

HYBRID EMITTER ALL BACK CONTACT SOLAR CELL

Inventors: Paul Loscutoff and Seung Rim

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5 DEVELOPMENT

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

10 TECHNICAL FIELD

[0002] Embodiments of the subject matter described herein relate generally to solar cells. More particularly, embodiments of the subject matter relate to solar cell fabrication processes and structures.

15 BACKGROUND

[0003] Solar cells are well known devices for converting solar radiation to electrical energy. A solar cell has a front side that faces the sun during normal operation to collect solar radiation and a backside opposite the front side. In an all back contact solar cell, all metal contacts and corresponding emitters are formed on the backside of the solar cell.
20 An external electrical circuit, e.g., a load, may be connected to the metal contacts to be powered by the solar cell.

[0004] To remain a commercially-viable renewable energy source, solar cells need to be manufactured at low cost. Embodiments of the present invention pertain to a hybrid emitter design that simplifies the manufacture of solar cells while retaining efficiency.

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BRIEF SUMMARY

[0005] According to a first aspect of the invention, an all back contact solar cell comprising

a single crystalline silicon substrate;

30 a thin dielectric layer formed on a backside surface of the single crystalline silicon substrate;

a first emitter of the solar cell, the first emitter of the solar cell being formed on the thin dielectric layer and comprising polycrystalline silicon doped to have a first polarity;

5 a second emitter of the solar cell, the second emitter of the solar cell being formed in the single crystalline silicon substrate and comprising single crystalline silicon doped to have a second polarity opposite the first polarity;

a first metal contact connected to the first emitter on a backside of the solar cell, the backside being opposite a front side of the solar cell that faces the sun during normal operation; and

10 a second metal contact connected to the second emitter on the backside of the solar cell. The all back contact solar cell has a hybrid emitter design. The solar cell may have a thin dielectric layer formed on a backside surface of a single crystalline silicon substrate. The thin dielectric layer may comprise silicon dioxide that

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is formed directly on the backside surface of the single crystalline silicon substrate. One emitter of the solar cell may comprise doped polycrystalline silicon that is formed on the thin dielectric layer. The other emitter of the solar cell may be formed in the single crystalline silicon substrate and comprise doped single crystalline silicon. The solar cell includes contact holes that allow metal contacts to connect to corresponding emitters.

[0005a] According to a second aspect of the invention, a method of manufacturing an all back contact solar cell is provided, comprising

forming a thin dielectric layer on a backside surface of a single crystalline silicon substrate;

forming a first emitter on the thin dielectric layer on a backside of the solar cell, the first emitter comprising polycrystalline silicon that is doped with dopants of a first polarity, the backside of the solar cell being opposite a front side of the solar cell that faces the sun during normal operation;

forming a second emitter in the single crystalline silicon substrate on the backside of the solar cell, the second emitter comprising single crystalline silicon that is doped with dopants of a second polarity opposite to the first polarity; and

forming a first metal contact connected to the first emitter and a second metal contact connected to the second emitter on the backside of the solar cell.

[0005b] According to a third aspect of the invention, a solar cell is manufactured with the method according to the second aspect.

[0005c] According to a further aspect of the invention, a solar cell is provided, comprising

a single crystalline silicon substrate;

a thin dielectric formed on a backside surface of the single crystalline silicon substrate;

a first emitter of the solar cell, the first emitter comprising doped polycrystalline silicon; and

a second emitter of the solar cell, the second emitter comprising doped single crystalline silicon and formed in the single crystalline silicon substrate.

[0006] 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.

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

[0007] A more complete understanding of the subject matter may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures. The drawings are not to scale.

10 **[0008]** FIGS. 1-12 show cross-sections that schematically illustrate a method of manufacturing a solar cell in accordance with an embodiment of the present invention.

[0009] FIG. 13 shows a flow diagram of a method of manufacturing a solar cell in accordance with an embodiment of the present invention.

15 **DETAILED DESCRIPTION**

[0010] In the present disclosure, numerous specific details are provided, such as examples of apparatus, 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.

20 **[0011]** FIGS. 1-12 show cross-sections that schematically illustrate a method of manufacturing a solar cell in accordance with an embodiment of the present invention. FIGS. 1-12 are not drawn to scale.

25 **[0012]** In FIG. 1, a thin dielectric layer 102 is formed on a single crystalline silicon substrate 101. The substrate 101 may comprise a high-lifetime N-type single crystalline

silicon wafer. In one embodiment, the thin dielectric layer 102 comprises silicon dioxide formed directly on a backside surface 131 of the single crystalline silicon substrate 101. The backside surface 131 is opposite a front side surface 132 of the single crystalline silicon substrate 101. The front side surface 132 is on the front side of the solar cell, which is also referred to as the “sun side” because it faces the sun during normal operation. The backside surface 131 is on the backside of the solar cell. The solar cell being manufactured is an all back contact solar cell in that the emitters and corresponding metal contacts are all formed on the backside of the solar cell.

[0013] The thin dielectric layer 102 may provide a tunneling function, e.g., as a tunnel oxide. In one embodiment, the thin dielectric layer 102 comprises silicon dioxide thermally grown directly on the backside surface 131 to a thickness less than or equal to 40 Angstroms (e.g., between 5 to 40 Angstroms, preferably 20 Angstroms).

[0014] In FIG. 2, a plurality of doped polycrystalline silicon emitters 103 are formed on the thin dielectric layer 102. Only one polycrystalline silicon emitter 103 is shown in the figures for clarity of illustration. The polycrystalline silicon emitter 103 may be deposited doped or doped after deposition. In the example of FIG. 2, the polycrystalline silicon emitter 103 is doped with a P-type dopant, such as boron. As can be appreciated, the polycrystalline silicon emitter 103 may also be doped with an N-type dopant with appropriate changes to the doping of other emitters and/or the single crystalline silicon substrate 101. In the example of FIG. 2, portions of the thin dielectric layer 102 that are not under the polycrystalline silicon emitter 103 may be removed, e.g., by wet or dry etching.

[0015] As will be more apparent below, the solar cell being manufactured only has one polarity (P-type in this example) of polycrystalline silicon emitters; the opposite polarity emitters are single crystalline silicon emitter. This advantageously allows the polycrystalline silicon emitter 103 to be doped in situ.

[0016] A polycrystalline silicon emitter 103 may be formed by forming a layer of polycrystalline silicon layer 201 on the thin dielectric layer 102 as shown in FIG. 9. The polycrystalline silicon layer 201 may be formed by a deposition process, e.g., by low pressure chemical vapor deposition (LPCVD), to a thickness of around 1000 Angstroms to 5000 Angstroms, for example. A patterning step, such as masking and etching,

follows to pattern the polycrystalline silicon layer 201 as shown in FIG. 10. In the example of FIG. 10, the thin dielectric layer 102 is patterned during patterning of the thin dielectric layer 102. The patterned polycrystalline silicon layer 201 serves as the polycrystalline silicon emitter 103. The polycrystalline silicon layer 201 may be doped before or after the patterning step.

[0017] The polycrystalline silicon emitter 103 may also be formed using other processing steps, including by printing as shown in FIG. 11. In the example of FIG. 11, an emitter 203 is selectively printed by a print head 205 of an inkjet printer. The emitter 203 may comprise silicon nanoparticles that are inkjet printed on the thin dielectric layer 102. The emitter 203 may be doped before or after the printing step. A thermal treatment step coalesces the silicon nanoparticles to form polycrystalline silicon, which serves as the polycrystalline silicon emitter 103. The thin dielectric layer 102 does not have to be etched because dopants for forming the single crystalline silicon emitter in the single crystalline silicon 101 may be diffused through the thin dielectric layer 102, advantageously removing a patterning step.

[0018] Continuing in FIG. 3, following formation of the polycrystalline silicon emitter 103, a dopant source layer 104 is formed on the polycrystalline silicon emitter 103 and the single crystalline silicon substrate 101. In the example of FIG. 3, the dopant source layer 104 comprises N-type dopants, such as phosphorus, to subsequently form an N-type emitter in the single crystalline silicon substrate 101. The dopants of the dopant source layer 104 may be changed (e.g., to P-type) to accommodate different dopant polarity requirements. In one embodiment, the dopant source layer 104 comprises a blanket layer of phosphorus-silicate-glass (PSG) formed to a thickness of about 1000 Angstroms by atmospheric pressure chemical vapor deposition (APCVD), for example.

[0019] In FIG. 4, a diffusion step is performed to diffuse dopants from the dopant source layer 104 to the single crystalline silicon substrate 101 to form single crystalline silicon emitters 108. In the example of FIG. 4, because the dopant source layer 104 comprises N-type dopants, the resulting emitters 108 comprise N-type doped single crystalline silicon. The diffusion step may be performed by thermal processing in a diffusion furnace, for example. During the diffusion step, some amount of dopants from the polycrystalline silicon emitter 103 may diffuse through the thin dielectric layer 102 to

form a doped region 109 in the single crystalline silicon substrate 101. In the example of FIG. 4, the doped region 109 is a P-type doped region because the polycrystalline silicon emitter 103 is doped with a P-type dopant.

[0020] To take advantage of the low charge carrier recombination under a polysilicon emitter 103, a polycrystalline silicon emitter 103 may cover more area of the back surface 131 of the single crystalline silicon substrate 101 compared to a single crystalline silicon emitter 108. For example, the polycrystalline silicon emitters 103 may have a total area that covers at least 80% of the total area of the back surface 131.

[0021] In FIG. 5, a material stack 105 is formed on the dopant source layer 104. The material stack 105 may comprise one or more layers of materials, such as moisture barrier, anti-reflective coating, and other materials depending on the particulars of the manufacturing process. The material stack 105 may be formed before or after the diffusion step.

[0022] In FIG. 6, contact holes 106 are formed to expose the single crystalline silicon emitters 108 and polycrystalline silicon emitters 103. Generally, there are a plurality of emitters 108 and 103 in the solar cell and each is connected to a corresponding metal contact through a corresponding contact hole 106. In the example of FIG. 6, to expose underlying emitters 103, contact holes 106 are formed through the stack of materials 105 and dopant source layer 104, but not through the thin dielectric layer 102. Also in the example of FIG. 6, to expose underlying emitters 108, contact holes 106 are formed through the stack of materials 105 and the dopant source layer 104. When portions of the thin dielectric 102 are left over the emitters 108 (e.g., as in the example of FIG. 12), corresponding holes 106 are also formed through the thin dielectric layer 102 to expose underlying emitters 108. The contact holes 106 may be formed by laser ablation, mask and etch, or other processing step.

[0023] In FIG. 7, metal contacts 107 are formed in the contact holes 106 to connect to corresponding emitters. A metal contact 107 may comprise a single layer or multilayer metal contact. For example, a metal contact 107 may comprise aluminum formed on an emitter (e.g., emitter 103 or 108), a diffusion barrier comprising titanium-tungsten formed on the aluminum, and a seed layer comprising copper formed on the diffusion barrier.

[0024] In the example of FIG. 7, a metal contact 107 connected to a single crystalline silicon emitter 108 is an N-polarity metal contact in that it is connected to an N-type doped emitter 108. Similarly, a metal contact 107 connected to a polycrystalline silicon emitter 103 is a P-polarity metal contact in that it is connected to a P-type doped emitter 103. N-polarity metal contacts are connected together and electrically insulated from P-polarity metal contacts, which are also connected together. N-polarity metal contacts may be interdigitated with P-polarity metal contacts.

[0025] The manufacture of the solar cell may also incorporate additional processing steps. As shown in FIG. 8, the front side surface 132 of the single crystalline silicon substrate 101 may be textured. In one embodiment, the front side surface 132 is textured with random pyramids using a wet etch process comprising potassium hydroxide and isopropyl alcohol. The textured surface helps increase solar radiation collection. The front side surface 132 may further include a stack of materials 133, which may comprise one or more layers of materials, such as anti-reflective coating, passivation layer, and so on. The texturing process and other processing on or under the front side surface 132 may be performed at any suitable step of the manufacturing process without detracting from the merits of the present invention.

[0026] The resulting solar cell, which is an all back contact solar cell in one embodiment, has a hybrid emitter design in that one polarity of emitters comprise doped polycrystalline silicon, while the other and opposite polarity of emitters comprise doped single crystalline silicon formed in a single crystalline silicon substrate. More particularly, in the example of FIG. 8, the emitter 103 comprises P-type doped polycrystalline silicon, while the emitters 108 comprise N-type doped single crystalline silicon and are formed in an N-type doped single crystalline silicon substrate. As can be appreciated, the polarity of the doping of the emitter 103, emitters 108, and the substrate 101 may be changed with appropriate changes to the doping of the other features. For example, in other embodiments, the single crystalline silicon substrate 101 may be P-type doped, the single crystalline silicon emitters 108 may be P-type doped, and the polycrystalline silicon emitter 103 may be N-type doped.

[0027] Generally speaking, in emitter designs where both the P-type and N-type doped emitters are in a single crystalline silicon substrate, the dopant concentration in the

emitters must be balanced between high dopant concentration desired for low contact resistance and low dopant concentration desired for high minority carrier lifetimes. The conflicting demands of low contact resistance and high minority carrier lifetimes lead to suboptimal solar cell structures.

[0028] Solar cells where both the P-type and N-type doped emitters are formed in polycrystalline silicon eliminate the trade-off between low contact resistance and high minority carrier lifetimes. In particular, a dielectric separating the polycrystalline silicon emitters from the single crystalline silicon substrate screens out minority carriers, allowing for higher dopant concentration while maintaining relatively high minority carrier lifetimes. A main disadvantage is the need to create a trench between the P-type and N-type doped emitters in the polycrystalline silicon. The trench requires an additional patterning step and specific passivation on the backside surface of the solar cell, increasing the cost of manufacturing the solar cell.

[0029] The hybrid emitter design of the present disclosure provides many benefits heretofore unrealized, including higher dopant concentration, and thus lower contact resistance, for the polycrystalline silicon emitters 103. This is achieved without having to form trenches by providing single crystalline silicon emitters 108 in the single crystalline silicon substrate 101. The absence of trenches between emitters saves on patterning and associated process steps. And because only one polarity of polycrystalline silicon emitters is involved, the polycrystalline silicon emitters may be doped in situ. The solar cells of the present disclosure thus provide most of the advantages of all polycrystalline silicon emitters with lower manufacturing cost.

[0030] Referring now to FIG. 13, there is shown a flow diagram of a method 300 of manufacturing a solar cell in accordance with an embodiment of the present invention. In the example of FIG. 13, a thin dielectric layer is formed on a backside surface of a single crystalline silicon substrate (step 301). In one embodiment, the silicon substrate comprises a high lifetime single crystalline silicon wafer that is doped with N-type dopants. The thin dielectric layer may comprise silicon dioxide thermally grown directly on the backside surface of the single crystalline silicon substrate. A first emitter comprising doped polycrystalline silicon is formed on the thin dielectric layer (step 302).

The first emitter may be polycrystalline silicon doped to have a first polarity. For example, the polycrystalline silicon may be doped with a P-type dopant.

[0031] The first emitter comprising polycrystalline silicon may be formed in accordance with a method 400 by forming a doped polycrystalline silicon layer on the thin dielectric layer (step 401) and thereafter patterning the doped polycrystalline silicon layer to form the first emitter (step 402). The first emitter comprising polycrystalline silicon may also be formed in accordance with a method 500 by printing doped silicon nanoparticles on the thin dielectric layer (step 501) and thereafter performing a heat treatment to coalesce the silicon nanoparticles to form polycrystalline silicon (step 502). The first emitter may be doped before or after formation on the thin dielectric layer.

[0032] A second emitter is formed in the single crystalline silicon substrate (step 303). In one embodiment, the second emitter is formed by forming a dopant source layer on the single crystalline silicon substrate, and thereafter diffusing dopants from the dopant source layer into the single crystalline silicon substrate to form the second emitter comprising single crystalline silicon. The second emitter may be doped to have a second polarity opposite to the first polarity of the polycrystalline silicon emitter. In the example where the polycrystalline silicon emitter is P-type doped, the single crystalline silicon emitter may be doped with N-type dopants, and the single crystalline silicon substrate may be doped with N-type dopants. In other examples where the polycrystalline silicon emitter is N-type doped, the single crystalline silicon emitter may be doped with P-type dopants, and the single crystalline silicon substrate may be doped with P-type dopants.

[0033] Interdigitated metal contacts are thereafter connected to the first and second emitters (step 304).

[0034] Hybrid emitter all back contact solar cells and methods 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.

CLAIMS

What is claimed is:

1. An all back contact solar cell comprising:
 - a single crystalline silicon substrate;
 - a thin dielectric layer formed on a backside surface of the single crystalline silicon substrate;
 - a first emitter of the solar cell, the first emitter of the solar cell being formed on the thin dielectric layer and comprising polycrystalline silicon doped to have a first polarity;
 - a second emitter of the solar cell, the second emitter of the solar cell being formed in the single crystalline silicon substrate and comprising single crystalline silicon doped to have a second polarity opposite the first polarity;
 - a first metal contact connected to the first emitter on a backside of the solar cell, the backside being opposite a front side of the solar cell that faces the sun during normal operation; and
 - a second metal contact connected to the second emitter on the backside of the solar cell.
2. The solar cell of claim 1 wherein the thin dielectric layer comprises silicon dioxide formed directly on the backside surface of the single crystalline silicon substrate.
3. The solar cell of claim 1 further comprising:
 - a first layer of material formed on the first emitter and the backside surface of the single crystalline silicon substrate, wherein the first metal contact connects to the first emitter through the first layer of material but not through the thin dielectric layer, and wherein the first layer of material is configured to be etched such that the first metal contact connects to the first emitter through the first layer of material but not through the thin dielectric layer.
4. The solar cell of claim 3 wherein the second metal contact connects to the second emitter through the first layer of material and the thin dielectric layer.
5. The solar cell of claim 1 wherein the first emitter is a P-type doped emitter, the second emitter is an N-type doped emitter, and the single crystalline silicon substrate is doped with an N-type dopant.

6. The solar cell of claim 1 wherein a total area of the first emitter and other emitters of the solar cell comprising polycrystalline silicon covers at least 80% of a total area of the backside surface of the single crystalline silicon substrate.

7. A method of manufacturing an all back contact solar cell, the method comprising:
forming a thin dielectric layer on a backside surface of a single crystalline silicon substrate;

forming a first emitter on the thin dielectric layer on a backside of the solar cell, the first emitter comprising polycrystalline silicon that is doped with dopants of a first polarity, the backside of the solar cell being opposite a front side of the solar cell that faces the sun during normal operation;

forming a second emitter in the single crystalline silicon substrate on the backside the solar cell, the second emitter comprising single crystalline silicon that is doped with dopants of a second polarity opposite to the first polarity; and

forming a first metal contact connected to the first emitter and a second metal contact connected to the second emitter on the backside of the solar cell.

8. The method of claim 7 wherein the single crystalline silicon substrate is doped with N-type dopants, the polycrystalline silicon of the first emitter is doped with P-type dopants, and the single crystalline silicon of the second emitter is doped with N-type dopants.

9. The method of claim 7 further comprising:

forming a first layer of material on the thin dielectric layer and the first emitter;

forming a contact hole through the first layer of material but not through the thin dielectric layer to expose the first emitter; and

forming another contact hole through the first layer of material and the thin dielectric layer to expose the second emitter, wherein the first layer of material is configured such that the contact hole can be formed through the first layer of material but not through the thin dielectric layer to expose the first emitter and the another contact hole can be formed through the first layer of material and the thin dielectric layer to expose the second emitter.

10. The method of claim 7 wherein forming the first emitter comprises:

depositing a polycrystalline silicon layer on the thin dielectric layer; and

patterning the polycrystalline silicon layer to form the first emitter.

11. The method of claim 7 wherein forming the first emitter comprises:

printing silicon nanoparticles on the thin dielectric layer; and

thermally processing the silicon nanoparticles to form polycrystalline silicon.

12. The method of claim 7 wherein the thin dielectric layer comprises silicon dioxide that is thermally grown directly on the backside surface of the single crystalline silicon substrate.

13. The method of claim 7 wherein forming the second emitter comprises:
forming a dopant source layer on the thin dielectric layer; and
diffusing dopants from the dopant source layer through the thin dielectric layer
and into the single crystalline silicon substrate.
14. The method of claim 13 wherein the dopant source layer comprises phosphorus-silicate glass (PSG).
15. A solar cell that is manufactured in accordance with the method of claim 7.
16. A solar cell comprising:
a single crystalline silicon substrate;
a thin dielectric formed on a backside surface of the single crystalline silicon
substrate;
a first emitter of the solar cell, the first emitter comprising doped polycrystalline
silicon doped to have a first polarity; and
a second emitter of the solar cell, the second emitter comprising doped single
crystalline silicon doped to have a second polarity opposite the first polarity and formed
in the single crystalline silicon substrate.
17. The solar cell of claim 16 wherein the first emitter is doped with P-type dopants,
the second emitter is doped with N-type dopants, and the single crystalline silicon
substrate is doped with N-type dopants.
18. The solar cell of claim 16 wherein the thin dielectric comprises silicon dioxide.
19. The solar cell of claim 16 further comprising a metal contact that is connected to
the second emitter through a contact hole in the thin dielectric layer.
20. The solar cell of claim 16 wherein the solar cell is in all back contact solar cell.