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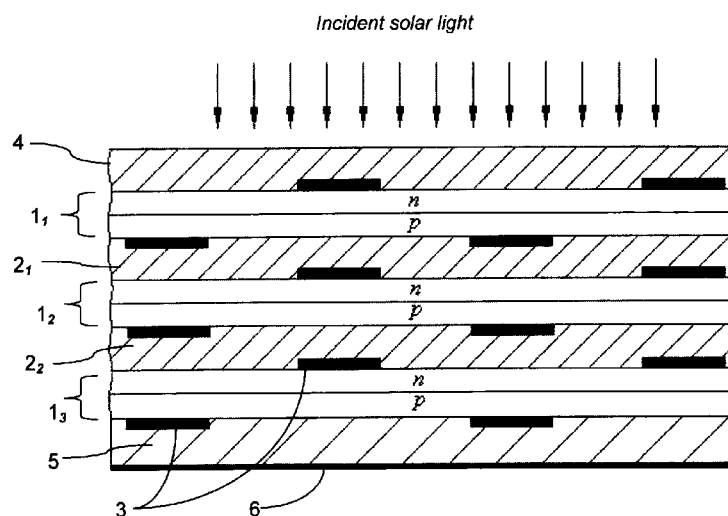


Fig. 4

(57) Abstract: Multijunction photovoltaic converter comprising at least two semiconductor layers (1,) having built-in p-n or n-p junctions, where "i" is serial number of the respective semiconductor layer along the luminous flux; transparent electrical insulator (2,) embedded between said semiconductor layers and meant additionally for their optical matching; and at least 2f pairs of (+) and (-) discrete contact electrodes, where f is number of semiconductor layers (1,) in said PVC, on condition that said (+) and (-) electrodes of each pair are connected respectively to p- and n- regions of each semiconductor layer (1,). SOLAR BATTERY comprises of at least one said multijunction PVC and current collectors.

MULTIJUNCTION PHOTOVOLTAIC CONVERTER AND
SOLAR BATTERY BASED THEREON

Field of the Invention

5 This invention relates to the structure of multijunction semiconductor photovoltaic converters (hereinafter PhVC) and solar batteries based thereon. These devices are meant to use preferably in solar power stations.

Background Art

10 It is well known that at the average 1400 J of solar electromagnetic radiation energy impinge every second in the middle latitudes on each 1 m² of the Earth surface faced to the Sun. In other words, average power density of this radiation is equal to 1.4 kW/m². This value is called *solar constant*.

15 It is also well known the inner photo-effect, i.e. electric charge carriers' redistribution in semiconductors and dielectrics under impact of electromagnetic radiation (especially infrared, visible and ultraviolet light). Thus, lighting of two tightly adjacent semiconductor layers having *n*- and *p*- impurity conduction causes photo-EMF on their interface.

Equipping of such layers by contact electrodes had been enabled creation of first photoelectric converters.

20 Development of semiconductors having built-in *p-n* (or *n-p*) junctions and production of theirs by epitaxial deposition of layers having desired compositions has been resulted in creation of PhVCs and solar batteries, efficiency of which was about 6% [see: D.M. Chapin, C.S. Fueller, G.L. Pearson. J. Appl. Phys., **25**, 676 (1954)]. Such batteries were used as spacecrafts' autonomous electric power sources during the sixties of the twentieth century.

25 At the end of the twentieth century, efficiency coefficient of solar batteries has exceeded 10%, and solar power engineering became a real environmentally safe alternative for the heat and nuclear power stations.

First decade of the twenty-first century has been marked by tremendous growth of industrial production of photoelectric devices having output power in the range from several watts (e.g., for use in pocket calculators) up to hundreds and more kilowatts (for local terrestrial solar power stations).

30 According to the European Photovoltaic Industry Association's forecast, sale of solar batteries would reach 12-22 GW in 2013; average annual growth can be 17-32% in 2008-2013 years depending on the governmental programs of helioenergetics development; and average annual growth of production capacity can reach up to 20-30% (*McKinsey Quarterly. The economic of solar power. June 2008*).

35 However, cost value of electrical energy produced by solar batteries is still high as compared to heat and nuclear power stations. Correspondingly, it is most necessary to simplify design, production, installation and exploitation of photovoltaic converters and solar batteries; and to increase efficiency of theirs.

Main methods and means to satisfy these requirements are considered –

(1) In review research paper of senior specialists of the A.F. Ioffe Physical-Technical Institute of the Russian Academy of Sciences (see: Ж.И. Алфёров, В.М. Андреев, В.Д. Румянцев. Тенденции и перспективы развития солнечной фотоэнергетики // Физика и техника полупроводников. 2004, том 38, выпуск 8, с.937–948; In English: Zh.I. Alferov, V.M. Andreev, V.D. Rumyantsev. Trends and Perspectives of Solar Photovoltaics // Physics and Technology of Semiconductors. Volume 38, issue 8, pp. 937–948), and

(2) In the Web-site Wikipedia.org articles, where are described –

- (a) Photovoltaic effect (gate photovoltaic effect or barrier-layer photo-effect) and its application in photovoltaic cells,
- (b) Unijunction and multijunction PhVCs (photovoltaic conversion; photovoltaic modules or converters), and
- (c) Solar batteries and panels.

Furthermore, there are rapidly growing number of scientific publications and patent documents on this topic, but their amount is so large that cannot review within any patent application in principle.

It is easy to specify theoretically two main objectives for improvement of photoelectric devices: firstly, intensification of light absorption for generation of charge carriers in the form of free electrons and holes; and, secondly, reducing of power losses owing to recombination of generated charge carriers during their movement to the *p-n* or *n-p* junction.

Unfortunately, co-attainment of these objectives is labored. In fact, light absorption can be easily intensified by thickening of the semiconductor layer (however, probability of generated charge carriers' recombination increases in this case too). Similarly, probability of said recombination can be decreased by thinning of the semiconductor layer (but probability of photons absorption and generation of charge carriers decreases in this case too).

Therefore, inventors are looking for alternative ways in order to improve efficiency of photoelectric devices and to reduce production and maintenance costs of theirs.

The simplest methods of improvement of photoelectric devices' efficiency provide:

(1) Decreasing of the incident light reflection factor down to 1% and less using preferable multilayer antireflection coatings of the external surfaces of photoelectric devices (these coatings are described in details on the Web-site <Wikipedia.org>), and,

(2) Solar light concentration onto external surfaces of any photoelectric devices (see chapter 5 of above-mentioned research paper) using, as a rule –

(2.1) a suitable mirror (e.g., parabolic reflector according to the WO/2010/059873), or mirror systems (e.g., a set of conic mirrors according to the WO/2010/131164 and others), orientation of which is usually changeable during the daylight hours according to the Sun position on the horizon in order to concentrated solar light would be steadily directed onto the surface of the solar battery under optimal angle; or

(2.2) stationary concentrators based on the Fresnel lenses (see Figs 9 and 10 of above-mentioned research paper, WO/2010/149813; WO/2010/132312 and others), which can be used to equip even individual PhVC.

It is clear that use of expensive additional accessories increase cost value of photoelectric devices and market price of electric energy. Moreover, high power density of the solar radiation can cause overheating and failures of individual photovoltaic cells or even PhVCs and solar batteries in whole.

- 5 Probability of such failures can be reduced by placement of PhVCs onto heat-conductive supports having high heat transfer and high heat emission coefficients (see, for example, WO/2010/096700) and/or by use of more heat-resistant, but more expensive semiconductors (e.g. gallium arsenide).

Efficiency of photovoltaic cells and PhVCs can be increased usually by use of
10 heterojunctions based on $A^{\text{III}}B^{\text{V}}$ (e.g., AlGaAs/GaAs). Specifically, efficiency up-to-date 27.6% was achieved when such heterojunctions were irradiated by concentrated solar light having AM1.5 spectrum [see M.E. Green, K. Emery, D.L. King, S. Igary, W. Warta. Progr. Photovolt.: Res. Appl., **10**, 355, 2002].

For the purpose of photons absorption increase, PhVCs of such kind were equipped
15 with incorporated by MOS hydride epitaxy Bragg reflectors, e.g. in the form of 12 pairs of AlAs (72 nm)/GaAs (59 nm) layers. They are having 96% reflection factor and were adjusted for the 850 nm wavelength [see fig.3b and figure legend text in the above-mentioned research paper, and, additionally, V.M. Andreev, I.V. Kochnev, V.M. Lantratov, M.Z. Shvarts. Proc. 2nd World Conf. on Photovolt. Solar Energy Conversion (Vienna, 1998) p.3537].

20 Bragg reflectors provide double pass of long-wave (i.e. infrared) solar radiation through the unijunction PhVCs and, hence, increase efficiency and radiation resistance of theirs.

It is obvious for any person skilled in the art that radiation resistance of PhVCs is non-critical for terrestrial solar power stations and that efficiency factor and cost value of PhVCs are main prerequisites of their practicability. Unfortunately, efficiency of the best PhVCs
25 having only one $p-n$ (or $n-p$) junction is significantly less than theoretical limit of 93% evaluated on the Carnot cycle basis, and their production by epitaxy is very expensive.

Therefore, development of multijunction (or otherwise, "cascade") PhVCs has been started at the beginning of the sixties of the twentieth century. Examples of their structures are disclosed in the chapter 4 of above-mentioned research paper (fig.6), in
30 WO/2010/048537, in WO/2010/067704 where current collectors are arranged in the bottom only, and also in many other documents. Classical PhVC of this kind comprises of:

- (a) Several (at present practically no more than three) photovoltaic cells, each of which has one $p-n$ or $n-p$ junction, and which are placed along the luminous flux and electrically connected in series;
- 35 (b) Tunnel junctions at the joints of these cells, and
- (c) Common to the entire PhVC solid sheet-like upper and lower (+) and (-) contact electrodes, which are meant to cut in an external electric circuit when operate.

Said tunnel junctions are required to decrease total electrical resistance of any known multijunction PhVC and its internal optical losses. Actually, without them the n -region of each
40 preceding $p-n$ junction would be connected directly to the p -region of each following $p-n$

junction that causes formation of parasitic *p-n-p* structures and mutual compensation of photocurrents generated in adjacent photovoltaic cells.

Theoretically, any multijunction PhVC is able to operate within overall solar spectrum due to adjustment of separate photovoltaic cells to the different spectral sub-bands.

5 However, these devices are complicated and expensive because must be produced almost completely using epitaxy. Moreover, said tunnel junctions increase active internal resistance of such PhVCs and decrease specific power of solar batteries on their basis.

Hence, use of several *p-n* (or *n-p*) junctions in combination with intermediate tunnel junctions does not guarantee significant approximation of such PhVCs efficiency to the said
10 theoretical limit 93%.

Therefore, optical filters are often used in order to increase efficiency coefficient.

For example, WO/2009/085601 discloses such multijunction PhVC, which includes semiconductor layers operating within the blue, green and red sub-bands of the solar spectrum respectively. Each said layer is equipped by adjacent dichroic filter. These filters
15 decompose white light that impinges onto the external PhVC's surface, transmit radiation of specific spectral sub-bands of the solar spectrum into respective semiconductor layers and reflect inside them respectively blue, green and red light, which was not absorbed during first pass. Thereby blue light affects on the semiconductor layer adjusted for operation in the blue sub-band, etc. Also this PhVC can be adjusted for interference in order to increase
20 absorption coefficient.

WO/2010/142626 discloses other structurally similar multijunction PhVC. It has two or three photovoltaic cells that are placed in series and equipped respectively with one or two optical filters able to reflect the light having wavelengths shorter than λ_x and to transmit the light having wavelengths longer than λ_x . According to applicant's opinion, it increases light
25 absorption between said filters of adjacent photovoltaic cells and efficiency of such PhVC.

Unfortunately, optical filters did not provide significant results because semiconductor layers of all above-mentioned multijunction PhVCs are connected electrically in series through aforesaid tunnel junctions.

An attempt to overcome this disadvantage is known from WO/2009/105683 and
30 WO/2009/105743 belonged to the same applicants and disclosed "Multi-layered electro-optic devices", which are substantially similar to the proposed below PhVCs and solar batteries.

A known planar semi-transparent preferably multijunction PhVC (originally specified as "planar photovoltaic semi-transparent module") contains in one embodiment a substrate, first and second solid sheet-like electroconductive layers, and at least two semiconductor layers,
35 which are placed between said electroconductive layers and interfaces of which are able to operate as *p-n* or *n-p* junctions. At least one said junction is meant for conversion of first solar spectrum sub-band energy into electric voltage and transmission of second solar spectrum sub-band to following junction meant for at least partial conversion of this second solar spectrum sub-band energy into electric voltage.

Band-gaps in two junctions can be different; moreover, junction having narrow band-gap must be located below the junction that has wide band-gap and is meant for partial absorption of other parts of the solar spectrum. Further, usually all layers must be flexible.

Other embodiment of the known PhVC includes electrically independent multijunction photovoltaic cells, which have supporting substrates texturized for light back-scattering inside each photovoltaic cell and, when operate, are cut in an external electric circuit in parallel.

Said PhVCs can be glued together in multi-component modules having upper and/or bottom protective coatings (see fig.6 in both above-mentioned publications).

Known solar battery has at least one row, but usually many rows of said PhVCs, solid sheet-like electroconductive layers of which are partially exposed for parallel connection to an external electric circuit (see fig.2 in both above-mentioned publications). It is clear –

Those solid sheet-like electroconductive layers in said multijunction PhVCs must be sufficiently transparent in order do not shade lower photovoltaic cells;

That two or more *p-n* (or *n-p*) junctions inside the same multijunction PhVC must be connected by aforesaid tunnel junctions or other functionally equivalent means, and

That decrease of *p-n* (or *n-p*) junctions' band-gaps along the luminous flux cannot by itself activate significantly inner photo-effect and increase efficiency of solar batteries.

Summary of the Invention

This invention is based on the problem to create more efficient multijunction photovoltaic converters and solar batteries based thereon by improvement of relative position and matching relative parameters of these photoelectric devices' components.

This problem is solved in that a multijunction PhVC *according to the invention* comprises of:

(a) at least two semiconductor layers (1_{*i*}) having built-in *p-n* or *n-p* junctions, where "*i*" is serial number of the respective semiconductor layer along the luminous flux;

(b) a transparent electrical insulator (2_{*i*}) embedded between said semiconductor layers and meant for their optical matching, where "*i*" is serial number of the respective insulator along the luminous flux;

(c) at least 2*f* pairs of (+) and (-) discrete contact electrodes, where *f* is number of semiconductor layers (1_{*i*}) in said PhVC, on condition that said (+) and (-) electrodes of each pair are connected to the respective *p*- and *n*- regions of each said layer (1_{*i*}).

Use of two or more optically matched and electrically insulated semiconductor layers provides simultaneously:

Firstly, selective absorption of photons by each semiconductor layer, decrease of multireflection and, hence, attenuation of undesired light scattering between the semiconductor layers within the multijunction PhVC,

Secondly, practical elimination of recombination generated charge carriers, and,

Finally, substantial increase of efficiency of light energy conversion into electric energy.

Additional feature consists in that in each arranged in series along the luminous flux group of the multijunction PhVC's details, namely:

«first semiconductor layer (1_i) – first transparent electric insulator (2_i) – second semiconductor layer (1_{i+1})»,
«second semiconductor layer (1_{i+1}) – second transparent electric insulator (2_{i+1}) – third semiconductor layer (1_{i+2})» etc.

- 5 all said insulators (2_i) are single-layered, and refraction indexes of said semiconductor layers and said insulators are matched using antireflection criterion.

Selection of materials having required refraction indexes and determination of the insulators' thicknesses using antireflection criterion decrease additionally multireflection and scattering of light between semiconductor layers within the PhVC, even if insulators are
10 single-layered.

Following additional feature consists in that in each arranged in series along the luminous flux group of the multijunction PhVC's details, namely:

- «first semiconductor layer (1_i) – first transparent electric insulator (2_i) – second semiconductor layer (1_{i+1})»,
15 «second semiconductor layer (1_{i+1}) – second transparent electric insulator (2_{i+1}) – third semiconductor layer (1_{i+2})» etc.

- at least one said insulator (2_i) is composed of at least two electro-insulating layers on conditions that refraction index of at least one such electro-insulating layer is higher as compared with the refraction indexes of adjacent semiconductor layers, and refraction index
20 of second such electro-insulating layer is lower as compared with the refraction indexes of adjacent semiconductor layers.

- Shaping of at least one (but preferably each) of the built-in the multijunction PhVC insulator as at least two-layered structure and fulfillment of said conditions of selection of refraction indexes provide the truest conformability of any such PhVC to the principles of
25 blooming of optical systems and permit to decrease up to technically feasible minimum multireflection and scattering of light between semiconductor layers within the PhVC.

- Next additional features consist in that said (+) and (-) discrete contact electrodes are placed either on the both sides, or on one side of each respective semiconductor layer. First variant of connection of said electrodes is the most ordinary, whereas second variant permit
30 to decrease light reflection from the contact electrodes into environment.

Still more additional feature consists in that the multijunction PhVC comprises of at least one antireflection surface dielectric faced to the light source when operates.

- Accurate selection of materials having required refraction indexes and thicknesses of these coatings permits to decrease solar light reflection from the PhVC's external surface into
35 environment and, additionally, to protect of the PhVC against environmental impacts.

- And, finally, additional feature consists in that the multijunction PhVC is mounted on at least single-layered transparent dielectric substrate, under which a reflector is placed. Accurate selection of materials having required refraction indexes, amount of substrate layers and thickness of each layer permits to decrease multireflection and scatterings of light
40 between said substrate and adjacent semiconductor layer, whereas the reflector provides

double pass of residual solar radiation through the multijunction PhVC. Owing to efficiency of such PhVC and solar batteries based thereon increases additionally.

Aforesaid problem is solved also in that a solar battery *according to the invention* comprises of:

- 5 (1) At least one multijunction PhVC, comprising:
 - (a) at least two semiconductor layers (1_i) having built-in *p-n* or *n-p* junctions, where "*i*" is serial number of the respective semiconductor layer along the luminous flux;
 - (b) at least single-layered transparent electrical insulator (2_i) embedded between each pairs of the adjacent semiconductor layers and meant also for their optical
 - 10 matching, where "*i*" is serial number of the respective insulator along the luminous flux;
 - (c) at least $2f$ pairs of (+) and (-) discrete contact electrodes, where *f* is number of semiconductor layers (1_i) in the PhVC, on condition that said (+) and (-) electrodes of each pair are connected to the respective *p*- and *n*- regions of each said layer (1_i).
- (2) Placed on both sides of each multijunction PhVC output (+) and (-) current
- 15 collectors, to which are connected said (+) and (-) contact electrodes, and which are meant to cut in an external electric circuit when operate;
- (3) At least single-layered antireflection coating of each multijunction PhVC entered into the solar battery composition;
- (4) At least single-layered transparent dielectric substrate of each multijunction PhVC
- 20 entered into the solar battery composition;
- (5) A reflector placed under said substrate.

Mass production of solar batteries based on described above multijunction PhVCs, each of which has optically matched and electrically insulated semiconductor layers connected independently to the said current collectors, would make it possible to increase

25 substantially specific output of solar power stations.

Additional feature consists in that all (+) and (-) discrete contact electrodes of identical polarity in each multijunction PhVC are arranged vertically one under another and shifted horizontally relative to the discrete contact electrodes of other polarity. This permits to decrease scattering of normally incident light by the contact electrodes of identical polarity and to exclude practically electrical breakdown between the opposite (+) and (-) discrete

30 contact electrodes.

Brief Description of the Drawings

This invention will now be explained by detailed description of structures and operation of multijunction photovoltaic converters and solar batteries with references to accompanying

35 drawings, in which:

Fig.1 shows an elementary multijunction PhVC comprising two semiconductor layers separated by a transparent electric insulator and discrete contact electrodes placed on opposite sides of both semiconductor layers (cross section);

Fig.2 shows a transparent electric insulator from the Fig.1 composed of several placed

40 in series dielectric layers (enlarged cross section);

Fig.3 shows an elementary multijunction PhVC comprising two semiconductor layers separated by transparent electric insulator and discrete contact electrodes placed on one side of each respective semiconductor layer (cross section);

Fig.4 shows a more complicated multilayered PhVC comprising three semiconductor layers separated by transparent electric insulators; discrete contact electrodes, placed on opposite sides of each semiconductor layer; an external antireflection coating; a transparent dielectric substrate; and a reflector (cross section);

Fig.5 shows more complicated multilayered PhVC comprising three semiconductor layers separated by transparent electric insulators; discrete contact electrodes, placed on one side of each respective semiconductor layer, an external antireflection coating; a transparent dielectric substrate; and a reflector (cross section);

Fig.6 shows an elementary solar battery based on single strip-shaped multijunction PhVC comprising two semiconductor layers (top view);

Fig.7 shows the same as Fig.6 (cross section by the vertical plane A-A);

Fig.8 shows the same as Fig.6 (cross section by the vertical plane B-B);

Fig.9 shows a solar battery based on three strip-shaped multijunction PVCs, each of which comprises of three semiconductor layers (top view);

Fig.10 shows the same as Fig.9 (cross section by the vertical plane A-A);

Fig.11 shows the same as Fig.9 (cross section by the vertical plane B-B);

Fig.12 shows a solar battery based on twelve multijunction PhVCs (top view).

Best Embodiments of the Invention

Each elementary multijunction PhVC (see Figs 1 and 3) comprises of:

Two semiconductor layers (1_1 and 1_2) arranged in series along the luminous flux; each such layer comprises of single *p-n* or *n-p* junction;

A transparent electric insulator 2_1 placed between of said adjacent semiconductor layers 1_1 and 1_2 ; and

At least two pairs of (+) and (-) discrete contact electrodes 3; said (+) and (-) electrodes 3 of each pair are connected to the respective *p*- and *n*- regions of each said semiconductor layer 1_1 and 1_2 .

More complicated multijunction PhVC (see Figs 4 and 5) comprises of:

Three semiconductor layers 1_1 , 1_2 , 1_3 arranged in series along the luminous flux; each such layer comprises of single *p-n* or *n-p* junction;

Transparent electric insulators 2_1 and 2_2 placed between said semiconductor layers 1_1 , 1_2 , 1_3 ; and

at least three pairs of (+) and (-) discrete contact electrodes 3; said (+) and (-) electrodes 3 of each pair are connected to the respective *p*- and *n*- regions of each said semiconductor layer.

Each multijunction PhVC (see Figs 4 and 5, 7 and 8, 10 and 11) can be equipped additionally with at least single-layered antireflection surface coating 4, a dielectric substrate 5 and a reflector 6 placed under said substrate 5.

Said contact electrodes 3 can be placed either on the both sides (see Figs 1 and 4), or on one side (see Figs 3 and 5) of each semiconductor layer 1_i , where "i" is serial number of the respective semiconductor layer along the luminous flux.

As a rule, actual number "f" of the semiconductor layers 1_i having built-in *p-n* or *n-p* junctions can be equal to two, three, four, etc. (while no more than three such layers are shown on Figs 4, 5, 10 and 11 for the sake of simplification). Correspondingly, number of the transparent electric insulators 2_i , where «i» is serial number of the respective insulator, can be more than one. Similarly, it is possible to use at least 2f pairs of (+) and (-) discrete contact electrodes 3 on condition that said (+) and (-) electrodes 3 of each pair are connected to the respective *p*- and *n*- regions of each said layer (1_i).

On the basis of known principles of blooming of optical systems, it is preferable, if at least one transparent electric insulator 2_i comprises of at least two transparent dielectric layers, but is more preferable, if each such insulator 2_i comprises of a set of transparent dielectric layers that is sufficient for the most effective optical matching of adjacent transparent PhVC's components. For example, Fig.2 shows enlarged view of first multi-layered transparent insulator 2_i composed of "r" placed sequentially transparent dielectric layers $2_{i1}, \dots, 2_{ij}, \dots, 2_{ir}$.

Selection of materials, which have refraction indexes and thicknesses that are appropriate for production of transparent electric insulators 2_i , antireflection surface coatings 4 and transparent dielectric substrates 5 (or individual dielectric layers of said insulators, coatings and substrates), must be grounded on following recommendations.

In case of use of single-layered transparent electric insulators 2_i , multireflection and scattering of light between semiconductor layers within any multijunction PhVC will be the less the less is difference of refraction indexes of each insulator 2_i and adjacent semiconductor layers 1_i . For example, if the semiconductor layers 1_i of some multijunction PhVC have produced from silicon having refraction index 3.5, it is desirable to produce the insulators 2_i from rutile (TiO_2) having refraction index 2.6. Difference of refraction indexes in about 25% provides only 2% reflection of normal incident light from the said layers' interface.

In case of use of multi-layered transparent electric insulators 2_i , their materials must be selected on conditions that refraction index of at least one of such dielectric layer is higher than refraction indexes of adjacent semiconductor layers 1_i (in particular, ferroelectric materials such as PbTiO_3 , BaTiO_3 , SrTiO_3 etc. can be used thereto), and that refraction index of at least one other dielectric layer is lower than refraction indexes of adjacent semiconductor layers 1_i .

Specific calculations of such multi-layered systems in order to minimize multireflection of light within any multijunction PhVC in the range of solar spectrum can be executed, for example, by the software product HFSS™ (3D Full-wave Electromagnetic Field Simulation).

These recommendations are valid also for the antireflection surface coatings 4 and for the transparent dielectric substrates 5.

An elementary solar battery (Fig.6) may comprise only one, in particular, strip-shaped multijunction PhVC 7, and two (+) and (-) current collectors 8 and 9 placed on both sides of the strip and meant for cut in an external electric circuit when the battery operates.

More complicated solar batteries may be composed either of several (for example, three) strip-shaped multijunction PhVCs 7 (Fig.9), or of arbitrary amount of a single sheet-shaped multijunction PhVCs 7 (Fig.12) equipped with several current collectors 8 and 9.

As it is shown on Figs 6, 7, 8, 11 and 12, said discrete (+) and (-) contact electrodes 3 of each PhVC 7 are connected in parallel to the respective current collectors 8 and 9.

Each solar battery (see Figs 7 and 8, 10 and 11) has usually in addition:

at least single-layered antireflection surface coating 4 of all PhVCs 7;

at least single-layered transparent dielectric substrate 5 of each PhVC 7 entered into the solar battery composition; and

a reflector 6 placed under the common substrate 5 (or under individual substrates 5).

As a rule (see Figs 1 and 4), said discrete contact electrodes 3 of the same (+) or (-) polarity being arranged vertically one under another and shifted horizontally relative to the discrete contact electrodes 3 of other polarity in each multijunction PhVC 7 entered into the solar battery composition.

It is obvious for each person skilled in the art that above-described embodiments of the invention do not restrict the scope of rights determined by the appended claims only, and that proposed PhVCs and solar batteries can produce using many known features such as:

Solar light concentrators (especially fixed concentrators based on the Fresnel lenses),
концентраторы солнечного света (в особенности неподвижные концентраторы на основе линз Френеля),

Decrease of band-gap's width of the semiconductor layers along the luminous flux, etc.

Specific characteristics of operation of above-described multijunction PhVCs and based thereon solar batteries are following.

Incident onto the PhVC's 7 surface solar light passes through the antireflection surface coating 4 and interacts sequentially with the semiconductor layers 1, those are pre-adjusted usually to absorption of photons related to the determined sub-bands of the solar spectrum. The reflector 6 provides return of residual light through the transparent dielectric substrate 5 into PhVCs 7 and double pass of this light through the semiconductor layers 1. Optical parameters matching of all dielectric and semiconductor layers, as it is described in details above, provides suppression of multireflection and undesired scattering of light between said layers within each PhVC 7. Respectively, it increases substantially probability of charge carriers' generation each semiconductor layer 1.

Because the semiconductor layers of all multijunction PhVCs are electrically insulated, recombination of generated charge carriers during their motion to each *p-n* (or *n-p*) junction is practically eliminated, and internal resistance to photocurrents is minimized. These characteristics of multijunction PhVCs cause substantial increase of their efficiency and specific output of the solar batteries based on such PhVCs.

Industrial Applicability

Any multijunction PhVCs according to the invention can be produced in large scale using various present technologies, including especially thermal-vacuum and/or ion-plasma deposition, any kinds of epitaxy, or any suitable combination of said processes, which are
5 able to create dielectric and semiconductor layers having specified chemical composition and to provide thickness accuracy at level of several nanometers.

Proposed multijunction PhVCs and solar batteries based thereon are substantially more effective, easy-produced, and more use- and serviceable in comparison with known analogues.

CLAIMS

1. Multijunction photovoltaic converter (further PhVC), comprising:

(a) at least two semiconductor layers (1_i) having built-in p - n or n - p junctions, where " i " is serial number of the respective semiconductor layer along the luminous flux;

5 (b) a transparent electrical insulator (2_i) embedded between said semiconductor layers and meant for their optical matching, where " i " is serial number of the respective insulator along the luminous flux;

(c) at least $2f$ pairs of (+) and (-) discrete contact electrodes, where f is number of semiconductor layers (1_i) in said PhVC, on condition that said (+) and (-) electrodes of each pair are connected to the respective p - and n - regions of each said layer (1_i).

2. Multijunction PhVC according to the claim 1, where in each arranged in series along the luminous flux group of the multijunction PhVC's details, namely:

«first semiconductor layer (1_i) – first transparent electric

insulator (2_i) – second semiconductor layer (1_{i+1})»,

15 «second semiconductor layer (1_{i+1}) – second transparent electric insulator (2_{i+1}) – third semiconductor layer (1_{i+2})» etc.

all said insulators (2_i) are single-layered, and refraction indexes of said semiconductor layers and said insulators are matched using antireflection criterion.

3. Multijunction PhVC according to the claim 1, where in each arranged in series along the luminous flux group of the multijunction PhVC's details, namely:

«first semiconductor layer (1_i) – first transparent electric

insulator (2_i) – second semiconductor layer (1_{i+1})»,

«second semiconductor layer (1_{i+1}) – second transparent electric insulator (2_{i+1}) – third semiconductor layer (1_{i+2})» etc.

25 at least one said insulator (2_i) is composed of at least two electro-insulating layers on conditions that refraction index of at least one such electro-insulating layer is higher as compared with the refraction indexes of adjacent semiconductor layers, and refraction index of second such electro-insulating layer is lower as compared with the refraction indexes of adjacent semiconductor layers.

30 4. Multijunction PhVC according to the claim 1, or to the claim 2 or to the claim 3, wherein said (+) and (-) contact electrodes (3) are placed on the both sides of each respective semiconductor layer (1_i).

5. Multijunction PhVC according to the claim 1, or to the claim 2 or to the claim 3, wherein said (+) and (-) contact electrodes (3) are placed on the one side of each respective semiconductor layer (1_i).

35 6. Multijunction PhVC according to the claim 1, or to the claim 2 or to the claim 3, which has at least single-layered antireflection surface dielectric coating (4) faced to the light source when operates.

7. Multijunction PhVC according to the claim 1, or to the claim 2 or to the claim, which is mounted on at least single-layered transparent dielectric substrate (5), under which a reflector (6) is placed.

8. Solar battery, comprising:

5 (1) At least one multijunction PhVC (7), comprising:

(a) at least two semiconductor layers (1_i) having built-in p - n or n - p junctions, where " i " is serial number of the respective semiconductor layer along the luminous flux;

(b) at least single-layered transparent electrical insulator (2_i) embedded between each pairs of the adjacent semiconductor layers and meant also for their optical matching, where
10 " i " is serial number of the respective insulator along the luminous flux;

(c) at least $2f$ pairs of (+) and (-) discrete contact electrodes (3), where f is number of semiconductor layers (1_i) in the PhVC (7), on condition that said (+) and (-) electrodes (3) of each pair are connected to the respective p - and n - regions of each said layer (1_i).

(2) Placed on both sides of each PhVC (7) output (+) and (-) current collectors (8) and
15 (9), to which are connected said (+) and (-) contact electrodes (3), and which are meant to cut in an external electric circuit when operate;

(3) At least single-layered antireflection coating (4) of each multijunction PhVC (7) entered into the solar battery composition;

(4) At least single-layered transparent dielectric substrate (5) of each PhVC (7) entered
20 into the solar battery composition;

(5) A reflector (6) placed under said substrate (5).

9. Solar battery according to claim 8, wherein all (+) and (-) discrete contact electrodes (3) of identical polarity in each PhVC (7) are arranged vertically one under another and shifted horizontally relative to the discrete contact electrodes (3) of other polarity.

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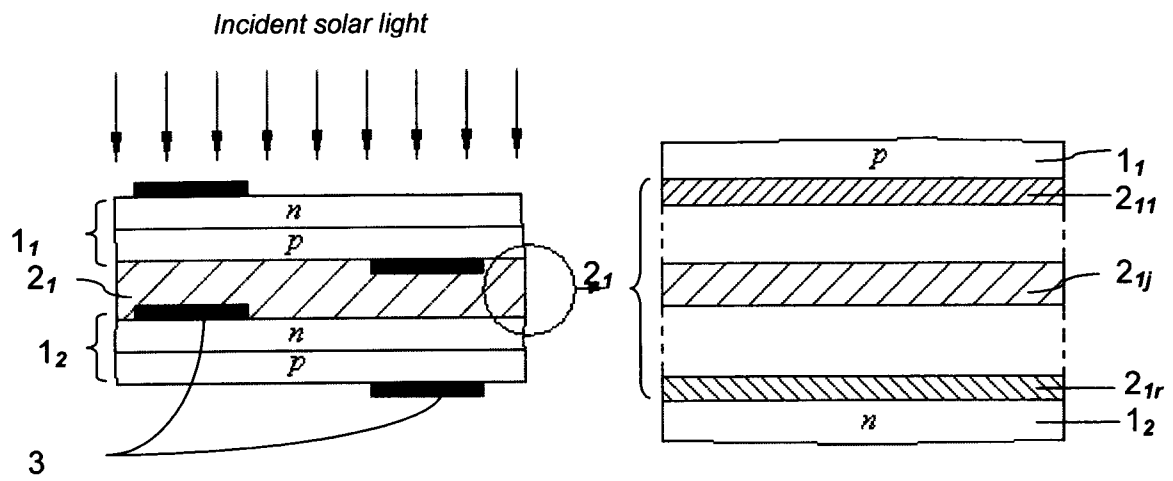


Fig. 1

Fig. 2

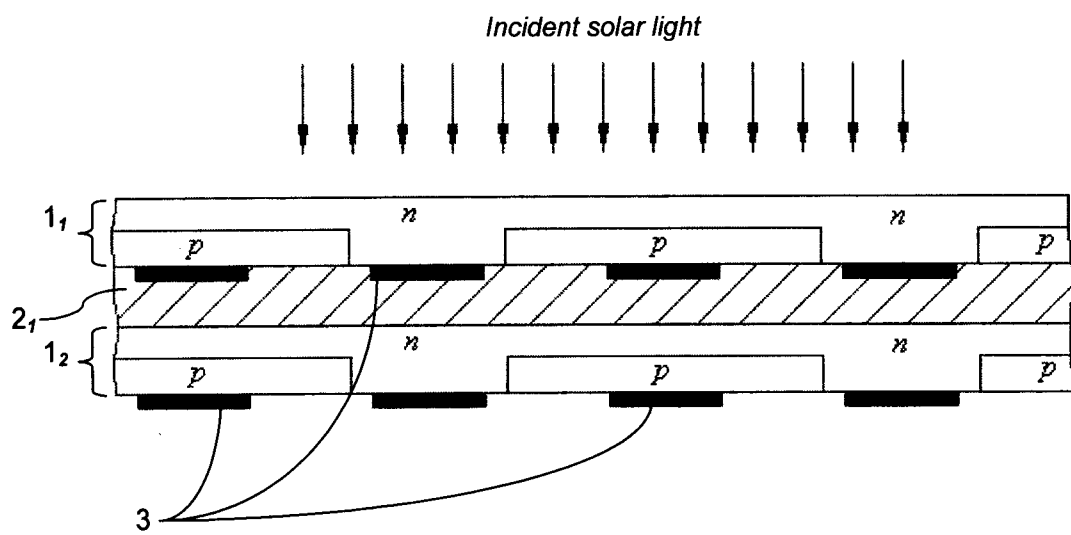


Fig. 3

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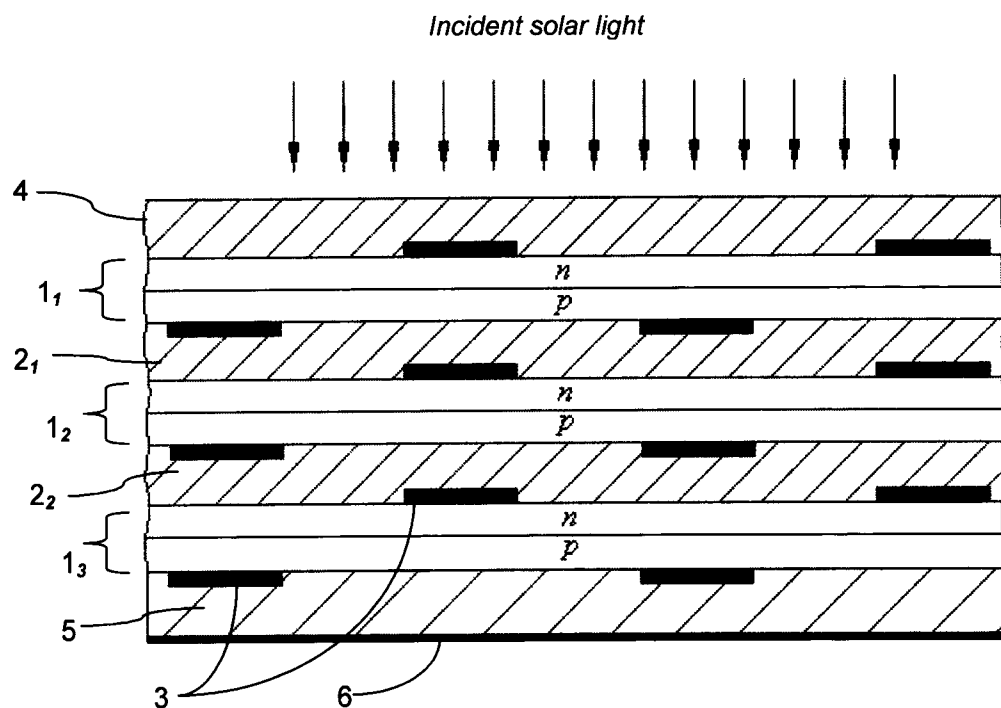


Fig. 4

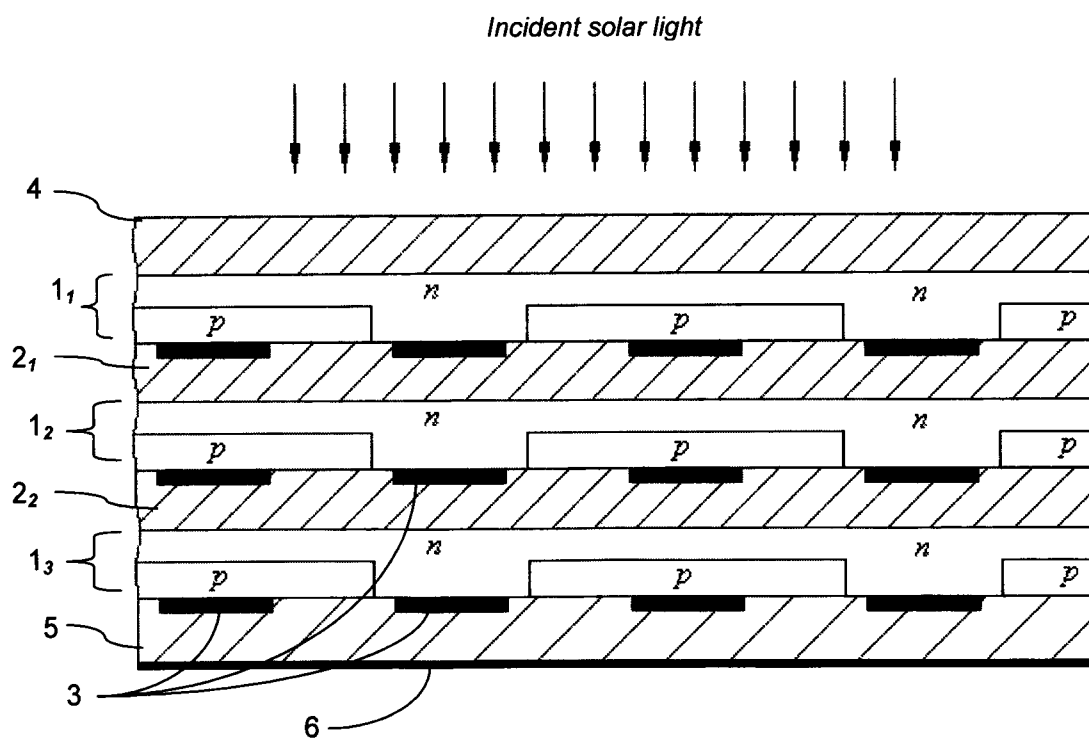


Fig. 5

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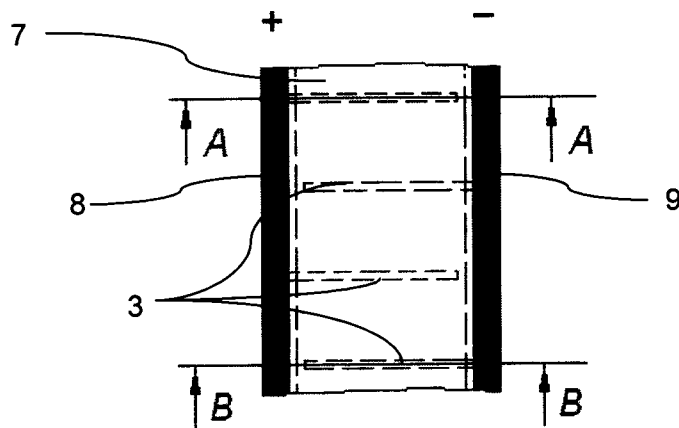


Fig. 6

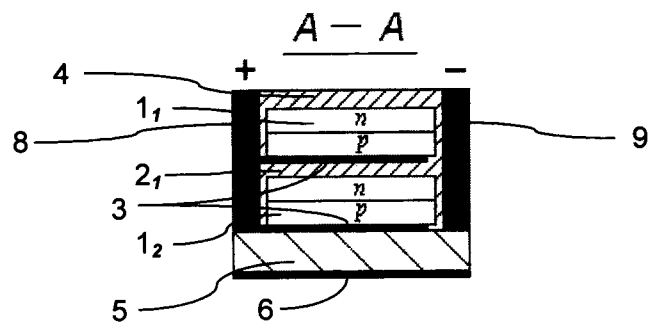


Fig. 7

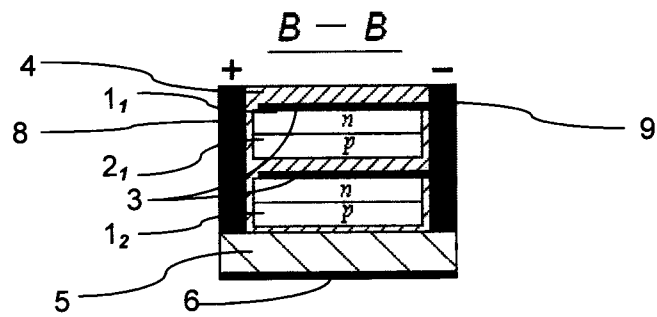


Fig. 8

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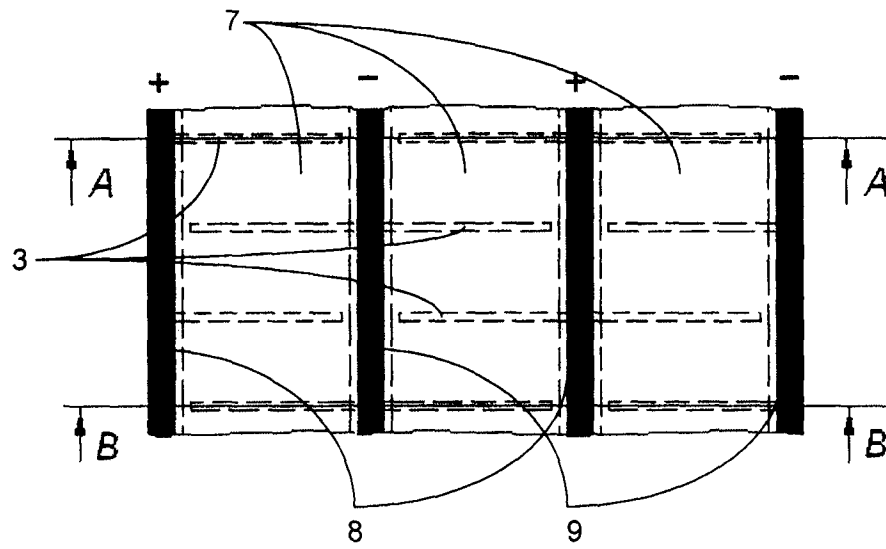


Fig. 9

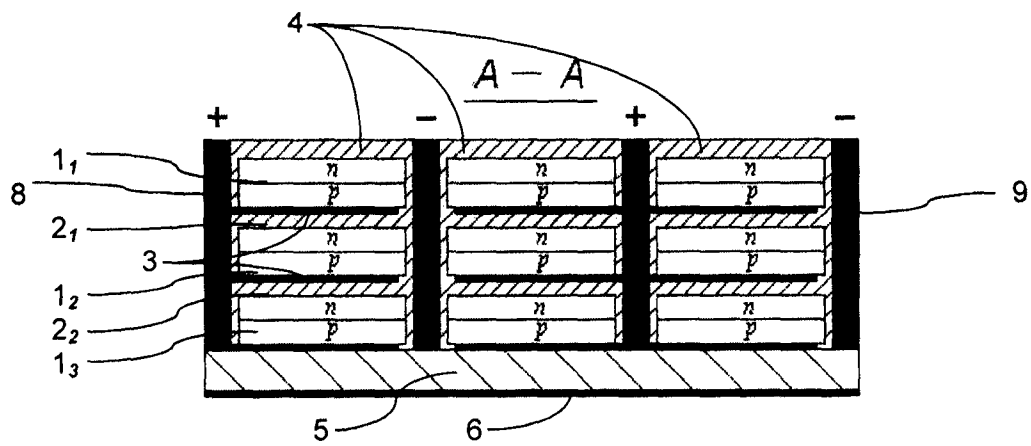


Fig. 10

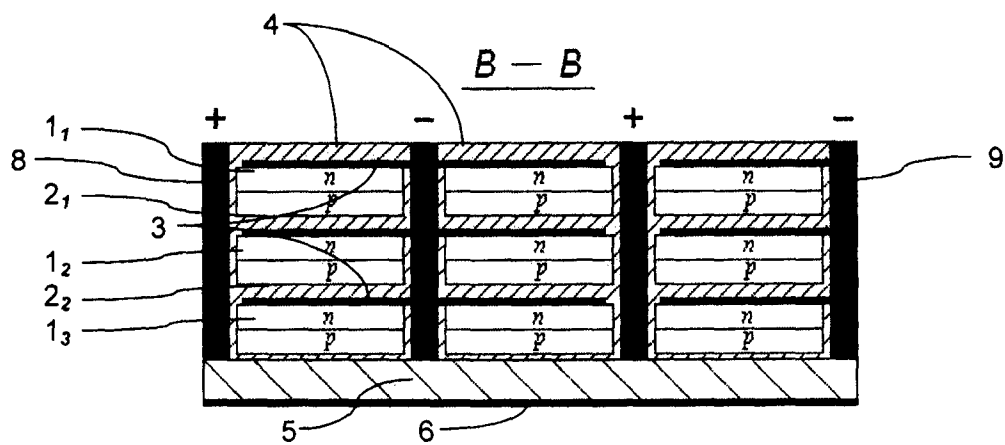


Fig. 11

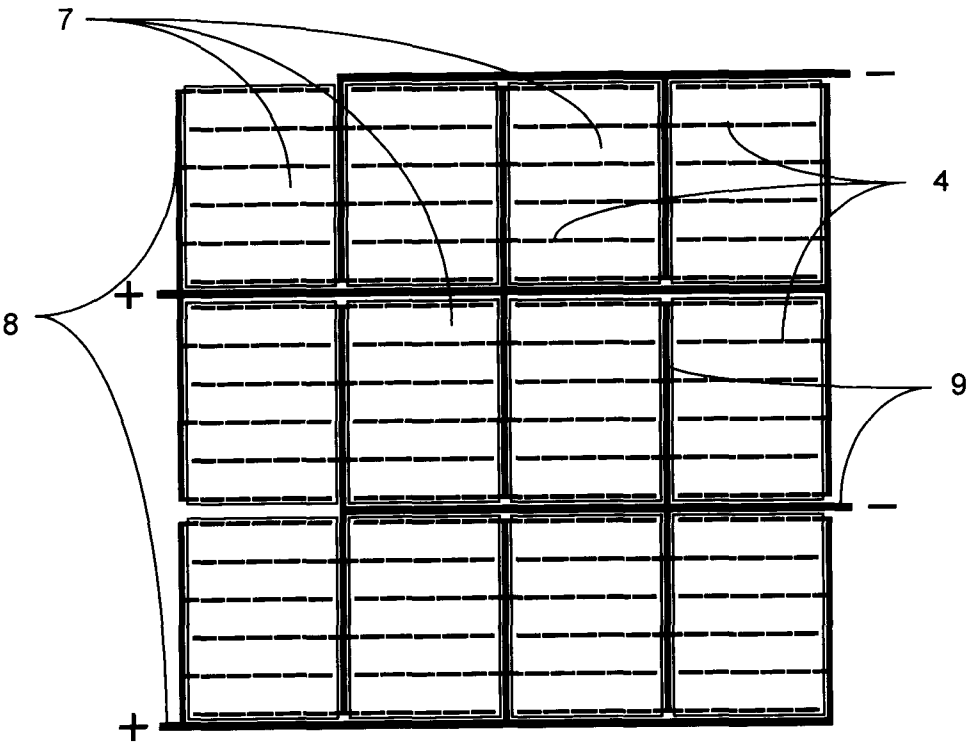


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/UA 2012/000015

A. CLASSIFICATION OF SUBJECT MATTER *H01L 31/042 (2006.01)*

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)

H01L 31/00, 31/04, 31/042, 31/05, 31/06, 31/068, 31/072

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

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

PatSearch (RUPTO internal), Esp@cenet, PAJ, DWPI, USPTO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RU 2376679 C1 (OBSHESTVO S OGRANICHENNOI OTVETSTVENNOSTIYU "TEKHOLOGIYA POLUPROVODNIKOVYKH KRISTALLOV") 20.12.2009	1-9
A	US 2008/0216885 A1 (SERGEY FROLOV et al.) 11.11.2008	1-9
A	RU 2377695 C1 (FEDERALNOE GOSUDARSTENNOE UNITARNOE PREDPRIYATIE "VSEROSYSKY ELEKTROTEKHNIЧЕСKY INSTITUT IM. V. I. LENINA" (FGUP BEI)) 27.12.2009	1-9



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document but published on or after the international filing date	"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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

16 February 2012 (16.02.2012)

Date of mailing of the international search report

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