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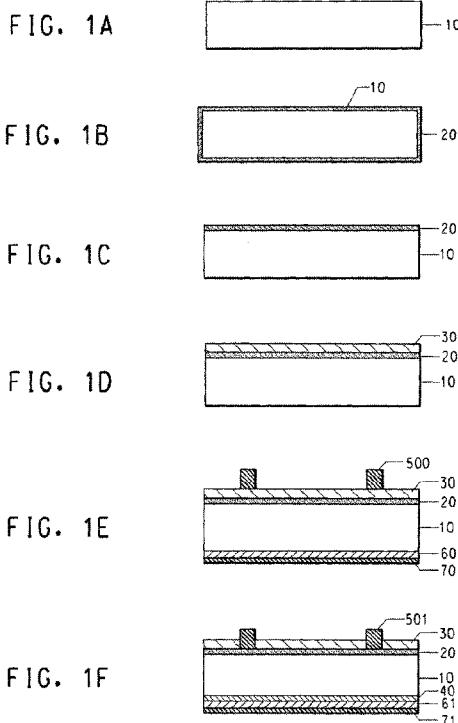
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(54) Title: LEAD-FREE CONDUCTIVE COMPOSITIONS AND PROCESSES FOR USE IN THE MANUFACTURE OF SEMICONDUCTOR DEVICES: FLUX MATERIALS

(57) Abstract: Embodiments of the invention relate to a silicon semiconductor device, and a conductive silver paste for use in the front side of a solar cell device.





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TITLE

LEAD-FREE CONDUCTIVE COMPOSITIONS AND PROCESSES
FOR USE IN THE MANUFACTURE OF SEMICONDUCTOR DEVICES:

5

FLUX MATERIALS

FIELD OF THE INVENTION

Embodiments of the invention relate to a silicon semiconductor
10 device, and a conductive silver paste for use in the front side of a solar cell
device.

TECHNICAL BACKGROUND OF THE INVENTION

15 A conventional solar cell structure with a p-type base has a negative electrode that is typically on the front-side or sun side of the cell and a positive electrode on the backside. It is well-known that radiation of an appropriate wavelength falling on a p-n junction of a semiconductor body serves as a source of external energy to generate hole-electron pairs
20 in that body. Because of the potential difference which exists at a p-n junction, holes and electrons move across the junction in opposite directions and thereby give rise to flow of an electric current that is capable of delivering power to an external circuit. Most solar cells are in the form of a silicon wafer that has been metallized, i.e., provided with
25 metal contacts that are electrically conductive.

Although various methods and compositions for forming solar cells exist, there is a need for compositions, structures, and devices which have improved electrical performance, and methods of making.

30

SUMMARY OF THE INVENTION

An embodiment of the present invention relates to a structure comprising:
(a) a thick film composition comprising:

a) an electrically conductive silver;

- b) one or more flux materials, wherein the flux materials are lead-free; dispersed in
 - c) an organic medium;
- (b) one or more insulating films;

5 wherein the thick film composition is formed on the one or more insulating films, and wherein, upon firing, the one or more insulating films is penetrated by components of the thick film composition and the organic medium is removed.

10 In an embodiment, the flux material comprises one or more glass frits.

In an aspect of the embodiment, the structure further comprises one or more semiconductor substrates. In a further aspect, the insulating films are formed on the one or more semiconductor substrates. An aspect of 15 the invention relates to semiconductor devices comprising the structure. A further aspect relates to a semiconductor device, comprising the structure, wherein the composition has been fired, wherein the firing removes the organic vehicle and sinters the silver and flux materials, and wherein the conductive silver and frit mixture penetrate the insulating film. A further 20 aspect relates to a solar cell comprising the structure.

In an aspect of the embodiment, the thick film composition further comprises an additive. In a further aspect, the additive is selected from: (a) a metal wherein said metal is selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, 25 Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or more of the metals selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof. In an embodiment, the additive is ZnO or MgO.

30 In an aspect of the embodiment, the glass frit comprises: Bi₂O₃, B₂O₃ 8-25 weight percent of the glass frit, and further comprises one or more components selected from the group consisting of: SiO₂, P₂O₅, GeO₂, and V₂O₅.

In an aspect of the embodiment, the insulating film comprises one or more components selected from: titanium oxide, silicon nitride, SiNx:H, silicon oxide, and silicon oxide/titanium oxide.

5 In an aspect of the embodiment, the structure is useful in the manufacture of photovoltaic devices.

In an aspect of the embodiment, the glass frit comprises a component selected from: (a) a metal wherein said metal is selected from Zn, Mg,

10 Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or more of the metals selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof.

15 An embodiment of the present invention relates to a structure comprising:
(a) a thick film composition comprising:

a) an electrically conductive silver;
b) one or more flux materials, wherein the flux materials are lead-free; dispersed in

20 c) an organic medium;

(b) one or more semiconductor substrates;

wherein the thick film composition is formed on the one or more semiconductor substrates, and wherein, upon firing, an electrical contact is formed between the conductive silver and the one or more semiconductor substrates.

In an embodiment, the flux material comprises one or more glass frits.

30 In an aspect of this embodiment, the structure does not comprise an insulating film. A further aspect relates to a semiconductor device, comprising the structure, wherein the composition has been fired, wherein the firing removes the organic vehicle and sinters the silver and flux materials. A further aspect relates to a solar cell comprising the structure.

In an aspect of the embodiment, the thick film composition further comprises an additive. In an aspect of the embodiment, the thick film composition further comprises an additive. In a further aspect, the additive is selected from: (a) a metal wherein said metal is selected from Zn, Mg, 5 Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or more of the metals selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof. In an embodiment, the additive is ZnO or MgO.

10 In an aspect of the embodiment, the glass frit comprises: Bi₂O₃, B₂O₃ 8-25 weight percent of the glass frit, and further comprises one or more components selected from the group consisting of: SiO₂, P₂O₅, GeO₂, and V₂O₅.

15 In an aspect of the embodiment, the structure is useful in the manufacture of photovoltaic devices.

An embodiment of the invention relates to a method of manufacturing a 20 semiconductor device. The method comprises the steps of: (a) providing one or more semiconductor substrates, one or more insulating films, and a thick film composition, wherein the thick film composition comprises: a) an electrically conductive silver, b) one or more flux materials, wherein the flux materials are lead-free, dispersed in c) an 25 organic medium,

(b) applying the insulating film on the semiconductor substrate,

(c) applying the thick film composition on the insulating film on the semiconductor substrate, and

(d) firing the semiconductor, insulating film and thick film composition,

30 wherein, upon firing, the organic vehicle is removed, the silver and glass frits are sintered, and the insulating film is penetrated by components of the thick film composition.

An embodiment of the invention relates to a method of manufacturing a semiconductor device. The method comprises the steps of:

(a) providing one or more semiconductor substrates, and a thick film composition, wherein the thick film composition comprises: a) an

5 electrically conductive silver, b) one or more flux materials, wherein the flux materials are lead-free, dispersed in c) an organic medium,

(b) applying the thick film composition on the one or more semiconductor substrates, and

10 (c) firing the semiconductor and thick film composition,

15 wherein, upon firing, the organic vehicle is removed, the silver and glass frits are sintered.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a process flow diagram illustrating the fabrication of

15 a semiconductor device.

Reference numerals shown in Figure 1 are explained below.

10: p-type silicon substrate

20: n-type diffusion layer

30: silicon nitride film, titanium oxide film, or silicon oxide film

20 40: p+ layer (back surface field, BSF)

50: silver paste formed on front side

51: silver front electrode (obtained by firing front side silver paste)

60: aluminum paste formed on backside

25 61: aluminum back electrode (obtained by firing back side aluminum paste)

70: silver or silver/aluminum paste formed on backside

71: silver or silver/aluminum back electrode (obtained by firing back side silver paste)

30 80: solder layer

500: silver paste formed on front side according to the invention

501: silver front electrode according to the invention (formed by firing front side silver paste)

5

Figure 2A provides a top side view of an exemplary semiconductor in which the thick film conductor composition has been printed on the substrate to form two busbars. Figure 2B provides a top side view of an exemplary semiconductor in which the thick film conductor composition has been printed on the substrate to form three busbars.

10

Figure 3 illustrates a comparison of Flux Based Silver Paste vs. Corresponding Glass Based Paste.

DETAILED DESCRIPTION OF THE INVENTION

The present invention addresses the need for semiconductor compositions with improved electrical performance, semiconductor devices, methods of manufacturing the semiconductor devices, and the like.

An embodiment of the present invention relates to thick film conductor compositions. In an aspect of the embodiment, the thick film conductor compositions may include: a conductive powder, a flux material, and an organic medium. The flux material may be glass frit or mixture of glass frits. The thick film conductor compositions may also include an additive. The thick film conductor compositions may include additional additives or components.

25

An embodiment of the present invention relates to structures, wherein the structures include the thick film conductor compositions. In an aspect, the structure also includes one or more insulating films. In an aspect, the structure does not include an insulating film. In an aspect, the structure includes a semiconductor substrate. In an aspect, the thick film conductor composition may be formed on the one or more insulating films. In an aspect, the thick film conductor composition may be formed on the semiconductor substrate. In the aspect wherein the thick film conductor

composition may be formed on the semiconductor substrate, the structure may not contain an applied insulating film.

In an embodiment, the thick film conductor composition may be
5 printed on the substrate to form busbars. The busbars may be more than
two busbars. For example, the busbars may be three or more busbars. In
addition to busbars, the thick film conductor composition may be printed
on the substrate to form connecting lines. The connecting lines may
contact a busbar. The connecting lines contacting a busbar may be
10 interdigitated between the connecting lines contacting a second busbar.

In an exemplary embodiment, three busbars may be parallel to
each other on a substrate. The busbars may be rectangular in shape.
Each of the sides of the middle busbar may be in contact with connecting
15 lines. On each of the side busbars, only one side of the rectangle may be
in contact with connecting lines. The connecting lines contacting the side
busbars may interdigitate with the connecting lines contacting the middle
busbar. For example, the connecting lines contacting one side busbar
may interdigitate with the connecting lines contacting the middle busbar on
20 one side, and the connecting lines contacting the other side busbar may
interdigitate with the connecting lines contacting the middle busbar on the
other side of the middle busbar.

Figure 2A provides an exemplary representation of an embodiment
25 in which there are two busbars. A first busbar 201 is in contact with a first
set of connecting lines 203. A second busbar 205 is in contact with a
second set of connecting lines 207. The first set of connecting lines 203
interdigitate with the second set of connecting lines 207.

30 Figure 2B provides an exemplary representation of an embodiment
in which there are three busbars. A first busbar 209 is in contact with a
first set of connecting lines 211. A second busbar 213 is in contact with
both a second set of connecting lines 215 and a third set of connecting
lines 217. The second set of connecting lines 215 contacts one side of the

second busbar 213; the third set of connecting lines 217 contacts the opposite side of the second busbar 213. A third busbar 219 is in contact with a fourth set of connecting lines 221. The first set of connecting lines 211 interdigitate with the second set of connecting lines 215. The third set 5 of connecting lines 217 interdigitate with the fourth set of connecting lines 221.

In an embodiment, the busbar formed on the substrate may consist of two busbars arrayed in a parallel arrangement with conductor lines 10 formed perpendicular to the busbar and arrayed in an interdigitated parallel line pattern. Alternately, the busbars may be three or more busbars. In the case of three busbars, the central busbar may serve as a common between the busbars to each side in a parallel arrangement. In this embodiment, the area coverage of the three busbars may be adjusted 15 to approximately the same as the case for the use of two busbars. In the case of three busbars, the perpendicular lines are adjusted to shorter dimensions appropriate to the spacing between pairs of busbars.

In an embodiment, the components of the thick film conductor 20 composition(s) are electrically functional silver powders, zinc-containing additive(s), and Pb-free glass frit dispersed in an organic medium. Additional additives may include metals, metal oxides or any compounds that can generate these metal oxides during firing. The components are discussed herein below.

25

I. Inorganic Components

An embodiment of the present invention relates to thick film conductor compositions. In an aspect of the embodiment, the thick film conductor compositions may include: a conductive material, a flux 30 material, and an organic medium. The conductive material may include silver. In an embodiment, the conductive material may be a conductive powder. The flux material may include a glass frit or glass frits. The glass frit may be lead-free. The thick film conductor compositions may also include an additive. The additive may be a metal/metal oxide additive

selected from (a) a metal wherein said metal is selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or more of the metals selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof. The thick film conductor compositions may include additional components.

As used herein, “busbars” means a common connection used for collection of electrical current. In an embodiment, the busbars may be rectangular shaped. In an embodiment, the busbars may be parallel.

As used herein, “flux material” means a substance used to promote fusion, or a substance that fuses. In an embodiment, the fusion may be at or below required process temperatures to form a liquid phase.

15 In an embodiment, the inorganic components of the present invention comprise (1) electrically functional silver powders; (2) Zn-containing additive(s); (3) Pb-free glass frit; and optionally (4) additional metal/metal oxide additive selected from (a) a metal wherein said metal is selected from Zn, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or more of the metals selected from Zn, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof.

A. Electrically Conductive Functional Materials

25 Electrically conductive materials may include Ag, Cu, Pd, and mixtures thereof. In an embodiment, the electrically conductive particle is Ag. However, these embodiments are intended to be non-limiting. Embodiments in which other conductive materials are utilized are contemplated and encompassed.

30 The silver may be in a particle form, a powder form, a flake form, spherical form, provided in a colloidal suspension, a mixture thereof, etc. The silver may be silver metal, alloys of silver, or mixtures thereof, for example. The silver may include silver oxide (Ag_2O) or silver salts such as $AgCl$, $AgNO_3$, or $AgOOCCH_3$ (silver acetate), silver orthophosphate,

Ag_3PO_4 , or mixtures thereof, for example. Any form of silver compatible with the other thick film components may be used, and will be recognized by one of skill in the art.

5 The silver may be any of a variety of percentages of the composition of the thick film composition. In a non-limiting embodiment, the silver may be from about 70 to about 99 % of the solid components of the thick film composition. In a further embodiment, the silver may be from about 70 to about 85 wt % of the solid components of the thick film
10 composition. In a further embodiment, the silver may be from about 90 to about 99 wt % of the solid components of the thick film composition.

In an embodiment, the solids portion of the thick film composition may include about 80 to about 90 wt % silver particles and about 1 to
15 about 10 wt % silver flakes. In an embodiment, the solids portion of the thick film composition may include about 75 to about 90 wt % silver particles and about 1 to about 10 wt % silver flakes. In another embodiment, the solids portion of the thick film composition may include about 75 to about 90 wt % silver flakes and about 1 to about 10 wt % of
20 colloidal silver. In a further embodiment, the solids portion of the thick film composition may include about 60 to about 90 wt % of silver powder or silver flakes and about 0.1 to about 20 wt % of colloidal silver.

In an embodiment, a thick film composition includes a functional
25 phase that imparts appropriate electrically functional properties to the composition. The functional phase may include electrically functional powders dispersed in an organic medium that acts as a carrier for the functional phase that forms the composition. In an embodiment, the composition may be applied to a substrate. In a further embodiment, the
30 composition and substrate may be fired to burn out the organic phase, activate the inorganic binder phase and to impart the electrically functional properties.

In an embodiment, the functional phase of the composition may be coated or uncoated silver particles which are electrically conductive. In an

embodiment, the silver particles may be coated. In an embodiment, the silver may be coated with various materials such as phosphorus. In an embodiment, the silver particles may be at least partially coated with a surfactant. The surfactant may be selected from, but is not limited to, 5 stearic acid, palmitic acid, a salt of stearate, a salt of palmitate and mixtures thereof. Other surfactants may be utilized including lauric acid, palmitic acid, oleic acid, stearic acid, capric acid, myristic acid and linolic acid. The counter-ion can be, but is not limited to, hydrogen, ammonium, sodium, potassium and mixtures thereof.

10

The particle size of the silver is not subject to any particular limitation. In an embodiment, an average particle size is less than 10 microns; in a further embodiment, the average particle size is less than 5 microns.

15

In an embodiment, silver oxide may be dissolved in the glass during the glass melting/manufacturing process.

B. Additive(s)

An embodiment of the present invention relates to thick film 20 compositions which may contain additives. In an aspect of this embodiment, the additive may be a metal/metal oxide additive selected from (a) a metal wherein said metal is selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or more of the metals selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and 25 Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof.

In an embodiment, the particle size of the additives is not subject to any particular limitation. In an embodiment, an average particle size may 30 be less than 10 microns; in an embodiment, an average particle size may be less than 5 microns. In an embodiment, the average particle size may be from 0.1 to 1.7 microns. In a further embodiment, the average particle size may be from 0.6 to 1.3 microns. In an embodiment, the average particle size may be from 7 to 100 nm.

In an embodiment, the particle size of the metal/metal oxide additive may be in the range of 7 nanometers (nm) to 125 nm. In an embodiment, the particle size of the metal/metal oxide additive may be in the range of 7 nanometers (nm) to 100 nm. In an embodiment, MnO_2 and 5 TiO_2 may be utilized in the present invention with an average particle size range (d_{50}) of 7 nanometers (nm) to 125 nm.

In an embodiment, the additive may be a Zn-containing additive. The Zn-containing additive may, for example be selected from (a) Zn, (b) 10 metal oxides of Zn, (c) any compounds that can generate metal oxides of Zn upon firing, and (d) mixtures thereof.

In one embodiment, the Zn-containing additive is ZnO , wherein the ZnO may have an average particle size in the range of 10 nanometers to 15 10 microns. In a further embodiment, the ZnO may have an average particle size of 40 nanometers to 5 microns. In still a further embodiment, the ZnO may have an average particle size of 60 nanometers to 3 microns. In a further embodiment, the Zn-containing additive may have an average particle size of less than 0.1 μm . In particular the Zn-containing 20 additive may have an average particle size in the range of 7 nanometers to less than 100 nanometers.

In a further embodiment the Zn-containing additive (for example Zn, Zn resinate, etc.) may be present in the total thick film composition in the 25 range of 2 to 16 weight percent. In a further embodiment the Zn-containing additive may be present in the range of 4 to 12 weight percent total composition. In an embodiment, ZnO may be present in the composition in the range of 2 to 10 weight percent total composition. In an embodiment, the ZnO may be present in the range of 4 to 8 weight 30 percent total composition. In still a further embodiment, the ZnO may be present in the range of 5 to 7 weight percent total composition.

In an embodiment, the additive may be a Mg-containing additive. The Mg-containing additive may, for example be selected from

(a) Mg, (b) metal oxides of Mg, (c) any compounds that can generate metal oxides of Mg upon firing, and (d) mixtures thereof.

In one embodiment, the Mg-containing additive is MgO, wherein the

5 MgO may have an average particle size in the range of 10 nanometers to 10 microns. In a further embodiment, the MgO may have an average particle size of 40 nanometers to 5 microns. In still a further embodiment, the MgO may have an average particle size of 60 nanometers to 3 microns. In a further embodiment, the MgO may have an average particle

10 size of 0.1 to 1.7 microns. In a further embodiment, the MgO may have an average particle size of 0.3 to 1.3 microns. In a further embodiment, the Mg-containing additive may have an average particle size of less than 0.1 μm . In particular the Mg-containing additive may have an average particle size in the range of 7 nanometers to less than 100 nanometers.

15

MgO may be present in the composition in the range of 0.1 to 10 weight percent total composition. In one embodiment, the MgO may be present in the range of 0.5 to 5 weight percent total composition. In still a further embodiment, the MgO may be present in the range of 0.75 to 3 weight percent total composition.

In a further embodiment the Mg-containing additive (for example Mg, Mg resinate, etc.) may be present in the total thick film composition in the range of 0.1 to 10 weight percent. In a further embodiment the Mg-
25 containing additive may be present in the range of 0.5 to 5 weight percent total composition. In still a further embodiment, the MgO may be present in the range of 0.75 to 3 weight percent total composition.

In a further embodiment, the Mg-containing additive may have an
30 average particle size of less than 0.1 μm . In particular the Mg-containing additive may have an average particle size in the range of 7 nanometers to less than 100 nanometers.

In an embodiment, the additive may contain a mixture of additives. The additive may be a mixture of metal/metal oxide additives selected from (a) a metal wherein said metal is selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (b) a metal oxide of one or 5 more of the metals selected from Zn, Mg, Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu and Cr; (c) any compounds that can generate the metal oxides of (b) upon firing; and (d) mixtures thereof.

Compounds that can generate metal oxides of Zn, Mg, Gd, Ce, Zr, 10 Ti, Mn, Sn, Ru, Co, Fe, Cu or Cr upon firing include, but are not limited to resonates, octoates, organic functional units, and the like.

In an embodiment, the additive may contain a mixture of ZnO and MgO.

15

C. Glass Frit

As used herein, "lead-free" means that no lead has been added. In an embodiment, trace amounts of lead may be present in a composition and the composition may still be considered lead-free if no 20 lead was added. In an embodiment, a lead-free composition may contain less than 1000 ppm of lead. In an embodiment, a lead-free composition may contain less than 300 ppm of lead. One of skill in the art will recognize that compositions containing lesser amounts of lead are encompassed by the term lead-free. In an embodiment, a lead-free 25 composition may not only be free of lead, but may also be free of other toxic materials, including Cd, Ni, and carcinogenic toxic materials, for example. In an embodiment, a lead-free composition may contain less than 1000 ppm of lead, less than 1000 ppm of Cd, and less than 1000 ppm of Ni. In an embodiment, the lead-free composition may contain 30 trace amounts of Cd and/or Ni; in an embodiment, no Cd, Ni, or carcinogenic toxic materials are added to a lead-free composition.

In an embodiment of the invention, the thick film composition may include glass materials. In an embodiment, glass materials may

include one or more of three groups of constituents: glass formers, intermediate oxides, and modifiers. Exemplary glass formers may have a high bond coordination and smaller ionic size; the glass formers may form bridging covalent bonds when heated and quenched from a melt.

5 Exemplary glass formers include, but are not limited to: SiO₂, B₂O₃, P₂O₅, V₂O₅, GeO₂ etc. Exemplary intermediate oxides include, but are not limited to: TiO₂, Ta₂O₅, Nb₂O₅, ZrO₂, CeO₂, SnO₂, Al₂O₃, HfO₂ and the like. Intermediate oxides may be used to substitute glass formers, as recognized by one of skill in the art. Exemplary modifiers may have a

10 more ionic nature, and may terminate bonds. The modifiers may affect specific properties; for example, modifiers may result in reduction of glass viscosity and/or modification of glass wetting properties, for example. Exemplary modifiers include, but are not limited to: oxides such as alkali metal oxides, alkaline earth oxides, PbO, CuO, CdO, ZnO, Bi₂O₃, Ag₂O,

15 MoO₃, WO₃ and the like.

In an embodiment, the glass materials may be selected by one of skill in the art to assist in the at least partial penetration of oxide or nitride insulating layers. As described herein, this at least partial

20 penetration may lead to the formation of an effective electrical contact to the silicon surface of a photovoltaic device structure. The formulation components are not limited to glass forming materials.

In an embodiment of the invention, glass frit compositions

25 (glass compositions) are provided. Non-limiting examples of glass frit compositions are listed in Table 1 below and described herein. Additional glass frit compositions are contemplated.

It is important to note that the compositions listed in Table 1 are

30 not limiting, as it is expected that one skilled in glass chemistry could make minor substitutions of additional ingredients and not substantially change the properties of the glass composition of this invention. In this way, substitutions of glass formers such as P₂O₅ 0-3, GeO₂ 0-3, V₂O₅ 0-

3 in weight % maybe used either individually or in combination to achieve similar performance. It is also possible to substitute one or more intermediate oxides, such as TiO_2 , Ta_2O_5 , Nb_2O_5 , ZrO_2 , CeO_2 , SnO_2 for other intermediate oxides (i.e., Al_2O_3 , CeO_2 , SnO_2) present in a glass

5 composition of this invention. It is observed from the data that generally higher SiO_2 content of the glass degrades performance. The SiO_2 is thought to increase glass viscosity and reduce glass wetting. Although not represented in the Table 1 compositions, glasses with zero SiO_2 are expected to perform well, as other glass formers such as P_2O_5 , GeO_2 etc.

10 may be used to replace the function of low levels of SiO_2 . The CaO , alkaline earth content, can also be partially or fully replaced by other alkaline earth constituents such as SrO , BaO and MgO .

Exemplary glass compositions in weight percent total glass

15 composition are shown in Table 1. In an embodiment, glass compositions found in the examples include the following oxide constituents in the compositional range of: SiO_2 0.1-8, Al_2O_3 0-4, B_2O_3 8-25, CaO 0-1, ZnO 0-42, Na_2O 0-4, Li_2O 0-3.5, Bi_2O_3 28-85, Ag_2O 0-3 CeO_2 0-4.5, SnO_2 0-3.5, BiF_3 0-15 in weight percent total glass composition. In a further

20 embodiment, the glass composition includes: SiO_2 4-4.5, Al_2O_3 0.5-0.7, B_2O_3 9-11, CaO 0.4-0.6, ZnO 11-14, Na_2O 0.7-1.1, Bi_2O_3 56-67, BiF_3 4-13 in weight percent total glass composition. In an embodiment, the glass frit may contain a low amount of, or no, B_2O_3 .

25 The composition listed in Table 1 includes BiF_3 as a fluoride component. BiF_3 is intended to be an exemplary, non-limiting, fluoride component. For example, other fluoride compounds may be used as an alternative or partial replacement. Non-limiting examples include: ZnF_2 , AlF_3 , and the like. For example, oxide plus fluorine compositions may be

30 used.

Table 1: Glass Composition(s) in Weight Percent Total Glass

Composition

Glass	Glass Component (wt% total glass composition)											
ID	SiO₂	Al₂O₃	B₂O₃	CaO	ZnO	Na₂O	Li₂O	Bi₂O₃	Ag₂O	CeO₂	SnO₂	BiF₃
Glass	4.00	2.50	21.00		40.00		30.00				2.50	
I												
Glass	4.00	3.00	24.00		31.00		35.00				3.00	
II												
Glass	4.30	0.67	10.21	0.55	13.35	0.94		57.85			12.12	
III												
Glass	4.16	0.65	9.87	0.53	12.90	0.91		66.29			4.69	
IV												
Glass	7.11	2.13	8.38	0.53	12.03			69.82				
V												
Glass	5.00	2.00	15.00	0.50		2.00	3.00	70.00			2.50	
VI												
Glass	4.00		13.00			3.00	1.00	75.00			4.00	
VII												
Glass	2.00		18.00			0.50		75.00	2.50	2.00		
VIII												
Glass	1.50		14.90			1.00	1.00	81.50			0.10	
IX												
Glass	1.30	0.11	13.76			0.54	1.03	82.52			0.74	
X												

Glass frits useful in the present invention include ASF1100 and 5 ASF1100B which are commercially available from Asahi Glass Company. An average particle size of the glass frit (glass composition) in an embodiment of the present invention may be in the range of 0.5-1.5 μm . In a further embodiment, an average particle size may be in the range of 0.8-1.2 μm . In an embodiment, the softening point of the glass frit (Ts:

second transition point of DTA) is in the range of 300-600°C. In an embodiment, the amount of glass frit in the total composition may be in the range of 0.5 to 4 wt. % of the total composition. In one embodiment, the glass composition is present in the amount of 1 to 3 weight percent total 5 composition. In a further embodiment, the glass composition is present in the range of 1.5 to 2.5 weight percent total composition.

The glasses described herein are produced by conventional glass making techniques. The glasses were prepared in 500-1000 gram 10 quantities. The ingredients may be weighed and mixed in the desired proportions and heated in a bottom-loading furnace to form a melt in platinum alloy crucibles. As is well-known in the art, heating is conducted to a peak temperature (1000°C-1200°C) and for a time such that the melt becomes entirely liquid and homogeneous. The molten glass is quenched 15 between counter rotating stainless steel rollers to form a 10-20 mil thick platelet of glass. The resulting glass platelet is then milled to form a powder with its 50% volume distribution set between 1-3 microns.

In an embodiment, one or more additives described herein, 20 such as ZnO, MgO, etc, may be contained in a glass. The glass frits which contain the one or more additives are useful in the embodiments described herein.

In an embodiment, the glass frit may include Bi₂O₃, B₂O₃ 25 8-25 weight percent of total glass composition, and further comprises one or more components selected from the group consisting of: SiO₂, P₂O₅, GeO₂, and V₂O₅.

In an embodiment, the glass frit may include one or more of 30 Al₂O₃, CeO₂, SnO₂, and CaO. In an aspect of this embodiment, based on weight percent of total glass composition, the amount of Al₂O₃, CeO₂, SnO₂, and CaO may be less than 6. In an aspect of this embodiment,

based on weight percent of total glass composition, the amount of Al_2O_3 , CeO_2 , SnO_2 , and CaO may be less than 1.5.

In an embodiment, the glass frit may include one or more of

5 BiF_3 and Bi_2O_3 . In an aspect of this embodiment, based on weight percent of total glass composition, the amount of BiF_3 and Bi_2O_3 may be less than 83. In an aspect of this embodiment, based on weight percent total of glass composition, the amount of BiF_3 and Bi_2O_3 may be less than 72.

10 In an embodiment, the glass frit may include one or more of Na_2O , Li_2O , and Ag_2O . In an aspect of this embodiment, based on weight percent of total glass composition, the amount of Na_2O , Li_2O , and Ag_2O may be less than 5. In an aspect of this embodiment, based on weight percent of total glass composition, the amount of Na_2O , Li_2O , and Ag_2O

15 may be less than 2.0.

In an embodiment, the glass frit may include one or more of Al_2O_3 , Si_2O_2 , and B_2O_3 . In an aspect of this embodiment, based on weight percent of total glass composition, the amount of Si_2O_2 , Al_2O_3 , and B_2O_3

20 may be less than 31.

In an embodiment, the glass frit may include one or more of Bi_2O_3 , BiF_3 , Na_2O , Li_2O , and Ag_2O . In an embodiment, based on weight percent of total glass composition, the amount of $(\text{Bi}_2\text{O}_3 + \text{BiF}_3) / (\text{Na}_2\text{O} + \text{Li}_2\text{O} + \text{Ag}_2\text{O})$ may be greater than 14.

Flux Materials

An embodiment of the present invention relates to a composition, structures and devices including, and methods of making the

30 structures and devices, wherein the composition includes flux materials. The flux materials, in an embodiment, may have properties similar to the glass materials, such as possessing lower softening characteristics. For example, compounds such as oxide or halogen compounds may be used. The compounds may assist penetration of an insulating layer in the

structures described herein. Non-limiting examples of such compounds include materials that have been coated or encased in organic or inorganic barrier coating to protect against adverse reactions with organic binder components of the paste medium. Non-limiting examples of such flux materials may include PbF₂, BiF₃, V₂O₅, alkali metal oxides and the like.

5 In an embodiment, the flux material may include Pb silicate (Pb₂SiO₄). In an aspect of this embodiment, 10 – 100 wt % of the flux material may be Pb₂SiO₄. In a further aspect, 50 – 99 wt % of the flux material may be 10 Pb₂SiO₄. In a further aspect, 60 – 80 wt % of the flux material may be Pb₂SiO₄. In an embodiment, the flux material may be Pb₂SiO₄.

15 In an embodiment, the flux material may include one or more components selected from the group consisting of: 4PbO-SiO₂, 2PbO-SiO₂, 5PbO-B₂O₃-SiO₂, ZnPbO₃, and Zn₂PbO₄. In a further embodiment, the flux material include one or more components selected from the group consisting of: ZnF₂, AgBi(PO₃)₄, AgZnF₃ – AgF, LiZn(PO₃)₃, Cu₃B₂O₆, CuPb₂F₆, CsPb(PO₃)₃, 2PbO-B₂O₃, and. 4PbO-B₂O₃. In an embodiment, the flux materials may also include glass frit.

20 In an embodiment, the flux materials may include one or more low-melting components, which melt below 750 °C, for example. Such low-melting components may be a metal, metal oxide, or other compounds.

25 In an embodiment, the flux materials may be 0.5 – 13 wt % of the total conductive composition. In a further embodiment, the flux materials may be 1 – 7 wt %; in a further embodiment, 1.5 – 5 wt %; in a further embodiment, 2 – 4 wt %, based on the weight of the total conductive composition.

30

Glass Blending

In an embodiment, one or more glass frit materials may be present as an admixture in the thick film composition. In an embodiment, a first glass frit material may be selected by one of skill in the art for its

capability to rapidly digest the insulating layer; further the glass frit material may have strong corrosive power and low viscosity.

In an embodiment, the second glass frit material may be

5 designed to slowly blend with the first glass frit material while retarding the chemical activity. A stopping condition may result which may effect the partial removal of the insulating layer but without attacking the underlying emitter diffused region potentially shunting the device is the corrosive action proceeds unchecked. Such a glass frit material may be

10 characterized as having a sufficiently higher viscosity to provide a stable manufacturing window to remove insulating layers without damage to the diffused p-n junction region of the semiconductor substrate.

In a non-limiting exemplary admixture, the first glass frit

15 material may be SiO₂ 1.7 wt%, ZrO₂ 0.5 wt%, B₂O₃ 12 wt% , Na₂O 0.4 wt%, Li₂O 0.8 wt%, and Bi₂O₃ 84.6 wt% and the second glass frit material may be as SiO₂ 27 wt%, ZrO₂ 4.1 wt%, Bi₂O₃ 68.9 wt%. The proportions of the blend may be used to adjust the blend ratio to meet optimal performance of the thick film conductor paste, under conditions recognized

20 by one of skill in the art..

Analytical Glass Testing

Several testing methods may be used to characterize glass materials as candidates for application to photovoltaic Ag conductor

25 formulation, and are recognized by one of skill in the art. Among these measurements are Differential Thermal Analysis, DTA and Thermo-mechanical Analysis, TMA for the determination of T_g and glass flow kinetics. As needed, many additional characterization methods may be employed such as dilatometry, thermogravimetric analysis, XRD, XRF,

30 and ICP

Inert gas Firing

In an embodiment, the processing of photovoltaic device cells utilize nitrogen or other inert gas firing of the prepared cells. The firing

temperature profile is typically set so as to enable the burnout of organic binder materials from dried thick film paste or other organic materials present. In an embodiment, the temperature may be between 300-525 Celsius. The firing may be conducted in a belt furnace using high

5 transport rates, for example between 40- 200 inches per minute. Multiple temperature zones may be used to control the desired thermal profile. The number of zones may vary between 3 to 9 zones, for example. The photovoltaic cells may be fired at set temperatures between 650 and 1000 C, for example. The firing is not limited to this type of firing, and other

10 rapid fire furnace designs known to one of skill in the art are contemplated.

D. Organic Medium

The inorganic components may be mixed with an organic medium by mechanical mixing to form viscous compositions called "pastes", having

15 suitable consistency and rheology for printing. A wide variety of inert viscous materials can be used as organic medium. The organic medium may be one in which the inorganic components are dispersible with an adequate degree of stability. The rheological properties of the medium must be such that they lend good application properties to the

20 composition, including: stable dispersion of solids, appropriate viscosity and thixotropy for screen printing, appropriate wettability of the substrate and the paste solids, a good drying rate, and good firing properties. In an embodiment of the present invention, the organic vehicle used in the thick film composition of the present invention may be a nonaqueous inert

25 liquid. Use can be made of any of various organic vehicles, which may or may not contain thickeners, stabilizers and/or other common additives. The organic medium may be a solution of polymer(s) in solvent(s). Additionally, a small amount of additives, such as surfactants, may be a part of the organic medium. The most frequently used polymer for this

30 purpose is ethyl cellulose. Other examples of polymers include ethylhydroxyethyl cellulose, wood rosin, mixtures of ethyl cellulose and phenolic resins, polymethacrylates of lower alcohols, and monobutyl ether of ethylene glycol monoacetate can also be used. The most widely used solvents found in thick film compositions are ester alcohols and terpenes

such as alpha- or beta-terpineol or mixtures thereof with other solvents such as kerosene, dibutylphthalate, butyl carbitol, butyl carbitol acetate, hexylene glycol and high boiling alcohols and alcohol esters. In addition, volatile liquids for promoting rapid hardening after application on the 5 substrate can be included in the vehicle. Various combinations of these and other solvents are formulated to obtain the viscosity and volatility requirements desired.

The polymer present in the organic medium is in the range of 8 wt. 10 % to 11 wt.% of the total composition. The thick film silver composition of the present invention may be adjusted to a predetermined, screen-printable viscosity with the organic medium.

The ratio of organic medium in the thick film composition to the 15 inorganic components in the dispersion is dependent on the method of applying the paste and the kind of organic medium used, and it can vary. Usually, the dispersion will contain 70-95 wt % of inorganic components and 5-30 wt % of organic medium (vehicle) in order to obtain good wetting.

20 An embodiment of the present invention relates to a thick film composition, wherein the thick film composition includes:
(a) an electrically conductive silver powder;
(b) one or more glass frits; dispersed in
(c) an organic medium;
25 wherein the glass frit includes: Bi_2O_3 , B_2O_3 8-25 weight percent of the total glass frit, and further comprises one or more components selected from the group consisting of: SiO_2 , P_2O_5 , GeO_2 , and V_2O_5 . In an aspect of this embodiment, the glass frits may be lead-free. In an aspect of this embodiment, the glass frit includes: Bi_2O_3 28-85, B_2O_3 8-25, and one or
30 more of: SiO_2 0-8, P_2O_5 0-3, GeO_2 0-3, V_2O_5 0-3. In an aspect of this embodiment, the glass frit includes SiO_2 0.1-8. In an aspect of this embodiment, the glass frit may include one or more intermediate oxides. Exemplary intermediate oxides include, but are not limited to: Al_2O_3 , CeO_2 , SnO_2 , TiO_2 , Ta_2O_5 , Nb_2O_5 , and ZrO_2 . In an aspect of this embodiment, the

glass frit may include one or more alkaline earth constituents. Exemplary alkaline earth constituents include, but are not limited to: CaO, SrO, BaO, MgO. In an embodiment, the glass frit may include one or more components selected from the group consisting of: ZnO, Na₂O, Li₂O, 5 AgO₂, and BiF₃.

In an aspect of this embodiment, the composition may also include an additive. Exemplary additives include: a metal additive, or a metal-containing additive, and wherein the metal additive or metal-containing 10 additive forms an oxide under processing conditions. The additive may be a metal oxide additive. For example, the additive may be a metal oxide of one or more of the metals selected from Gd, Ce, Zr, Ti, Mn, Sn, Ru, Co, Fe, Cu, and Cr.

15 An embodiment of the invention relates to a semiconductor device including the composition including:

- (a) an electrically conductive silver powder;
- (b) one or more glass frits; dispersed in
- (c) an organic medium;

20 wherein the glass frit includes: Bi₂O₃, B₂O₃ 8-25 weight percent of the total glass frit, and further comprises one or more components selected from the group consisting of: SiO₂, P₂O₅, GeO₂, and V₂O₅. An aspect of this embodiment relates to a solar cell including the semiconductor device.

25 An embodiment of the invention relates to a structure including:

- (a) the thick film composition including:
 - (a) an electrically conductive silver powder;
 - (b) one or more glass frits; dispersed in
 - (c) an organic medium;

30 wherein the glass frit includes: Bi₂O₃, B₂O₃ 8-25 weight percent of the total glass frit, and further comprises one or more components selected from the group consisting of: SiO₂, P₂O₅, GeO₂, and V₂O₅; and

- (b) an insulating film

wherein the thick film composition is formed on the insulating film, and wherein, upon firing, the insulating film is penetrated by components of the thick film composition and the organic medium is removed.

5 **Structures**

An embodiment of the present invention relates to structure including a thick film composition and a substrate. In an embodiment, the substrate may be one or more insulating films. In an embodiment, the substrate may be a semiconductor substrate. In an embodiment, the 10 structures described herein may be useful in the manufacture of photovoltaic devices. An embodiment of the invention relates to a semiconductor device containing one or more structures described herein; an embodiment of the invention relates to a photovoltaic device containing one or more structures described herein; an embodiment of the invention 15 relates to a solar cell containing one or more structures described herein; an embodiment of the invention relates to a solar panel containing one or more structures described herein.

An embodiment of the present invention relates to an electrode formed 20 from the thick film composition. In an embodiment, the thick film composition has been fired to remove the organic vehicle and sinter the silver and glass particles. An embodiment of the present invention relates to a semiconductor device containing an electrode formed from the thick film composition. In an embodiment, the electrode is a front side 25 electrode.

An embodiment of the present invention relates to structures described herein, wherein the structures also include a back electrode.

30 An embodiment of the present invention relates to structures, wherein the structures include thick film conductor compositions. In an aspect, the structure also includes one or more insulating films. In an aspect, the structure does not include an insulating film. In an aspect, the structure includes a semiconductor substrate. In an aspect, the thick film

conductor composition may be formed on the one or more insulating films. In an aspect, the thick film conductor composition may be formed on the semiconductor substrate. In the aspect wherein the thick film conductor composition may be formed on the semiconductor substrate, the structure 5 may not contain an insulating film.

Thick film conductor and insulating film structure:

An aspect of the present invention relates to a structure including a thick film conductor composition and one or more insulating films. The thick film 10 composition may include: (a) an electrically conductive silver powder; (b) one or more glass frits; dispersed in c) an organic medium. In an embodiment, the glass frits may be lead-free. In an embodiment, the thick film composition may also include an additive, as described herein. The structure may also include a semiconductor substrate. In an embodiment 15 of the invention, upon firing, the organic vehicle may be removed and the silver and glass frits may be sintered. In a further aspect of this embodiment, upon firing, the conductive silver and frit mixture may penetrate the insulating film.

20 The thick film conductor composition may penetrate the insulating film upon firing. The penetration may be partial penetration. The penetration of the insulating film by the thick film conductor composition may result in an electrical contact between the conductor of the thick film composition and the semiconductor substrate.

25 The thick film conductor composition may be printed on the insulating film in a pattern. The printing may result in the formation of busbars with connecting lines, as described herein, for example.

30 The printing of the thick film may be by plating, extrusion, inkjet, shaped or multiple printing, or ribbons, for example.

A layer of silicon nitride may be present on the insulating film. The silicon nitride may be chemically deposited. The deposition method may be CVD, PCVD, or other methods known to one of skill in the art.

5 **Insulating films**

In an embodiment of the invention, the insulating film may include one or more component selected from: titanium oxide, silicon nitride, SiNx:H, silicon oxide, and silicon oxide/titanium oxide. In an embodiment of the invention, the insulating film may be an anti-reflection coating (ARC). In 10 an embodiment of the invention, the insulating film may be applied; the insulating film may be applied to a semiconductor substrate. In an embodiment of the invention, the insulating film may be naturally forming, such as in the case of silicon oxide. In an embodiment, the structure may not include an insulating film that has been applied, but may contain a 15 naturally forming substance, such as silicon oxide, which may function as an insulating film.

Thick film conductor and semiconductor substrate structure:

20 An aspect of the present invention relates to a structure including a thick film conductor composition and a semiconductor substrate. In an embodiment, the structure may not include an insulating film. In an embodiment, the structure may not include an insulating film which has been applied to the semiconductor substrate. In an embodiment, the 25 surface of the semiconductor substrate may include a naturally occurring substance, such as SiO₂. In an aspect of this embodiment, the naturally occurring substance, such as SiO₂, may have insulating properties.

30 The thick film conductor composition may be printed on the semiconductor substrate in a pattern. The printing may result in the formation of busbars with connecting lines, as described herein, for example. An electrical contact may be formed between the conductor of the thick film composition and the semiconductor substrate.

A layer of silicon nitride may be present on the semiconductor substrate.

The silicon nitride may be chemically deposited. The deposition method may be CVD, PCVD, or other methods known to one of skill in the art.

5

Structure in which the silicon nitride may be chemically treated

An embodiment of the invention relates to a structure in which the silicon nitride of the insulating layer may be treated resulting in the removal of at least a portion of the silicon nitride. The treatment may be chemical

- 10 treatment. The removal of at least a portion of the silicon nitride may result in an improved electrical contact between the conductor of the thick film composition and the semiconductor substrate. The structure may have improved efficiency.
- 15 In an aspect of this embodiment, the silicon nitride of the insulating film may be part of the anti-reflective coating (ARC). The silicon nitride may be naturally forming, or chemically deposited, for example. The chemical deposition may be by CVD or PCVD, for example.

20 **Structure in which the thick film composition includes flux materials that are not glass frit**

An embodiment of the invention relates to a structure including a thick film composition and one or more insulating films, in which the thick film composition includes an electrically conductive silver powder, one or more

- 25 flux materials, and an organic medium, and wherein the structure further comprises one or more insulating films. In an aspect of this embodiment, the flux materials are lead-free. In an aspect, the flux materials are not glass frit. In an embodiment, the structure may further include a semiconductor substrate.

30

The thick film conductor composition may penetrate the insulating film upon firing. The penetration may be partial penetration. For example, a portion of the surface of the insulating film may be penetrated by the thick film conductor composition. The penetration of the insulating film by the

thick film conductor composition may result in an electrical contact between the conductor of the thick film composition and the semiconductor substrate.

- 5 In an embodiment of the present invention, a method and structure are provided in which a conductor has been applied directly to the semiconductor substrate. In an aspect of this embodiment, a mask may have been applied to the semiconductor substrate in a pattern correlating to the pattern of the conductor. An insulating may have then been applied, 10 with subsequent removal of the mask. The conductor composition may have then been applied to the semiconductor substrate in a pattern correlating to the area from which the mask was removed.
- 15 An embodiment of the present invention relates to a semiconductor device which includes a composition, wherein, prior to firing, the composition includes:
 - an electrically conductive silver powder;
 - one or more glass frits wherein said glass frits are lead-free; dispersed in 20 an organic medium.
- 25 In an aspect of this embodiment, the composition may include an additive. Exemplary additives are described herein. An aspect of this embodiment relates to a solar cell including the semiconductor device. An aspect of this embodiment relates to a solar panel including the solar cell.

BUSBARS

In an embodiment, the thick film conductor composition may be 30 printed on the substrate to form busbars. The busbars may be more than two busbars. For example, the busbars may be three or more busbars. In addition to busbars, the thick film conductor composition may be printed on the substrate to form connecting lines. The connecting lines may

contact a busbar. The connecting lines contacting a busbar may be interdigitated between the connecting lines contacting a second busbar.

In an exemplary embodiment, three busbars may be parallel to

5 each other on a substrate. The busbars may be rectangular in shape. Each of the longer sides of the middle busbar may be in contact with connecting lines. On each of the side busbars, only one side of the longer rectangle may be in contact with connecting lines. The connecting lines contacting the side busbars may interdigitate with the connecting lines

10 contacting the middle busbar. For example, the connecting lines contacting one side busbar may interdigitate with the connecting lines contacting the middle busbar on one side, and the connecting lines contacting the other side busbar may interdigitate with the connecting lines contacting the middle busbar on the other side of the middle busbar.

15

Figure 2A provides an exemplary representation of an embodiment in which there are two busbars. A first busbar 201 is in contact with a first set of connecting lines 203. A second busbar 205 is in contact with a second set of connecting lines 207. The first set of connecting lines 203 interdigitate with the second set of connecting lines 207.

Figure 2B provides an exemplary representation of an embodiment in which there are three busbars. A first busbar 209 is in contact with a first set of connecting lines 211. A second busbar 213 is in contact with both a second set of connecting lines 215 and a third set of connecting lines 217. The second set of connecting lines 215 contacts one side of the second busbar 213; the third set of connecting lines 217 contacts the opposite side of the second busbar 213. A third busbar 219 is in contact with a fourth set of connecting lines 221. The first set of connecting lines 211 interdigitate with the second set of connecting lines 215. The third set of connecting lines 217 interdigitate with the fourth set of connecting lines 221.

Description of Method of Manufacturing a Semiconductor Device

An embodiment of the invention relates to a method of manufacturing a semiconductor device. An aspect of this embodiment includes the steps

5 of:

- (a) providing a semiconductor substrate, one or more insulating films, and a thick film composition, wherein the thick film composition comprises: a) an electrically conductive silver powder, b) one or more glass frits, dispersed in c) an organic medium,
- 10 (b) applying one or more insulating films on the semiconductor substrate,
- (c) applying the thick film composition on the one or more insulating films on the semiconductor substrate, and
- (d) firing the semiconductor, one or more insulating films and thick film composition,

15 wherein, upon firing, the organic vehicle is removed, the silver and glass frits are sintered, and the insulating film is penetrated by components of the thick film composition.

In an aspect of this embodiment, the glass frits may be lead-free. In an

20 aspect of this embodiment, the one or more insulating films may be selected from the group including: silicon nitride film, titanium oxide film, SiNx:H film, silicon oxide film and a silicon oxide/titanium oxide film.

An embodiment of the invention relates to semiconductor device formed

25 by a method described herein. An embodiment of the invention relates to a solar cell including a semiconductor device formed by a method described herein. An embodiment of the invention relates to a solar cell including an electrode, which includes a silver powder and one or more glass frits, wherein the glass frits are lead-free.

30

An embodiment of the present invention provides a novel composition(s) that may be utilized in the manufacture of a semiconductor device. The semiconductor device may be manufactured by the following method from a structural element composed of a junction-bearing

semiconductor substrate and a silicon nitride insulating film formed on a main surface thereof. The method of manufacture of a semiconductor device includes the steps of applying (for example, coating and printing) onto the insulating film, in a predetermined shape and at a predetermined position, the conductive thick film composition of the present invention having the ability to penetrate the insulating film, then firing so that the conductive thick film composition melts and passes through the insulating film, effecting electrical contact with the silicon substrate. In an embodiment, the electrically conductive thick film composition may be a thick-film paste composition, as described herein, which is made of a silver powder, Zn-containing additive, a glass or glass powder mixture having a softening point of 300 to 600°C, dispersed in an organic vehicle and optionally, additional metal/metal oxide additive(s).

15 In an embodiment, the composition may include a glass powder content of less than 5% by weight of the total composition and a Zn-containing additive combined with optional additional metal/metal oxide additive content of no more than 6% by weight of the total composition. An embodiment of the invention also provides a semiconductor device 20 manufactured from the same method.

25 In an embodiment of the invention, silicon nitride film or silicon oxide film may be used as the insulating film. The silicon nitride film may be formed by a plasma chemical vapor deposition (CVD) or thermal CVD process. In an embodiment, the silicon oxide film may be formed by thermal oxidation, thermal CFD or plasma CFD.

30 In an embodiment, the method of manufacture of the semiconductor device may also be characterized by manufacturing a semiconductor device from a structural element composed of a junction-bearing semiconductor substrate and an insulating film formed on one main surface thereof, wherein the insulating layer is selected from a titanium oxide silicon nitride, $\text{SiN}_x:\text{H}$, silicon oxide, and silicon oxide/titanium oxide film, which method includes the steps of forming on

the insulating film, in a predetermined shape and at a predetermined position, a metal paste material having the ability to react and penetrate the insulating film, forming electrical contact with the silicon substrate. The titanium oxide film may be formed by coating a titanium-containing organic liquid material onto the semiconductor substrate and firing, or by a thermal CVD. In an embodiment, the silicon nitride film may be formed by PECVD (plasma enhanced chemical vapor deposition). An embodiment of the invention also provides a semiconductor device manufactured from this same method.

10

In an embodiment of the invention, the electrode formed from the conductive thick film composition(s) of the present invention may be fired in an atmosphere composed of a mixed gas of oxygen and nitrogen. This firing process removes the organic medium and sinters the glass frit with the Ag powder in the conductive thick film composition. The semiconductor substrate may be single-crystal or multicrystalline silicon, for example.

FIG. 1(a) shows a step in which a substrate is provided, with a textured surface which reduces light reflection. In an embodiment, a semiconductor substrate of single-crystal silicon or of multicrystalline silicon is provided. In the case of solar cells, substrates may be sliced from ingots which have been formed from pulling or casting processes. Substrate surface damage caused by tools such as a wire saw used for slicing and contamination from the wafer slicing step may be removed by etching away about 10 to 20 μm of the substrate surface using an aqueous alkali solution such as aqueous potassium hydroxide or aqueous sodium hydroxide, or using a mixture of hydrofluoric acid and nitric acid. In addition, a step in which the substrate is washed with a mixture of hydrochloric acid and hydrogen peroxide may be added to remove heavy metals such as iron adhering to the substrate surface. An antireflective textured surface is sometimes formed thereafter using, for example, an aqueous alkali solution such as aqueous potassium hydroxide or aqueous sodium hydroxide. This gives the substrate, 10.

Next, referring to FIG. 1(b), when the substrate used is a p-type substrate, an n-type layer is formed to create a p-n junction. The method used to form such an n-type layer may be phosphorus (P) diffusion using phosphorus oxychloride (POCl₃). The depth of the diffusion layer in this case can be varied by controlling the diffusion temperature and time, and is generally formed within a thickness range of about 0.3 to 0.5 μm. The n-type layer formed in this way is represented in the diagram by reference numeral 20. Next, p-n separation on the front and backsides may be carried out by the method described in the background of the invention.

These steps are not always necessary when a phosphorus-containing liquid coating material such as phosphosilicate glass (PSG) is applied onto only one surface of the substrate by a process, such as spin coating, and diffusion is effected by annealing under suitable conditions. Of course, where there is a risk of an n-type layer forming on the backside of the substrate as well, the degree of completeness can be increased by employing the steps detailed in the background of the invention.

Next, in FIG. 1(d), a silicon nitride film or other insulating films including SiNx:H (i.e., the insulating film comprises hydrogen for 20 passivation during subsequent firing processing) film, titanium oxide film, and silicon oxide film, 30, which functions as an antireflection coating is formed on the above-described n-type diffusion layer, 20. This silicon nitride film, 30, lowers the surface reflectance of the solar cell to incident light, making it possible to greatly increase the electrical current 25 generated. The thickness of the silicon nitride film, 30, depends on its refractive index, although a thickness of about 700 to 900Å is suitable for a refractive index of about 1.9 to 2.0. This silicon nitride film may be formed by a process such as low-pressure CVD, plasma CVD, or thermal CVD. When thermal CVD is used, the starting materials are often dichlorosilane 30 (SiCl₂H₂) and ammonia (NH₃) gas, and film formation is carried out at a temperature of at least 700°C. When thermal CVD is used, pyrolysis of the starting gases at the high temperature results in the presence of substantially no hydrogen in the silicon nitride film, giving a compositional ratio between the silicon and the nitrogen of Si₃N₄ which is substantially

stoichiometric. The refractive index falls within a range of substantially 1.96 to 1.98. Hence, this type of silicon nitride film is a very dense film whose characteristics, such as thickness and refractive index, remain unchanged even when subjected to heat treatment in a later step. The 5 starting gas used when film formation is carried out by plasma CVD is generally a gas mixture of SiH₄ and NH₃. The starting gas is decomposed by the plasma, and film formation is carried out at a temperature of 300 to 550°C. Because film formation by such a plasma CVD process is carried out at a lower temperature than thermal CVD, the hydrogen in the starting 10 gas is present as well in the resulting silicon nitride film. Also, because gas decomposition is effected by a plasma, another distinctive feature of this process is the ability to greatly vary the compositional ratio between the silicon and nitrogen. Specifically, by varying such conditions as the flow rate ratio of the starting gases and the pressure and temperature 15 during film formation, silicon nitride films can be formed at varying compositional ratios between silicon, nitrogen and hydrogen, and within a refractive index range of 1.8 to 2.5. When a film having such properties is heat-treated in a subsequent step, the refractive index may change before and after film formation due to such effects as hydrogen elimination in the 20 electrode firing step. In such cases, the silicon nitride film required in a solar cell can be obtained by selecting the film-forming conditions after first taking into account the changes in film qualities that will occur as a result of heat treatment in the subsequent step.

25 In FIG. 1(d), a titanium oxide film may be formed on the n-type diffusion layer, 20, instead of the silicon nitride film, 30, functioning as an antireflection coating. The titanium oxide film is formed by coating a titanium-containing organic liquid material onto the n-type diffusion layer, 20, and firing, or by thermal CVD. It is also possible, in FIG. 1(d), to form 30 a silicon oxide film on the n-type diffusion layer, 20, instead of the silicon nitride film 30 functioning as an antireflection layer. The silicon oxide film is formed by thermal oxidation, thermal CVD or plasma CVD.

Next, electrodes are formed by steps similar to those shown in FIGS. 10(e) and (f). That is, as shown in FIG. 1(e), aluminum paste, 60, and back side silver paste, 70, are screen printed onto the back side of the substrate, 10, as shown in FIG. 1(e) and successively dried. In addition, a 5 front electrode-forming silver paste is screen printed onto the silicon nitride film, 30, in the same way as on the back side of the substrate, 10, following which drying and firing are carried out in an infrared furnace; the set point temperature range may be 700 to 975°C for a period of from one minute to more than ten minutes while a mixed gas stream of oxygen and 10 nitrogen are passed through the furnace.

As shown in FIG. 1(f), during firing, aluminum diffuses as an impurity from the aluminum paste into the silicon substrate, 10, on the back side, thereby forming a p+ layer, 40, containing a high aluminum 15 dopant concentration. Firing converts the dried aluminum paste, 60, to an aluminum back electrode, 61. The backside silver paste, 70, is fired at the same time, becoming a silver back electrode, 71. During firing, the boundary between the backside aluminum and the backside silver assumes the state of an alloy, thereby achieving electrical connection. 20 Most areas of the back electrode are occupied by the aluminum electrode, partly on account of the need to form a p+ layer, 40. At the same time, because soldering to an aluminum electrode is impossible, the silver or silver/aluminum back electrode is formed on limited areas of the backside as an electrode for interconnecting solar cells by means of copper ribbon 25 or the like.

On the front side, the front electrode silver paste, 500, of the invention is composed of silver, Zn-containing additive, glass frit, organic medium and optional metal oxides, and is capable of reacting and 30 penetrating through the silicon nitride film, 30, during firing to achieve electrical contact with the n-type layer, 20 (fire through). This fired-through state, i.e., the extent to which the front electrode silver paste melts and passes through the silicon nitride film, 30, depends on the quality and thickness of the silicon nitride film, 30, the composition of the front

electrode silver paste, and on the firing conditions. The conversion efficiency and moisture resistance reliability of the solar cell clearly depend, to a large degree, on this fired-through state.

5

EXAMPLES

The thick film composition(s) of the present invention are described herein below in Table 2-6

Paste Preparation

10 Paste preparations were, in general, accomplished with the following procedure: The appropriate amount of solvent, medium and surfactant was weighed then mixed in a mixing can for 15 minutes, then glass frits and metal additives were added and mixed for another 15 minutes. Since Ag is the major part of the solids of the present invention, 15 it was added incrementally to ensure better wetting. When well mixed, the paste was repeatedly passed through a 3-roll mill for at progressively increasing pressures from 0 to 400 psi. The gap of the rolls was adjusted to 1 mil. The degree of dispersion was measured by fineness of grind (FOG). The FOG value may be equal to or less than 20/10 for conductors.

20

The ASF1100 glass frit (available from Asahi Glass Company) used in the following examples was not used as supplied. It was milled to a D_{50} in the range of 0.5-0.7 microns prior to use.

25

Test Procedure-Efficiency

The solar cells built according to the method described above were placed in a commercial IV tester for measuring efficiencies (ST-1000). The Xe Arc lamp in the IV tester simulated the sunlight with a known intensity and radiated the front surface of the cell. The tester used a four 30 contact method to measure current (I) and voltage (V) at approximately 400 load resistance settings to determine the cell's I-V curve. Both fill factor (FF) and efficiency (Eff) were calculated from the I-V curve.

Paste efficiency and fill factor values were normalized to corresponding values obtained with cells contacted with industry standard PV145 (E. I. du Pont de Nemours and Company).

5 Test Procedure-Adhesion

After firing, a solder ribbon (copper coated with 96.5Sn/3.5 Ag) was soldered to the bus bars printed on the front of the cell. In an embodiment, solder reflow was achieved at 365°C for 5 seconds. Flux used was non-activated Alpha-100. The soldered area was approximately 10 2mm x 2mm. The adhesion strength was obtained by pulling the ribbon at an angle of 90° to the surface of the cell. Normalized adhesion strength was calculated to compare vs. a minimum adhesion value of 300g.

Table 2: Effect of Glass Composition on Thick Film Silver Paste

15

Glass ID No.	%	%	FF (%) Norm		Eff (%) Norm	
			Frit	ZnO	FF	Eff
Glass I	1.8	6	54.7	74.7	9.8	74.8
Glass II	1.8	6	59	80.6	10.3	78.6
Glass III	1.8	6	73.6	100.5	13.3	101.5
Glass IV	1.8	6	71.8	98.1	13.1	100.0
Glass V	1.8	6	63.1	86.2	11.2	85.5
Glass VI	1.8	6	50.7	69.3	8.0	61.1
Glass VII	1.8	6	56.7	77.5	9.3	71.0
Glass	1.8	6	67.2	91.8	12.0	91.6
VIII						
Glass IX	1.8	6	70.0	100.0	12.8	97.7
Glass X	1.8	6	65.7	93.9	11.8	90.1
Control I			73.2	100.0	13.1	100.0
(PV145)*						
Control II			70.0	100.0	13.1	100.0
(PV145)*						

* Control I and Control II represent PV145 a high performance thick film composition comprising a Pb bearing glass frit commercially available from E. I. du Pont de Nemours and Company.

5 Percents of glass frit and ZnO given in Table 2 are given in percent total thick film composition.

Thick films containing Glasses III, IV, VIII, and IX achieved especially good contact to the solar cell as demonstrated by good cell performance similar
10 to that of the Control I and Control II thick film paste compositions.

Table 3: Effect of ZnO Additions on Thick Film Silver Paste

Add	Add %	% Frit	ASF	FF Norm	Eff Norm	
			1100*	to PV145	Eff (%)	to PV145
None	0	1.8	29.6	38.8	3.3	23.9
ZnO	4	1.2	72.6	95.3	13.0	94.2
ZnO	4	2.4	71.2	93.4	13.3	96.4
ZnO	6	1.8	76.3	100.1	14.1	102.2
ZnO	8	1.2	76.4	100.3	13.7	99.3
ZnO	8	2.4	75.8	99.5	13.9	100.7
PV145			76.2	100.0	13.8	100.0

Control

*ASF1100 glass frit is commercially available from Asahi Glass

15 Company

Percents of glass frit and additive given in Table 3 are given in percent total thick film composition.

20 Thick film silver paste compositions containing ZnO have superior electrical performance as compared to silver paste with no ZnO. With addition of ZnO, silver pastes attain electrical performance similar to or

better than high performance control paste PV145 commercially available from E. I. du Pont de Nemours and Company.

Table 4 Effect of Various Zn Additions on Thick Film Silver

Add	Add %	ASF		FF		Eff Norm	
		1100		Norm		Eff to PV145 (%)	Eff to PV145 (%)
		% Frit	FF to PV145 (%)	FF to PV145 (%)	FF to PV145 (%)		
None	0	1.8	29.6	40.4	3.3	25.6	
Zn	6	1.8	74	101.0	13.2	102.3	
ZnO Fine	5.4	1.8	74.3	101.4	12.5	96.9	
ZnO Fine	6	1.8	72.4	98.8	12.7	98.4	
Zn	12	1.2	67.9	92.6	12.1	93.8	
Resinate							
Zn	16	1	69.3	94.5	11.8	91.5	
Resinate							
PV145 Control			73.3	100.0	12.9	100.0	

Percents of glass frit and additive given in Table 4 are given in percent total thick film composition.

10 Experiments conducted and detailed in Table 4 illustrate the use of various types of Zn-containing additives and their effect on the thick film composition. Thick film silver paste compositions containing other forms and particle sizes of Zn and ZnO also achieve excellent electrical contact to Si solar cells. The Zn resinate used was 22% Zinc Hex-Cem
15 obtained from OMG, Cleveland, OH.

Table 5: Effect of Mixed Oxide Additions on Thick Film Silver**Paste**

Add	Add	ASF		FF Norm		Eff Norm	
		1100		FF	to PV145	Eff	to
		%	Frit				
None		0	1.8	29.6	42.3	3.3	25.2
ZnO +	4/1.5	1.8	63.4		90.6	11.4	87.0
FeO							
ZnO +	4.5/2.	1.8	70.8	101.1	13.2	100.8	
SnO ₂	3						
ZnO +	4.5/1.	1.8	69.6	99.4	12.7	96.9	
GdO	5						
PV145 Control			70.0	100.0	13.1	100.0	

5 Percents of glass frit and additive given in Table 5 are given in percent total thick film composition.

Thick film silver paste compositions comprising a mixture of oxide frits also demonstrate much improved performance.

Table 6: Effect of Other Oxide Additions on Thick Film Silver Paste

Add	Add %	ASF		FF		Eff	
		1100*		Norm		Norm	
		Frit	FF (%)	to PV145	Eff (%)	to PV145	
None	0	1.8	29.6	41.6	3.3	26.0	
TiO ₂	6	1.8	53.4	75.1	9.2	72.4	
Cr ₂ O ₃	6	1.8	55.5	78.1	10.1	79.5	
MnO	6	1.8	26.8	37.7	1.6	12.6	
MnO	3	1.8	33.3	46.8	5.1	40.2	
MnO ₂	6	1.8	28.7	40.4	2.3	18.1	
FeO	6	1.8	59.4	83.5	10.5	82.7	
CoO	6	1.8	50.6	71.2	8.9	70.1	
Cu ₂ O	6	1.8	44.4	62.4	7.6	59.8	
ZnO	6	1.8	72	101.3	12.8	100.8	
ZrO ₂	6	1.8	30.5	42.9	4.4	34.6	
MoO ₃	4	1.8	25.8	36.3	1.4	11.0	
RuO ₂	6	1.8	34	47.8	5.8	45.7	
SnO ₂	6	1.8	58.4	82.1	9.7	76.4	
SnO ₂	9	1.8	58.9	82.8	10.1	79.5	
WO ₃	4	1.8	52.3	73.6	9.0	70.9	
CeO ₂	6	1.8	54	75.9	9.4	74.0	
GdO	6	1.8	62	87.2	11.2	88.2	
FeCoCrO	6	1.8	61.2	86.1	10.7	84.3	
x							
CoCrO _x	6	1.8	38.2	53.7	5.7	44.9	
CuCrO _x	6	1.8	59	83.0	10.6	83.5	
CuRuO ₃	6	1.8	54	75.9	9.5	74.8	
PV145 Control			71.1	100.0	12.7	100.0	

*ASF1100 glass frit is commercially available from Asahi Glass

Percents of glass frit and additive given in Table 6 are given in percent total thick film composition.

5 All oxide additions, detailed in Table 6 above, to thick film silver paste result in solar cell performance improvement.

Table 7: Effect of ZnO Additive Level on Thick Film Silver Paste Adhesion to Si

ASF	% ZnO	Adh (g)	Normalized Adh (%)
1100			
Frit			
1.2	4	558	186
2.4	4	466	155
1.8	6	441	147
1.2	8	332	111
2.4	8	282	94

10

*ASF1100 glass frit is commercially available from Asahi Glass Company

15

Percents of glass frit and additive given in Table 7 are given

in weight percent of total thick film composition.

Example

Mg-containing additives

20

Using 6 inch 200um wafers from Q-Cells, the effect of MgO was assessed over a range of processing temperatures. The Ag content was 82%.

25

Table 8 : Efficiency of cells with %MgO additions

	% MgO	Process Set			
		Temperature	900 C	925 C	950 C
Sample 1	0	6.51	5.53	6.53	
Sample 2	0.25	5.12	7.72	7.78	
Sample 3	0.5	10.09	13.45	10.06	
Sample 4	0.75	11.57	13.08	11.95	
Sample 5	1	14.64	15.86	14.78	
Sample 6	1.5	15.52	15.62	15.40	
Sample 7	3	14.61	13.82	13.08	
Sample 8	4	14.68	13.50	10.64	

5

Table 9: Electrical Results on fired cells

Frit	%Fr it	[Mg O]	[ZnO]	Zone 4	Voc	%Eff	%FF	Isc
Glass A	1.5	1.0		925	595. 8	14.2 4	70.4 9	8.2 5
Glass A	2.0	1.0		925	598. 4	15.2 5	74.6 7	8.3 0
Glass B	1.0	0.75	1.25	925	596. 6	15.6 8	77.8 8	8.2 1
Glass B	1.0	1.0	1.0	925	597. 8	15.4 4	75.0 0	8.3 8
Glass B	1.0	1.25	0.75	925	598. 1	13.9 5	69.2 8	8.1 0

Example**Flux-containing composition**

A flux-containing conductive composition (silver paste) was prepared as
 5 shown in Table 10. Components are expressed as wt % of total
 composition. Column A describes pastes which include glass frit, silver,
 and organic vehicle; Column B describes pastes which include flux
 material, silver, and organic vehicle. The pastes described in column B
 include 0% glass frit. The flux material Pb silicate (Pb_2SiO_4) was used in
 10 the pastes described in Column B.

TABLE 10

	A	B
Pastes	Glass frit	Flux
	(wt %)	(wt %)
Silver	80	80
Active Agent	3.4	2.4
Organic	16.6	17.6
Total	100	100

Example

**Comparison of Flux Based Silver Paste vs.
 15 Corresponding Glass Based Paste: effect on solar cell efficiency**

Pastes A and B of Table 10 were used to form the front electrode of solar
 cells, made by methods described herein. Figure 3 illustrates the
 observed efficiency of the resulting solar cells. The efficiency of the solar
 20 cell using Paste A to form the front electrode is shown in the column
 termed "Glass". The efficiency of the solar cell using Paste B to form the
 front electrode is shown in the column termed "Flux".

CLAIMS**What is claimed is:**

5

1. . A conductive composition comprising:
 - a) electrically conductive silver;
 - b) one or more flux materials, wherein the flux materials are lead-free; dispersed in
 - c) organic vehicle.

2. The composition of claim 1, wherein the composition comprises 0.5 – 13 wt % flux materials, based on the weight of the conductive composition.

- 15 3. The composition of claim 2, wherein the composition comprises 1.5 – 5 wt % flux materials, based on the weight of the conductive composition.

4. The composition from claim 1, where the flux material comprises one or more components selected from the group consisting of: ZnF_2 , $AgBi(PO_3)_4$, $AgZnF_3 - AgF$, $LiZn(PO_3)_3$, and $Cu_3B_2O_6$.

- 20 5. The composition of claim 1, further comprising one or more zinc-containing additives.

- 25 6. The composition of claim 1, further comprising one or more glass frits.

7. The composition of claim 6, wherein the one or more glass frits are 0-1 wt % of the total composition.

- 30 8. A structure comprising:
 - (a) a thick film composition comprising:
 - a) an electrically conductive silver;
 - b) one or more flux materials, wherein the flux materials are lead-free; dispersed in

c) an organic medium;

(b) one or more insulating films;
wherein the thick film composition is formed on the one or more insulating films, and wherein, upon firing, the organic medium is removed.

5

9. The structure of claim 8, wherein the one or more insulating films is penetrated by components of the composition.

10. The structure of claim 8, further comprising one or more semiconductor substrates.

11. The structure of claim 10, wherein the structure is a solar cell.

12. The structure of claim 8, wherein the insulating film comprises one or 15 more components selected from: titanium oxide, silicon nitride, SiNx:H, silicon oxide, and silicon oxide/titanium oxide.

13. A method of manufacturing a semiconductor device, comprising the steps of:

20 (a) providing one or more semiconductor substrates, one or more insulating films, and a thick film composition, wherein the thick film composition comprises: a) an electrically conductive silver, b) one or more flux materials, wherein the flux materials are lead-free, dispersed in c) an organic medium,

25 (b) applying the insulating film on the semiconductor substrate,
(c) applying the thick film composition on the insulating film on the semiconductor substrate, and
(d) firing the semiconductor, insulating film and thick film composition, wherein, upon firing, the organic vehicle is removed, the silver and flux

30 materials are sintered.

1/4

FIG. 1A



FIG. 1B

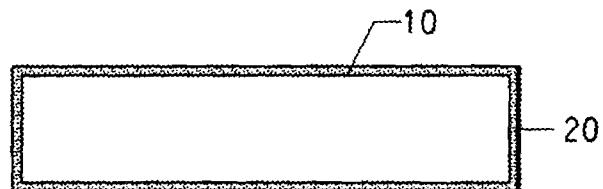


FIG. 1C

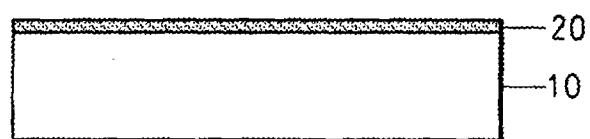


FIG. 1D

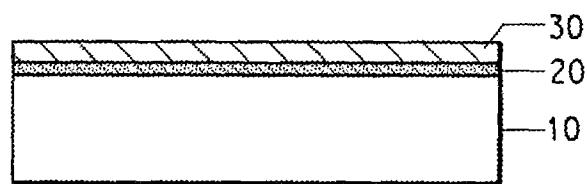


FIG. 1E

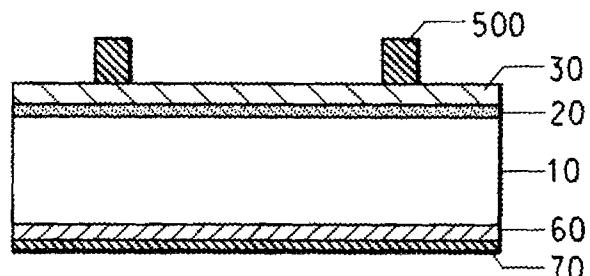
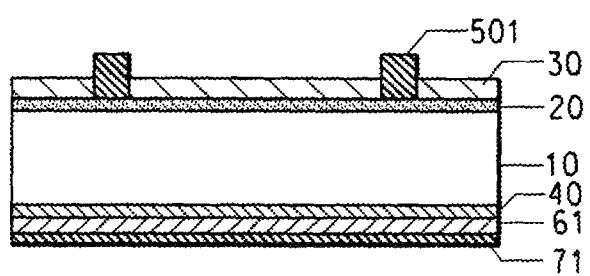


FIG. 1F



2/4

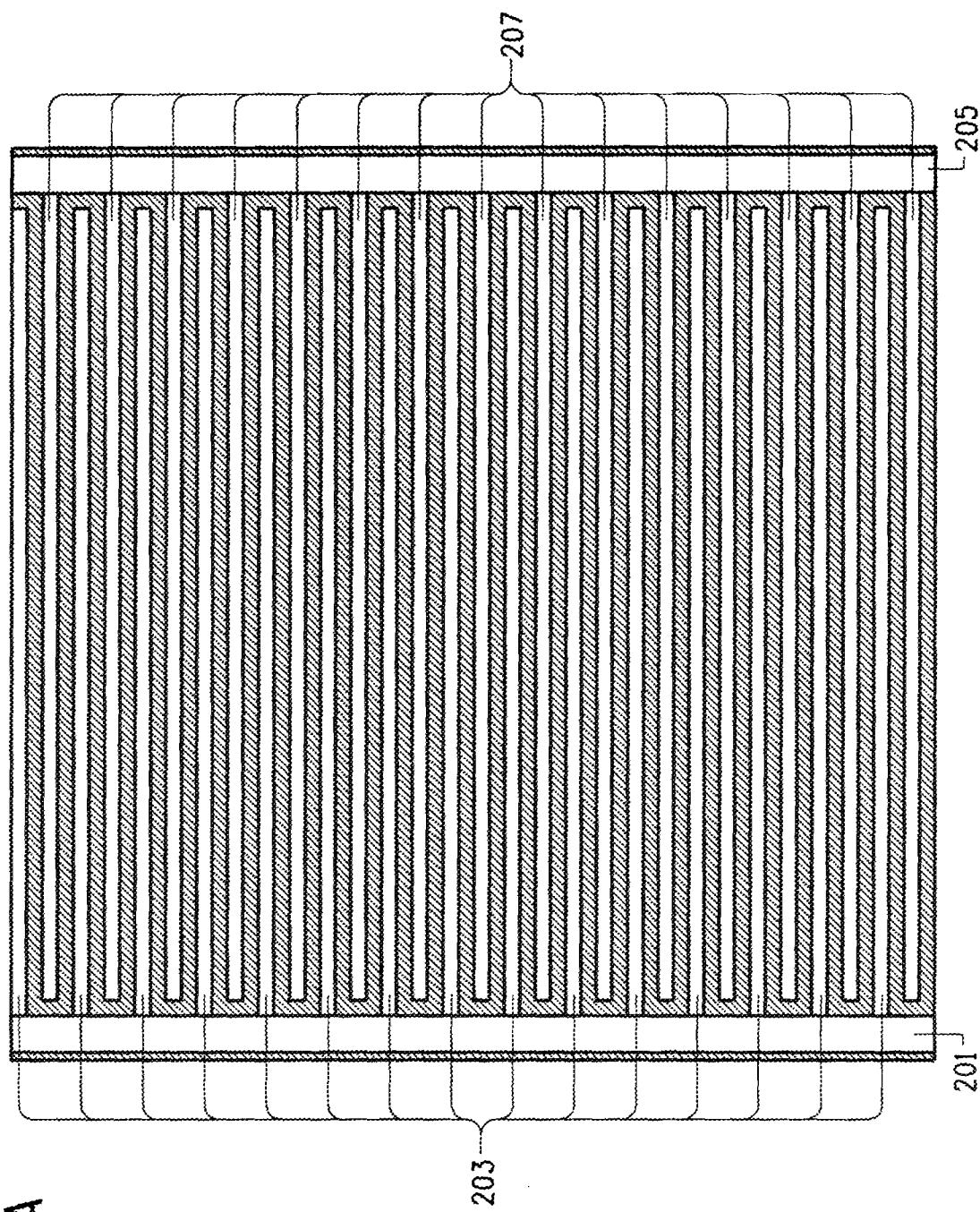


FIG. 2A

3/4

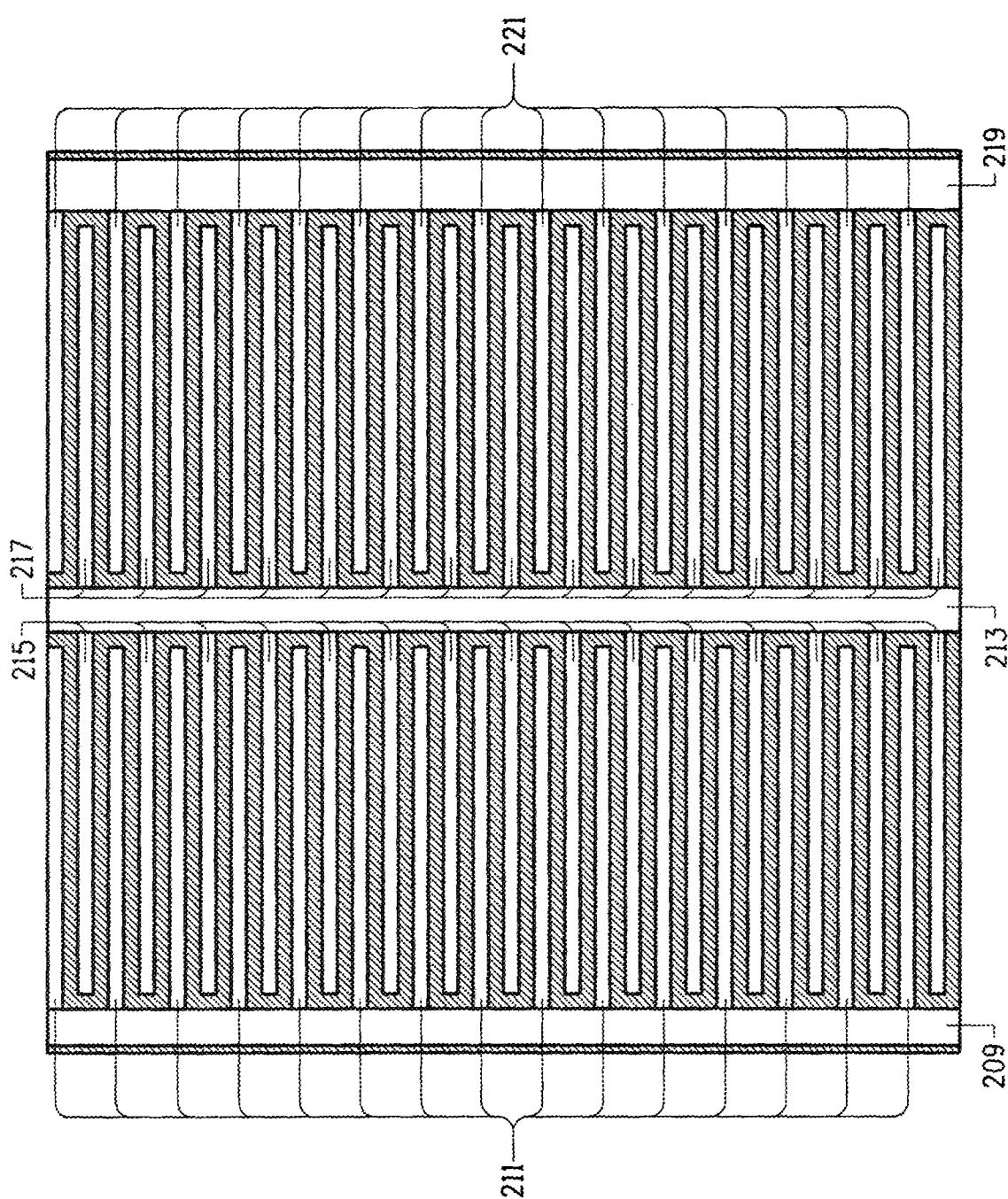
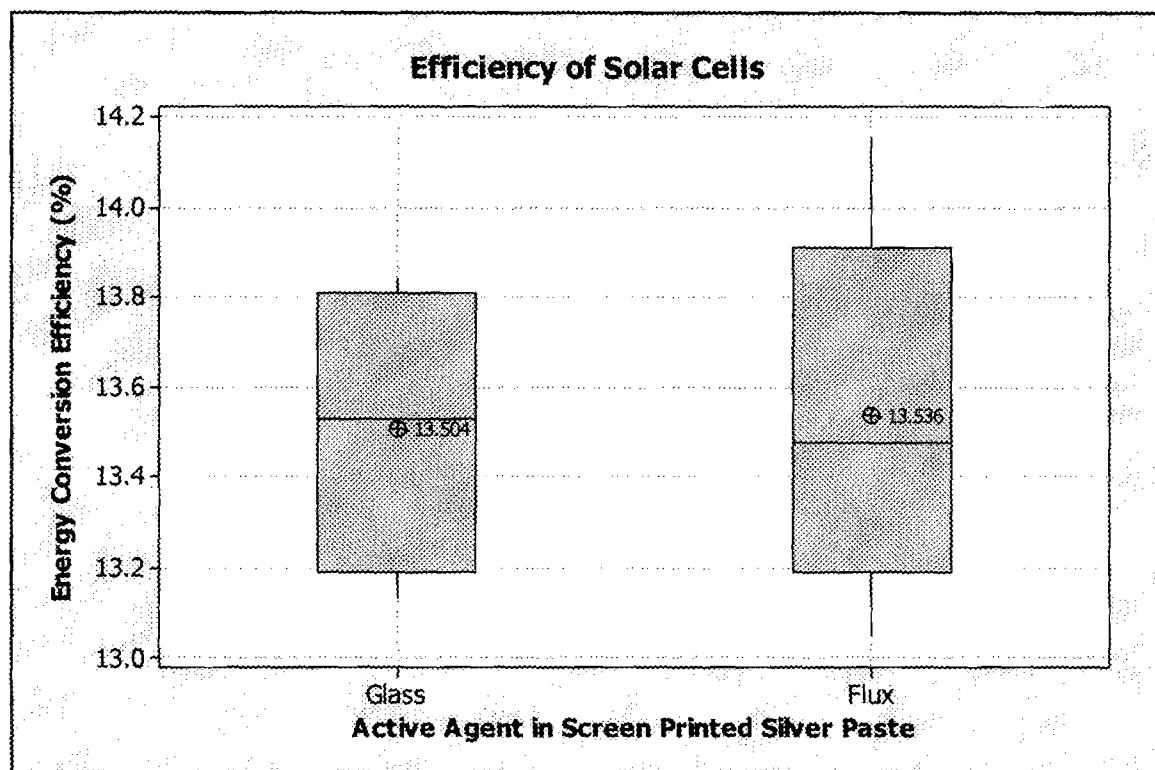


FIG. 2B

Comparison of Flux Based Silver Paste vs. Corresponding Glass Based Paste**FIGURE 3**

INTERNATIONAL SEARCH REPORT

International application No PCT/US2008/080409

A. CLASSIFICATION OF SUBJECT MATTER INV. H01B1/16 H01B1/22 C03C8/18 C03C17/00 C03C17/06
--

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01B C03C

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 713 092 A (DU PONT [US]) 18 October 2006 (2006-10-18) claims 1-11; table 6 -----	1-13

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
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- *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

4 February 2009

Date of mailing of the international search report

11/02/2009

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2008/080409

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP 1713092	A 18-10-2006	AU 2006201558 A1		02-11-2006
		CN 101055896 A		17-10-2007
		JP 2006332032 A		07-12-2006
		KR 20060108545 A		18-10-2006
		US 2006231801 A1		19-10-2006