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(54) Title: A PHOTOVOLTAIC DEVICE WITH AN INTEGRATED SENSOR

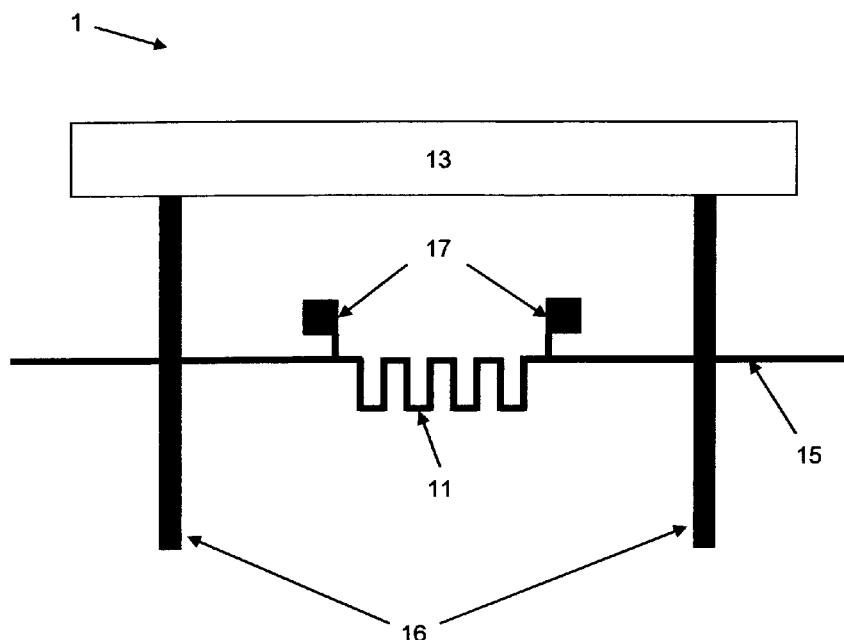


FIG. 1a

(57) Abstract: The present invention relates to a photovoltaic device (1, 2, 3) for generating electricity and sensing environmental parameters. The photovoltaic device (1, 2, 3) comprises a semiconductor junction (12), a front contact (13), a back contact (14), at least one metal collector finger (15, 25, 35), at least two busbars (16, 26, 36), and at least one sensor (11, 21, 31). The at least one sensor (11, 21, 31) is a portion of the at least one metal collector finger (15, 25, 35) shaped in a serpentine manner to sense environmental parameters such as temperature, humidity, gas content and the like.

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A PHOTOVOLTAIC DEVICE WITH AN INTEGRATED SENSOR

FIELD OF INVENTION

The present invention relates to a photovoltaic device and more particularly,
5 the present invention relates to a photovoltaic cell integrated with at least one sensor.

BACKGROUND OF THE INVENTION

Photovoltaic cells convert energy from sunlight into electrical energy which
can be used to power up electronic devices. A conventional photovoltaic cell
10 comprises of a single or multiple p-n or p-i-n junction(s), a back contact, and front
contact(s) connected to a plurality of metal collector fingers and busbar structures.

Photovoltaic cells are often placed in an open environment to allow it to
absorb sunlight for supplying electrical energy to electronic devices. Since it is placed
15 in an open environment, it is useful to integrate photovoltaic cells with a sensor
device for measuring environmental parameters. At present, there are prior arts that
integrate photovoltaic cells with a sensor device to detect light properties such as
ultraviolet, infrared and light sensor.

20 US Patent No. 7,241,999 discloses the use of a photovoltaic element as
sensor for checking the functionality of transmitters in the infrared range.

US Patent Application No. 20070145499 discloses a photovoltaic ultraviolet
sensor that comprises a zinc oxide single crystal substrate. On the +c face of the zinc
oxide single crystal substrate, an ultraviolet receiver is formed. The exemplary
25 ultraviolet receiver includes a Schottky electrode which, when receiving ultraviolet
rays, produces a voltage in cooperation with the zinc oxide single crystal substrate.
The ultraviolet sensor does not have any sensitivity to the visible rays. The ultraviolet
sensor has a relatively fast response of several microseconds.

30

However, none of the prior arts integrates photovoltaic cells with sensor
device to measure environmental parameters such as temperature, humidity, gas
content and the like. The integration of photovoltaic cells with such sensor device
needs to ensure that the sensor device does not heavily affect the electrical energy
35 produced by either highly consuming the electrical energy produced by the

photovoltaic cells or arranging the sensor device in a manner that limits the sunlight absorption area of the photovoltaic cells. Moreover, the integration must also consider the effect of exposing the sensor device to direct sunlight. The photovoltaic cells should also be able to integrate with an array of sensors to increase sensitivity and performance in sensing the environment parameters.

Therefore, there is a need to provide a photovoltaic device that integrates photovoltaic cells with at least one sensor device for sensing environmental parameters such as temperature, humidity, gas content and the like.

SUMMARY OF INVENTION

The present invention relates to a photovoltaic device (1, 2, 3) for generating electricity and sensing environmental parameters. The photovoltaic device (1, 2, 3) comprises a semiconductor junction (12), wherein the semiconductor junction (12) functions to generate electricity from light, a front contact (13, 23, 33) provided on top of the semiconductor junction (12), wherein the front contact (13, 23, 33) is to allow connection with an external circuit for supplying electricity, a back contact (14) provided underneath the semiconductor junction (12), wherein the back contact (14) is to allow connection with an external circuit for supplying electricity, at least one metal collector finger (15, 25, 35) provided on top of the semiconductor junction (12), wherein the at least one metal collector finger (15, 25, 35) is to allow current flow from the semiconductor junction (12) to the front contact (13, 23, 33), and at least one busbar (16, 26, 36) connected to the front contact (13, 23, 33) and the at least one metal collector finger (15, 25, 35). Moreover, the photovoltaic device (1, 2, 3) is characterised in that it further comprises at least one sensor (11, 21, 31), and wherein the at least one sensor (11, 21, 31) is a portion of the at least one metal collector finger (15, 25, 35) shaped in a serpentine manner.

Preferably, the semiconductor junction (12) is a single or multiple type junction(s). Moreover, the semiconductor junction is preferably either a p-n junction, p-i-n junction, schottky junction or any combination thereof.

Preferably, the at least one sensor (11, 21, 31) occupies an area of less than 300 μm^2 .

Preferably, the at least one sensor (15, 25, 35) is provided with two electrical contact pads (17, 27) in between the serpentine structure for connection with an external sensing circuit.

5 Preferably, the at least one sensor (15, 25, 35) is provided in between the at least two busbars (16, 26, 36), and wherein each busbar (16, 26, 36) is provided with electrical contact pad (37) for connection with an external sensing circuit.

10 Preferably, the at least one metal collector finger (15, 25, 35) and the at least one sensor (11, 21, 31) are made of metallic conductive material.

15 Preferably, the at least one sensor (15, 25, 35) is covered with metal oxide membrane to sense specific ions, and wherein the metal oxide membrane is suitably made out of one of the following materials: tin oxide (SnO_2), tungsten oxide (WO_x), tantalum pent-oxide (Ta_2O_5), aluminium oxide (Al_2O_3), copper oxide (CuO), iron oxide (Fe_2O_3), titanium oxide (TiO), Neodymium Oxide (Nd_2O_3) or zinc oxide (ZnO).

20 Preferably, the at least one sensor (15, 25, 35) is covered with nanotubes or nanowires membrane.

BRIEF DESCRIPTION OF THE DRAWINGS

25 The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

30 **FIG. 1a** illustrates a top view of a photovoltaic device (1) in accordance with a first embodiment of the present invention.

FIG. 1b illustrates a cross sectional view of a photovoltaic device (1) in accordance with a first embodiment of the present invention.

FIG. 2 illustrates a top view of a photovoltaic device (2) in accordance with a second embodiment of the present invention.

FIG. 3 illustrates a top view of a photovoltaic device (3) in accordance with a third embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

5 A preferred embodiment of the present invention will be described herein below with reference to the accompanying drawings. In the following description, well known functions or constructions are not described in detail since they would obscure the description with unnecessary detail.

10 Referring now to **FIGS. 1(a-b)**, there is provided a first embodiment of a photovoltaic device (1) wherein a photovoltaic cell is integrated with a sensor (11). The photovoltaic device (1) has dual function whereby it is able to generate electricity from light as well as sensing environmental parameters such as temperature, humidity, gas content and the like. The photovoltaic device (1) comprises a p-n
15 junction (12), a front contact (13), a back contact (14), a metal collector finger (15), two busbars (16), and a sensor (11).

 The p-n junction (12) comprises two separate semiconductors sandwiched together. Preferably, the p-n junction comprises a negative-type silicon (12a) which
20 has excess electrons sandwiched with a positive-type silicon (12b) which has excess holes. Sandwiching the negative-type silicon (12a) and the positive-type silicon (12b) together creates electron-hole pairs at their interface, thereby creating an electric field. When sunlight, in the form of photons, is provided, its energy breaks apart the electron-hole pairs. Each photon with enough energy frees an electron, and resulting
25 in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the negative-type silicon (12a) and the hole to the positive-type silicon (12b). If an external circuit is connected between the front contact (13) and the back contact (14), electrons will flow through the circuit to the positive-type silicon (12b) to
30 unite with the holes. The electron flow provides the current, and the electric field causes a voltage.

 The front and back contacts (13, 14) are provided to allow connection with an external circuit for supplying electrical power. The front contact (13) is provided on
35 top of the negative-type silicon (12a), whereas the back contact (14) is provided

underneath the positive-type silicon (12b). The front contact (13) is connected to the metal collector finger (15) through the busbars (16).

The metal collector finger (15) is a finer area of metallization to allow the current flow from the negative-type silicon (12a) to the front contact (13) through the busbars (16). The metal collector finger (15) is integrated with a sensor (11) on top of the p-n junction (12). The sensor (11) is a resistive type sensor wherein a portion of the metal collector finger (15) is shaped in a serpentine manner and it is provided with two electrical contact pads (17) in between the sensor (11) for connection with an external sensing circuit. The sensor (11) occupies a small area of the metal collectors (15) to minimize the impact on the overall efficiency of the p-n junction (12) to generate electrical power. Preferably, the sensor (11) occupies an area of less than $300\text{ }\mu\text{m}^2$. Preferably, the metal collector finger (15) and sensor (11) are made of metallic conductive material such as aluminium, silver, gold, platinum, tungsten, copper, or nickel. Moreover, the metal collector finger (15) which includes the sensor (11) is preferably formed by sputtering, evaporation, screen printing, electroplating or chemical vapour deposition.

Alternatively, the sensor (11) can be covered with sensing membrane to sense specific ions, and thus, allowing multiple sensor types to be integrated onto the photovoltaic device (1). The sensing membrane may further improve the sensor sensitivity by having a large surface to volume ratio. The sensing membrane is preferably a metal oxide membrane or a nanostructure membrane. The metal oxide membrane can be made of but not limited to tin oxide (SnO_2), tungsten oxide (WO_x), tantalum pent-oxide (Ta_2O_5), aluminium oxide (Al_2O_3), copper oxide (CuO), iron oxide (Fe_2O_3), titanium oxide (TiO), Neodymium Oxide (Nd_2O_3) or zinc oxide (ZnO). The nanostructure membrane can be made of nanotubes or nanowires such as single-walled carbon nanotubes (SWNTs), multi-walled carbon nanotubes (MWNTs), silicon nanowires, tungsten nanowires, gold nanowires.

The output from the sensor (11) is measured via the two electrical contact pads (17) when there is a change in resistance which is determined by the dimensions and conductive material properties of the sensor (11), using the formula below:

$$R = \rho_s \cdot L / W$$

where ρ_s is the sheet resistance of the conductive material, L is the length of the sensor (11) and W is the width of the sensor (11).

5 In order to use the sensor (11) for temperature sensing, the sensor (11) comprises only the serpentine structure of the metal collector finger (15). There is a linear relationship between the change in temperature and the change in resistivity and therefore, a change in temperature affects the resistivity of the sensor (11).

10 In order to use the sensor (11) for gas or humidity sensing, the sensor (11) comprises the serpentine structure of the metal collector finger (15) with a thin film or nanostructures on top of it. Preferably, the serpentine structure is covered with polyimide film or carbon nanotubes for humidity sensing to absorb moisture in the environment. Thus, a change in humidity affects the resistivity of the sensor (11). For
15 gas sensing application, the serpentine structure is preferably coated with metal oxide thin film or nanowires. The reaction between the metal oxide and gas induces a change in the resistivity of the sensor (11).

Referring now to FIG 2, there is provided a second embodiment of a
20 photovoltaic device (2) wherein an array of sensors (21) are integrated in series to a metal collector finger (25). The photovoltaic device (2) has dual function whereby it is able to generate electricity from light as well as sensing environmental parameters such as temperature, humidity, gas content and the like. The photovoltaic device (2) comprises a p-n junction (not shown), a front contact (23), a back contact (not
25 shown), a plurality of metal collector fingers (25), three busbars (26) and an array of sensors (21).

The p-n junction (not shown) comprises two separate semiconductors sandwiched together. Preferably, the p-n junction (not shown) comprises a negative-
30 type silicon sandwiched with a positive-type silicon. The p-n junction is functioned to generate electricity from absorbing light.

The front contact (23) is provided on top of the p-n junction (not shown), whereas the back contact (not shown) is provided underneath the p-n junction (not
35 shown). The front and back contacts are provided to allow connection with an

external circuit for supplying electrical power. The front contact (23) is connected to the plurality of metal collector fingers (25) through the busbars (26).

5 The plurality of metal collector fingers (25) is finer areas of metallization to allow the current flow from the p-n junction (not shown) to the front contact (23) through the busbars (26). One of the metal collector fingers (25) is provided with an array of sensors (21). The sensors (21) are serially integrated to the metal collector finger (25). Each sensor (21) is a resistive type sensor wherein a portion of the metal collector finger (25) is shaped in a serpentine manner and it is provided with two
10 electrical contact pads (27) in between the serpentine structure for connection with an external sensing circuit.

Referring now to FIG. 3, there is provided a third embodiment of a photovoltaic device (3) wherein an array of sensors (31) are serially integrated. The
15 photovoltaic device (3) has dual function whereby it is able to generate electricity from light as well as sensing environmental parameters such as temperature, humidity, gas content and the like. The photovoltaic device (3) comprises a p-n junction (not shown), a front contact (33), back contact (not shown), a plurality of metal collector fingers (35), two busbars (36) and an array of sensors (31).

20

The p-n junction (not shown) comprises two separate semiconductors sandwiched together. Preferably, the p-n junction (not shown) comprises a negative-type silicon sandwiched with a positive-type silicon. The p-n junction (32) is functioned to generate electricity from absorbing light.

25

The front contact (33) is provided on top of the p-n junction (not shown), whereas the back contact is provided underneath the p-n junction (not shown). The front and back contacts are provided to allow connection with an external circuit for supplying electrical power. The front contact (33) is connected to the plurality of
30 metal collector fingers (35) through the busbars (36) on top of the p-n junction (not shown).

Each metal collector finger (35) is integrated with a sensor (31). Each sensor (31) is a resistive type sensor wherein a portion of the metal collector finger (35) is
35 shaped in a serpentine manner. Each sensor (31) is serially connected to each other

through the busbars (36). One end of the busbars (36) is connected to the front contact (33) whereas another end of the busbars (36) is provided with electrical contact pad (37) for connection with an external sensing circuit. The serial integration of sensors (31) may further improve the photovoltaic device (3) sensitivity and
5 performance in sensing environmental parameters.

Although described in the description that the p-n junction is used to generate electrical power, any other semiconductor junction that is capable of generating electrical power from light can be used. Non-limiting example of the semiconductor
10 junction may include p-i-n junction, schottky junction or any combination thereof.

While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrated and describe all possible forms of the invention. Rather, the words used in the specifications are words of description
15 rather than limitation and various changes may be made without departing from the scope of the invention.

CLAIMS

1. A photovoltaic device (1, 2, 3) for generating electricity and sensing environmental parameters comprising:

a) a semiconductor junction (12), wherein the semiconductor junction (12) functions to generate electricity from light,

b) a front contact (13, 23, 33) provided on top of the semiconductor junction (12), wherein the front contact (13, 23, 33) is to allow connection with an external circuit for supplying electricity,

c) a back contact (14) provided underneath the semiconductor junction (12), wherein the back contact (14) is to allow connection with an external circuit for supplying electricity,

d) at least one metal collector finger (15, 25, 35) provided on top of the semiconductor junction (12), wherein the at least one metal collector finger (15, 25, 35) is to allow current flow from the semiconductor junction (12) to the front contact (13, 23, 33), and

e) at least one busbar (16, 26, 36) connected to the front contact (13, 23, 33) and the at least one metal collector finger (15, 25, 35);

characterised in that the photovoltaic device further comprising:

f) at least one sensor (11, 21, 31), and wherein the at least one sensor (11, 21, 31) is a portion of the at least one metal collector finger (15, 25, 35) shaped in a serpentine manner.

2. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the semiconductor junction (12) is a single or multiple type junction(s).

3. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the semiconductor junction (12) is either a p-n junction, p-i-n junction, schottky junction or any combination thereof.

4. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the at least one sensor (11, 21, 31) occupies an area of less than $300\text{ }\mu\text{m}^2$.
5. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the at least one sensor (15, 25, 35) is provided with two electrical contact pads (17, 27) in between the serpentine structure for connection with an external sensing circuit.
- 10 6. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the at least one sensor (15, 25, 35) is provided in between the at least two busbars (16, 26, 36), and wherein each busbar (16, 26, 36) is provided with electrical contact pad (37) for connection with an external sensing circuit.
- 15 7. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the at least one metal collector finger (15, 25, 35) and the at least one sensor (11, 21, 31) are made of metallic conductive material.
- 20 8. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the at least one sensor (15, 25, 35) is covered with metal oxide membrane to sense specific ions, and wherein the metal oxide membrane is made out of one of the following materials: tin oxide (SnO_2), tungsten oxide (WO_x), tantalum pent-oxide (Ta_2O_5), aluminium oxide (Al_2O_3), copper oxide (CuO), iron oxide (Fe_2O_3), titanium oxide (TiO), Neodymium Oxide (Nd_2O_3) or zinc oxide (ZnO).
- 25 9. A photovoltaic device (1, 2, 3) as claimed in claim 1, wherein the at least one sensor (15, 25, 35) is covered with nanotubes or nanowires membrane.

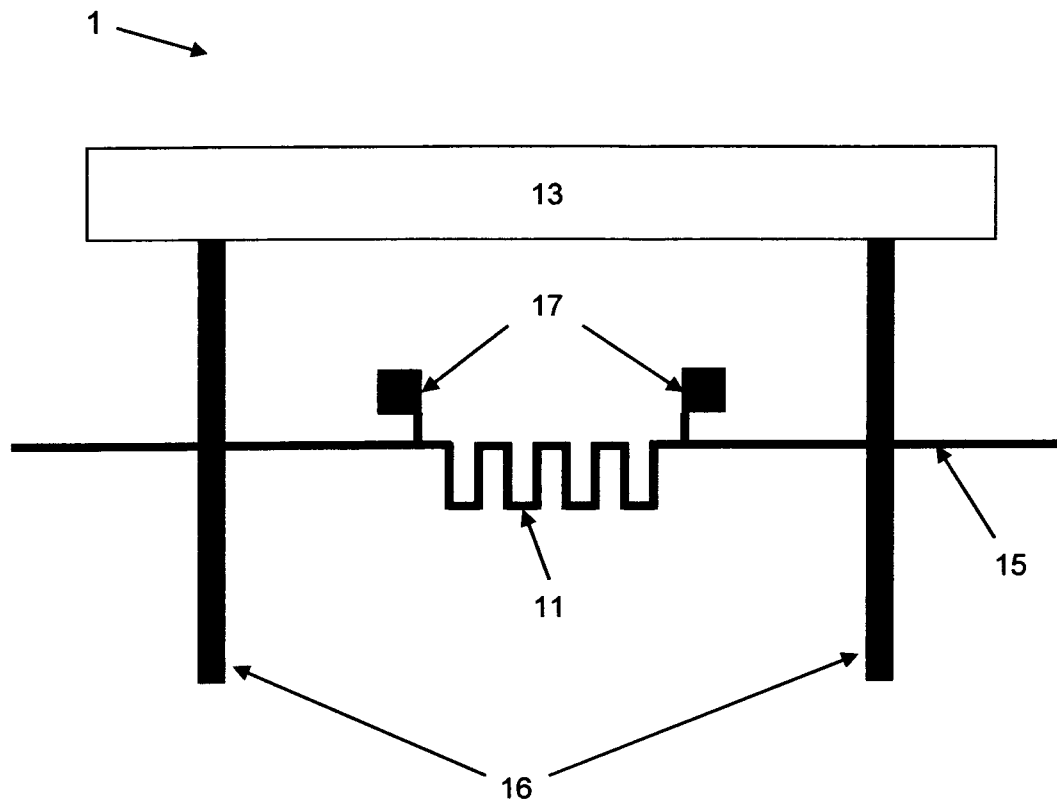


FIG. 1a

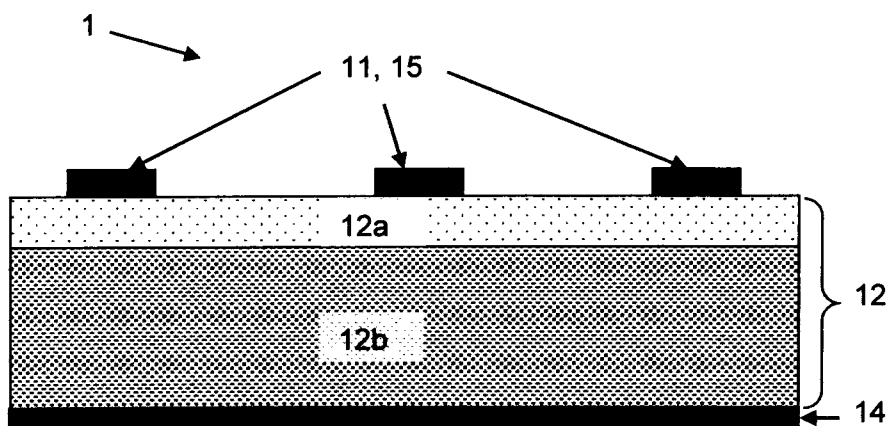


FIG. 1b

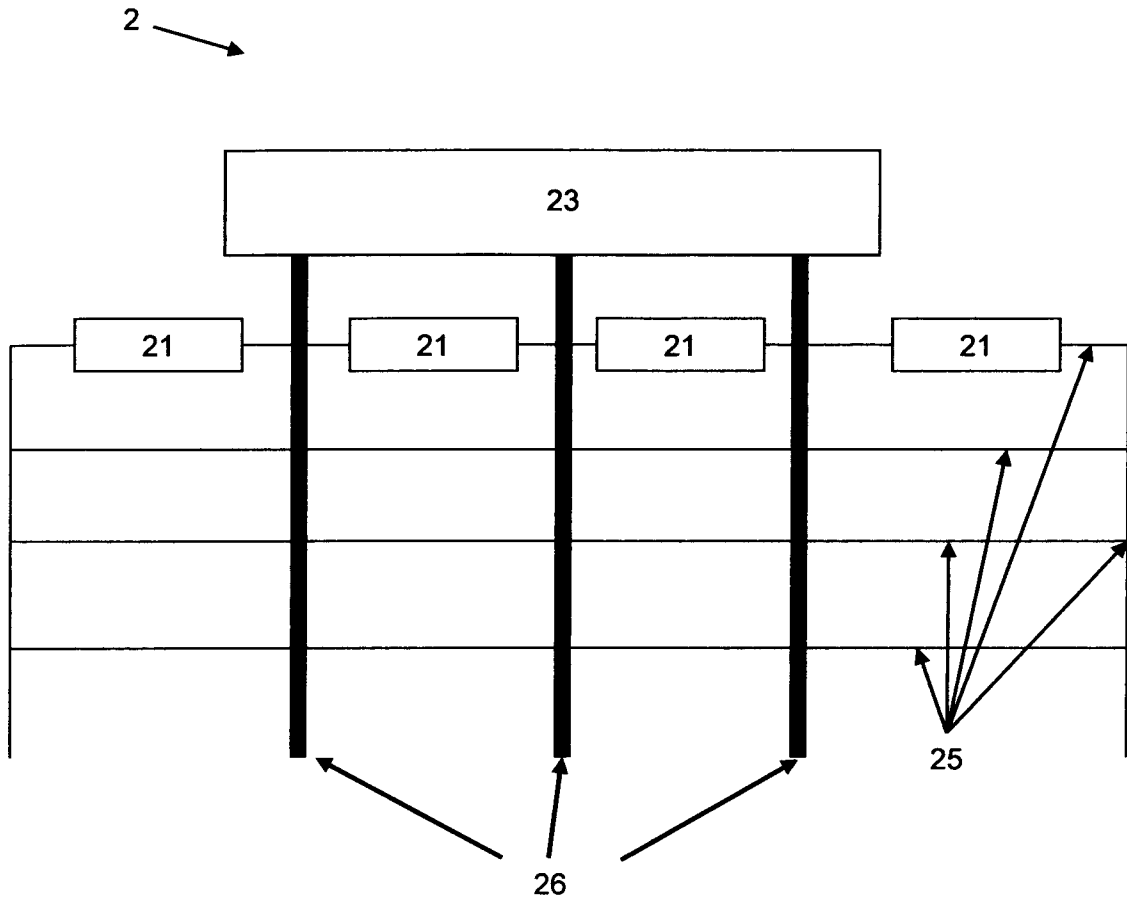


FIG. 2

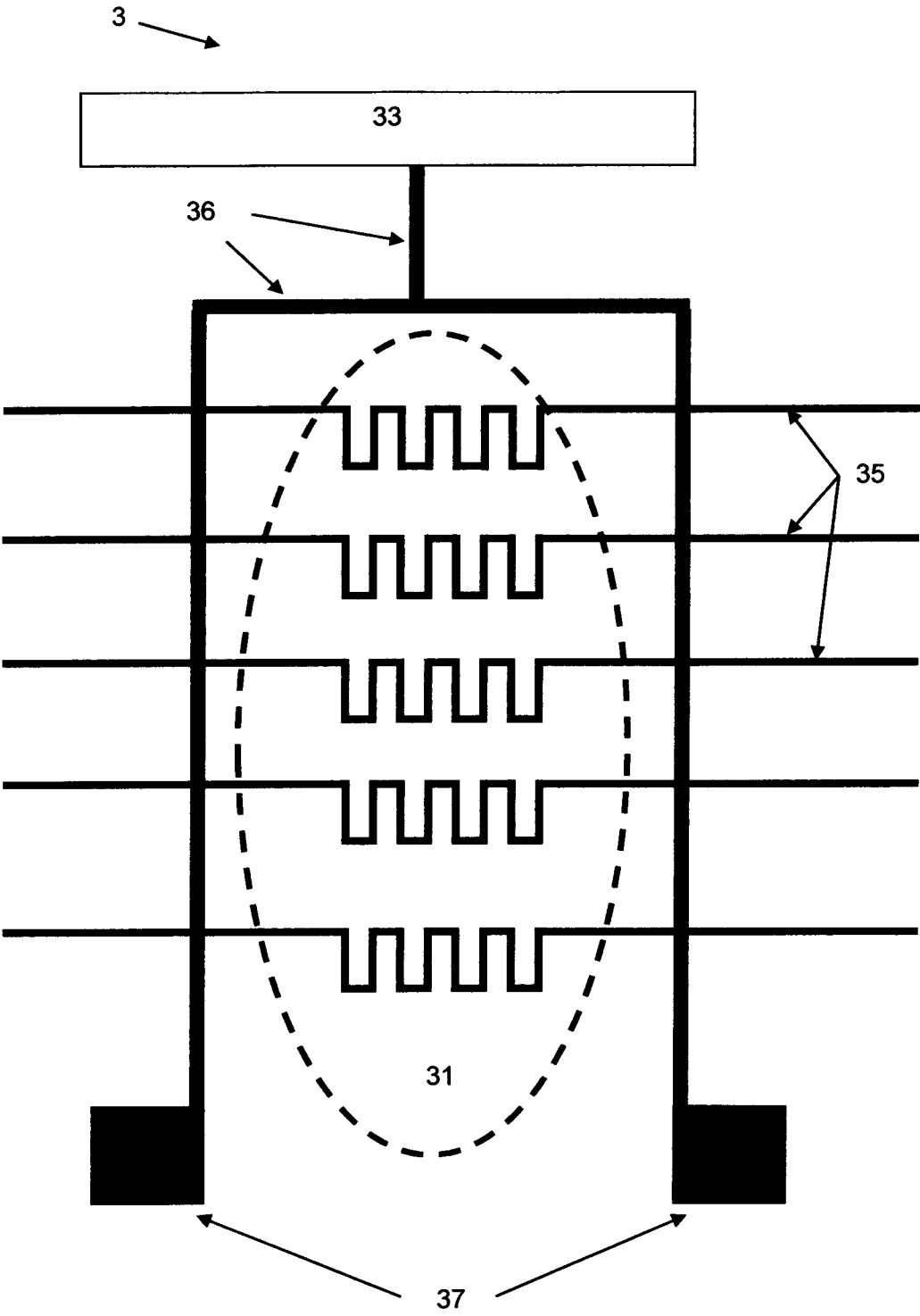


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/MY2012/000026

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H01L 31/06 (2012.01) H01L 31/0224 (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)

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)

EPODOC, WPI: IPC (H01L31/00) & Keywords (photovoltaic, solar, cell, device, module, sensor, detector, analysis, serpentine, winding, zigzag, resistive, environment, air, temperature, humidity, gas, ion, electrode, busbar, finger, grid, line, metal, silver, gold, aluminium, integrated, combined, membrane, layer, nano, and similar terms); Google Scholar: photovoltaic, resistive, sensor, collector, finger, serpentine; EPODOC via Espacenet: MIMOS as Applicant AND photovoltaic/photo/solar in Title/Abstract; Daniel Bien Chia Sheng as Inventor; Lee Hing Wah as Invnetor.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/0300509 A1 (RAYMOND et al.) 2 December 2010 Entire document, in particular Abstract; Fig. 1; Fig. 2.	
A	US 2010/0116325 A1 (NIKOONAHAD) 13 May 2010 Entire document, in particular Abstract; paragraphs 56, 71, 88, 111.	
A	US 2005/0212066 A1 (ARANA et al.) 29 September 2005 Entire document, in particular Abstract; Fig. 1; paragraphs 14-15.	



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	"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
"E" earlier application or patent but published on or after the international filing date	"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
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"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"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
22 May 2012

Date of mailing of the international search report
25 May 2012

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/MY2012/000026

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report			Patent Family Member		
US	2010300509	NONE			
US	2010116325	CN 102217084	WO	2010056764	
US	2005212066	CN 1926421	EP	1728059	JP 2007522481
		US 7087451	WO	2005098386	
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.					
END OF ANNEX					