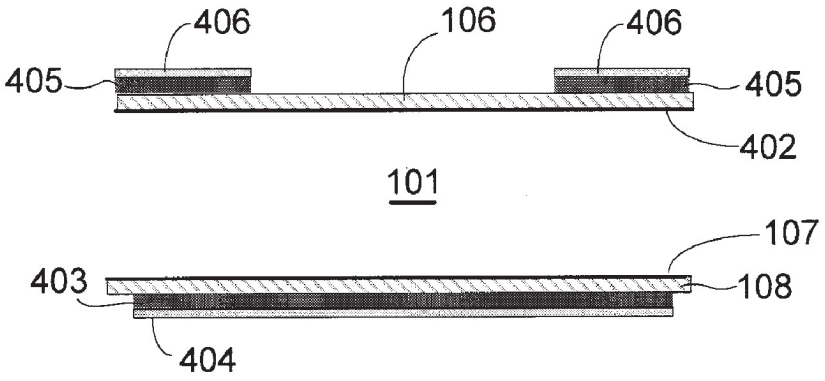


FIG. 9



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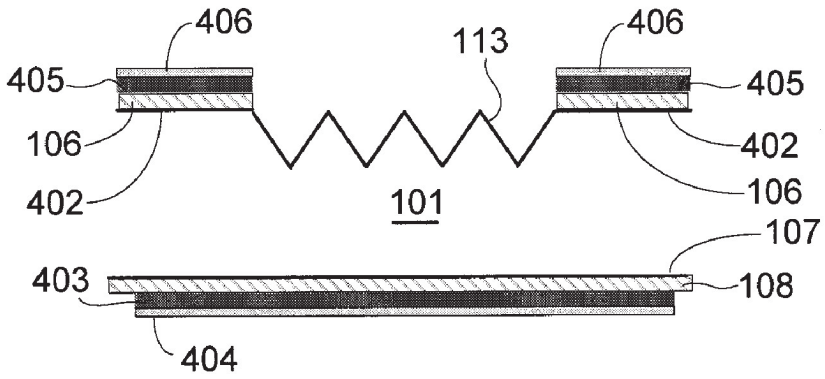

FIG. 11

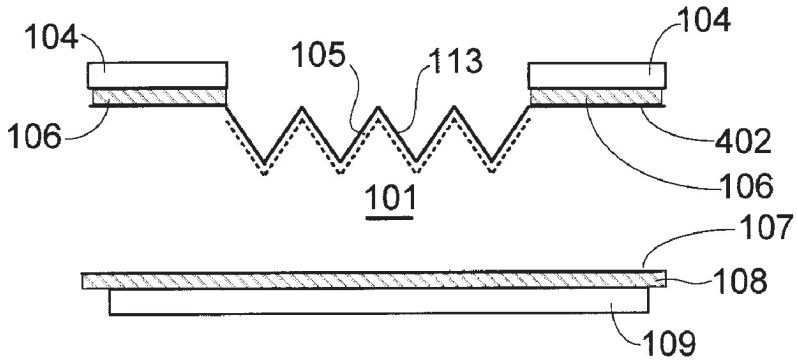

FIG. 12

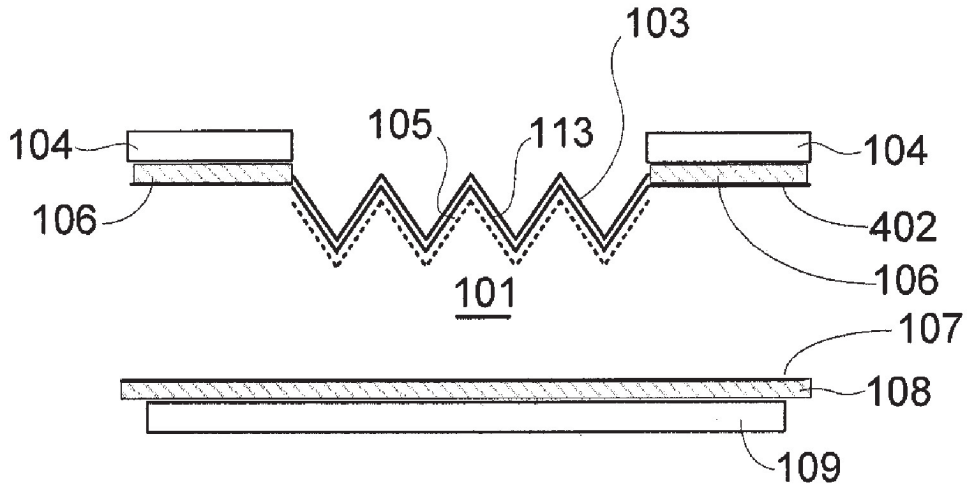
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FIG. 13

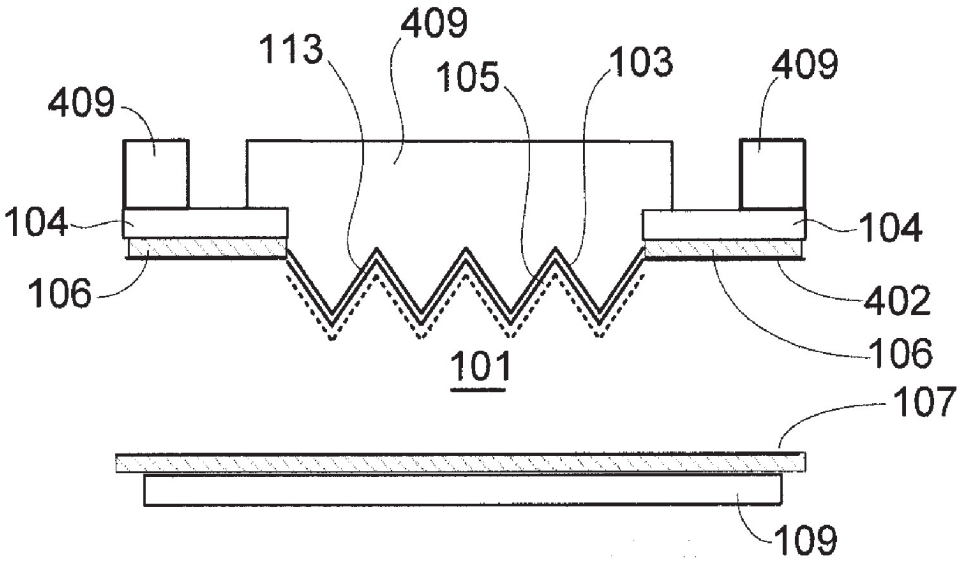
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FIG. 14

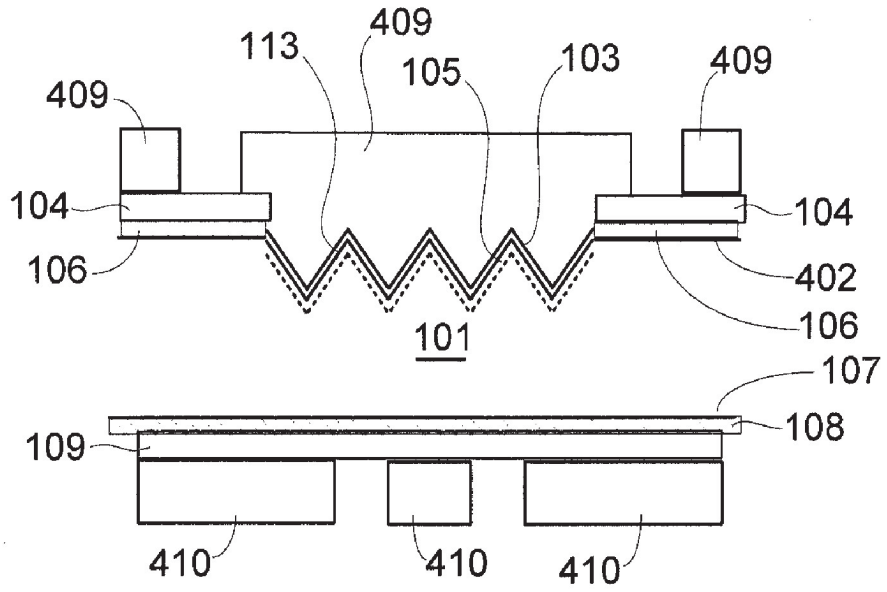
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FIG. 15

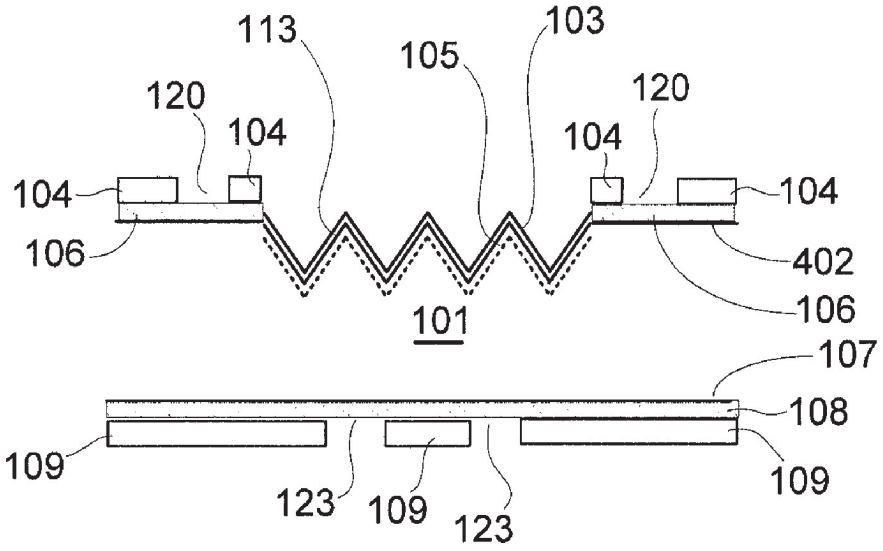
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FIG. 16

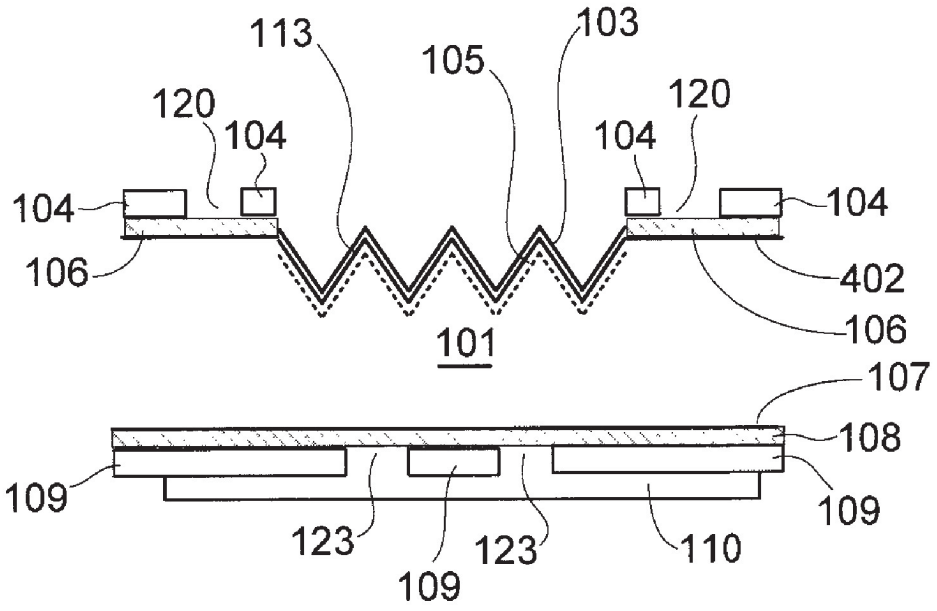
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FIG. 17

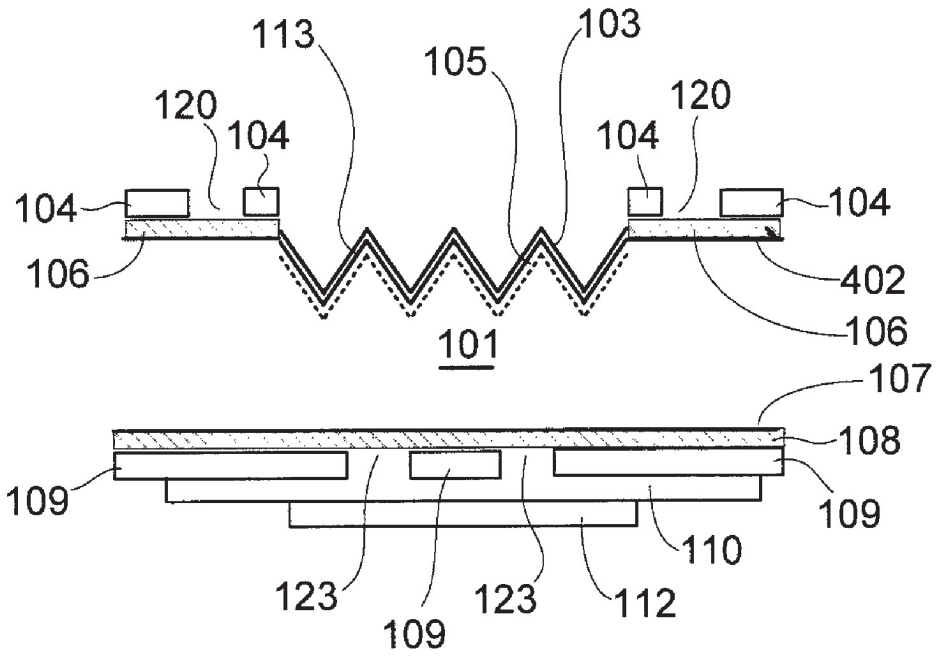
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FIG. 18

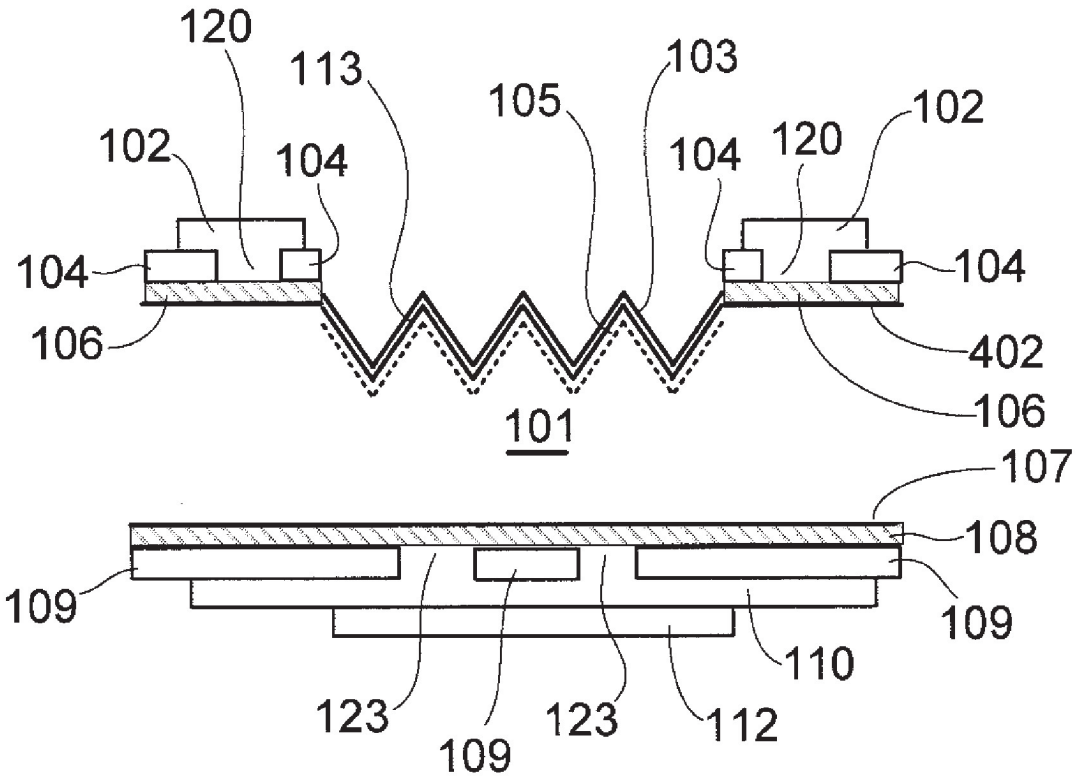
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FIG. 19

FRONT CONTACT SOLAR CELL WITH FORMED ELECTRICALLY CONDUCTING LAYERS ON THE FRONT SIDE AND BACKSIDE

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The invention described herein was made with Governmental support under contract number DE-FC36-07G017043 awarded by the United States Department of Energy. The Government may have certain rights in the invention.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to solar cells, and more particularly but not exclusively to solar cell fabrication processes and structures.

2. Description of the Background Art

Solar cells are well known devices for converting solar radiation to electrical energy. They may be fabricated on a semiconductor wafer using semiconductor processing technology. A solar cell includes P-type and N-type diffusion regions that form a junction. Solar radiation impinging on the solar cell creates electrons and holes that migrate to the diffusion regions, thereby creating voltage differentials between the diffusion regions. In a backside contact solar cell, both the diffusion regions and the metal contacts coupled to them are all on the backside of the solar cell. The metal contacts allow an external electrical circuit to be coupled to and be powered by the solar cell.

In a front contact solar cell, at least one of the metal contacts making an electrical connection to a diffusion region is on the front side of the solar cell. While backside contact solar cells have an aesthetic advantage over front contact solar cells due to the absence of metal contacts on the front side, and are thus preferred for residential applications, aesthetics is not a major requirement for power plants and other applications where power generation is the main concern. Disclosed herein are structures for a relatively efficient and cost-effective front contact solar cell and processes for manufacturing same.

SUMMARY

In one embodiment, a bipolar solar cell includes a backside junction formed by a silicon substrate and a first doped layer of a first dopant type on the backside of the solar cell. A second doped layer of a second dopant type makes an electrical connection to the substrate from the front side of the solar cell. A first metal contact of a first electrical polarity electrically connects to the first doped layer on the backside of the solar cell, and a second metal contact of a second electrical polarity electrically connects to the second doped layer on the front side of the solar cell. For example, the first doped layer may be polysilicon doped with a P-type dopant, while the second doped layer may be polysilicon doped with an N-type dopant. An external electrical circuit may be electrically connected to the first and second metal contacts to be powered by the solar cell.

These and other features of the present invention will be readily apparent to persons of ordinary skill in the art upon reading the entirety of this disclosure, which includes the accompanying drawings and claims.

DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically shows a cross-section of a solar cell in accordance with an embodiment of the present invention.

FIG. **2** is a plan view schematically showing the front side of the solar cell of FIG. **1** in accordance with an embodiment of the present invention.

FIG. **3** is a plan view schematically showing the backside of the solar cell of FIG. **1** in accordance with an embodiment of the present invention.

FIGS. **4-19** schematically illustrate the fabrication of the solar cell of FIG. **1** in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

In the present disclosure, numerous specific details are provided, such as examples of apparatus, process parameters, materials, process steps, and structures, to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details. In other instances, well-known details are not shown or described to avoid obscuring aspects of the invention.

The present invention pertains to a low cost, high-efficiency front contact solar cell. Another such front contact solar cell is also disclosed in commonly-owned U.S. application Ser. No. 12/070,742, entitled "FRONT CONTACT SOLAR CELL WITH FORMED EMITTER," filed by Peter John Cousins on Feb. 20, 2008, having Express Mail No. EM142856406US.

FIG. **1** schematically shows a cross-section of a bipolar front contact solar cell **100** in accordance with an embodiment of the present invention. The solar cell **100** has a front side where metal contacts **102** are located and a backside on a same side as the metal contact **110**. The front side, which is opposite the backside, faces the sun during normal operation to collect solar radiation. The front side of the solar cell includes layers formed on the front side surface of a substrate **101**, and the backside of the solar cell includes layers formed on the backside surface of the substrate **101**.

In the example of FIG. **1**, the solar cell **100** includes a backside junction formed by a P-type doped polysilicon layer **108** serving as a P-type diffusion region and the N-type silicon substrate **101** servings as an N-type diffusion region. In one embodiment, the polysilicon layer **108** has an emitter saturation current of about 10 $fA \cdot cm^{-2}$ The N-type silicon substrate **101** may comprise a long lifetime (e.g., 2 to 5 ms) N-type silicon wafer and may have a thickness of about 100 to 250 μm as measured from the backside surface to a tip of the textured front side surface of the substrate (see dimension D**24**). The front side surface of the substrate **101** may be randomly textured (labeled as **113**) and includes an N-type doped region **105** formed in the substrate. The N-type doped region **105** provides low front surface recombination and improves lateral conductivity whilst not compromising the blue response of the solar cell. The N-type doped region **105** may have a sheet resistance of 100 to 500 Ω/sq.

An N-type doped polysilicon layer **106** on the front side of the solar cell **100** provides low contact resistance and minimizes contact recombination. The polysilicon layer **106** is also referred to as an "N-dot" because, in one embodiment, it forms a dot-shape to minimize the area of heavily diffused regions on the front surface of the substrate **101**. In one embodiment, the polysilicon layer **106** has an emitter saturation current of about 5 $fa \cdot cm^{-2}$. The polysilicon layer **106** may be formed on a thin dielectric layer **402**. The thin dielectric layer **402** may comprise silicon dioxide thermally grown to a thickness of about 10 to 50 Angstroms on the front side surface of the substrate **101**. In one embodiment, the thin

dielectric layer **402** is not on the textured front side surface **113** because it is removed by the texturing step.

An antireflective coating (ARC) of silicon nitride layer **103** may be formed on the textured front side surface **113** of the substrate **101**. The texture front side surface **113** and the antireflective coating help improve solar radiation collection efficiency. A passivating oxide **135** may be formed on the textured front side surface **113** under the silicon nitride layer **103**. In one embodiment, the passivating oxide **135** is thermally grown on the textured front side surface of the substrate **101** to a thickness of about 10 to 250 Angstroms.

In one embodiment, the polysilicon layer **108** is formed on a thin dielectric layer **107**. The polysilicon layer **108** may be formed by forming a layer of polysilicon by Chemical Vapor Deposition (CVD), such as Low Pressure CVD (LPCVD) or Plasma Enhanced CVD (PECVD), and thermal anneal. The polysilicon layer **108** may have a sheet resistance of about 100 Ω/sq. The thin dielectric layer **107** may comprise silicon dioxide thermally grown to a thickness of about 10 to 50 Angstroms on the backside surface of the substrate **101**. A metal contact **110** electrically connects to the polysilicon layer **108** through contact holes **123** formed through a dielectric comprising a silicon dioxide layer **109**. The silicon dioxide layer **109** provides electrical isolation and allows the metal contact **110** to serve as an infrared reflecting layer for increased solar radiation collection. As will be more apparent below, the silicon dioxide layer **109** may also serve as a dopant source in the diffusion of dopants into the polysilicon layer **108**.

In one embodiment, the metal contact **110** comprises aluminum having a sheet resistance of about 15 mΩ/sq and formed to a thickness of about 10 to 30 μm by a printing process. A bus bar **112** electrically connects to the metal contact **110** to provide a positive polarity terminal for electrically connecting an external electrical circuit to the solar cell **100**. In one embodiment, the bus bar **112** comprises silver and has a conductance of about 5-25 mΩ·cm and a thickness of about 15-35 μm.

The metal contact **110** may also comprise a stack of materials comprising aluminum formed towards the substrate **101**, a diffusion barrier layer comprising titanium-tungsten formed on the aluminum, and a seed layer of copper formed on the diffusion barrier layer. In that configuration, the bus bar **112** may comprise copper electroplated onto the seed layer.

On the front side of the solar cell **100**, each metal contact **102** electrically connects to the polysilicon layer **106** through a contact hole **120** formed through the silicon dioxide layer **104**. Similar to the silicon dioxide layer **109**, the silicon dioxide layer **104** may serve as a dopant source in diffusing dopants to the polysilicon layer **106**. As can be appreciated, the polysilicon layers **108** and **106** may also be pre-doped before formation on the substrate **101**.

A metal contact **102** provides a negative polarity terminal to allow an external electrical circuit to be coupled to and be powered by the solar cell **100**. In one embodiment, the metal contact **102** comprises silver having a sheet resistance of about 5-25 mΩ·cm and a thickness of about 15-35 μm.

The pitch between adjacent metal contacts **102** separated by a textured front side surface **113** (see dimension D**21**) may be about 4200 μm. The diameter of a polysilicon layer **104** (see dimension D**22**) may be about 390 μm.

FIG. **2** is a plan view schematically showing the front side of the solar cell **100** in accordance with an embodiment of the present invention. In the example of FIG. **2**, two bus bars **201** run parallel on the front side of the substrate **101**. The contact holes **120**, in which the metal contacts **102** are formed, may each have a diameter of about 50 to 200 μm. A plurality of metal contacts **102** is formed perpendicular to the bus bars **201**. Each metal contact **102** may have a width of about 60-120 μm (see dimension D**23** in FIG. **1**).

FIG. **3** is a plan view schematically showing the backside of the solar cell **100** in accordance with an embodiment of the present invention. In the example of FIG. **3**, the bus bars **112** run parallel on the backside. In practice, the bus bars **201** and **112** will be electrically connected to corresponding bus bars of adjacent solar cells to form an array of solar cells.

Solar cells have gained wide acceptance among energy consumers as a viable renewable energy source. Still, to be competitive with other energy sources, a solar cell manufacturer must be able to fabricate an efficient solar cell at relatively low cost. With this goal in mind, a process for manufacturing the solar cell **100** is now discussed with reference to FIGS. **4-19**.

FIGS. **4-19** schematically illustrate the fabrication of the solar cell **100** in accordance with an embodiment of the present invention.

In FIG. **4**, an N-type silicon substrate **101** is prepared for processing into a solar cell by undergoing a damage etch step. The substrate **101** is in wafer form in this example, and is thus typically received with damaged surfaces due to the sawing process used by the wafer vendor to slice the substrate **101** from its ingot. The substrate **101** may be about 100 to 250 microns thick as received from the wafer vendor. In one embodiment, the damage etch step involves removal of about 10 to 20 μm from each side of the substrate **101** using a wet etch process comprising potassium hydroxide. The damage etch step may also include cleaning of the substrate **101** to remove metal contamination.

In FIG. **5**, thin dielectric layers **402** and **107** are formed on the front and back surfaces, respectively, of the substrate **101**. The thin dielectric layers **402** and **107** may comprise silicon dioxide thermally grown to a thickness of about 10 to 50 Angstroms on the surfaces of the N-type silicon substrate **101**. A layer of polysilicon is then formed on the thin dielectric layers **402** and **107** to form the polysilicon layer **106** on the front side and the polysilicon layer **108** on the backside, respectively. Each of the polysilicon layer **106** and the polysilicon layer **108** may be formed to a thickness of about 1000 to 2000 Angstroms by CVD.

In FIG. **6**, a P-type dopant source **403** is formed on the polysilicon layer **108** on the backside of the solar cell. As its name implies, the P-type dopant source **403** provides a source of P-type dopants for diffusion into the polysilicon layer **108** in a subsequent dopant drive-in step. A dielectric capping layer **404** is formed on the P-type dopant source **403** to prevent dopants from escaping from the backside of the solar cell during the drive-in step. In one embodiment, the P-type dopant source **403** comprises BSG (borosilicate glass) deposited to a thickness of about 500 to 1000 Angstroms by atmospheric pressure CVD (APCVD) and has a dopant concentration of 5 to 1% by weight, while the capping layer **404** comprises undoped silicon dioxide formed to a thickness of about 2000 to 3000 Angstroms also by APCVD. Formation of the P-type dopant source **403** and the capping layer **404** may be followed by a cleaning step to remove possible contamination from the front side of the source cell in preparation for formation of an N-type dopant source on the front side of the solar cell.

In FIG. **7**, an N-type dopant source **405** is formed on the polysilicon layer **106** on the front side of the solar cell. As its

name implies, the N-type dopant source **405** provides a source of N-type dopants for diffusion into the polysilicon layer **106** in a subsequent dopant drive-in step. A dielectric capping layer **406** is formed on the N-type dopant source **405** to prevent dopants from escaping from the front side of the solar cell during the drive-in step. In one embodiment, the N-type dopant source **405** comprises PSG (phosphosilicate glass) deposited to a thickness of about 500 to 1000 Angstroms by atmospheric pressure CVD (APCVD) and has a dopant concentration of 5 to 10% by weight, while the capping layer **406** comprises undoped silicon dioxide formed to a thickness of about 2000 to 3000 Angstroms also by APCVD.

In FIG. **8**, a mask **407** is formed on the capping layer **406** on the front side of the solar cell. The mask **407** defines and protects regions where metal contacts **102** will be formed during subsequent etching of the capping layer **406** and N-type dopant source **405**.

In FIG. **9**, a mask **408** is formed on the capping layer **404** on the backside of the solar cell. The mask **408** protects the backside surface of the solar cell during etching of the capping layer **406** and the N-type dopant source **405** on the front side of the solar cell. In the example of FIG. **9**, edges of the backside of the solar cell are not covered, i.e., exposed, by the mask **408** to allow for formation of an isolation trench on the edges of the solar cell. The masks **407** and **408** may comprise an acid resistance organic material, such as a resist, and formed using a printing process, such as screen printing or inkjet printing.

In FIG. **10**, portions of the capping layer **406** and N-type dopant source **405** not covered by the mask **407** (see FIG. **9**) and portions of the capping layer **404** and P-type dopant source **403** not covered by the mask **408** are etched in an oxide etch step. The oxide etch step exposes the region where the textured front side surface **113** (see FIG. **1**) is subsequently formed. In one embodiment, the oxide etch step comprises a BOE (buffered oxide etch) process. The masks **407** and **408** are removed after the oxide etch step.

In FIG. **11**, exposed portions of the substrate **101** on the front side are randomly textured to form the textured front side surface **113**. In one embodiment, the front side surface of the substrate **101** is textured with random pyramids using a wet etch process comprising potassium hydroxide and isopropyl alcohol. The texturing process etches away exposed portions of the polysilicon layer **106**.

In FIG. **12**, a dopant drive-in step is performed to diffuse N-type dopants from the N-type dopant source **405** (see FIG. **11**) into the polysilicon layer **106**, to diffuse P-type dopants from the P-type dopant source **403** to the polysilicon layer **108**, and to diffuse N-type dopants into the front side of the substrate **101** to form the N-type doped region **105**. Silicon dioxide layer **109** represents the P-type dopant source **403** and the capping layer **404** after the drive-in step. Similarly, silicon dioxide layer **104** represents the N-type dopant source **405** and the capping layer **406** after the drive-in step.

The polysilicon layer **108** becomes a P-type doped layer and the polysilicon layer **106** becomes an N-type doped layer after the drive-in step. The N-type doped region **105** may be formed by exposing the sample of FIG. **11** to phosphorus in the diffusion furnace during the drive-in step, for example. The use of the N-type dopant source **405**, instead of simply exposing the polysilicon layer **106** in a phosphorus environment, advantageously allows for a more controlled and concentrated N-type diffusion to the N-type doped polysilicon layer **106**. A passivating oxide layer (not shown in FIG. **11**; see layer **135** in FIG. **1**) may be grown on the textured surface **113** during the drive-in process.

In one embodiment, the drive-in step to dope the polysilicon layer **108** on the backside, to dope the polysilicon layer **106** on the front side, and to form the N-type doped region **105** may be formed in-situ, which in the context of the present disclosure means a single manual (i.e., by fabrication personnel) loading of the substrate **101** in a furnace or other single chamber or multi-chamber processing tool. In one embodiment, the drive-in step is performed in a diffusion furnace. The preceding sequence of steps leading to the drive-in step allows for in-situ diffusion, which advantageously helps in lowering fabrication cost.

In FIG. **13**, the antireflective coating of silicon nitride layer **103** is formed over the textured front side surface **113**. The silicon nitride layer **103** may be formed to a thickness of about 450 Angstroms by PECVD, for example.

In FIG. **14**, a mask **409** is formed on the front side of the solar cell. The mask **409** defines the regions where the contact holes **120** (see FIG. **1**) will be subsequently formed.

In FIG. **15**, a mask **410** is formed on the backside of the solar cell. The mask **410** defines the regions where the contact holes **123** (see FIG. **1**) will be subsequently formed. The masks **409** and **410** may comprise an acid resistance organic material, such as a resist, and formed using a printing process, such as screen printing or inkjet printing.

In FIG. **16**, contact holes **120** and **123** are formed by removing portions of the silicon dioxide layers **104** and **109** exposed through the masks **409** and **410**, respectively. In one embodiment, the contact holes **120** are formed by using a selective contact etch process that removes exposed portions of the silicon dioxide layer **104** and stops on the polysilicon layer **106**. The same contact etch process removes exposed portions of the silicon dioxide layer **109** and stops on the polysilicon layer **108**. In one embodiment, the contact etch process comprises a BOE (buffered oxide etch) process. The masks **409** and **410** are removed after the contact etch process.

In FIG. **17**, the metal contact **110** is formed on the silicon dioxide layer **109** to fill the contact holes **123** and make electrical connection to the polysilicon layer **108**. The metal contact **110** may be formed using a printing process, such as screen printing. The metal contact **110** may comprise aluminum, which, together with the silicon dioxide layer **109**, makes an excellent backside infrared reflector to increase solar radiation collection efficiency.

In FIG. **18**, the metal contact **123** is formed on the metal contact **110** to make electrical connection to the polysilicon layer **108**. The metal contact **123** may be formed using a printing process, such as screen printing. The metal contact **110** may comprise silver, for example.

In FIG. **19**, the metal contacts **102** are formed on the silicon dioxide layer **104** to fill the contact holes **120** and make electrical connection to the substrate **101** by way of the polysilicon layer **106**. The metal contacts **120** may comprise silver and formed using a printing process, such as screen printing.

Formation of the metal contacts **102** and **110** may be followed by a firing step. The firing step is applicable when using screen printed silver paste as metal contacts, but not when using other processes or metals. The solar cell **100** may then be visually inspected and tested.

An improved front contact solar cell and method of manufacturing same have been disclosed. While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure.

What is claimed is:

1. A solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the solar cell comprising:

a silicon substrate;

a first layer of doped polysilicon formed over a back surface of the substrate, the first layer of doped polysilicon forming a backside junction with the substrate;

a second layer of doped polysilicon formed over a front surface of the substrate, the second layer of doped polysilicon making an electrical connection to the substrate;

a first silicon dioxide layer between the first layer of doped polysilicon and the back surface of the substrate;

a second silicon dioxide layer between the second layer of doped polysilicon and the front surface of the substrate;

a first metal contact making an electrical connection to the first layer of doped polysilicon on the backside of the solar cell;

a second metal contact making an electrical connection to the second layer of doped polysilicon on the front side of the solar cell, the first metal contact and the second metal contact being configured to allow an external electrical circuit to be powered by the solar cell;

a doped region under a textured portion of the front surface of the substrate, the doped region being of a same conductivity type as the second layer of doped polysilicon; wherein the dielectric layer is not the first silicon dioxide layer or the second silicon dioxide layer, and

a dielectric layer formed over the first layer of doped polysilicon, and wherein the first metal contact comprises aluminum formed over the dielectric layer.

2. The solar cell of claim 1 further comprising an antireflective layer over the textured portion of the front surface of the substrate.

3. The solar cell of claim 2 wherein the antireflective layer comprises silicon nitride.

4. The solar cell of claim 1 wherein the substrate comprises an N-type silicon substrate, the first layer of doped polysilicon comprises a P-type doped polysilicon, and the second layer of doped polysilicon comprises an N-type doped polysilicon.

5. The solar cell of claim 1 wherein the first silicon dioxide layer is formed to a thickness between 10 and 50 Angstroms.

6. The solar cell of claim 1 further comprising a third metal contact formed over the first metal contact.

7. The solar cell of claim 1 wherein the first metal contact forms an infrared reflecting layer with the dielectric layer on the backside of the solar cell.

8. A solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the solar cell comprising:

an N-type silicon substrate;

a textured surface on the N-type silicon substrate on the front side of the solar cell;

an antireflective layer over the textured surface of the N-type silicon substrate;

a P-type polysilicon layer forming a backside junction with the N-type silicon substrate;

an N-type polysilicon layer over the front side of the solar cell;

a first silicon dioxide layer between the N-type silicon substrate and the N-type polysilicon layer;

a second silicon dioxide layer between the p-type polysilicon and the back surface of the substrate;

a negative polarity metal contact making an electrical connection to the N-type polysilicon layer from the front side of the solar cell;

a positive polarity metal contact making an electrical connection to the P-type polysilicon layer from the backside of the solar cell;

an N-type doped region under the textured surface on the N-type silicon substrate on the front side of the solar cell; and

a dielectric layer formed over the P-type polysilicon layer, wherein the dielectric layer is not the first silicon dioxide layer or the second silicon dioxide layer, and wherein the positive polarity metal contact comprises aluminum formed over the dielectric layer.

9. The solar cell of claim 8 wherein the antireflective layer comprises a layer of silicon nitride.

10. The solar cell of claim 8 further comprising a dielectric capping layer over the N-type polysilicon layer.

11. The solar cell of claim 8 wherein the positive polarity metal contact forms an infrared reflecting layer with the dielectric layer formed over the P-type polysilicon layer.

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