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SOLAR CELL

Abstract

Discussed is a solar cell including a semiconductor substrate comprising a base region, an emitter region having a conductive type opposite to that of the base region, and a back surface field region having the same conductive type as the base region and a higher doping concentration than the base region, and a first electrode and a second electrode respectively connected to the emitter region and the back surface field region, wherein the base region has a specific resistance of 0.3 Ωcm to 2.5 Ωcm.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority benefit of Korean Patent Application No. 10-2013-0115450, filed on Sep. 27, 2013 in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The embodiments of the invention relate to a solar cell, and more particularly, to a solar cell having an improved structure.

2. Description of the Related Art

[0003] In recent years, as conventional energy resources such as petroleum and coal are running out, interest in alternative energy resources replacing these energy resources is on the rise. Of these, solar cells are attracting considerable attention as next generation cells which convert solar energy into electrical energy.

[0004] Such a solar cell is manufactured by forming various layers and electrodes according to design. Efficiency of solar cells may be determined according to the design of various layers and electrodes. Low efficiency should be overcome so that solar cells can be put to practical use. Accordingly, various layers and electrodes should be designed such that solar cell efficiency is maximized.

SUMMARY OF THE INVENTION

[0005] It is an object of the embodiment of the invention to provide a solar cell with improved efficiency.

[0006] In accordance with one aspect of the embodiment of the invention, the above and other objects can be accomplished by the provision of a solar cell including a semiconductor substrate including a base region, an emitter region having a conductive type opposite to that of the base region, and a back surface field region having the same conductive type as the base region and a higher doping concentration than the base region, and a first electrode and a second electrode respectively connected to the emitter region and the back surface field region, wherein the base region has a specific resistance of 0.3 Ωcm to 2.5 Ωcm.

[0007] The back surface field region may be locally formed corresponding to an area of the semiconductor substrate in which the second electrode is formed.

[0008] A ratio of a total area of the back surface field region to a total area of the semiconductor substrate may be 0.1 to 0.5.

[0009] The back surface field region may include a portion having a width of 200 μm to 1,000 μm.

[0010] The specific resistance of the base region may be 0.3 Ωcm to 1.35 Ωcm.

[0011] The specific resistance of the base region may be 0.3 Ωcm to 1.05 Ωcm.

[0012] The specific resistance of the base region may be 0.76 Ωcm to 1.35 Ωcm.

[0013] The base region and the back surface field region may be n-conductive type.

[0014] The emitter region may be disposed on one surface of the semiconductor substrate and the back surface field region may be disposed on the other surface of the semiconductor substrate.

[0015] The first electrode may be formed in a predetermined pattern on the one surface of the semiconductor substrate and the second electrode may be formed in a predetermined pattern on the other surface of the semiconductor substrate to form a bi-facial structure of the solar cell.

[0016] The second electrode may include a plurality of finger electrodes, and at least one bus bar electrode connecting the plurality of finger electrodes, and the back surface field region may include a first region corresponding to each of the plurality of finger electrodes.
[0017] The solar cell may further include at least one of a passivation film and an anti-reflection film formed on the emitter region, wherein the finger electrode passes through at least one of the passivation film and the anti-reflection film and is connected to the emitter region, and the bus bar electrode is formed on at least one of the passivation film and the anti-reflection film.
[0018] The solar cell may further include at least one of the passivation film and the anti-reflection film formed on the emitter region. The plurality of finger electrodes and the at least one bus bar electrode may pass through at least one of the passivation film and the anti-reflection film and may be connected to the emitter region. The back surface field region may further include a second region corresponding to the at least one bus bar electrode.
[0019] The back surface field region may have a doping concentration of 3×10.sup.15/cm.sup.3 to 15×10.sup.15/cm.sup.3.
[0020] The back surface field region may have a sheet resistance of 5 to 90 Ω/□.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0021] The above and other objects, features and other advantages of the embodiments of the invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:
[0022] FIG. **1** is a sectional view illustrating a solar cell according to an embodiment of the invention;
[0023] FIG. **2** is a back plan view illustrating the solar cell shown in FIG. **1**;
[0024] FIG. **3** is a sectional view illustrating a solar cell according to another embodiment of the invention;
[0025] FIG. **4** is a graph showing fill factor, short-circuit current density and open-circuit voltage of solar cells manufactured according to Examples 1 to 6 and Comparative Example 1;
[0026] FIG. **5** is a graph showing efficiency of solar cells manufactured according to Examples 1 to 6 and Comparative Example 1; and
[0027] FIG. **6** is a graph showing efficiency of the solar cell according to specific resistance of a base region obtained by simulation.
DETAILED DESCRIPTION OF THE EMBODIMENTS
[0028] Reference will now be made in detail to the embodiments of the invention, examples of which are illustrated in the accompanying drawings. The invention is not limited to the embodiments and the embodiments may be modified into various forms.
[0029] In the drawings, parts unrelated to the description are not illustrated for clear and brief description of the embodiments of the invention, and the same reference numbers will be used throughout the specification to refer to the same or considerably similar parts. In the drawings, the thickness or size may be exaggerated or reduced for clearer description. In addition, the size or area of each constituent element is not limited to that illustrated in the drawings.
[0030] It will be further understood that, throughout this specification, when one element is referred to as “comprising” another element, the term “comprising” specifies the presence of another element but does not preclude the presence of other additional elements, unless context clearly indicates otherwise. In addition, it will be understood that when one element such as a layer, a film, a region or a plate is referred to as being “on” another element, the one element may be directly on the another element, and one or more intervening elements may also be present. In contrast, when one element such as a layer, a film, a region or a plate is referred to as being

"directly on" another element, one or more intervening elements are not present.

[0031] Hereinafter, a solar cell according to an embodiment of the invention will be described in more detail with reference to the annexed drawings.

[0032] FIG. **1** is a sectional view illustrating a solar cell according to an embodiment of the invention.

[0033] Referring to FIG. **1**, the solar cell **100** according to the embodiment includes a semiconductor substrate **110** including a base region **10** and conductive type regions **20** and **30**, and electrodes **42** and **44** electrically connected to the base region **10** and/or the conductive type regions **20** and **30**. The conductive type regions **20** and **30** may include an emitter region **20** (or a first conductive type region) and a back surface field region **30** (or a second conductive type region) and the electrodes **42** and **44** may include a first electrode **42** electrically connected to the emitter region **20** and a second electrode **44** electrically connected to the back surface field region **30**. The solar cell **100** may further include passivation films **22** and **32**, an anti-reflective film **24**, a capping film **34** and the like. This configuration will be described in more detail.

[0034] The semiconductor substrate **110** includes the conductive type regions **20** and **30** and the base region **10** where the conductive type regions **20** and **30** are not disposed. The base region **10** may be composed of silicon (for example, a silicon wafer) including a first conductive type dopant. The base region **10** may be composed of a crystalline semiconductor including a first conductive type dopant. The silicon may be monocrystalline or polycrystalline silicon and the first conductive type dopant may be p-or n-type.

[0035] When the base region **10** is p-type, it may include monocrystalline or polycrystalline silicon doped with boron (B), aluminum (Al), gallium (Ga), indium (In) or the like. When the base region **10** is n-type, it may include monocrystalline or polycrystalline silicon doped with phosphorous (P), arsenic (As), bismuth (Bi), antimony (Sb) or the like. The base region **10** may be formed of a variety of materials other than the materials described above.

[0036] For example, the base region **10** may include n-type impurities as the first conductive type dopant. As a result, the emitter region **20** forming a pn-junction with the base region **10** is p-type. When light is emitted to the pn junction, electrons produced by photoelectric effect are moved to a second surface (hereinafter, referred to as a "back surface") of the semiconductor substrate **110** and are collected by the second electrode **44**, while holes are moved to the front surface of the semiconductor substrate **110** and are collected by the first electrode **42**. As a result, electrical energy is generated. Holes having a low drift velocity move to the front surface of the semiconductor substrate **110**, rather than the back surface thereof, thereby improving photoelectric conversion efficiency, but the embodiment of the invention is not limited thereto. The base region **10** and the back surface field region **30** may be p-type and the emitter region **20** may be n-type.

[0037] The front surface and/or the back surface of the semiconductor substrate **110** are textured so that the surface (or surfaces) has a pyramidal shape or the like with irregularities. When surface roughness is increased due to the irregularities formed on the front surface or the like of the semiconductor substrate **10** by texturing, reflection of light incident upon the front surface or the like of the semiconductor substrate **110** can be reduced. Accordingly, an amount of light reaching the pn junction formed at the boundary between the base region **10** and the emitter region **20** is increased and light loss is thus minimized. However, the embodiment of the invention is not limited to this configuration and irregularities through texturing may not be formed on the front or back surface of the semiconductor substrate **110**.

[0038] The emitter region **20** having a conductive type opposite to the base region **10** may be formed on the front surface of the semiconductor substrate **110**. In the embodiment, when the emitter region **20** is n-type, it may include monocrystalline or polycrystalline silicon doped with phosphorous (P), arsenic (As), bismuth (Bi), antimony (Sb) or the like. When the emitter region **20** is p-type, it may include monocrystalline or polycrystalline silicon doped with aluminum (Al), gallium (Ga), indium (In) or the like.

[0039] Referring to the drawings, the emitter region **20** may have a homogeneous structure with an overall uniform doping concentration, but the embodiment of the invention is not limited thereto. In another embodiment, the emitter region **20** may have a selective structure, as shown in FIG. **3**. That is, the emitter region **20** includes a first portion **20***a* which has a relatively high doping concentration and thus a relatively low resistance and a second portion **20***b* which has a relatively low doping concentration and thus a relatively high resistance. As a result, the second portion **20***b* having a relatively high resistance is formed between the first electrodes **24** upon which light is incident, thereby implementing a shallow emitter. As a result, current density of the solar cell **100** can be improved. Furthermore, the first portion **20***a* having a relatively low resistance is formed adjacent to the first electrode **24**, thereby reducing contact resistance with the first electrode **24**. When the emitter region **20** has a selective structure, efficiency of the solar cell **100** can be maximized. However, the emitter region **20** may have various structures, as described above.
[0040] In the embodiment, the doping region formed by doping a second conductive type dopant on the front surface of the semiconductor substrate **110** constitutes the emitter region **20**, but the embodiment of the invention is not limited thereto. The emitter region **20** may have various configurations and is for example formed as a separate layer on the front surface of the semiconductor substrate **110**.
[0041] The passivation film **22** and the anti-reflection film **24** are disposed in order on the semiconductor substrate **110**, more specifically, on the emitter region **20** disposed on the semiconductor substrate **110** and the first electrode **42** is connected (for example, connected by contact) to the emitter region **20** via the passivation film **22** and the anti-reflection film **24**.
[0042] The passivation film **22** and the anti-reflection film **24** may be substantially formed over the entire surface of the semiconductor substrate **110**, excluding a part corresponding to the first electrode **42**.
[0043] The passivation film **22** contacts the emitter region **20** and passivates defects present on the surface or in the bulk of the emitter region **20**. As a result, recombination sites of minority carriers are removed and open-circuit voltage (Voc) of the solar cell **100** is thus increased. The anti-reflection film **24** reduces reflection of light incident upon the front surface of the semiconductor substrate **110**. For this reason, it is possible to increase an amount of light which reaches the p-n junction formed at the boundary between the semiconductor substrate **110** and the emitter region **20**. Accordingly, open-circuit voltage of the solar cell can be increased. As such, efficiency of the solar cell **100** can be improved by increasing open-circuit voltage and short-circuit current of the solar cell **100** by the anti-reflective film **22** and the anti-reflection film **24**.
[0044] The passivation film **22** may be formed of a variety of materials. For example, the passivation film **22** may be a single film selected from the group consisting of a silicon nitride film, a silicon nitride film containing hydrogen, a silicon oxide film, a silicon oxide nitride film, an aluminum oxide film, MgF.sub.2, ZnS, TiO.sub.2 and CeO.sub.2, or a multilayer film including a combination of two or more of these films. For example, when the emitter region **20** is n-type, the passivation film **22** may include a silicon oxide film, a silicon nitride film or the like, each having a fixed positive charge and when the emitter region **20** is p-type, the passivation film **22** may include an aluminum oxide film having a fixed negative charge or the like.
[0045] The anti-reflection film **24** may be formed of a variety of materials. For example, the anti-reflection film **24** may be a single film selected from the group consisting of a silicon nitride film, a silicon nitride film containing hydrogen, a silicon oxide film, a silicon oxide nitride film, an aluminum oxide film, MgF.sub.2, ZnS, TiO.sub.2 and CeO.sub.2, or a multilayer film including a combination of two or more of these films. For example, the anti-reflection film **24** may be silicon nitride.
[0046] However, the embodiment of the invention is not limited thereto, and the passivation film **22** and the anti-reflection film **24** may include a variety of materials. One of the passivation film **22** and the anti-reflection film **24** may perform both anti-reflection and passivation functions and the

other may be thus not provided. In addition, various films other than the passivation film **22** and the anti-reflection film **24** may be formed on the semiconductor substrate **110**. Various other modifications are possible.

[0047] The first electrode **42** is electrically connected to the emitter region **20** through an opening **104** formed in the passivation film **22** and anti-reflection film **24** (that is, while passing through the passivation film **22** and the anti-reflection film **24**). The first electrode **42** may be formed in various shapes using various materials. The shape of the first electrode **42** will be described later with reference to FIG. **4**.

[0048] A back surface field region **30** having the same first conductivity type as the base region **10** and comprising a first conductivity type impurity in a higher doping concentration than the base region **10** is formed on the back surface of the semiconductor substrate **110**. In the embodiment, the back surface field region **30** may include a doping region formed by doping the first conductive type dopant on the back surface of the semiconductor substrate **110**.

[0049] The back surface field region **30** may have a local structure. That is, the back surface field region **30** may be locally formed in a region where the second electrode **44** is disposed. In addition, an entirety or part of the back surface field region **30** may contact the second electrode **44**. The structure or the like of the back surface field region **30** will be described in more detail together with the shape of the second electrode **44**, specific resistance of the base region **110** or the like.

[0050] The back surface field region **30** functions as a barrier on the second conductive type of minority carriers (for example, a hole when the back surface field region **30** is n-type and an electron when the back surface field region **30** is p-type) on the back surface of the semiconductor substrate **110** to prevent minority carriers from moving to the back surface field region **30** and being recombined on the back surface of the semiconductor substrate **110**. In addition, the back surface field region **30** has a relatively low specific resistance due to relatively high doping concentration, thus reducing contact resistance with the second electrode **44**.

[0051] The passivation film **32** and the capping film **34** are formed in order on the back surface of the semiconductor substrate **110**, more specifically, on the back surface field region **30** formed on the semiconductor substrate **110** and the second electrode **44** is connected to the back surface field region **30** via the passivation film **32** and the anti-reflection film **34**.

[0052] The passivation film **32** and the capping film **34** may be substantially formed over the entire back surface of the semiconductor substrate **110**, excluding a part corresponding to the second electrode **44**.

[0053] The passivation film **32** contacts the back surface field region **30** and passivates defects present on the surface or in the bulk of the back surface field region **30**. As a result, recombination sites of minority carriers are removed and open-circuit voltage of the solar cell **100** is thus increased. The capping film **34** prevents contamination of the passivation film **32** or diffusion of undesired matter into the passivation film **32**. For example, the capping film **34** prevents a material for forming the second electrode **44** or the like from diffusing into the passivation film **32** in the process of forming the second electrode **44** or the like.

[0054] The passivation film **32** may be formed of a variety of materials. For example, the passivation film **32** may be a single film selected from the group consisting of a silicon nitride film, a silicon nitride film containing hydrogen, a silicon oxide film, a silicon oxide nitride film, an aluminum oxide film, MgF.sub.2, ZnS, TiO.sub.2 and CeO.sub.2, or a multilayer film including a combination of two or more of these films. For example, when the back surface field region **30** is n-type, the passivation film **32** may include a silicon oxide film or a silicon nitride film, each having a fixed positive charge, or the like and when the back surface field region **30** is p-type, the passivation film **32** may include an aluminum oxide film having a fixed negative charge, or the like.

[0055] The capping film **34** may be formed of a variety of materials. For example, the capping film **34** may be a single film selected from the group consisting of a silicon nitride film, a silicon nitride film containing hydrogen, a silicon oxide film, a silicon oxide nitride film, an aluminum oxide film, MgF.sub.2, ZnS, TiO.sub.2 and CeO.sub.2, or a multilayer film including a combination of two or more of these films. For example, the capping film **34** may include aluminum oxide, but the embodiment of the invention is not limited thereto, and the passivation film **32** and the capping film **34** may include a variety of materials. In addition, the capping film **34** may be not provided. In addition, various films other than the passivation film **32** and the capping film **34** may be formed on the semiconductor substrate **110**. Various other modifications are possible.

[0056] The second electrode **44** is electrically connected to the back surface field region **30** through an opening **102** formed in the passivation film **32** and the capping film **34**. The second electrode **44** may be formed in various shapes using a variety of materials.

[0057] Hereinafter, specific resistance of the base region **110** will be described together with the shape of the second electrode **44** and the shape of the back surface field region **30** with reference to FIGS. **1** and **2**. FIG. **2** is a back plan view illustrating the solar cell shown in FIG. **1**, which mainly shows the back surface field region **30** and the second electrode **44** disposed on the back surface of the semiconductor substrate **110**.

[0058] Referring to FIG. **2**, the second electrode **44** may include a plurality of finger electrodes **44***a* having a predetermined pitch and being disposed in parallel to one another. As illustrated in the drawing, the finger electrodes **44***a* are disposed in parallel to an edge of the semiconductor substrate **110**, but the embodiment of the invention is not limited thereto. In addition, the second electrode **44** may include at least one bus bar electrode **44***b* which is formed in a direction crossing a direction in which the finger electrodes **24***a* are disposed and connects the finger electrodes **24***a*. The bus bar electrode **44***b* may be one in number or a plurality of bus bar electrodes including the bus bar electrode **44***b* having a pitch larger than that of the finger electrodes **44***a* may be provided, as shown in FIG. **2**. In this case, the width of the bus bar electrode **44***b* may be greater than that of the finger electrode **44***a*, but the embodiment of the invention is not limited thereto and the width of the bus bar electrode **44***b* may be same as or smaller than that of the finger electrode **44***a*.

[0059] Viewing this structure in cross section, both the finger electrode **44***a* and the bus bar electrode **44***b* pass through the passivation film **32** and the capping: film **34**. That is, the opening **102** may be formed corresponding to both the finger electrode **44***a* and the bus bar electrode **44***b* of the second electrode **44**, but the embodiment of the invention is not limited thereto. In another embodiment, the finger electrode **44***a* of the second electrode **44** passes through the passivation film **32** and the capping film **34**, and the bus bar electrode **44***b* is formed on the passivation film **32** and the capping film **34** and is connected to the finger electrodes **44***a*.

[0060] In addition, the back surface field region **30** formed corresponding to an area where the second electrode **44** is formed may include a first region **302** formed corresponding to each finger electrode **44***a*. A plurality of first regions including the first region **302** may be for example disposed in parallel. In addition, the back surface field region **30** may further include a second region **304** formed corresponding to the bus bar electrode **44***b*. That is, according to embodiments, the back surface field region **30** may include only the first region **302**, or both the first region **302** and the second region **304**. For example, when both the finger electrode **44***a* and the bus bar electrode **44***b* of the second electrode **44** pass through the passivation film **32** and the capping film **34**, the back surface field region **30** includes the first and second regions **302** and **304** and is formed in a part of the second electrode **44** contacting the semiconductor substrate **110**. In another embodiment, when the finger electrode **44***a* of the second electrode **44** passes through the passivation film **32** and the capping film **34**, and does not pass through the bus bar electrode **44***b*, the back surface field region **30** includes the first region **302** which is formed in a part of the finger electrodes **44***a* of the second electrode **44** contacting the semiconductor substrate **110**, but the embodiment of the invention is not limited thereto.

[0061] In the embodiment, the back surface field region **30** is locally formed in the part corresponding to the second electrode **44** to reduce contact resistance with the second electrode **44** and maintain excellent fill factor (FF) properties. In addition, the back surface field region **30** including the doping region is not formed in the region where the second electrode **44** is not formed, to reduce recombination that may result from formation of the doping region and thereby improve short-circuit current (Jsc) and open-circuit voltage. In addition, in the region where the back surface field region **30** is not formed, internal quantum efficiency (IQE) is excellent and properties associated with light of long wavelengths are considerably excellent. Accordingly, properties associated with light of long wavelengths can be greatly improved, as compared to the homogeneous structure and the selective structure in which the doping region is entirely formed. The back surface field region **30** having a local structure maintains high fill factor, short-circuit current density and open-circuit voltage associated with efficiency of the solar cell **100** and thereby improves efficiency of the solar cell **100**.

[0062] In the embodiment, a ratio of a total area of the back surface field region **30** to a total area of the semiconductor substrate **110** may be 0.1 to 0.5. When the ratio is less than 0.1, the area of the back surface field region **30** is minimized and alignment error with the second electrode **44** caused by process error may be great. For this reason, contact resistance between the semiconductor substrate **110** and the second electrode **44** is increased and fill factor is greatly When the ratio exceeds 0.5, the area of the deteriorated. doping region, i.e. the back surface field region **30**, is increased and short-circuit current density and open-circuit voltage are thus deteriorated.

[0063] In addition, the width of the first region **30***a* is greater than that of the finger electrode **44***a* so that the finger electrode **44***a* entirely contacts the back surface field region **30** having a local structure. The reason for this is that a predetermined margin is secured to compensate for alignment error, although the alignment error is present. For example, the width of the first region **30***a* may be 200 μm to 1,000 μm and the width of the finger electrodes **44***a* may be 30 μm to 300 μm, but the embodiment of the invention is not limited thereto. The width of the first region **30***a* and the width of the finger electrodes **44***a* may be changed.

[0064] Although the width of the first region **30***a* or the like is controlled, the second electrode **44** may be connected (for example, by contact) in the region where the back surface field region **30** is not formed. The alignment errors are generated in various directions including vertical, longitudinal and rotational directions in various apparatuses such that they overlap one another. For this reason, it is difficult to prevent all the alignment errors although a predetermined margin is present. As such, when alignment of the back surface field region **30** and the second electrode **44** is not accurately implemented, the second electrode **44** contacts the base region **10**, rather than the back surface field region **30**. Accordingly, contact resistance is increased and fill factor is readily degraded. Accordingly, although the back surface field region **30** having the local structure has superior effects, the back surface field region **30** having the local structure may not exert such effects upon practical application. In consideration of this point, in the embodiment, the solar cell **100** using the back surface field region **30** having the local structure has a limited specific resistance of the base region **10** to prevent deterioration in fill factor although the alignment error is present.

[0065] The specific resistance of the base region **10** is directly related to fill factor, short-circuit current density and open-circuit voltage. That is, when the specific resistance of the base region **10** is high, lifetime of carriers generated in the base region **10** increases and short-circuit current density thus increases, but contact resistance with the second electrode **44** increases and fill factor is deteriorated. In addition, when the specific resistance of the base region **10** is high, built-in potential may be deteriorated due to difference in work function between the base region **10** and the emitter region **20** caused by low doping concentration and open-circuit voltage may be thus deteriorated. That is, when specific resistance of the base region **10** is high, short-circuit current density is high, and fill factor and open-circuit voltage properties are bad. On the other hand, when specific resistance of the base region **10** is low, short-circuit current density is low, and fill factor and open-circuit voltage properties are good.

[0066] As such, the specific resistance of the base region **10** causes a trade-off between short-circuit current density, fill factor and open-circuit voltage. As described above, the back surface field region **30** having the local structure may be greatly deteriorated in fill factor due to alignment. In the embodiment, specific resistance of the base region **10** is kept low as compared to conventional cases and fill factor properties are thus improved. That is, fill factor can be maintained excellent due to specific resistance of the base region **10** although alignment error is generated in the back surface field region **30** having the local structure.

[0067] For example, specific resistance of the base region **10** may be 0.3 Ωcm to 2.5 Ωcm. When specific resistance of the base region **10** is less than 0.3 Ωcm, reliability of the solar cell **100** may be deteriorated. More specifically, the semiconductor substrate **110** obtained from a lower part of an ingot for manufacturing the semiconductor substrate **110** (for example, a silicon wafer substrate) should be used so that specific resistance of the base region **10** is adjusted to a level lower than 0.3 Ωcm. However, as various impurities are aggregated in the lower part of the ingot, the semiconductor substrate **110** obtained from the lower part has a bad impurity uniformity and the solar cell **100** manufactured using the same has low efficiency and a deteriorated reliability due to great efficiency difference. In addition, when specific resistance of the base region **10** exceeds 2.5 Ωcm, inaccurate alignment between the second electrode **44** and the back surface field region **30** having the local structure may cause deterioration of contact resistance in an area where the second electrode **44** contacts the base region **10**. For this reason, fill factor is degraded and efficiency of the solar cell **100** is deteriorated.

[0068] More specifically, specific resistance of the base region **10** may be 1.35 Ωcm or less (that is, 0.3 Ωcm to 1.35 Ωcm). The reason for this is that, when specific resistance of the base region **10** is 1.35 Ωcm or less, fill factor and open-circuit voltage are broadly deteriorated although specific resistance is increased, and when the specific resistance of the base region **10** exceeds 1.35 Ωcm, fill factor and open-circuit voltage are sharply deteriorated with increase in specific resistance. In consideration of this point, specific resistance of the base region **10** is adjusted to a level of 1.35 Ωcm or less, so that better fill factor and open-circuit voltage can be maintained without greatly reducing specific resistance of the base region **10**. Specific resistance of the base region **10** may be 0.3 Ωcm to 1.05 Ωcm to maintain better fill factor and open-circuit voltage.

[0069] When taking into consideration difficulty in forming the base region **10** having a low specific resistance, the specific resistance of the base region **10** may be 0.76 Ωcm or more (that is, 0.76 Ωcm to 2.5 Ωcm, for example, 0.76 Ωcm to 1.35 Ωcm). The case in which the specific resistance of the base region **10** is 0.76 Ωcm or more provides fill factor and open-circuit voltage comparable to the case in which the specific resistance of the base region **10** is 0.3 Ωcm. Accordingly, the semiconductor substrate **110** is more easily manufactured and reliability of the solar cell **100** is thus improved by slightly increasing specific resistance. Specific resistance of the base region **10** may be 0.76 Ωcm to 1.05 Ωcm so that fill factor and open-circuit voltage can be better maintained.

[0070] The base region **10** having the specific resistance range defined above may have better effects when it has an n-conductive type. This will be described in more detail. When the base region **10** is p-type, the back surface field region **30** is formed by diffusing a material (for example, aluminum) contained in the second electrode **44** without additional doping so that great deterioration in short-circuit current density and open-circuit voltage can be prevented. On the other hand, when the base region **10** is n-type, the back surface field region **30** is formed by additional doping such as ion implantation, and short-circuit current density and open-circuit voltage may be greatly deteriorated during this process. Accordingly, when the base region **10** is n-type, the area of the back surface field region **30** should be minimized in consideration of short-circuit current density and open-circuit voltage so as to greatly improve efficiency of the solar cell **100**. The decrease in area of the back surface field region **30** may have a negative effect on fill factor. Great effects can be obtained by adjusting specific resistance of the base region **10** to a

relatively low level as in the embodiment.
[0071] In addition, the base region **10** is applied to a bi-facial solar cell **100** to maximize effects thereof. As described above, the bi-facial solar cell **100** means a solar cell wherein the emitter region **20** is disposed on one surface of the semiconductor substrate **110**, the back surface field region **30** is disposed on the other surface of the semiconductor substrate **110**, and the first and second electrodes **42** and **44** have a predetermined pattern. A back-contact solar cell having a back contact structure (that is, a solar cell wherein all of the emitter region and the back surface field region, and first and second electrodes connected thereto are disposed on the back surface of the semiconductor substrate) has a lifetime of carriers as an essential factor and thus has a limitation on reduction of specific resistance of the base region **10**. The bi-facial solar cell **100** according to the embodiment in which lifetime of carriers is less essential maximizes efficiency of the solar cell **100** by using the base region **10** having a relatively low specific resistance, but the embodiment of the invention is not limited thereto.
[0072] In the embodiment, the doping concentration of the back surface field region **30** may be 3×10.sup.15/cm.sup.3to 15×10.sup.15/cm.sup.3. When the doping concentration of the back surface field region **30** is less than 3×10.sup.15/cm.sup.3, effects of the back surface field region **30** having a local structure cannot be maximized due to difficulty in minimization of contact resistance with the second electrode **44**. When the doping concentration of the back surface field region **30** exceeds 15×10.sup.15/cm.sup.3, open-circuit voltage and short-circuit current density may be deteriorated.
[0073] The back surface field region **30** may have a sheet resistance may be 5 Ω/□ to 90 Ω/□. When the sheet resistance of the back surface field region **30** is less than the range defined above, open-circuit voltage and short-circuit current density may be deteriorated due to high doping concentration. When the sheet resistance of the back surface field region **30** exceeds the range defined above, effects of the back surface field region **30** having the local structure cannot be maximized due to difficulty in minimization of contact resistance with the second electrode **44**, but the embodiment of the invention is not limited thereto, and the doping concentration and sheet resistance of the back surface field region **30** may be changed.
[0074] As such, in the embodiment, the solar cell **100** having the back surface field region **30** having a local structure can compensate for fill factor by limiting the specific resistance of the base region **10** to a predetermined range. Accordingly, fill factor, short-circuit current density and open-circuit voltage associated with efficiency of the solar cell **100** having the back surface field region **30** having a local structure are improved and efficiency of the solar cell **100** is thus maximized. Such an effect can be maximized in the bi-facial solar cell **100** having an n-type base region **10**.
[0075] Although not additionally shown, the first electrode **42** may have a similar structure to the second electrode **44**. That is, the first electrode **42** may include finger electrodes corresponding to finger electrodes **44***a* of the second electrode **44** and bus bar electrodes corresponding to the bus bar electrode **44***b* of the second electrode **44**. Viewing this structure in cross section, both the finger electrode and the bus bar electrode of the first electrode **42** may pass through the passivation film **22** and the anti-reflection film **24**. That is, the opening **104** may be formed corresponding to the finger electrode and the bus bar electrode of the first electrode **42**, but the embodiment of the invention is not limited thereto. In another embodiment, the finger electrode of the first electrode **42** passes through the passivation film **22** and the anti-reflection film **24**, and the bus bar electrode is connected to the finger electrode of the first electrode **42** in the passivation film **22** and the anti-reflection film **24**. The width, pitch and the like of the finger electrode and the bus bar electrode of the first electrode **42** may be the same as or different from those of the second electrode **44** and the bus bar electrode **44***b* of the finger electrodes **44***a*. Other details of the finger electrode and the bus bar electrode of the first electrode **42** are similar to those of the finger electrodes **44***a* and the bus bar electrode **44***b* of the second electrode **44** and explanation thereof is thus omitted.
[0076] Hereinafter, the embodiment of the invention will be described in more detail based on the

following test examples. However, the test examples are only provided to illustrate the embodiment of the invention and should not be construed as limiting the embodiment of the invention.

Example 1

[0077] A semiconductor substrate having a specific resistance of 0.3 Ωcm and an n-type base region was prepared. A front surface of the semiconductor substrate was doped with boron (B) by ion implantation to form an emitter region and a back surface of the semiconductor substrate was doped with phosphorous (P) by ion implantation to form a back surface field region. At this time, the back surface field region was locally formed in only the part corresponding to the second electrode.

[0078] A passivation film and an anti-reflection film were formed on the front surface of the semiconductor substrate and a passivation film and a capping film were formed on the back surface of the semiconductor substrate. In addition, a first electrode electrically connected to the emitter region and a second electrode electrically connected to the back surface field region were formed, to manufacture a solar cell.

Example 2

[0079] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 0.76 Ωcm.

Example 3

[0080] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 1.05 Ωcm.

Example 4

[0081] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 1.35 Ωcm.

Example 5

[0082] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 1.6 Ωcm.

Example 6

[0083] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 2.5 Ωcm.

Comparative Example 1

[0084] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 3.22 Ωcm.

Comparative Example 2

[0085] A solar cell was manufactured in the same manner as in Example 1, except that specific resistance of the base region was 0.1 Ωcm.

[0086] Measurement results of fill factor, short-circuit current density and open-circuit voltage of solar cells according to Examples 1 to 6, and Comparative Example 1 are shown in FIG. **4** and efficiency thereof is shown in FIG. **5**. In FIGS. **4** and **5**, the fill factor and open-circuit voltage are represented relative to 100% values of the solar cell manufactured according to Example 1 and the short-circuit current density is represented relative to the 100% value of the solar cell manufactured according to Example 6. The solar cell according to Comparative Example 2 has low reliability and bad properties, thus making it impossible to measure fill factor, short-circuit current density and open-circuit voltage. An efficiency graph of the solar cell according to specific resistance of the base region was obtained by simulation and is shown in FIG. **6**.

[0087] Referring to FIGS. **4** and **5**, as specific resistance of the base region increases, fill factor and open-circuit voltage are deteriorated and short-circuit current density is improved. In Comparative Example 1 using a base region having a high specific resistance, fill factor and short-circuit current density are greatly deteriorated to 98% or less, and efficiency is also degraded to 96.5% or less. Accordingly, in Comparative Example 1 having a specific resistance of the base region higher than 2.5 Ωcm, efficiency of the solar cell is greatly degraded due to deterioration in fill factor and short-

circuit current density.
[0088] Although specific resistance of the base region is increased, open-circuit voltage and efficiency of the solar cell are greatly decreased in a range greater than a predetermined specific resistance (1.35 Ωcm) of the base region, and are broadly decreased in a range less than the specific resistance. Accordingly, open-circuit voltage properties and efficiency can be greatly improved by setting the specific resistance of the base region to 1.35 Ωcm or less. In addition, although specific resistance of the base region is increased, fill factor of the solar cell is greatly decreased in a range greater than a predetermined specific resistance (1.05 Ωcm) of the base region, and are broadly decreased in a range less than the specific resistance. Accordingly, superior open-circuit voltage and fill factor properties can be maintained and efficiency of the solar cell can thus be more improved by setting the specific resistance of the base region to 1.05 Ωcm or less.
[0089] As can be seen from FIG. **6**, efficiency of the solar cell is considerably low in a section in which specific resistance of the base region is lower than 0.3 Ωcm, and efficiency of the solar cell is low in a section in which specific resistance of the base region is higher than 2.5 Ωcm. In addition, efficiency of the solar cell is high in a section in which specific resistance of the base region is 0.3 to 1.35 Ωcm, and efficiency of the solar cell is much higher in a section in which specific resistance of the base region is 0.3 to 1.05 Ωcm.
[0090] Although the embodiments of the invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.

Claims

1. A solar cell comprising: a semiconductor substrate having: a base region; an emitter region having a conductivity type opposite to that of the base region, the emitter region being disposed on a front surface of the semiconductor substrate; and a plurality of back surface field regions having the same conductivity type as the base region and a doping concentration higher than the base region, the plurality of back surface field regions being locally disposed on a back surface of the semiconductor substrate and separated from each other so that the base region is located between the plurality of back surface field regions from the back surface of the semiconductor substrate; a first passivation layer disposed on the emitter region; a plurality of first electrodes connected to the emitter by penetrating through the first passivation layer, a second passivation layer disposed on the back surface of the semiconductor substrate; a capping film disposed on the second passivation layer; and a plurality of second electrodes connected to the plurality of back surface field regions, respectively, by penetrating through the second passivation layer, wherein the plurality of second electrodes includes a plurality of finger electrodes extending in a first direction and least one bus bar electrode extending in a second direction crossing the first direction and connecting the plurality of finger electrodes, wherein the solar cell has a bi-facial structure that receives light to the back surface of the semiconductor substrate through the second passivation layer and receives light to the front surface of the semiconductor substrate through the first passivation layer, wherein the capping film includes aluminium oxide, the capping film is an outermost film on the back surface of the semiconductor substrate, the capping film covers only a part of the back surface of the semiconductor substrate.
2. The solar cell according to claim 1, wherein the capping film is adapted to prevent a material for forming the plurality of second electrodes from diffusing into the second passivation layer in a process of forming the plurality of second electrodes.
3. The solar cell according to claim 1, wherein the base region has a specific resistance of 0.3 Ωcm to 2.5 Ωcm.
4. The solar cell according to claim 3, wherein the specific resistance of the base region is 0.76

Ωcm to 1.05 Ωcm.
5. The solar cell according to claim 1, wherein a ratio of a total area of the plurality of back surface field regions to a total area of the back surface of the semiconductor substrate is 1:10 to 1:2.
6. The solar cell according to claim 1, wherein the base region and the plurality of back surface field regions are n-type, and the emitter region is p-type.
7. The solar cell according to claim 1, wherein the plurality of back surface field regions has a doping concentration of 3×10.sup.15/cm.sup.3 to 15×10.sup.15/cm.sup.3.
8. The solar cell according to claim 1, wherein the plurality of the back surface field regions has a sheet resistance of 5 Ω/sq to 90 Ω/sq.
9. The solar cell according to claim 1, wherein a width of at least one of the plurality of the back surface field regions is greater than a width of a corresponding second electrode.
10. The solar cell according to claim 9, wherein the width of the at least one of the plurality of the back surface field regions is 200 μm to 1,000 μm, and the width of the corresponding second electrode is 30 μm to 300 μm.
11. The solar cell according to claim 1, wherein a distance between two adjacent back surface field regions of the plurality of back surface field regions is greater than a width of at least one of the plurality of back surface field regions.
12. The solar cell according to claim 1, wherein the second passivation layer includes a silicon nitride film.
13. The solar cell according to claim 12, wherein the base region and the plurality of back surface field regions are n-type, the second passivation layer is in direct contact with the back surface of the semiconductor substrate, and the silicon nitride film has a fixed positive charge based on the plurality of back surface field regions having the n-type.