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(54) EMITTER STRUCTURE BASED ON SILICON COMPONENTS TO BE USED IN A PHOTOVOLTAIC CONVERTER AND A METHOD FOR PRODUCTION OF THE PHOTOVOLTAIC DEVICE

(76) Inventors: **Zbigniew Kuznicki**, Hoenheim (FR); **Patrick Meyrueis**, Strasbourg (FR)

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CPC ***H01L 31/02363*** (2013.01)
USPC **136/255**; 438/96; 438/71

(57) ABSTRACT

This invention aims to reduce and preferably to cancel the carrier collection limit effect in order to considerably encrease the conversion efficiency. This improvement is achieved by a suitable modification of the amorphized layer thickness or even by discontinuities separating amorphizing beams or amorphized nanopellets.

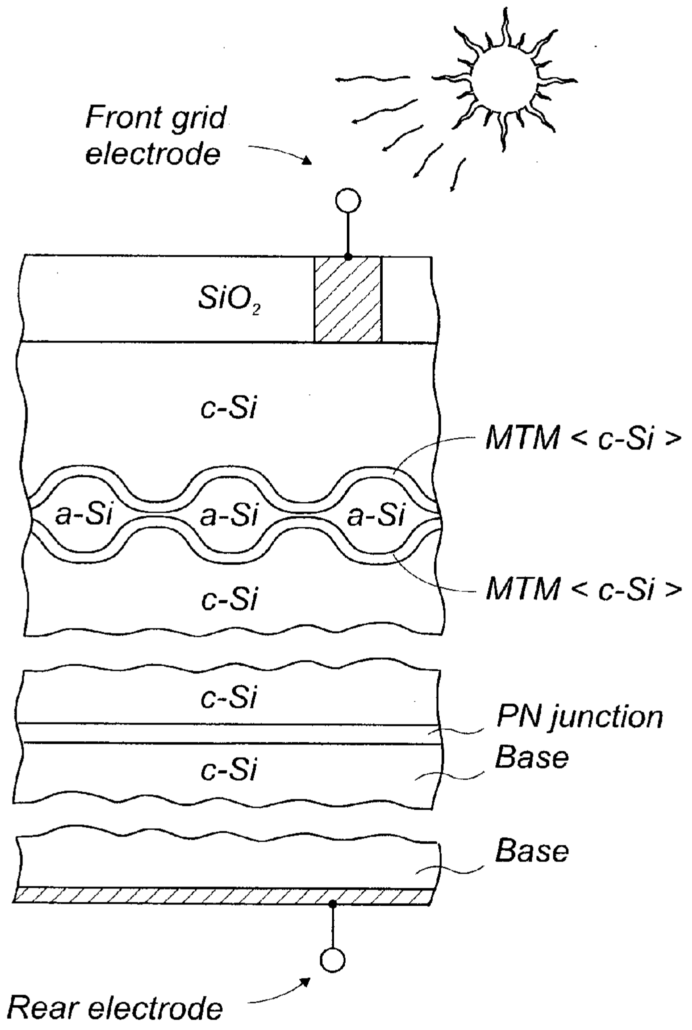


FIG. 1

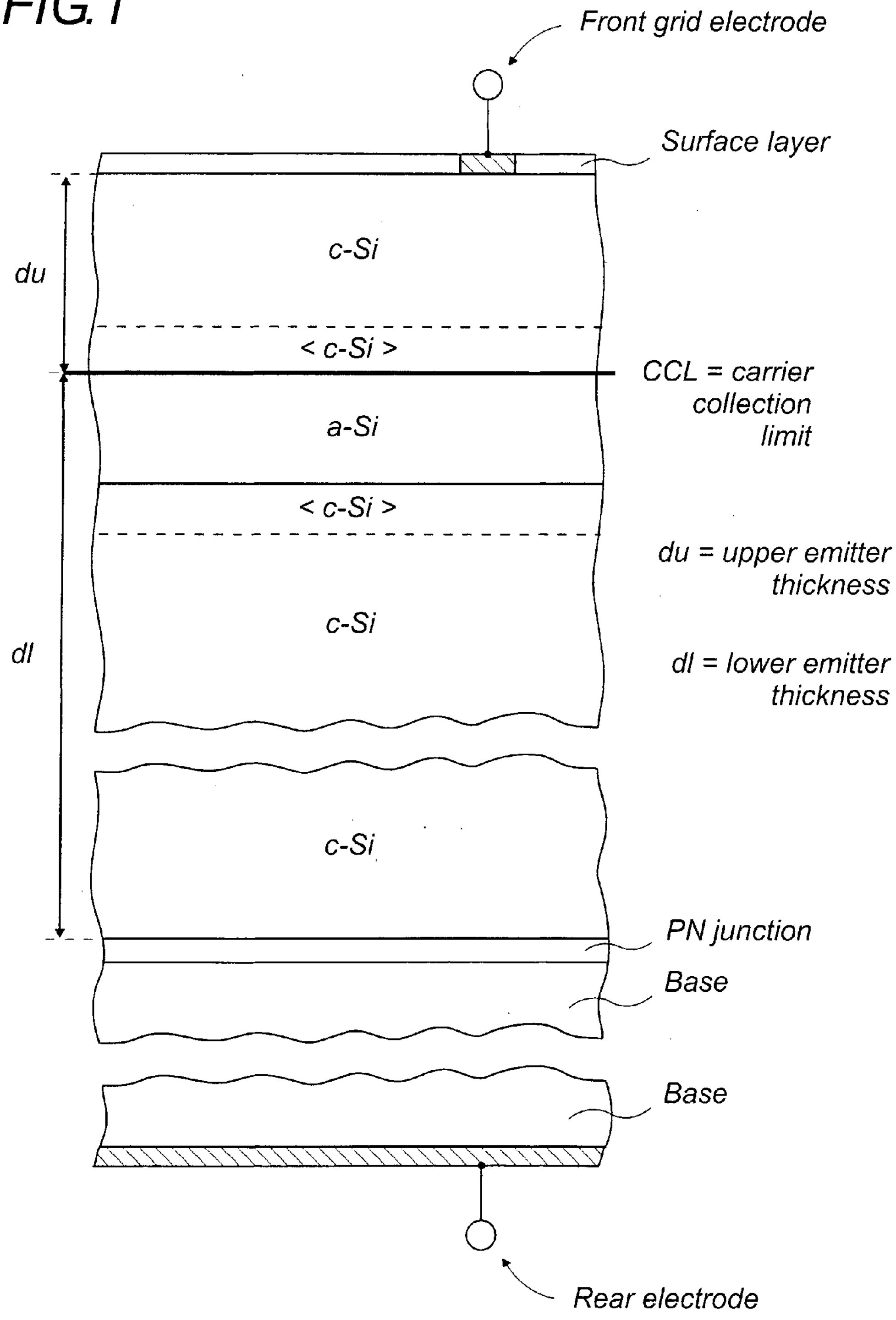

Front grid electrode
Surface layer
c-Si
du
< c-Si >
CCL = carrier collection limit
a-Si
< c-Si >
du = upper emitter thickness
c-Si
dl
dl = lower emitter thickness
c-Si
PN junction
Base
Base
Rear electrode

FIG.2

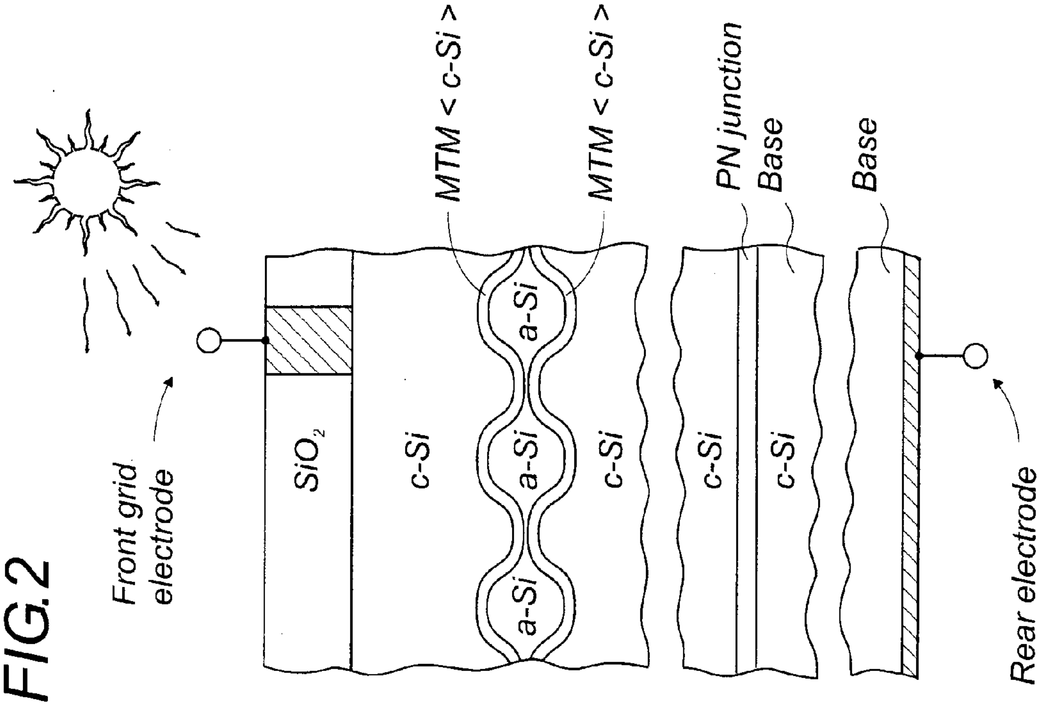

Front grid electrode
SiO$_2$
c-Si
a-Si
a-Si
a-Si
c-Si
MTM < c-Si >
MTM < c-Si >
c-Si
PN junction
c-Si
Base
Base
Rear electrode

FIG.3

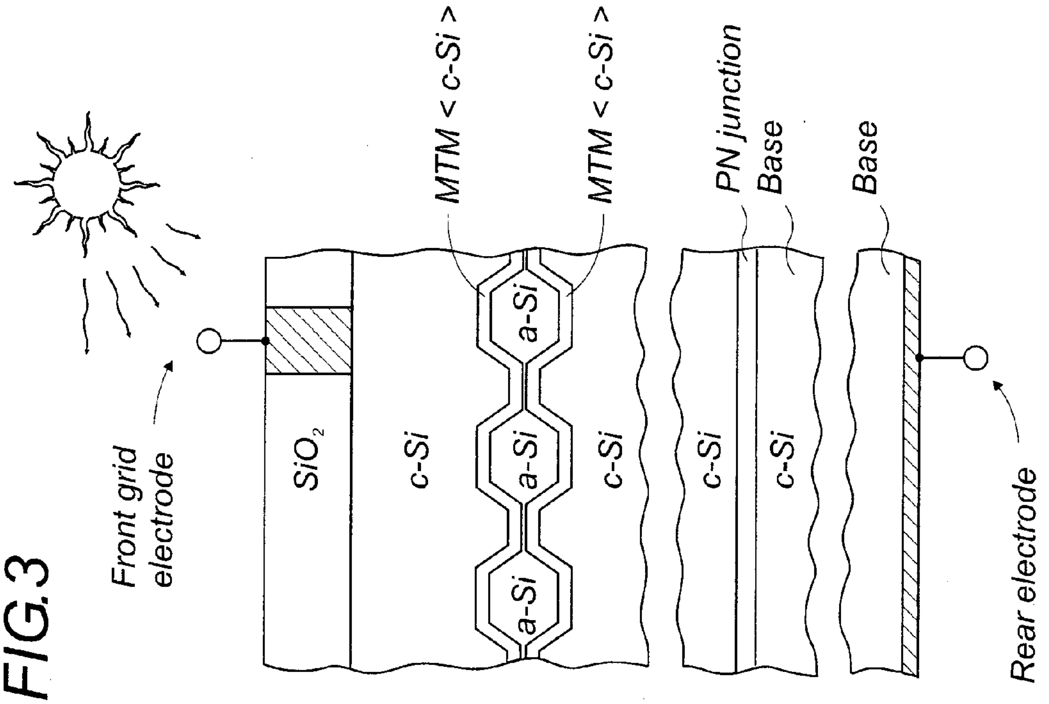

Front grid electrode
SiO$_2$
c-Si
a-Si
a-Si
a-Si
c-Si
MTM < c-Si >
MTM < c-Si >
c-Si
PN junction
c-Si
Base
Base
Rear electrode

FIG.4

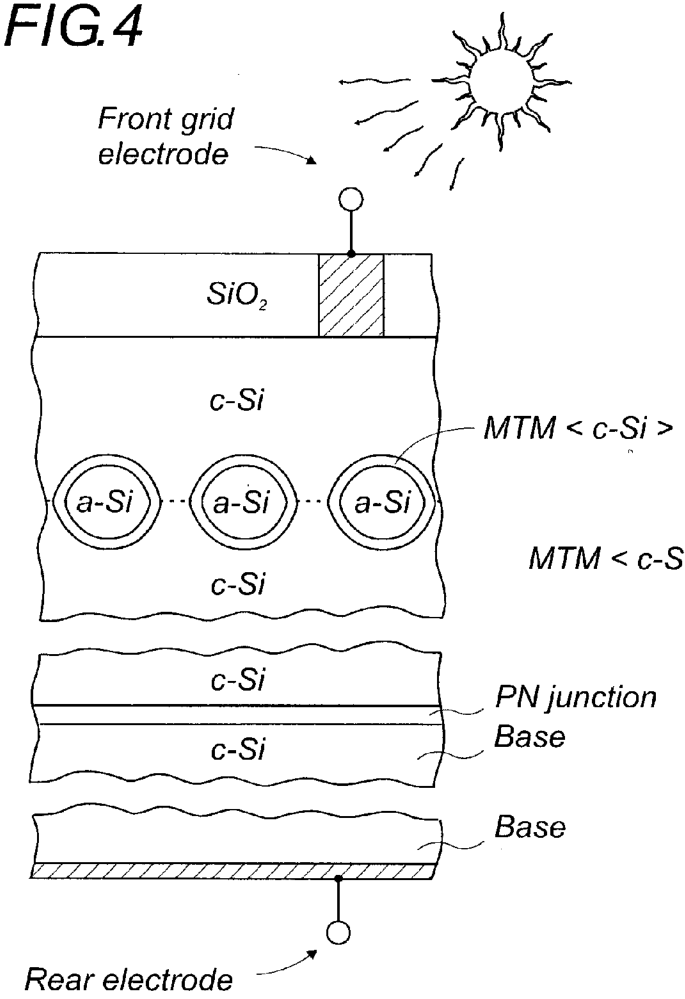

Front grid electrode
SiO₂
c-Si
MTM < c-Si >
a-Si
a-Si
a-Si
c-Si
c-Si
PN junction
Base
c-Si
Base
Rear electrode

FIG.5

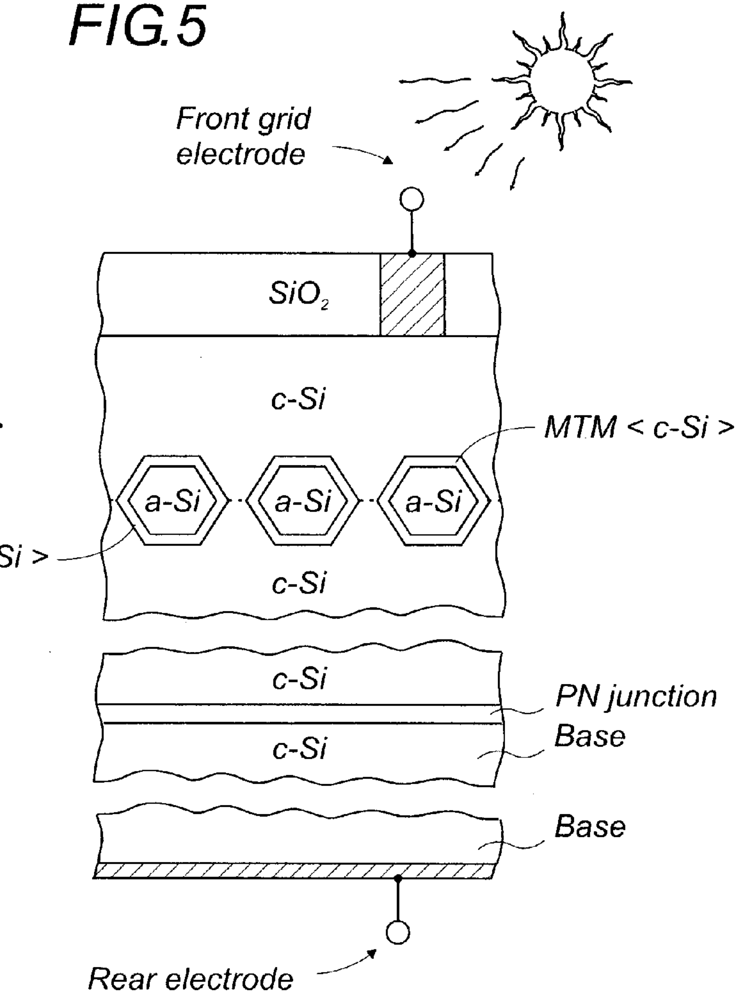

Front grid electrode
SiO₂
c-Si
MTM < c-Si >
a-Si
a-Si
a-Si
MTM < c-Si >
c-Si
c-Si
PN junction
Base
c-Si
Base
Rear electrode

FIG.7

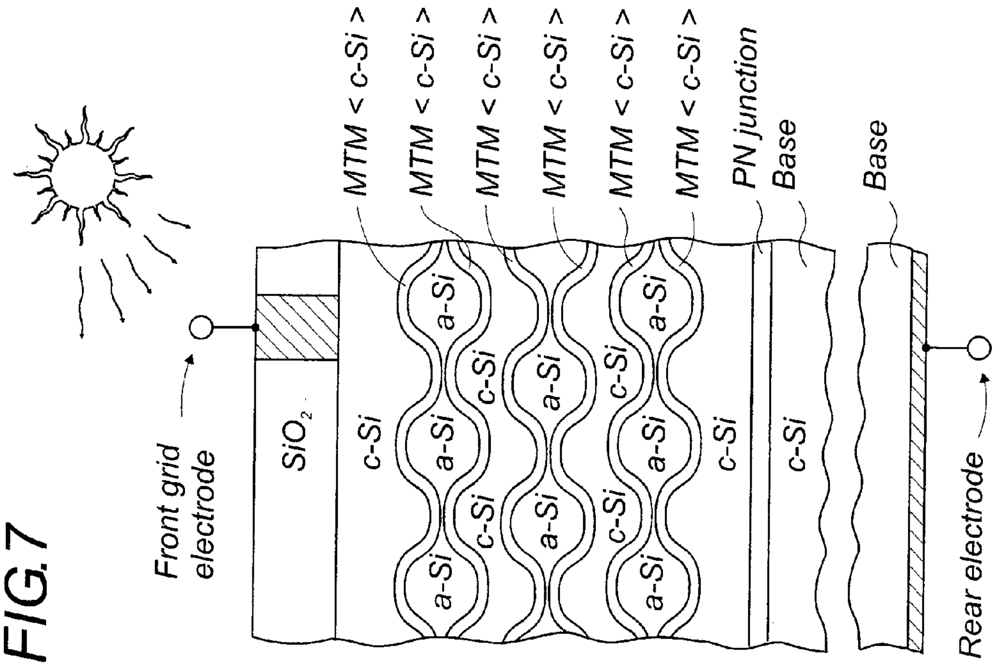

Front grid electrode
SiO2
c-Si
a-Si
c-Si
a-Si
c-Si
a-Si
c-Si
c-Si
Rear electrode
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
PN junction
Base
Base

FIG.6

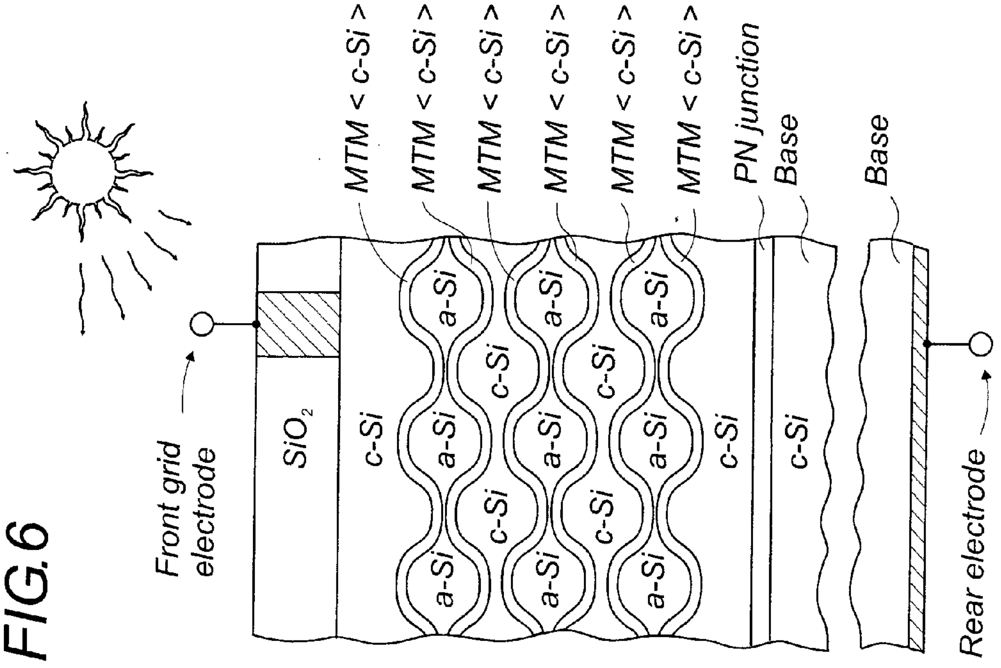

Front grid electrode
SiO2
c-Si
a-Si
c-Si
a-Si
c-Si
a-Si
c-Si
c-Si
Rear electrode
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
MTM < c-Si >
PN junction
Base
Base

FIG. 8

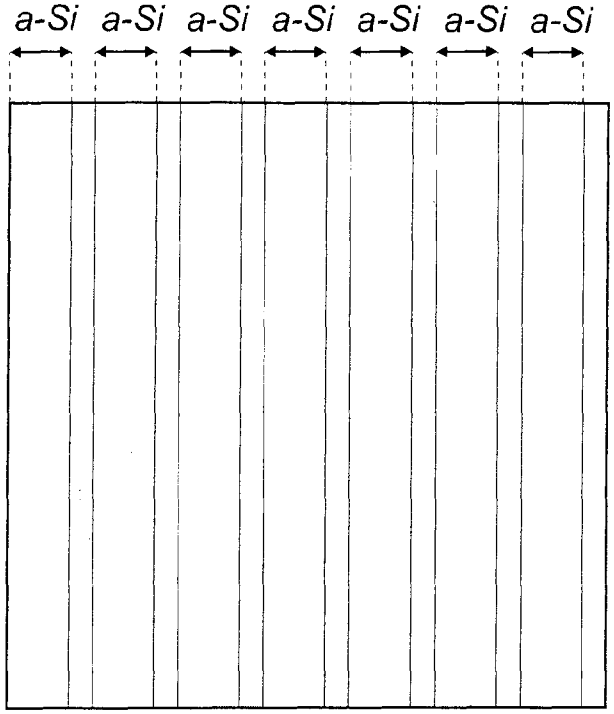


FIG. 9

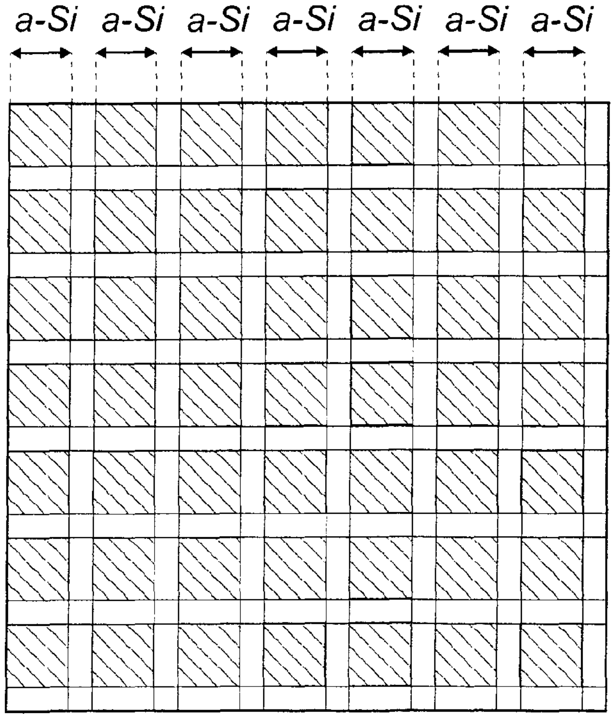


FIG. 10

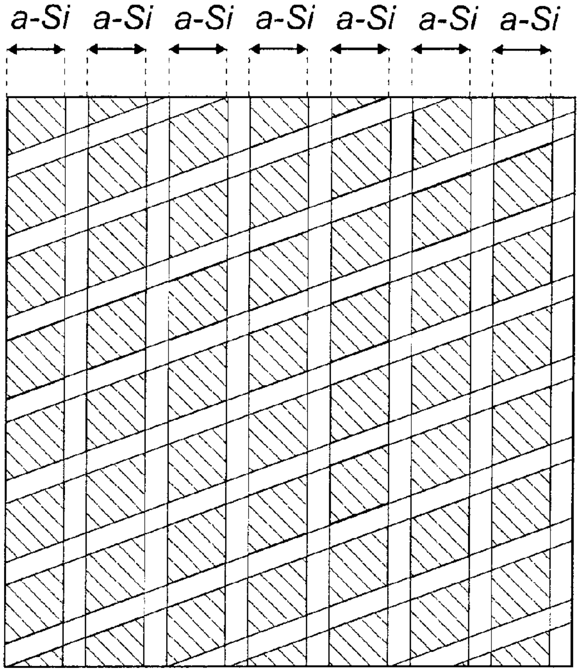


FIG. 11

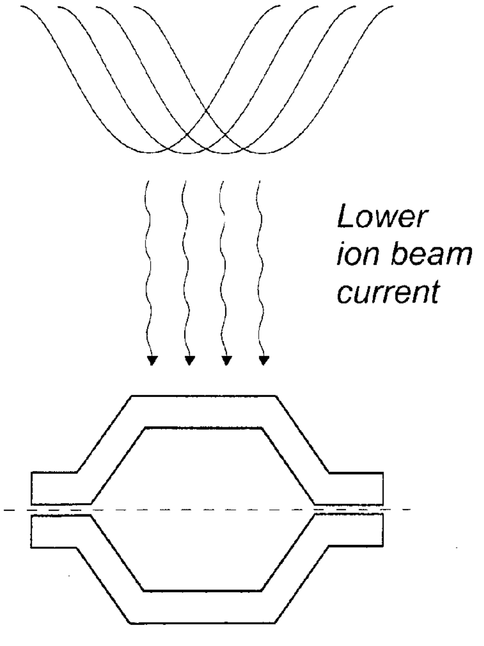
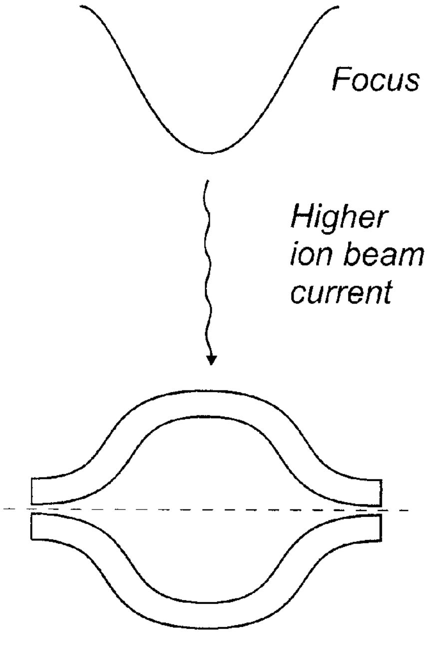


FIG. 12



EMITTER STRUCTURE BASED ON SILICON COMPONENTS TO BE USED IN A PHOTOVOLTAIC CONVERTER AND A METHOD FOR PRODUCTION OF THE PHOTOVOLTAIC DEVICE

FIELD OF THE INVENTION

[0001] This invention relates to an improved emitter structure of multi-interface novel devices for a light-to-electricity conversion in a photovoltaic converter to produce electricity from light particularly from solar radiation and a method for its production.

BACKGROUND OF THE INVENTION

[0002] This invention derives from the schematic structure of the previously disclosed photovoltaic emitter according to WO **2010/089624** in the name of the same inventors Zbigniew T. KUZNICKI and Patrick MEYRUEIS, which is incorporated herein by way of reference.

[0003] This previous photovoltaic device is able to exploit high energy photons, in particular UV and visible photons, in addition to near IR photons, said device comprising a slab, wafer or chip of p-type or n-type photovoltaic material produced according to the method claims of WO 2010/089624, having a top surface intended to be exposed to photonic radiation, having a built-in P-N junction delimiting an emitter part and a base part, having front and rear carrier collection and extraction means and comprising at least one area or region specifically designed or adapted to absorb high energy or energetic photons and located adjacent or near at least one hetero-interface. This device is characterised in that said slab, wafer or chip of photovoltaic material comprises also at least one metamaterial field or region forming a low-energy secondary carrier generation cavity, which is contiguous or proximate to the at least one absorption area or region for the energetic photons and subjected to a built-in or applied electrical field having an intensity sufficient to withdraw and move away the secondary electrons libe-rated by the primary hot electrons from their initial sites within the concerned metamaterial area or region, at a speed sufficient to prevent their return into said metamaterial region or field, thus forming a substructure performing multistage conversion, wherein the density of divacancies within the metametallic field(s) or region(s) is greater than 10^{18} divacancies/cm^3, preferably greater than 10^{19} diva-cancies/cm^3, most preferably greater than 10^{20} divacancies/cm^3 and the conduction between the metamaterial and the respectively adjacent n-type material has a time constant which is at the most of the same magnitude that the secondary carrier generation time constant, wherein the thickness of the or each planar amorphous semiconductor material layer is comprised between 10 nm and 50 nm and wherein the width of the respectively associated metamaterial field(s) or re-gion(s), in the shape of (a) continuous or discontinuous layer(s), is less than 10 nm, the semiconductor material having preferably a thickness comprised with-in 5 μm and 500 μm, preferably between 10 μm and 280 μm.

[0004] This previous invention is also characterised by a carrier collection limit designated here as CCL which is the limit separating the emitter in two parts: the upper emitter which is an electronically dead zone, and the lower emitter which is electronically fully active. As shown on FIG. **1**, the converter is composed of a surface layer connected to a front grid electrode and a base connected to a rear electrode and between them an emitter structure divided in an upper emitter and a lower emitter. The thicknesses of the upper and lower emitters are respectively designated as <<du>> and <<dl>> (FIG. **1**). These upper and lower emitters are separated by the limit zone called CCL for the Carrier Collection Limit. This photovoltaic emitter structure is readily visible on FIG. **1** on which the CCL limit is shown by a solid black line.

[0005] The CCL can be defined as the interface with its potential barrier blocking generated carriers to move towards the PN collection junction. So the carriers of opposite signs generated within the upper emitter cannot be collected because it is not possible for them to be separated one each from the other with regard to the CCL.

[0006] The goal of this present invention is multiple.

[0007] The first one is to proceed with the collection of the whole photo-generated population of free carriers from all components of the light-to-electricity converter i.e. particularly from the upper emitter located between the front face and the nanoscale silicon layered system.

[0008] The second one is to reduce and preferably to cancel the CCL effect in order to considerably increase the conversion efficiency.

[0009] The last one is to improve further the conversion efficiency by suitable modifications of the amorphized silicon layer.

[0010] This enhancement is obtained through this present invention by means of at least a double transformation which results of an amorphization beam that scans the silicon wafer. The suitable scanning process leads to discontinous or locally thinned and very thin amorphized layer. The process can be performed by an ion beam implantation process or an electron beam irradiation process. The ions can be for example, silicon or phosphorous ions.

[0011] The CCL effect is suppressed by a suitable structure discontinuity or by, for example, the tunnel conduction across locally thinned CCL.

[0012] In such a case, the structure conveys carriers through limited special thin zones the carriers that have to reach the collection PN junction. They can pass through the crystalline passages of the buried substructure or through the very thin zones where the thickness of the buried structure is so reduced that the tunnel conduction effect can appear. All these passages have to be not too much spaced with respect of the carrier movements along the buried substructure, i.e. movements perpendicular to the collecting PN junction.

[0013] These and other benefits of this invention will become clear from the following description by reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a schematic transverse sectional view of a photovoltaic emitter according to WO 2010/089624 where the CCL zone is shown by means of a large solid black line;

[0015] FIGS. **2** to **7** are schematic cross-sectional views of an improved photovoltaic emitter where the CCL is suppressed, wherein, more particularly:

[0016] FIG. **2** is a schematic cross-sectional view of an amorphized silicon layer wherein the a-Si shape is that of an undulation;

[0017] FIG. **3** is a schematic cross-sectional view of an amorphized silicon layer wherein the a-Si shape is that of a trapeziform;

[0018] FIG. **4** is a schematic cross-sectional view of an amorphized silicon layer similar to that of FIG. **2** but with discontinuities;

[0019] FIG. **5** is a schematic cross-sectional view of an amorphized silicon layer similar to that of FIG. **3** but with discontinuities;

[0020] FIG. **6** is a schematic cross-sectional view of an amorphized silicon layer with three buried nanoscale Si-layered systems, i.e. three amorphized a-Si layers buried at different depths;

[0021] FIG. **7** is a schematic cross-sectional view of an amorphized silicon layer which is substantially the same as that of FIG. **6** but with the second layer shifted with respect to the first and third layers;

[0022] FIGS. **8** and **9** are schematic plan views of a wafer which shows three different patterns of ion or electron beam scanning comprising the use of length-wise passages, crossed passages, and oblique passages;

[0023] FIGS. **11** and **12** are schematic views of the amorphizing beam tips and the shapes thus created, wherein, more particularly:

[0024] FIG. **11** discloses the use of a pattern comprising several close passages and the use of a relatively low ion beam current; and

[0025] FIG. **12** discloses the use of a pattern comprising one single passage and the use of a relatively high ion beam current.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0026] The silicone wafer is first treated according partially to the method disclosed within WO **210/089624** which is incorporated herein by way of reference.

[0027] 1. Insertion of the Amorphized Silicon Layer within the Single Crystal Wafer.

[0028] This process is performed either by way of an ion beam implantation or by way of an electron beam irradiation. The ions are, for example, preferably silicon ions or phosphorous ions.

[0029] The general purpose is to create a relief which consists of a succession of concavities or protrusions and hollows or discontinuities as shown on FIGS. **2** to **7** in or with the amorphized silicon layer a-Si. These forms are separated from the silicon crystalline mass c-Si by a nanolayer of nanometamaterial MTM which is a metamaterial derived from crystalline silicone c-Si by way of an ion beam implantation or an electron beam irradiation or some equivalent process. This metamaterial MTM of this nanolayer is designated by the label <c-Si>. It is inserted on the single-crystal silicon side of the hetero-interface between amorphized/crystalline (a-Si/c-Si) silicon. The labels a-Si and c-Si are the same as defined in the figures of the drawings.

[0030] During one of these processes it occurs insertion by penetration of the ions or electrons within the structure and interaction with it and finally stabilisation at a certain depth.

[0031] This insertion process by means of implantation or irradiation occurs after having built-in the PN junction structure which results of a particular P doping diffusion or by epitaxy. So the PN junction is already built-in and the P doping profile is a heavily doped profile and simultaneously the N part of this PN junction has to be heavily doped and then the scanning process may occur.

[0032] This insertion may be achieved by scanning the structure with an ion beam or with an electron beam in order to proceed with an ion implantation or electron irradiation process with more or less energy and dose i.e more or less ion current or electron velocity.

[0033] We use scan steps with an ion implantation beam or irradiation by an electron beam. As shown on the figures, we can proceed for a low ion beam current with multiple close passages or for a high ion beam current with one passage at a time necessary for locally controlled amorphization as illustrated by the relevant FIGS. **11** and **12**.

[0034] We can use either several close passages with low energy dose beams as shown on the FIG. **11** or one single passage with a high energy dose beam (FIG. **12**).

[0035] The scanning may proceed with one or several passages and then shift the beams in order to create discontinuities between the concavities or protrusions i.e the strips a-Si (FIGS. **8** to **10**).

[0036] The scanning with the electron beam is rather the same in order to obtain the scanning patterns as shown in the related figures.

[0037] An alternative manner is to first scan along one direction of the wafer and then along another direction of the wafer perpendicular to the first one as shown in FIG. **9**.

[0038] It is also possible to first scan in a straight manner and then in an oblique manner as shown in FIG. **10**.

[0039] The strips designated by a-Si between the lines shown on these FIGS. **8** to **10** define the width of the passage or passages of the beam in order to form the protrusions of a-Si material with the limits created by the ion implantation or electron irradiation work which is the metamaterial MTM derived from crystal silicone and labelled <c-Si>.

[0040] The ion implantation energy ranges from 10 to 300 keV and the dose of ions is comprised between 5×10^{14} cm^{-2} and 5×10^{16} cm^{-2} with a heavily doped profile.

[0041] The electron irradiation energy i.e. the acceleration potential ranges from 200 keV to 5 MeV.

[0042] The ion beam current or the depositing energy depends on the ion profile. At least one passage is required if the implanted charge is sufficient to obtain amorphization. But several paths are needed to locally accumulate the depositing energy if the single charge is not sufficient to obtain amorphization of the silicon which is in the crystal state.

[0043] If the doping profile is previously brought to emitter then silicon ions can be used to operated a buried amorphization in silicon structure by the self-implantation of silicon.

[0044] The tip of the beam must be properly shaped as well as the focus settings in order to ensure a proper result.

[0045] The forms as shown on the FIGS. **2**, **3** and **4**, that is, the succession of concavities or platforms and hollows, demonstrates the creation of pass-ages between them through which the carriers will pass by a tunnel effect.

[0046] As implanted, the amorphized layer a-Si has mismatched interface zones with the surrounding silicone crystals. As this mismatched interface is of no practical interest, a thermal treatment is necessary in order to render this device usable.

[0047] 2. Thermal Treatment

[0048] Then follows the thermal treatment which will render the limits properly thin and clear and which consists of several thermal cycles.

[0049] In order to obtain an abrupt c-Si/a-Si interface, a suitable thermal treatment is applied.

[0050] For example, the thermal treatment consists in one initial continuous annealing step, followed by at least one cycle of successive discontinuous annealing sequences.

[0051] The annealing rate is to be limited to avoid structural defects. The low temperature is selected for stabilizing the solid state epitaxy for example approximately 100° C. while the high temperature is approximately 500° C. Each exposure to high temperature lasts for example from 2 to 5 minutes with a recuperation time of for example 1 to 4 minutes which may be reduced by means of appropriate gradients of temperature. For example, three to six cycles are necessary.

[0052] After the thermal treatment is completed, the c-Si/a-Si limits between the material phases are clean, clear and accurate.

[0053] The above described emitter is to be used in light-to-electricity converter which must be completed by front and rear electrodes as well as by different conventional components and by an appropriate optic block or platform to concentrate the solar radiation onto the wafer.

[0054] The light-to-electricity converter so produced results in a high conversion efficiency so that the total active surface does not have to be large, and therefore an appropriate concentration optic is required.

1-20. (canceled)

21. Emitter structure made of silicon nano components to be used in a photovoltaic converter able to convert high energy photons into free electrons in particular UV and visible photons as well as IR photons, this improved emitter structure being part of a slab, wafer or chip of p-type or n-type photovoltaic material, having a top surface intended to be exposed to photonic radiation mainly to sun radiation, having a built-in PN junction delimiting an emitter part and a base part, having front and rear electrodes and comprising at least one area or region specifically designed or adapted to absorb high energy or energetic photons and located adjacent or near one hetero-interface, said slab, wafer or chip of photovoltaic material comprises also at least one nanometamaterial MTM region forming a low-energy secondary carrier generation cavity, which is contiguous or proximate to the at least one absorption area or region for the energetic photons and subjected to a built-in or applied electrical field having an intensity sufficient to withdraw and move away the secondary electrons liberated by the primary hot electrons from their initial sites within the concerned nanometamaterial MTM region, at a speed sufficient to prevent their return into said nanometamaterial MTM region, thus forming a substructure performing multi-stage conversion, wherein the density of divacancies within the nanometamematerial MTM region(s) is greater than 10^{18} diva-cancies/cm^3, preferably greater than 10^{19} divacancies/cm^3, most preferably greater than 10^{20} divacancies/cm^3 and the conduction between the nanometamaterial MTM and the respectively adjacent n-type material has a time constant which is at the most of the same magnitude that the secondary carrier generation time constant, in which a carrier collection limit CCL separates the emitter in two parts: the upper emitter which is an electronically dead zone and the lower emitter which is electronically active, this carrier collection limit CCL being defined as the interface with its potential barrier blocking generated carriers to move towards the PN collection junction, characterized in that the amorphous semiconductor material layer is conformed by a process of insertion, deposition or implantation of ions or electrons or any equivalent process into a relief made of a succession of concavities or protrusions or platforms separated by interruptions or discontinuities in one or several continuous or discontinuous layer(s) and in that the upper surfaces of these reliefs of amorphous semi-conductor consist in a nanometamaterial MTM.

22. Emitter structure according to claim **21** characterized in that the succession of protrusions are strips in succession resulting each from at least one passage of a beam for ion implantation or electron irradiation or equivalent, these reliefs are made of amorphized silicon a-Si with a modified upper surface consisting in a nanometamaterial MTM and separated by interruptions or discontinuities.

23. Emitter structure according to claim **21**, characterized in that the nanometamaterial MTM is derived from crystalline silicon by way of an ion beam implantation or an electron beam irradiation or equivalent process.

24. Emitter structure according to claim **21**, characterized in that the nanometamaterial MTM is inserted on the single crystal silicon side of the hetero-interface between the amorphized/crystalline silicon.

25. Emitter structure according to claim **22** characterized in that the successive strips of protrusions are shifted according to a constant pitch.

26. Emitter structure according to claim **22**, characterized in that the form of the amorphized silicon layer concavities or protrusions is that of a succession of an undulation or double undulation.

27. Emitter structure according to claim **21** characterized in that the succession is discontinuous.

28. Emitter structure according to claim **22** characterized in that the form of the amorphized silicon layer is that of a succession of concavities or platforms and interruptions continuous or discontinuous.

29. Emitter structure according to claim **22** characterized in that the form of the amorphized silicon layer concavities or protrusions is that of a succession of trapezes or double trapezes.

30. Emitter structure according to claim **2** characterized in that the form of the amorphized silicon layer concavities or protusions is that of a succession of spheres.

31. Emitter structure according to claim **22** characterized in that the amorphized silicon layer comprises three amorphized silicon layers buried at different depths.

32. Emitter structure according to claim **31** characterized in that the second layer is shifted with respect to the first and the third layers.

33. Emitter structure according to claim **21** characterized in that the nanometamaterial MTM is a heavily doped crystal silicone <c-Si>.

34. A method for producing a photovoltaic material able to absorb and exploit high energy or energetic photons, in particular UV and visible photons, in which the method comprises the steps of:

a) providing or producing a conventional p-type or n-type photovoltaic material made of inorganic crystalline semiconductor material(s), such as Si or GaS, having a top surface intended to be exposed to photonic radiation, having a built-in PN junction delimiting an emitter part and a base part and comprising at least one area or region specifically designed, treated or adapted to absorb high energy or energetic photons, located adjacent or near at least one hetero-interface;

b) generating or maintaining structural defects within an n-type area of said emitter and/or base part of the material consisting of divacancies able to function as low-energy secondary generation centers grouped to-gether in (a) nanometric formation(s) and persistent under production process and photovoltaic conversion conditions;

c) introducing, in particular diffusing or implanting, n-type doping impurities, such as phosphorus or arsenic, according to determined intensity, energy and profile in order to put the divacancies into an electrical charge state in which they are saturated with weakly bonded electrons and to provide an excellent conduction within said or each region of implanted impurities, such as metallic type conduction in heavily doped semiconductor material;

wherein steps b) an c) are performed in such a way that they result in at least one semiconductor based metamaterial field or region being created, as a transitional region of the or a hetero-interface;

d) providing a built-in electric field or means to apply an electric field which encompasses or extends over said or each metamaterial field or region and shows an intensity sufficient to withdraw and move away said liberated secondary electrons from their initial sites within the concerned metamaterial area or region, at a speed sufficient to prevent their return into said meta-material region or field;

e) providing a succession of protrusions or platforms at the amorphous semiconductor material level conformed by a process of insertion, deposition or implantation of ions or electrons or any equivalent process into a relief made of a succession of protrusions separated by hollows or interruptions or discontinuities in the shape of one or several continuous or discontinuous layer(s),

wherein said method also comprises, preferably after step c), and/or after e) at least one thermal treatment step of the material of determined duration and intensity, with a total energy balance of the thermal treatment for one continuous nanoscale planar metamaterial layer buried within the emitter part of the photovoltaic material which is approximately equivalent to that of a continuous thermal annealing of a duration of about 30 to 50 minutes, preferably of about 40 minutes, at a temperature comprised between 450° C. and 600° C., preferably of about 500° C.,

wherein the at least metamaterial field or region is created, as a result of above steps b) and c), in an area located continuous or proximate to the or an absorption area or region for the energetic photons of the photonic radiation impacting said photovoltaic material, at least within the range of thermalization of the primary electrons liberated directly by said energetic photons and which collide with metamaterial low-energy generation centers liberating secondary generation electrons in a multistage processing, the order of which depends on remaining energy kept by the primary electrons at the moment of their generation collision,

wherein the setting of the parameters of the successive operational production steps are such that the thickness of the or each planar amorphous semiconductor material layer is comprised between 10 nm and 50 nm and that the width of the respectively associated material field(s) or region(s), in the shape of (a) continuous or discontinous layer(s), is less than 10 nm, the semiconductor material having preferably a thickness comprised within 5 μm and 500 μm, preferably between 10 μm and 280 μm, and,

wherein steps b) and c) are further performed in such a way that, on the one hand, the density of divacancies within the metamaterial field(s) or region(s) is greater than 10^{18} divacancies/cm^3, preferably greater than 10^{19} divacancies/cm^3, most preferably greater than 10^{20} divacancies/cm^3 and, on the other hand, the conduction between the metamaterial and the respectively adjacent N-type material has a time constant which is at the most of the same magnitude than the secondary carrier generation time constant in order to create a relief which consists of a succession of concavities or protrusions and hollows or interruptions or discontinuities in or with the amorphized silicon layer a-Si in which these forms are separated from the silicon crystalline mass c-Si by a nanometamaterial MTM which is a metamaterial derived from crystalline silicone c-Si.

35. Method according to claim **34**, characterized in that it comprises in creating the nanometamaterial MTM in generating divacancies in the vicinity of the or a hetero-interface between two phases of the semiconductor material or two types of semiconductor materials by means of an energy beam, for example If the doping profile is previously brought to emitter then silicon ions can be used to operate a buried amorphization in silicon structure by the self-implantation of silicon.

36. Method according to claim **34** characterized in that the doping profile is previously brought to emitter and so silicon ions are used to operated a buried amorphization in silicon structure by the self-implantation of silicon.

37. Method according to claim **34** characterised in that ions used for the transplantation are silicon or phosphorous ions.

38. Method according to claim **34** characterized in that by way of an ion beam implantation or an electron beam irradiation or some equivalent process is inserted on the single-crystal silicon side of the hetero-interface between amorphized/crystalline (a-Si/c-Si) silicon.

39. Method according to claim **34** characterised in that the ion implantation energy ranges from 10 to 300 keV and the dose of ions is comprised between 5×10^{14} cm^{-2} and 5×10^{16} cm^{-2} with a heavily doped profile.

40. Method according to claim **34** characterised in that the energy of the electron beam ranges from 200 keV to 5 MeV.

41. Method according to claim **34**, characterised in that it comprises in amorphizing at least repetitive small areas or regions of the semiconductor material in order to create corresponding absorption areas or regions for the energetic photons, and then preserving the structural defects generated during amorphization during the following production steps.

42. Method according to claim **34**, characterized in that the thermal treatment comprises in one initial continuous annealing step, followed by at least one cycle of successive discontinuous annealing sequences.

43. Method according to claim **34**, characterized in that it comprises forming one continuous or discontinuous semiconductor nanometamaterial MTM layer or field intimately associated with a continuous or discontinuous area or region of amorphized semiconductor material, located at or near the top surface of the semiconductor material, both field and region together forming a front substructure.

44. Method according to claim **34**, characterized in that it comprises forming, simultaneously or in successive production cycles, at least two continuous or discontinuous semiconductor metamaterial nanoscale layers or fields, at least one of which being buried within the thickness of said material in the emitter or base part and intimately associated with a respective continuous or discontinuous area or region of amorphized semiconductor material, comprising the same type of doping impurities and forming, with the respectively associated nanometamaterial MTM layer or field, a substructure.

45. Method according to claim **34**, characterized in that the thermal treatment consists in laser annealing or RTA/RTP annealing combined with epitaxial layer deposition to adapt the geometry in terms of disposition, distances, thermalization restraints and time constant optimization.

46. Method according to claim **34**, characterized in that it consists in forming locally implanted amorphised conductive material protusions in the shape of successive concavities or platforms separated by interruptions.

47. Method according to claim **34** characterized in that the scanning pattern of the beam is a crossed passages pattern.

48. Method according to claim **47** characterized in that said crossed passages pattern is an oblique line pattern.

49. Method according to claim **34** characterized in that said scanning pattern is a succession of parallel passages separated by strip intervals in which the strips define the width of the passage or passages of the beam in order to form the protrusions of amorphous silicon material with the limits created by the ion implantation or electron irradiation work which is the metamaterial MTM derived from crystal silicon.

50. Method according to claim **34** characterized in that after the insertion process by ion beam implantation or electron beam irradiation or equivalent process, a thermal treatment occurs which consists in one initial continuous annealing step, followed by at least one cycle of successive discontinuous annealing sequences in that the annealing rate is to be limited to avoid structural defects in that the low temperature is selected for stabilizing the solid state epitaxy for example approximately 100° C. while the high temperature is approximately 500° C.

51. Method according to claim **34** characterized in that each exposure to high temperatures last for example from 2 to 5 minutes with a recuperation time of for example 1 to 4 minutes which may be reduced by means of appropriate gradients of temperature and in that three to six cycles are necessary.

52. A method for producing a photovoltaic device able to exploit high energy photons, in particular UV and visible photons, preferably in addition to IR photons, comprising the steps of:

providing a slab, wafer or chip of the photovoltaic material produced, with at least one active substructure comprising at least one absorption area or region for the energetic photons and at least one nanoscale field or region of metamaterial;

forming front and rear conductive structures on said slab, wafer or chip able to extract the carriers generated within the photovoltaic materiel;

subjecting the front and/or rear surface of said slab, wafer or chip to (an) additional treatment(s) in order to alter their reflection and/or conversion properties.

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