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Smith et al.

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(45) **Date of Patent: Feb. 14, 2006**

(54) **USE OF DOPED SILICON DIOXIDE IN THE FABRICATION OF SOLAR CELLS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/946,564**

(22) Filed: **Sep. 21, 2004**

Related U.S. Application Data

(60) Provisional application No. 60/508,772, filed on Oct. 3, 2003.

(51) **Int. Cl.**
H01L 21/00 (2006.01)

(52) **U.S. Cl.** **438/48**; 438/57; 438/73; 136/243; 136/249; 136/252

(58) **Field of Classification Search** 438/48, 438/57, 73; 136/243, 249, 252
See application file for complete search history.

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(57) **ABSTRACT**

In one embodiment, a method of forming doped regions in a substrate of a back side contact solar cell includes the steps of depositing a first doped oxide layer on a back side of a substrate, depositing a first undoped oxide layer over the first doped oxide layer, diffusing a first dopant from the first doped oxide layer into the substrate to form a first doped region in the substrate, and diffusing a second dopant into the substrate by way of a front side of the substrate, wherein the diffusion of the first dopant and the second dopant into the substrate are performed in-situ. The method may further include the steps of patterning the first doped and undoped oxide layers to expose portions of the back side of the substrate and depositing a second doped and undoped oxide layers on the back side of the substrate.

20 Claims, 3 Drawing Sheets

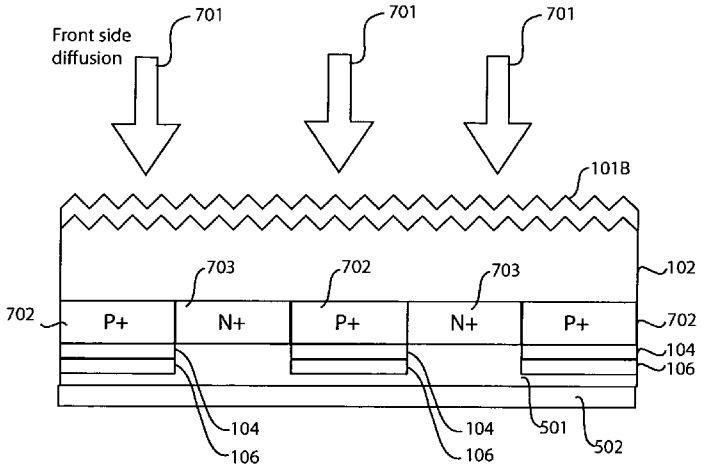

FIG. 7

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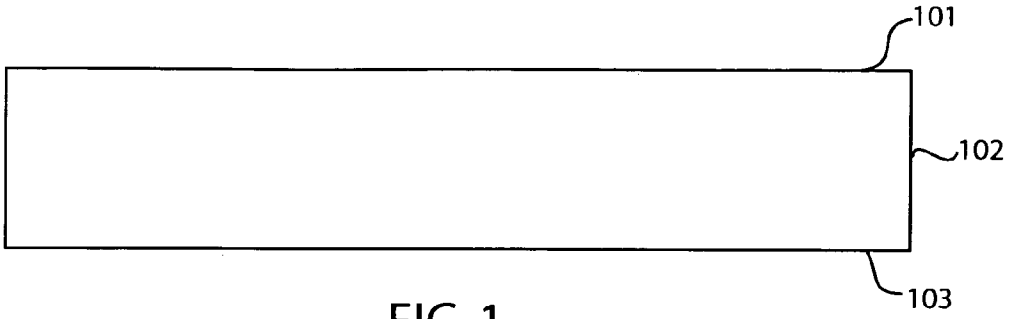


FIG. 1

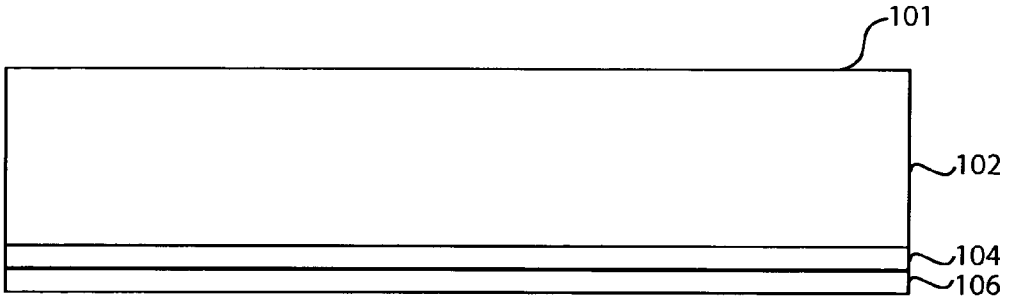


FIG. 2

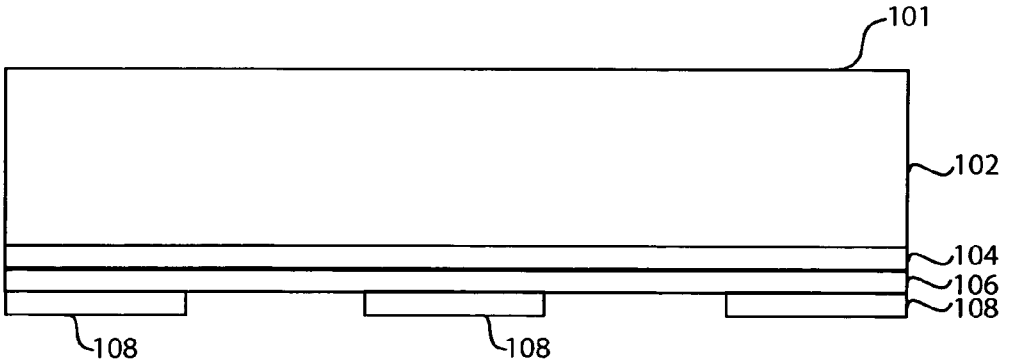


FIG. 3

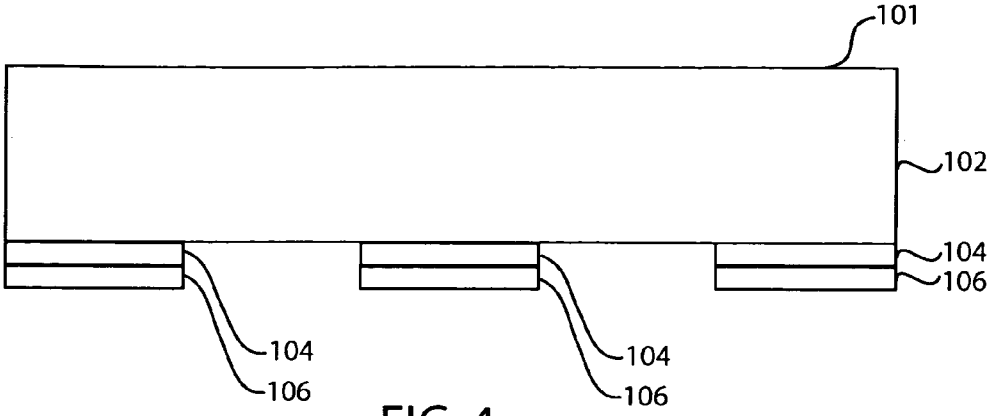


FIG. 4

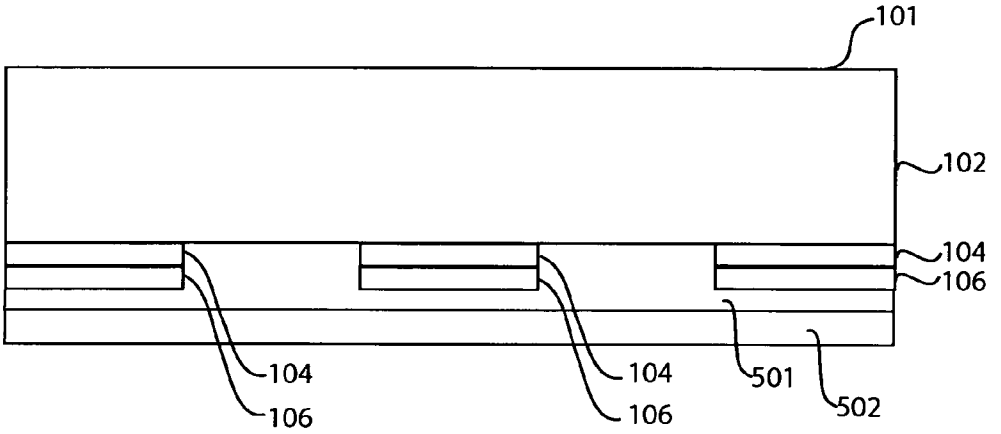


FIG. 5

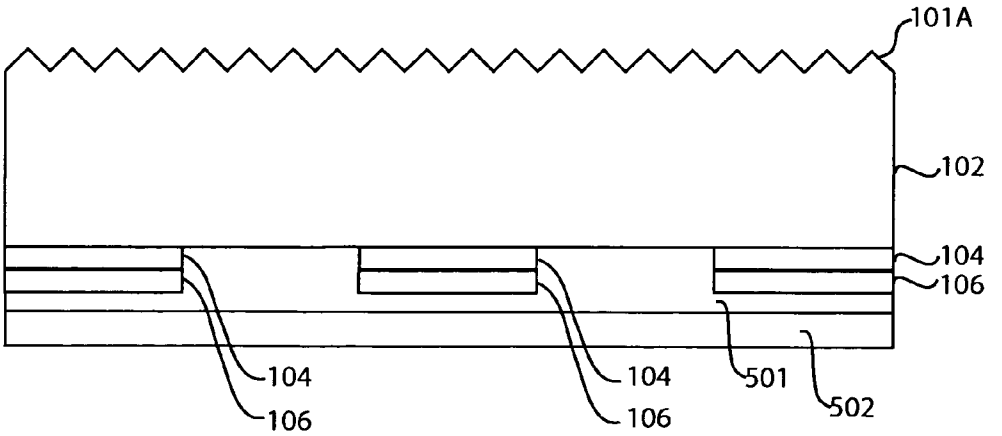


FIG. 6

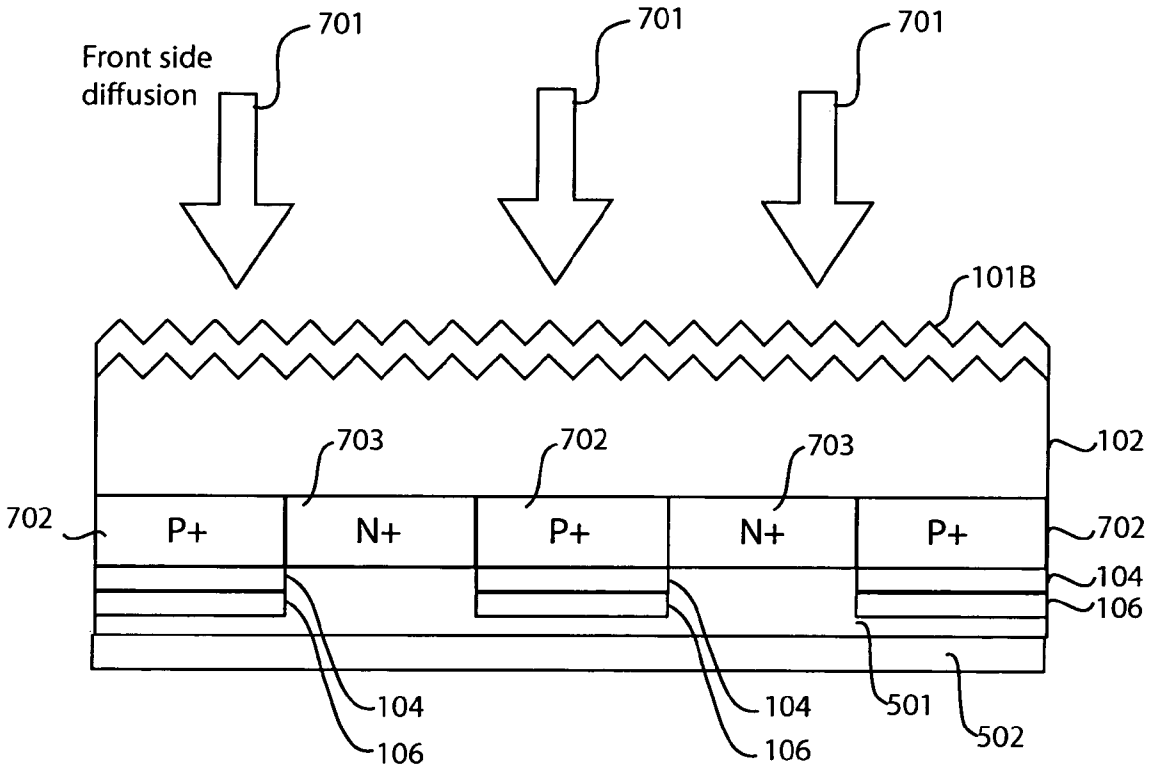

Front side
diffusion
701
701
701
101B
703
702
703
102
702
P+
N+
P+
N+
P+
702
104
106
104
106
104
106
501
502

FIG. 7

USE OF DOPED SILICON DIOXIDE IN THE FABRICATION OF SOLAR CELLS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/508,772, entitled "Use Of Doped Silicon Dioxide In The Fabrication Of Solar Cells," filed by David D. Smith, Michael J. Cudzinovic, and Keith McIntosh on Oct. 3, 2003, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to solar cells, and more particularly but not exclusively to methods and apparatus for fabricating solar cells.

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. Generally speaking, a solar cell may be fabricated by forming p-doped and n-doped regions in a silicon substrate. Solar radiation impinging on the solar cell creates electrons and holes that migrate to the p-doped and n-doped regions, thereby creating voltage differentials between the doped regions. In a back side contact solar cell, the doped regions are coupled to metal contacts on the back side of the solar cell to allow an external electrical circuit to be coupled to and be powered by the solar cell. Back side contact solar cells are also disclosed in U.S. Pat. Nos. 5,053,083 and 4,927,770, which are both incorporated herein by reference in their entirety.

Just like in most manufacturing processes, each step employed in the manufacture of solar cells has an associated cost. Thus, techniques for simplifying the fabrication of solar cells are generally desirable.

SUMMARY

In one embodiment, a method of forming doped regions in a substrate of a back side contact solar cell includes the steps of depositing a first doped oxide layer on a back side of a substrate, depositing a first undoped oxide layer over the first doped oxide layer, diffusing a first dopant from the first doped oxide layer into the substrate to form a first doped region in the substrate, and diffusing a second dopant into the substrate by way of a front side of the substrate, wherein the diffusion of the first dopant and the second dopant into the substrate are performed in-situ. The method may further include the steps of patterning the first doped and undoped oxide layers to expose portions of the back side of the substrate and depositing a second doped and undoped oxide layers on the back side of the substrate.

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

FIGS. **1–7** schematically illustrate a method of fabricating a solar cell in accordance with an embodiment of the present invention.

The use of the same reference label in different drawings indicates the same or like components. Drawings are not necessarily to scale unless otherwise noted.

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 disclosure relates to the fabrication of solar cells. Solar cell fabrication processes are also disclosed in the following commonly-assigned disclosures, which are incorporated herein by reference in their entirety: U.S. application Ser. No. 10/412,638, entitled "Improved Solar Cell and Method of Manufacture," filed on Apr. 10, 2003 by William P. Mulligan, Michael J. Cudzinovic, Thomas Pass, David Smith, Neil Kaminar, Keith McIntosh, and Richard M. Swanson; and U.S. application Ser. No. 10/412,711, entitled "Metal Contact Structure For Solar Cell And Method Of Manufacture," filed on Apr. 10, 2003 by William P. Mulligan, Michael J. Cudzinovic, Thomas Pass, David Smith, and Richard M. Swanson.

FIGS. **1–7** schematically illustrate a method of fabricating a solar cell in accordance with an embodiment of the present invention.

In FIG. **1**, an N-type FZ silicon wafer **102** is processed to a thickness of about 280 μm. Wafer **102** serves as the substrate of the solar cell being fabricated. Wafer **102** has a front side **101** and a back side **103**. Front side **101** is the side of the solar cell configured to receive solar radiation, and thus faces the sun in operation. Wafer **102** is thinned to a thickness of about 240 μm using a process that also etches damages from the surfaces of the wafer. The aforementioned process is also referred to as "bath damage etch/critical clean," and, in one embodiment, comprises a wet etch using potassium hydroxide (e.g., two parts potassium hydroxide to water).

In FIG. **2**, a boron-doped silicon dioxide (SiO_2) ("BSG") **104** is deposited on the back side of wafer **102**. In one embodiment, boron-doped silicon dioxide **104** is deposited to a thickness of about 1000 Angstroms using an atmospheric pressure chemical vapor deposition process (APCVD). The thickness of boron-doped silicon dioxide **104**, and other materials disclosed herein, may be varied depending on the application. For example, boron-doped silicon dioxide **104** may also be deposited to a thickness of about 500 Angstroms by APCVD. Thereafter, an undoped silicon dioxide **106** is deposited over boron-doped silicon dioxide **104**. In one embodiment, undoped silicon dioxide **106** is deposited to a thickness of about 1200 Angstroms also by APCVD. The use of a deposition process, such as APCVD, to deposit the boron-doped silicon dioxide and the undoped silicon dioxide advantageously allows for one-sided deposition. This is particularly useful in the manufacture of back side contact solar cells where only one side of the solar cell is textured. Note that depending on the application, doped silicon dioxide **104** may also be doped with P-type dopants other than boron.

In FIG. **3**, a mask **108** is formed over the silicon dioxide stack comprising the boron-doped and undoped silicon dioxide. Mask **108** will be used in a subsequent etch process

(see FIG. **4**) exposing the would be N+region of the wafer. Mask **108** may comprise an ink formed by a printing process such as screen printing, pad printing, or ink-jet printing. In one embodiment, the ink comprises a particle-free ink, and may be of the same type as the Coates ER-3070 ink available from Coates Screen of St. Charles, Ill. The particle-free ink may be applied by screen printing. The use of a printing process, such as screen printing, is advantageous in that sufficiently small feature sizes can be achieved with lower process costs.

In FIG. **4**, mask **108** is employed in patterning the silicon dioxide stack comprising boron-doped silicon dioxide **104** and undoped silicon dioxide **106**. In one embodiment, the silicon dioxide stack is patterned using a wet etch process comprising buffered hydrofluoric acid. The wet etch process uses the silicon of wafer **102** as an etch stop, and etches portions of the silicon dioxide stack not covered by mask **108**. Mask **108** is thereafter removed.

In FIG. **5**, a phosphorus-doped silicon dioxide **501** is deposited over the sample of FIG. **4**. Thereafter, an undoped silicon dioxide **502** is deposited over phosphorus-doped silicon dioxide **501**. In one embodiment, phosphorus-doped silicon dioxide **501** is deposited to a thickness of about 500 Angstroms by APCVD, while undoped silicon dioxide **502** is deposited to a thickness of about 2400 Angstroms also by APCVD. Note that depending on the application, doped silicon dioxide **501** may also be doped with N-type dopants other than phosphorus. Phosphorus-doped silicon dioxide **501** and undoped silicon dioxide **502** are preferably conformal to their respective underlying layers.

In FIG. **6**, front side **101** is textured using a wet etch process comprising potassium hydroxide and isopropyl alcohol. The wet etch textures front side **101** with random pyramids, thereby improving the solar radiation collection efficiency. Undoped oxide **502** advantageously protects the materials on the back side of wafer **102** from the texturing solution. In FIG. **6**, front side **101** has been relabeled as "**101**A" to indicate that it has been textured.

In FIG. **7**, the sample of FIG. **6** is subjected to in-situ steps. The steps are in-situ in that they are performed in one loading of wafer **102** into the wafer processing tool. In one embodiment, the in-situ steps are performed in a furnace. In the first in-situ step, wafer **102** is heated to about 1000° C. for one hour to diffuse dopants from boron-doped silicon dioxide **104** and phosphorus-doped silicon dioxide **501** into wafer **102**. This results in the formation of P+ regions **702** (due to boron-doped silicon dioxide **104**) and N+ regions **703** (due to phosphorus-doped silicon dioxide **501**) in wafer **102**. Note that during the first in-situ step, undoped silicon dioxide **106** beneficially prevents phosphorus from phosphorus-doped silicon dioxide **501** from diffusing into boron-doped silicon dioxide **104**. Also, undoped silicon dioxide **502** beneficially prevents phosphorus from phosphorus-doped silicon dioxide **501** from diffusing into the furnace.

In the second in-situ step, the furnace conditions are changed to about 750° C. with an atmosphere containing phosphorus oxychloride, then to about 975° C. with an atmosphere containing oxygen to diffuse phosphorus as an N-type dopant into wafer **102** from its front side, and to grow a thin layer of silicon dioxide on both sides of wafer **102**. Front side **101** is now labeled as "**101**B" to indicate that there is a thin layer of silicon dioxide on its surface. The thin layer of silicon dioxide advantageously leads to better passivation of the front side and back side surfaces of wafer **102**. In FIG. **7**, the front side diffusion of N-type dopants into wafer **102** is schematically represented by arrows **701**. As can be appreciated the use of in-situ steps to drive dopants into wafer **102** simplifies the fabrication process.

The fabrication of the sample of FIG. **7** may be completed using a back-end process to form electrodes coupled to the P+ and N+ regions of wafer **102** and to include an anti-reflective coating (e.g., silicon nitride) on front side **101**B. For example, a back-end process similar to that disclosed in U.S. application Ser. No. 10/412,638 may be employed to complete the fabrication of the sample of FIG. **7**. Conventional solar cell back-end processes may also be employed without detracting from the merits of the present invention.

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 method of forming doped regions in a substrate of a back side contact solar cell, the method comprising:

depositing a first doped oxide layer on a back side of a substrate;

depositing a first undoped oxide layer over the first doped oxide layer;

diffusing a first dopant from the first doped oxide layer into the substrate to form a first doped region of a solar cell in the substrate;

diffusing a second dopant into the substrate by way of a front side of the substrate; and

wherein the diffusion the first dopant from the first doped oxide layer and the diffusion the second dopant into the substrate are performed in-situ.

2. The method of claim **1** further comprising:

prior to diffusing the first dopant from the first doped oxide layer:

patterning the first doped oxide layer and the first undoped oxide layer to expose portions of the back side of the substrate;

depositing a second doped oxide layer on the back side of the substrate;

depositing a second undoped oxide layer over the second doped oxide layer; and

diffusing a dopant from the second doped oxide layer into the substrate to form a second doped region of the solar cell, wherein the dopant from the second doped oxide layer is diffused in-situ with the first dopant from the first doped oxide layer.

3. The method of claim **1** wherein the first doped oxide layer comprises boron-doped silicon dioxide.

4. The method of claim **2** wherein the second doped oxide layer comprises phosphorus-doped silicon dioxide.

5. The method of claim **1** further comprising:

forming a printed mask over the first doped oxide layer and the first undoped oxide layer.

6. The method of claim **5** wherein the mask is formed by screen printing.

7. The method of claim **5** wherein the mask comprises a particle-free ink.

8. The method of claim **1** wherein the first dopant is a P-type dopant and the second dopant is an N-type dopant.

9. A method of fabricating a solar cell, the method comprising:

providing a substrate having a front side and a back side, the front side of the substrate being configured to receive solar radiation for a solar cell;

forming a first doped oxide layer on the back side of the substrate;

diffusing a first dopant from the first doped oxide layer into the substrate to form a first doped region of the solar cell; and

diffusing a second dopant into the substrate from the front side of the substrate in-situ with the diffusion of the first dopant from the first doped oxide layer.

10. The method of claim **9** further comprising:

forming a second doped oxide layer on the back side of the substrate; and

diffusing a dopant from the second doped oxide layer into the substrate to form a second doped region of the solar cell, the diffusion of the dopant from the second doped oxide layer being performed in-situ with the diffusion of the first dopant from the first doped oxide layer.

11. The method of claim **10** further comprising:

forming a first undoped oxide layer over the first doped oxide layer to minimize diffusion of the dopant from the second doped oxide layer into the first doped oxide layer.

12. The method of claim **11** further comprising:

forming a second undoped oxide layer over the second doped oxide layer to minimize diffusion of the dopant from the second doped oxide layer into a processing environment where the substrate is heated.

13. The method of claim **10** further comprising:

prior to forming the second doped oxide layer:

patterning the first doped oxide layer and first undoped oxide layer to expose a portion of the back side of the substrate; and

forming the second doped oxide layer on exposed portions of the back side of the substrate.

14. The method of claim **9** wherein the first dopant from the first doped oxide layer comprises a P-type dopant and the second dopant diffused from the front side of the substrate comprises an N-type dopant.

15. The method of claim **9** wherein the substrate comprises an N-type silicon wafer.

16. The method of claim **9** further comprising:

texturing the front side of the substrate to improve solar radiation collection efficiency of the solar cell.

17. A method of fabricating a solar cell, the method comprising:

diffusing a first dopant from a first doped oxide layer into a back side of a substrate to form a first doped region of a solar cell in the substrate;

diffusing a second dopant into the substrate from a front side of the substrate;

wherein the diffusion of the first dopant and the second dopant are performed in one loading of the substrate into a processing tool.

18. The method of claim **17** wherein the first dopant comprises boron and the second dopant comprises phosphorus.

19. The method of claim **17** wherein the first dopant comprises a P-type dopant and the second dopant comprises an N-type dopant.

20. The method of claim **17** further comprising:

diffusing a dopant from a second doped oxide layer into a back side of the substrate to form a second doped region of the solar cell, the diffusion of the dopant from the second doped oxide layer, the first dopant from the first doped oxide layer, and the second dopant diffused from the front side of the substrate being performed in the same loading of the substrate into the processing tool.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

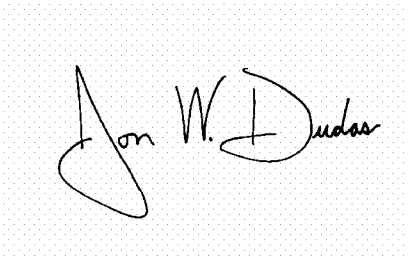
PATENT NO. : 6,998,288 B1
DATED : February 14, 2006
INVENTOR(S) : Smith et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 4,
Lines 29 and 30, after "diffusion", insert -- of --.

Signed and Sealed this

Ninth Day of May, 2006



JON W. DUDAS
Director of the United States Patent and Trademark Office