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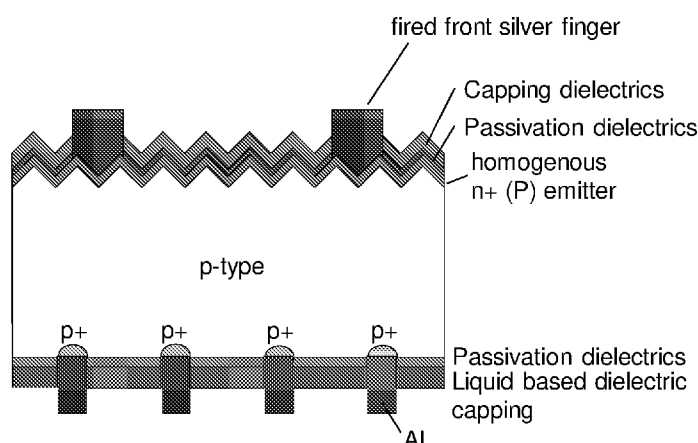
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(54) Title: A METHOD OF MANUFACTURING A PHOTOVOLTAIC DEVICE

Figure 4



(57) Abstract: There is provided a method of manufacturing a photovoltaic (PV) device, the method comprising: providing a substrate; depositing a dielectric passivation layer on a substrate surface; depositing a dielectric capping layer on the dielectric passivation layer, wherein the depositing comprises liquid-based depositing; and forming a contact to a bulk of the substrate, wherein the contact penetrates the dielectric passivation layer and the dielectric capping layer, such that the forming does not comprise providing a dielectric opening. There is also provided a PV device formed from the disclosed method.

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A method of manufacturing a photovoltaic deviceTechnical Field

The present invention relates to a method of manufacturing a photovoltaic device.

5 Background

Photovoltaic (PV) devices such as passivated emitter and rear contact (PERC) silicon wafer solar cells have the potential of achieving high energy conversion efficiency by minimal modification of existing silicon wafer solar cell industrial manufacturing facilities. By inserting a good surface passivation dielectric layer (e.g. vacuum based
10 plasma enhanced chemical vapour deposition (PECVD), atomic layer deposition (ALD) or plasma vapour deposition (PVD) AlO_x or thermally grown SiO_x) capped by PECVD/PVD SiN_x layer/layers, it is possible to reduce rear surface recombination velocity of minority carriers and therefore improve the open circuit voltage of the solar cell. Meanwhile, the mirror-like rear dielectrics/dielectric stack will also reflect the
15 photons back into the absorber (silicon wafer) to increase the short circuit current and hence the efficiency of the solar cell. Such dielectrics/dielectric stack on the rear surface will be locally opened by laser scribing/chemical etching, allowing a metal paste to form a good contact and back surface field in the silicon wafer to extract the light induced current efficiently.

20 The conventional PERC solar cell fabrication process in the current Si PV industry includes heavy capital expense on passivation layer deposition machine and laser ablation machine. Such high costs hinder PV solar cells from being more cost-effective for application in low-cost industrial solar cell manufacturing lines.

Bifacial PERC solar cells with rear grid-patterned metallization are attracting more
25 interests from top solar cell manufacturers. Unlike PERC cells with full-area rear metals, incident photons received from the rear side of bifacial PERC solar cells can also contribute to the power generation. However, manufacturing such bifacial PERC solar cells requires good alignment between the dielectric opening (laser scribing/etching paste) and the subsequent rear metallization. This requirement adds
30 additional complexity to the process and hence results in cost increase and production yield loss.

There is therefore a need for an improved method for manufacturing PV devices.

Summary of the invention

The present invention seeks to address these problems, and/or to provide an improved method for manufacturing PV devices.

5 In general terms, the invention relates to a low cost and simpler method of manufacturing PV devices such as solar cells such as silicon wafers solar cells, particularly reducing the number of processing steps, therefore being more cost-effective. The method is also a simple method which may be easily implemented, making it a scalable method.

10 According to a first aspect, the present invention provides a method of manufacturing a photovoltaic (PV) device, the method comprising:

- providing a substrate;
- depositing a dielectric passivation layer on a substrate surface;
- depositing a dielectric capping layer on the dielectric passivation layer,
- 15 wherein the depositing comprises liquid-based depositing; and
- forming a contact to a bulk of the substrate, wherein the contact penetrates the dielectric passivation layer and the dielectric capping layer, such that the forming does not comprise providing a dielectric opening.

20 The liquid-based depositing may comprise any suitable liquid-based depositing method. For example, the liquid-based depositing may comprise, but is not limited to: spin coating, spray coating, aerosol coating, dip coating, roller coating, inkjet printing, slot-die, blade coating, or a combination thereof.

The dielectric capping layer may have a suitable thickness. For example, the dielectric
25 capping layer may have a thickness of 10-300 nm.

The method may further comprise preparing a precursor solution prior to the depositing a dielectric capping layer on the dielectric passivation layer. According to a particular aspect, the preparing a precursor solution may comprise:

- mixing a metal precursor in a solvent;
- 30 - adding a stabiliser to form a mixture; and

- aging the mixture.

The metal precursor may be any suitable metal and/or metalloid precursor. For example, the metal precursor may comprise, but is not limited to: metal alkoxide, metal salt, or a combination thereof. In particular, the metal precursor may be: tetraethyl orthosilicate, titanium isopropoxide, titanium n-butoxide, titanium chloride, aluminium isopropoxide, aluminium sec butoxide, aluminium nitrate nonahydrate, aluminium chloride hexahydrate, aluminium hydroxide, zinc nitrate hexahydrate, zinc oxide, zinc acetate dihydrate, tantalum ethoxide, tungsten oxychloride, tungsten hexachloride, tungsten hexacarbonyl, niobium chloroethoxide, molybdenum isopropoxide, molybdenum trichloride isopropoxide, Molybdenum trioxide, molybdenum chloride, nickel acetate tetrahydrate, nickel nitrate hexahydrate, or a combination thereof.

The solvent may be any suitable solvent. For example, the solvent may be an organic solvent. In particular, the solvent may comprise, but is not limited to: isopropanol, ethanol, methanol, 2-isopropoxyethanol, dimethoxyethane, 2-methoxyethanol, 2 propoxy ethanol, DEG monobutylether, 1,3-propanediol, ethylene glycol, diethylene glycol, or a combination thereof.

The stabiliser may be any suitable stabiliser. For example, the stabiliser may be, but not limited to: acetyl acetone, water, urea, polyvinyl alcohol, glycerol, ethyl acetoacetate, ethyl acetate, diethyl malonate, ethanol amine, ammonia, potassium hydroxide, sodium hydroxide, ethanolamine, oxalic acid, citric acid, hydrochloric acid, nitric acid, sulphuric acid, or a combination thereof.

According to a particular aspect, the forming may comprise providing a metal paste and heating the metal paste at a pre-determined temperature. The pre-determined temperature may be any suitable temperature. For example, the pre-determined temperature may be 200-900°C.

According to a particular aspect, the method may further comprise texturing the substrate surface prior to the depositing a dielectric passivation layer on the substrate surface. The texturing may comprise, but is not limited to, etching the substrate surface, polishing the substrate surface, or a combination thereof.

According to a second aspect, the present invention provides a photovoltaic (PV) device formed from the method according to the first aspect. For example, the PV device may be, but not limited to, a passivated emitter and rear contact (PERC) solar cell, passivated emitter rear locally diffused (PERL) cell, n-type front and back contact solar cell, or passivated contact solar cell.

Brief Description of the Drawings

In order that the invention may be fully understood and readily put into practical effect there shall now be described by way of non-limitative example only exemplary embodiments, the description being with reference to the accompanying illustrative drawings. In the drawings:

Figure 1 shows a schematic representation of a substrate following surface texturing and junction formation according to one embodiment of the present invention;

Figure 2 shows a schematic representation of a substrate following double-side surface passivation;

Figure 3 shows a schematic representation of a substrate following double-side capping layer deposition;

Figure 4 shows a schematic representation of a PV device formed from the method according to one embodiment of the present invention; and

Figure 5 shows the fill factors of 10 different p-type bifacial PERC solar cells fabricated from the method according to one embodiment of the present invention.

Detailed Description

As explained above, there is a need for an improved method of manufacturing photovoltaic (PV) devices such as solar cells which is cost effective.

The method of the present invention enables a cheaper coating method to be utilised in providing the dielectric layers. In particular, the dielectric layers may be provided by a liquid-based coating method. Further, the precursor used for depositing onto the PV device substrate to form the dielectric layer may be prepared from safe, non-toxic and easily available precursors, thereby reducing the cost and at the same time, making the method safer.

Due to the liquid-based dielectric coatings, physical/chemical opening (e.g. laser scribing / etching paste) is not required in the PV device manufacturing processing steps. The method of the present invention avoids heavy initial investment on PECVD, ALD and laser machines, resulting in less depreciation and capital costs. Further, as the liquid-based coatings do not require a cleanroom environment, the costs in terms of cleanroom facility and maintenance can also be minimized in PV device manufacturing. All these advantages add up to a significant total cost reduction in manufacturing PV devices.

In general terms, the method of the present invention describes a method to passivate a PV device surface using a thin film or thin film stacks consisting of at least one liquid-based coating. This may be followed by a self-alignment metallization process to form contacts on the junction/rear surface field/front surface field. In summary, the method of the present invention reduces the number of processing steps to manufacture a PV device.

According to a first aspect, the present invention provides a method of manufacturing a photovoltaic (PV) device, the method comprising:

- providing a substrate;
- depositing a dielectric passivation layer on a substrate surface;
- depositing a dielectric capping layer on the dielectric passivation layer, wherein the depositing comprises liquid-based depositing; and
- forming a contact to a bulk of the substrate, wherein the contact penetrates the dielectric passivation layer and the dielectric capping layer, such that the forming does not comprise providing a dielectric opening.

The substrate may be any suitable substrate for manufacturing the PV device. For example, the substrate may be a wafer of a solar cell. The substrate may be, but is not limited to, a silicon substrate, III-V substrate, germanium substrate, sapphire substrate, and the like. The substrate may be a n-type or p-type substrate. In particular, the substrate may be a p-type silicon-based substrate.

According to a particular aspect, the method may further comprise texturing the substrate surface prior to the depositing a dielectric passivation layer. The texturing may be by any suitable method. For example, the texturing may be by etching,

polishing, or a combination thereof. In particular, the texturing may comprise etching the substrate surface. The etching may be by caustic etch or standard saw damage. For example, the etching may be by using, but not limited to, potassium hydroxide (KOH), sodium hydroxide (NaOH), tetramethylammonium hydroxide (TMAH), plasma, or a combination thereof.

The depositing a dielectric passivation layer on a substrate surface may be by any suitable deposition method. For example, the depositing may comprise, but is not limited to: PECVD, LPCVD, ALD, sputtering, liquid-based deposition, or a combination thereof.

10 The dielectric passivation layer may have a suitable thickness. For example, the dielectric passivation layer may have a thickness of 1-100 nm. In particular, the thickness may be 5-90 nm, 10-85 nm, 15-80 nm, 20-75 nm, 25-70 nm, 30-60 nm, 40-50 nm. Even more in particular, the thickness of the dielectric passivation layer may be 1-20 nm.

15 The dielectric passivation layer may comprise any suitable material. For example, the dielectric passivation layer may comprise, but is not limited to: silicon oxide (SiO_x), silicon nitride (SiN_x), aluminium oxide (AlO_x), amorphous silicon (a-Si:H), metal oxides such as AlO_x , TiO_x , or a mixture of different doped or undoped metal oxides, or stacks of these materials. According to a particular aspect, the dielectric passivation layer may
20 comprise: thermal silicon oxide (SiO_2), PECVD/LPCVD grown silicon oxide (SiO_x), PECVD/LPCVD or sputtered silicon nitride (SiN_x), PECVD/ALD/LPCVD or sputtered aluminium oxide (AlO_x), PECVD grown or sputtered hydrogenated amorphous silicon (a-Si:H), liquid coated doped or undoped metal or metalloid oxides (e.g., doped or undoped SiO_x , AlO_x , TiO_x , ZnO_x , WO_x , NiO_x , MoO_x , TaO_x , NbO_x , or a mixture of
25 different metal oxides), or stacks of these materials.

The depositing a dielectric capping layer on the dielectric passivation layer comprising liquid-based depositing may be by any suitable liquid-based depositing. For example, the liquid-based depositing may be, but is not limited to: spin coating, spray coating, aerosol coating, dip coating, roller coating, inkjet printing, slot-die, blade coating, or a
30 combination thereof.

The depositing a dielectric capping layer may further comprise heating the deposited dielectric capping layer. The heating may comprise soft baking the deposited dielectric capping layer. The heating may be at a suitable temperature. For example, the heating may be at a temperature of 80-200°C. In particular, the heating may be at a temperature of 90-190°C, 100-180°C, 110-170°C, 120-160°C, 130-150°C, 140-145°C. Even more in particular, the heating may be at a temperature of 100-150°C. The heating may be for a suitable period of time. For example, the heating may be for 10 seconds-10 minutes. In particular, the heating may be for 30 seconds-8 minutes, 1-7 minutes, 2-6 minutes, 3-5 minutes. Even more in particular, the heating may be for 30 seconds-2 minutes.

The depositing a dielectric capping layer may further comprise curing the deposited dielectric capping layer following the heating. The curing may be at a suitable temperature. For example, the curing may be at a temperature of 250-900°C. In particular, the curing may be at a temperature of 300-850°C, 350-800°C, 400-750°C, 450-700°C, 500-650°C, 550-600°C. Even more in particular, the curing may be at a temperature of 300-550°C. The curing may be for a suitable period of time. For example, the curing may be for 2 seconds-120 minutes. The curing may be under an inert atmosphere such as a nitrogen atmosphere, or in air.

The dielectric capping layer may have a suitable thickness. For example, the dielectric capping layer may have a thickness of 10-300 nm. In particular, the thickness may be 20-190 nm, 30-150 nm, 50-120 nm, 80-100 nm, 90-95 nm. Even more in particular, the thickness of the dielectric capping layer may be 30-150 nm.

The dielectric capping layer may comprise any suitable material. For example, the dielectric capping layer may comprise doped or undoped metal or metalloid oxides such as doped or undoped AlO_x , TiO_x , SiO_x , ZnO_x , WO_x , NiO_x , MoO_x , TaO_x , NbO_x , or a mixture of different metal oxides, or stacks of these materials. According to a particular aspect, the dielectric passivation layer may comprise liquid coated doped or undoped metal or metalloid oxides.

The dielectric passivation layer may be provided for reducing surface recombination rate. The dielectric capping layer may be provided for improving passivation stability and quality provided by the underlying dielectric passivation layer, and also to serve the

necessary optical functions by forming proper anti-reflective coating or acting as an effective optical reflector for long-wavelength photons, such as infrared photons.

The method may further comprise preparing a precursor solution prior to the depositing a dielectric capping layer on the dielectric passivation layer. According to a particular aspect, the preparing a precursor solution may comprise:

- mixing a metal precursor in a solvent;
- adding a stabiliser to form a mixture; and
- aging the mixture.

10 The metal precursor may be any suitable metal and/or metalloid precursor. The metal precursor may be doped or undoped. For example, the metal precursor may comprise, but is not limited to: metal alkoxide, metal salt, or a combination thereof. In particular, the metal precursor may be: tetraethyl orthosilicate, titanium isopropoxide, titanium n-butoxide, titanium chloride, aluminium isopropoxide, aluminium sec butoxide, tantalum ethoxide, aluminium nitrate nonahydrate, aluminium chloride hexahydrate, aluminium hydroxide, zinc nitrate hexahydrate, zinc oxide, zinc acetate dihydrate, tantalum ethoxide, tungsten oxychloride, tungsten hexachloride, tungsten hexacarbonyl, niobium chloroethoxide, molybdenum isopropoxide, molybdenum trichloride isopropoxide, Molybdenum trioxide, molybdenum chloride, nickel acetate tetrahydrate, nickel nitrate hexahydrate, or a combination thereof.

The metal precursor may be of a suitable concentration. For example, the concentration of the metal precursor may be 0.005-1 M, particularly 0.05-0.5 M.

25 The solvent may be any suitable solvent. For example, the solvent may be an organic solvent. In particular, the solvent may comprise, but is not limited to: isopropanol, ethanol, methanol, 2-isopropoxyethanol, dimethoxyethane, 2-methoxyethanol, 2 propoxy ethanol, DEG monobutylether, 1,3-propanediol, ethylene glycol, diethylene glycol, or a combination thereof.

30 The stabiliser may be any suitable stabiliser. For example, the stabiliser may be, but not limited to: acetyl acetone, water, urea, polyvinyl alcohol, glycerol, ethyl acetoacetate, ethyl acetate, diethyl malonate, ethanol amine, ammonia, potassium hydroxide, sodium hydroxide, ethanolamine, oxalic acid, citric acid, hydrochloric acid,

nitric acid, sulphuric acid, or a combination thereof. Any suitable amount of stabiliser may be added to the precursor solution. In particular, the amount of stabiliser in the precursor solution may be ≤ 20 vol %, based on the total volume of the precursor solution.

- 5 According to a particular aspect, the precursor solution may comprise 0.5-15 vol% of the metal precursor, 0.5-8 vol% stabiliser and 85-98 vol% solvent.

The aging the mixture may be under suitable conditions. For example, the aging may be under ambient conditions. The aging may comprise aging the mixture while stirring the mixture.

- 10 According to a particular aspect, the forming may comprise providing a metal paste and heating the metal paste at a pre-determined temperature. The metal paste may comprise any suitable metal. In particular, the metal comprised in the metal paste is the metal from which the contact is formed. The metal paste may comprise a metal or metal alloy. In particular, the metal comprised in the metal paste may be silver,
15 aluminium, or alloys of metals thereof. According to a particular embodiment, the metal paste may comprise fritted glass-metal paste, which provide good contact resistance when the paste is heated. In particular, the glass-metal paste is fired through the dielectric passivation layer and the dielectric capping layer.

- The forming may comprise screen printing the metal paste to form the contact. The
20 forming may further comprise heating the screen-printed metal paste at a pre-determined temperature.

The pre-determined temperature for the heating may be any suitable temperature. For example, the pre-determined temperature may be 200-900°C.

- In view of the liquid-based depositing of the dielectric capping layer, the method of the
25 present invention avoids the need to carry out laser ablation to open the dielectric stack comprising the dielectric passivation layer and the dielectric capping layer for forming the metal contact. Such laser ablation step is usually very challenging for industrial process to align the final metal contact printing with the laser ablated lines.

- According to a particular aspect, the substrate may comprise a front surface and a rear
30 surface. The depositing a dielectric passivation layer and/or a dielectric capping layer

may be on the front surface and/or rear surface of the substrate. The depositing of a dielectric passivation layer on the front surface and rear surface may be by concurrent deposition in a single process or separately in a two-step deposition process.

According to a particular aspect, the method of manufacturing a photovoltaic (PV) comprises:

- providing a substrate having a bulk and exhibiting a front surface and a rear surface;
- depositing a dielectric passivation layer on at least the rear surface substrate surface;
- depositing a dielectric capping layer on the dielectric passivation layer on the rear surface, wherein the depositing comprises liquid-based depositing; and
- forming a contact to the bulk of the substrate, wherein the contact penetrates the dielectric passivation layer and the dielectric capping layer, such that the forming does not comprise providing a dielectric opening.

The substrate may be as described above. The depositing a dielectric passivation layer and the forming a contact may be as described above.

The depositing a dielectric capping layer may be as described above. In particular, the liquid-based depositing may comprise any suitable liquid-based depositing method. For example, the liquid-based depositing may be as described above.

The method may further comprise depositing a dielectric passivation layer on the front surface of the substrate.

The method may further comprise depositing a dielectric capping layer on the dielectric passivation layer on the front surface of the substrate. The depositing a dielectric capping layer may be by any suitable method. For example, the depositing a dielectric capping layer may comprise, but is not limited to: plasma enhanced chemical vapour deposition (PECVD), low pressure chemical vapour deposition (LPCVD), sputtering, atomic layer deposition, spin coating, spray coating, aerosol coating, dip coating, roller coating, or a combination thereof. In particular, the depositing a dielectric capping layer may comprise any suitable liquid-based depositing method. For example, the liquid-based depositing method may be as described above.

According to a second aspect, the present invention provides a photovoltaic (PV) device formed from the method according to the first aspect. The PV device may be any suitable PV device. In particular, the PV device may be a Si-based PV device, or a III-V PV device.

- 5 According to a particular aspect, the PV device may be a solar cell. For example, the PV device may be a monocrystalline, multicrystalline, mono- or bi-facial solar cell. The solar cell may be a n-type or p-type solar cell. In particular, the PV device may be a passivated emitter and rear contact (PERC) solar cell, passivated emitter rear locally diffused (PERL) cell, n-type front and back contact solar cell, or passivated contact
10 solar cell.

Having now generally described the invention, the same will be more readily understood through reference to the following embodiment which is provided by way of illustration, and is not intended to be limiting.

Example

- 15 A cross-sectional view of a starting silicon wafer is shown in Figure 1. The wafer was doped p-type in the resistivity range of 0.5-10 Ohm-cm and had a starting thickness of 50-200 μm and a bulk minority carrier lifetime of greater than 0.3 ms. A standard alkaline texturing by KOH was used to texture the front surface of the wafer.

- The wafer was a monocrystalline wafer of the orientation $\langle 100 \rangle$, and this led to the
20 formation of upright pyramids with $\langle 111 \rangle$ oriented sidewalls. The typical height of the pyramids was in the range of 1-10 μm . The texture reduced reflection losses at the front surface, thereby improving the efficiency of the solar cell by raising the short-circuit current density.

- The front surface doping was realised by standard high-temperature tube furnace
25 diffusion. Typical p-n junction depth was around 0.1-2 μm and the sheet resistance was in the range of 5-150 Ohm/square.

- Following the texturing, a wet etch was performed to remove the phosphosilicate glass (PSG) and the junction on the rear and the subsequent deposition of a passivation layer on both the front and rear surfaces to form the wafer as shown in Figure 2. In
30 particular, the front surface was deposited with a PECVD SiN_x passivation layer having

a thickness of 70 nm and a passivation layer comprising Al_2O_3 of a thickness of about 8 nm and deposited by ALD was used as the passivation layer for the rear surface.

Following the depositing of the dielectric passivation layers, dielectric capping layers were deposited on each of the front passivation layer and the rear passivation layer.

5 The depositing of the dielectric capping layers was by spin coating a precursor solution comprising isopropoxide, isopropanol and acetylacetone. In particular, the precursor solution was formed by mixing 3 ml of titanium isopropoxide in 50 ml of isopropanol and 1.1 ml of acetylacetone. The mixture was left to stir for 24 hours at room temperature to form the precursor solution. The dielectric capping layer formed was a
10 70 nm TiO_x layer. A schematic representation of the wafer formed following the depositing of the dielectric capping layer is as shown in Figure 3.

As the last step, as shown in Figure 4, the solar cell was completed with a H-patterned screen-print metallization on both front surface and rear surface using silver and aluminium, respectively, to form bifacial solar cells. The metal pastes were fritted glass-
15 metal pastes, which provided a good contact resistance by firing the pastes at high temperature through the dielectric surface passivation stack. The firing temperature was about 780°C. Due to the unique property of the liquid based dielectric capping, the metal paste was able to penetrate the dielectric stack on the rear surface and form good contacts (good quality aluminium back surface field) at the rear Si interface,
20 without the need of localized dielectric openings before screen printing. Accordingly, the manufacturing the bifacial PERC solar cell as shown in Figure 4 did not require the complex step of ensuring good alignment between a dielectric opening (laser scribing / etching paste) and the subsequent rear metallization.

10 p-type bifacial PERC solar cells were prepared using the method described in the
25 Example. Figure 5 shows the fill factor (FF) values measured for all finished cells. Without additional dielectric opening step, excellent localized contacts were formed on the rear surfaces. In particular, the fill factor measures the ratio of maximum obtainable power to the solar cell of the open-circuit voltage and short-circuit current.

Whilst the foregoing description has described exemplary embodiments, it will be
30 understood by those skilled in the technology concerned that many variations may be made without departing from the present invention.

Claims

1. A method of manufacturing a photovoltaic (PV) device, the method comprising:
- providing a substrate;
 - depositing a dielectric passivation layer on a substrate surface;
 - 5 - depositing a dielectric capping layer on the dielectric passivation layer, wherein the depositing comprises liquid-based depositing; and
 - forming a contact to a bulk of the substrate, wherein the contact penetrates the dielectric passivation layer and the dielectric capping layer, such that the forming does not comprise providing a dielectric
 - 10 opening.
2. The method according to claim 1, wherein the liquid-based depositing comprises: spin coating, spray coating, aerosol coating, dip coating, roller coating, inkjet printing, slot-die, blade coating, or a combination thereof.
- 15 3. The method according to claim 1 or 2, wherein the method further comprises preparing a precursor solution prior to the depositing a dielectric capping layer on the substrate surface.
- 20 4. The method according to claim 3, wherein the preparing a precursor solution comprises:
- mixing a metal precursor in a solvent;
 - adding a stabiliser to form a mixture; and
 - aging the mixture.
- 25 5. The method according to claim 4, wherein the metal precursor comprises: metal alkoxide, metal salt, or a combination thereof.
6. The method according to claim 4 or 5, wherein the metal precursor comprises:
- 30 tetraethyl orthosilicate, titanium isopropoxide, titanium n-butoxide, titanium chloride, aluminium isopropoxide, aluminium sec butoxide, tantalum ethoxide, aluminium nitrate nonahydrate, aluminium chloride hexahydrate, aluminium hydroxide, zinc nitrate hexahydrate, zinc oxide, zinc acetate dihydrate, tantalum ethoxide, tungsten oxychloride, tungsten hexachloride, tungsten hexacarbonyl, niobium chloroethoxide,

molybdenum isopropoxide, molybdenum trichloride isopropoxide, Molybdenum trioxide, molybdenum chloride, nickel acetate tetrahydrate, nickel nitrate hexahydrate, or a combination thereof.

5 7. The method according to any of claims 4 to 6, wherein the solvent comprises: isopropanol, ethanol, methanol, 2-isopropoxyethanol, dimethoxyethane, 2-methoxyethanol, 2 propoxy ethanol, DEG monobutylether, 1,3-propanediol, ethylene glycol, diethylene glycol, or a combination thereof.

10 8. The method according to any of claims 4 to 7, wherein the stabiliser comprises: acetyl acetone, water, urea, polyvinyl alcohol, glycerol, ethyl acetoacetate, ethyl acetate, diethyl malonate, ethanol amine, ammonia, potassium hydroxide, sodium hydroxide, ethanolamine, oxalic acid, citric acid, hydrochloric acid, nitric acid, sulphuric acid, or a combination thereof.

15 9. The method according to any preceding claim, wherein the dielectric capping layer has a thickness of 10-300 nm.

10 10. The method according to any preceding claim, wherein the forming comprises providing a metal paste and heating the metal paste at a pre-determined temperature.

11. The method according to claim 10, wherein the pre-determined temperature is 200-900°C.

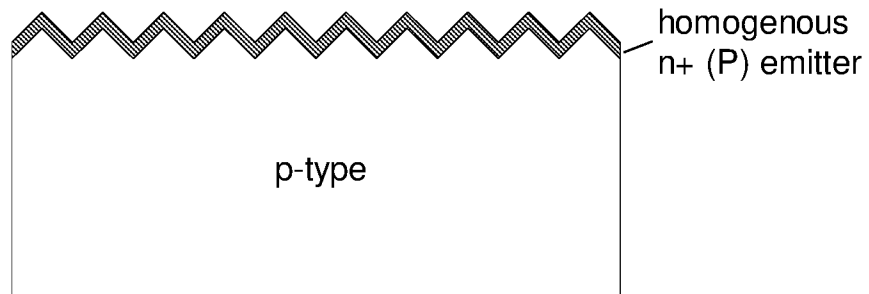
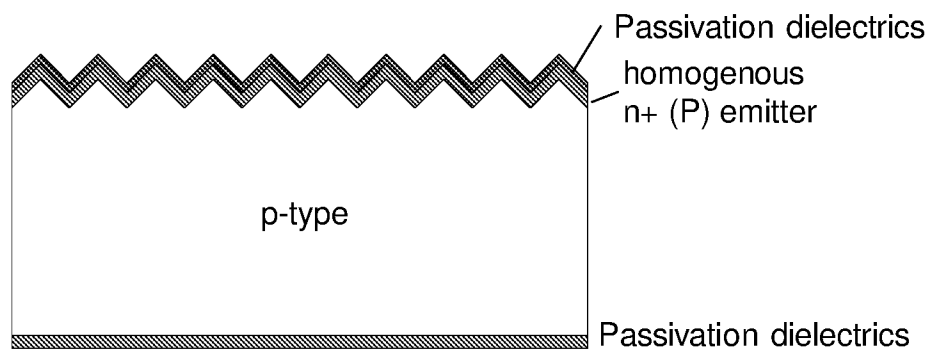
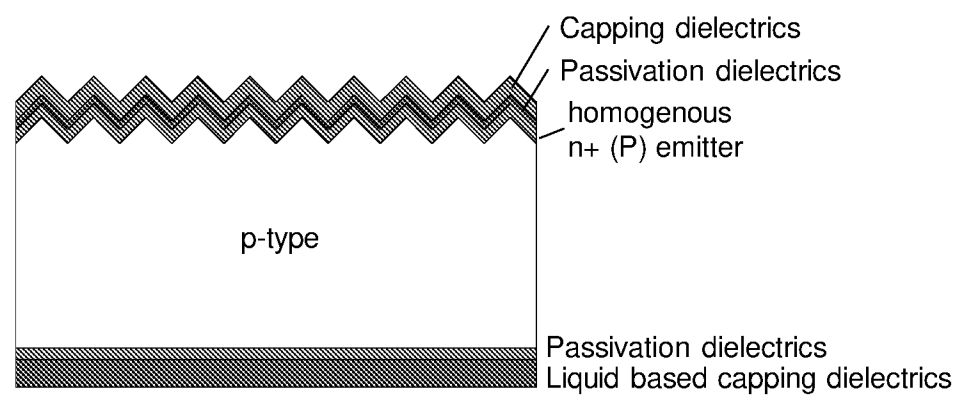
25 12. The method according to any preceding claim, wherein the method further comprises texturing the substrate surface prior to the depositing a dielectric passivation layer on the substrate surface.

30 13. The method according to claim 12, wherein the texturing may comprise etching and/or polishing the substrate surface.

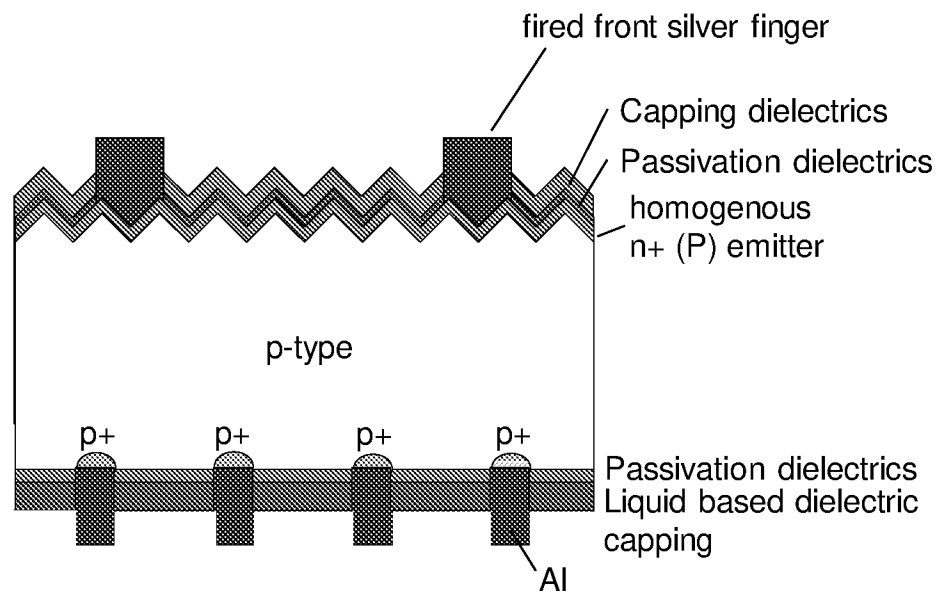
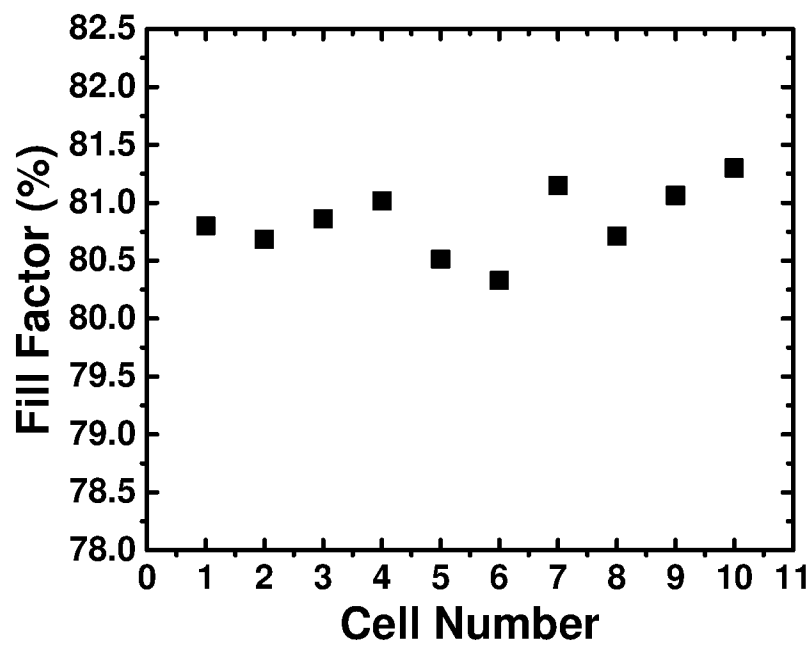
14. A photovoltaic (PV) device formed from the method of any preceding claim.

15. The PV device according to claim 14, wherein the PV device is a passivated emitter and rear contact (PERC) solar cell, passivated emitter rear locally diffused (PERL) cell, n-type front and back contact solar cell, or passivated contact solar cell.

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Figure 1**Figure 2****Figure 3**

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Figure 4**Figure 5**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2018/050604

A. CLASSIFICATION OF SUBJECT MATTER

See Supplemental Box

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

FAMPAT, IEEE Xplore:

solar, dielectric layer, liquid based deposition, spin coating, contact, electrode, self-alignment metallization, fire through paste, 光伏, 介电层, 液相沉积, 旋涂, 电接触, 电极, 自对准, 烧穿浆料 and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2014/0060632 A1 (LAUGHLIN B. J. ET AL.) 6 March 2014 Whole document, especially para. [0009], [0011], [0016], [0094], [0098], [0099], [0100], [0108], fig.1.	1-4, 9-15 5-8
X	US 2015/0255638 A1 (KÄRKKÄINEN A. ET AL.) 10 September 2015 Whole document, especially para. [0046], [0049]	1-4
Y	CN 104508830 A (HITACHI CHEMICAL) 8 April 2015 Whole document, especially [0068], [0079], [0080], [0192], [0194] of the original non-English language document (a machine translation is enclosed only for your reference)	5-8

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

*Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

16/01/2019

(day/month/year)

Date of mailing of the international search report

01/02/2019

(day/month/year)

Name and mailing address of the ISA/SG



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2018/050604

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/0095604 A1 (BIRO D. ET AL.) 18 April 2013 Whole document, especially [0009]-[0011], [0040]	
A	US 2014/0137934 A1 (GEERLIGS L. J.) 22 May 2014 Whole document, especially para. [0012]-[0016]	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2018/050604

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 2015/0255638 A1	10/09/2015	WO 2014/044924 A1 FI 20125988 A CN 104919568 A EP 2898112 A1	27/03/2014 25/03/2014 16/09/2015 29/07/2015
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2018/050604

Supplemental Box (Classification of Subject Matter)

Int. Cl.

H01L 21/02 (2006.01)

H01L 21/28 (2006.01)

H01L 31/0224 (2006.01)

H01L 31/0216 (2014.01)

H01L 31/18 (2006.01)