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(54) **Title:** A RESISTIVE GAS SENSOR DEVICE

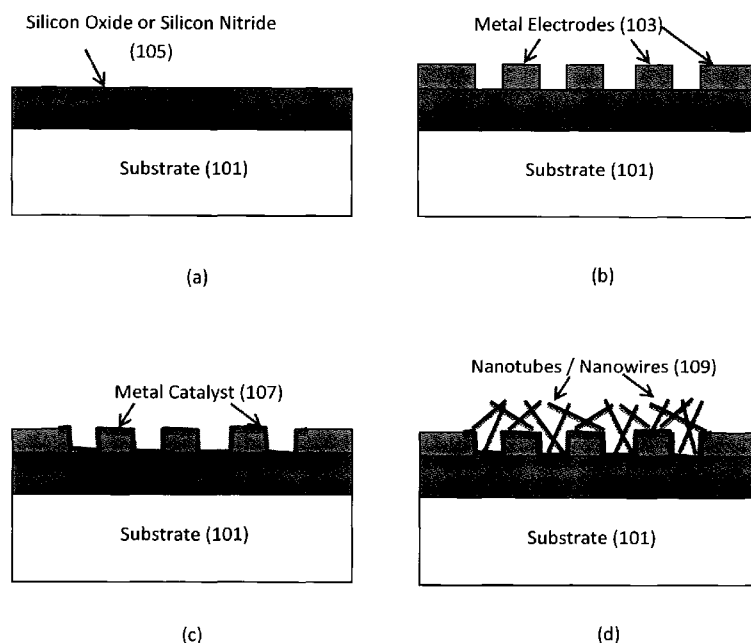


Figure 4

(57) **Abstract:** A resistive gas sensor device, wherein the gas sensor device operates based on changes in electrical resistivity using nanomaterials interconnectable by conductive bridge electrodes between contact electrodes.



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A RESISTIVE GAS SENSOR DEVICE

FIELD OF INVENTION

- 5 The present invention relates to a resistive gas sensor device and a method of fabricating the resistive gas sensor device.

BACKGROUND OF INVENTION

- 10 Chemical gas detection has many applications in agriculture, environmental monitoring, biomedical and industrial processes. Typical gas sensor devices comprise thin film sensing membrane on top of a microhotplate platform where the microhotplate is used to heat up the sensing membrane to a few hundred degrees Celsius to improve device sensitivity. However, microhotplates are considered active devices which are of high power
15 consumption, hence not feasible for continuous monitoring.

US 2009/0151429 describes a resistive gas sensor device that uses a microheater as a platform. However, this prior art does not address the problem of high power consumption which is not ideal for monitoring.

20

Therefore, there is a need for an alternative method of producing and using gas sensors without heating to high temperatures.

SUMMARY OF INVENTION

Accordingly, there is provided a resistive gas sensor device, wherein the gas sensor device operates based on changes in electrical resistivity using nanomaterials interconnectable by
5 conductive bridge electrodes between contact electrodes.

Further, there is provided a method of fabricating a resistive gas sensor device, characterized in that, the method includes the steps of depositing an insulating layer on a silicon substrate layer, depositing a conductive metal layer onto the insulating layer,
10 depositing a thin metallic catalyst layer covering a surface of the conductive metal layer and etching the metal catalyst layer and growing nanostructures from the metal catalyst layer that is exposed, such that the nanostructures are interconnected with each other and the conductive metal layer.

15 The present invention consists of several novel features and a combination of parts hereinafter fully described and illustrated in the accompanying description and drawings, it being understood that various changes in the details may be made without departing from the scope of the invention or sacrificing any of the advantages of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be fully understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only, and thus
5 are not limitative of the present invention, wherein:

Figure 1 shows a cross sectional view of a resistive gas sensor device in the present embodiment of the invention;

Figure 2 shows a flowchart showing a method of fabricating a resistive gas sensor device in the present embodiment of the invention;

10 Figure 3 shows a top view of contact electrodes in the preferred embodiment of the invention;

Figure 4 shows a cross sectional view of the device in the method of fabricating the same in the present invention;

Figure 5 shows a cross sectional view of the method of fabrication in an alternative
15 embodiment of the invention; and

Figure 6 shows a cross sectional view of the device illustrating that the insulating layer may be etched further to form high aspect ratio trenches.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention relates to a method of fabricating a resistive gas sensor device and a
5 resistive gas sensor device. Hereinafter, this specification will describe the present invention
according to the preferred embodiment of the present invention. However, it is to be
understood that limiting the description to the preferred embodiment of the invention is
merely to facilitate discussion of the present invention and it is envisioned that those skilled
in the art may devise various modifications and equivalents without departing from the scope
10 of the appended claims.

The following detailed description of the preferred embodiment will now be described in
accordance with the attached drawings, either individually or in combination.

15 Figure 2 illustrates a method of fabricating a resistive gas sensor device. The method
includes the steps of depositing an insulating layer (105) on a silicon substrate layer (101),
depositing a conductive metal layer (103) onto the insulating layer (105), depositing a thin
metallic catalyst layer (107) covering a surface of the conductive metal layer (103) and
etching the metal catalyst layer (107) and growing nanostructures (109) from the metal
20 catalyst layer (107) that is exposed, such that the nanostructures (109) are interconnected
with each other and the conductive metal layer (103).

The insulating layer (105) is constructed of silicon dioxide or silicon nitride deposited by
physical or chemical vapour deposition (PVD or CVD) or silicon dioxide grown by thermal
25 oxidation method. The oxide/nitride layer acts to isolate conductive metal bridge and contact
electrodes from underlying silicon substrate layer (101) (Figure 4a).

The conductive metal layer (103) is deposited onto the oxide/nitride surface by either PVD or CVD method to form the bridge and contact electrodes (Figure 4b). This conductive metal layer (103) needs to be able to withstand high growth temperature of nanomaterials such as, but not restricted to nanotubes, nanowires and graphene, which is typically above 300 °C.

- 5 The material(s) can be selected from a group including but not limited to gold, platinum, and tungsten.

A thin metal catalyst layer (107) is deposited to cover the surface of the bridge electrodes and in between the bridges (Figure 4c). The metal catalyst (107) type will depend on the
10 required nanomaterial such as, carbon nanotubes, graphene, tungsten oxide nanowires, zinc oxide nanowires, indium oxide nanowires, tin oxide nanowires, or combination thereof. to grow carbon nanotubes and graphene and gold catalyst to grow zinc oxide (ZnO) and tin oxide (SnO₂) nanowires. The nanomaterials are used to grow nanostructures (109) on the thin metal catalyst layer (107). The nanomaterials are of vertical or multidirectional arrays.

15 The nanostructures (109) are grown from exposed metal catalyst (107) on and in between the bridge electrodes (Figure 4d). The nanostructures (109) are interconnected within themselves and with the bridge electrodes to form connectivity between the contact electrodes.

20 As shown in Figure 5, an alternative growth method is to deposit the metal catalyst only on top surface of the bridge electrode. This allows the nanomaterials to laterally grow across the bridge electrodes hence connecting the electrodes with one another.

25 To allow further gas penetration beneath the nanomaterial, the insulating layer (105) can be etched further to form high aspect ratio trenches prior to metal catalyst deposition and nanomaterial growth (Figure 6). Also, as an alternative to growing nanomaterial directly onto the silicon substrate layer (101) as described above is to drop cast or spin coat the

nanomaterial onto the bridge electrodes. If an insulator type substrate is used the initial oxide or nitride insulating layer will not be required.

The method describes connecting the contact electrodes, by insulating the substrate material to provide electrical isolation, forming the conductive bridge and contact electrodes, depositing metal catalyst on top of the bridge electrode surface, and growing of nanomaterial using the metal catalyst layer.

Figure 1 shows cross section of a resistive gas sensor device that is fabricated using the method as described above. The resistive gas sensor device operates based on changes in electrical resistivity using nanomaterials interconnectable by conductive bridge electrodes between contact electrodes.

The device is of passive type which operates based on a change in electrical resistance when receptive ions are detected by the nanomaterial. The device includes at least one pair of conductive contact electrodes for electrical connection, an array of conductive bridge electrodes in between the contact electrodes and an array of nanomaterial covering a top surface and in between the bridge electrode. Typical nanomaterials that are associated with gas sensors include carbon nanotubes, graphene, ZnO nanowires and SnO₂ nanowires. As the nanotubes and nanowires are typically short, the bridge electrodes acts as a link to connect them together. Without nanomaterials, the electrical connections between the contact electrodes are of open circuit. As most nanowires used for gas sensing are of semiconductor materials, the bridge electrodes helps to improve the overall device conductivity and response time. The bridge electrodes must not cause electrical shorting between the contact electrodes and can have a design of but not limited to isolated square or circular islands (Figure 3a); long electrode structures which are disconnected from the main contacts (Figure 3b) and alternating long electrode structures connecting to one of the main contacts (Figure 3c).

The invention is an improvement over typical gas sensor devices as the use of nanomaterials such as nanotube, nanowire, grapheme, as new sensing elements, now allows passive type gas sensing platform to be developed. This is because the high surface to volume ratio of these nanomaterials improves device sensitivity without heating to elevated temperatures, unlike those of the prior art.

This invention is adapted for chemical gas detection. The disclosed invention is suitable, but not restricted to, for use in agriculture, environmental monitoring, biomedical and industrial processes.

CLAIMS

1. A resistive gas sensor device, wherein the gas sensor device operates based on changes in electrical resistivity using nanomaterials interconnectable by conductive bridge electrodes between contact electrodes.

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2. The device as claimed in claim 1, wherein the nanomaterial covers a top surface of the bridge electrodes and in between the bridge electrodes.

10

3. The device as claimed in claim 1, wherein the nanomaterial includes carbon nanotubes, conductive nanowires, semiconductor nanowires, nanoporous structures or grapheme.

4. A method of fabricating a resistive gas sensor device, characterized in that, the method includes the steps of:

15

- i. depositing an insulating layer (105) on a silicon substrate layer (101);
- ii. depositing a conductive metal layer (103) onto the insulating layer (105);
- iii. depositing a thin metallic catalyst layer (107) covering a surface of the conductive metal layer (103) and etching the metal catalyst layer (107); and

20

- iv. growing nanostructures (109) from the metal catalyst layer (107) that is exposed,
such that the nanostructures (109) are interconnected with each other and the conductive metal layer (103).

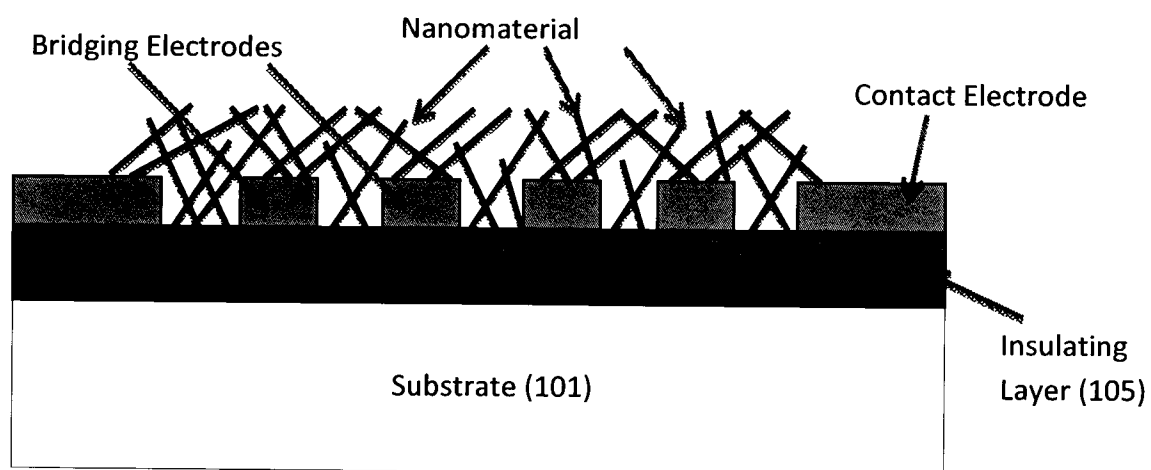
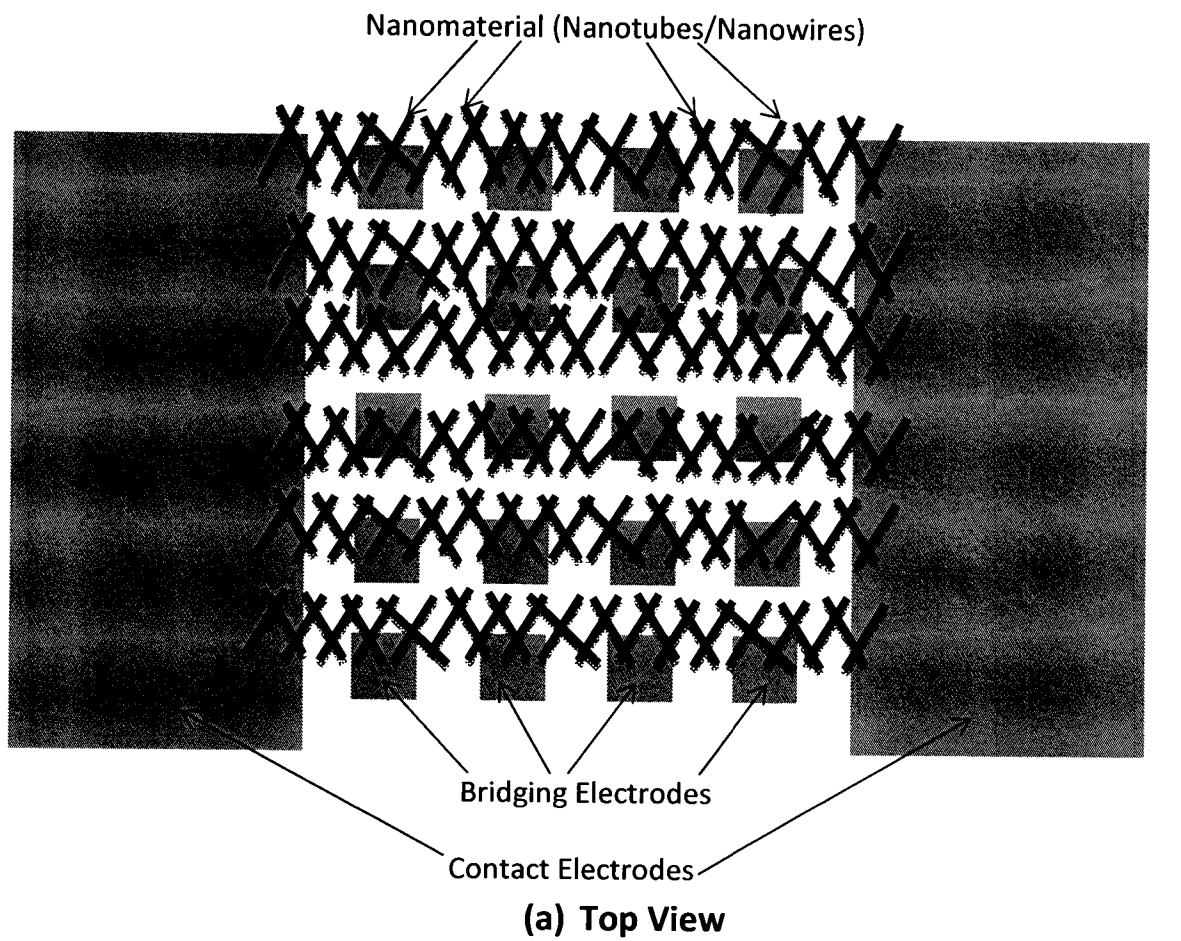
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5. The method as claimed in claim 4, wherein the insulating layer (105) is an oxide/nitride layer.

6. The method as claimed in claim 4, wherein the conductive metal layer (103) forms bridge and contact electrodes.

7. The method as claimed in claim 4, wherein the nanomaterials is selected from a group consisting and not limited to carbon nanotubes, graphene, tungsten oxide nanowires, zinc oxide nanowires, indium oxide nanowires, tin oxide nanowires, or combination thereof.

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(b) Cross Sectional View

Figure 1

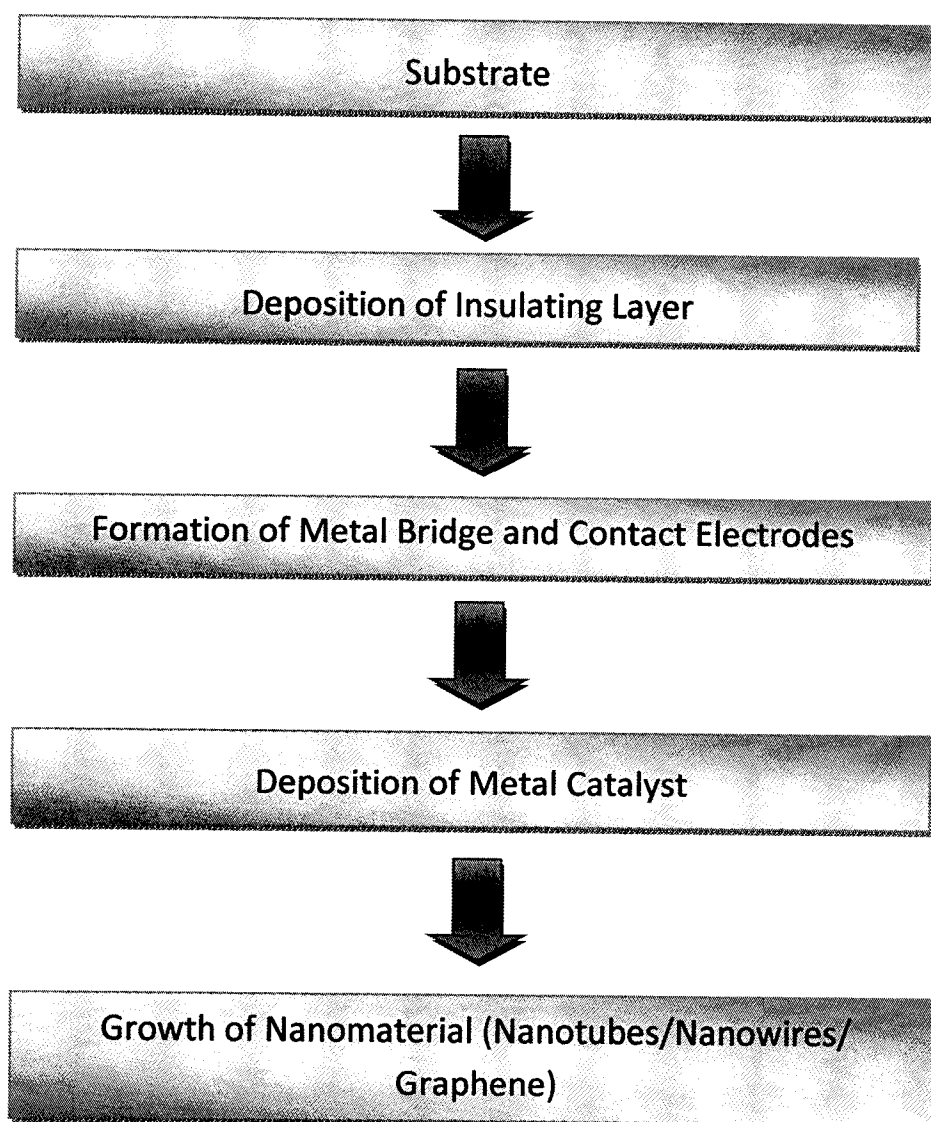


Figure 2

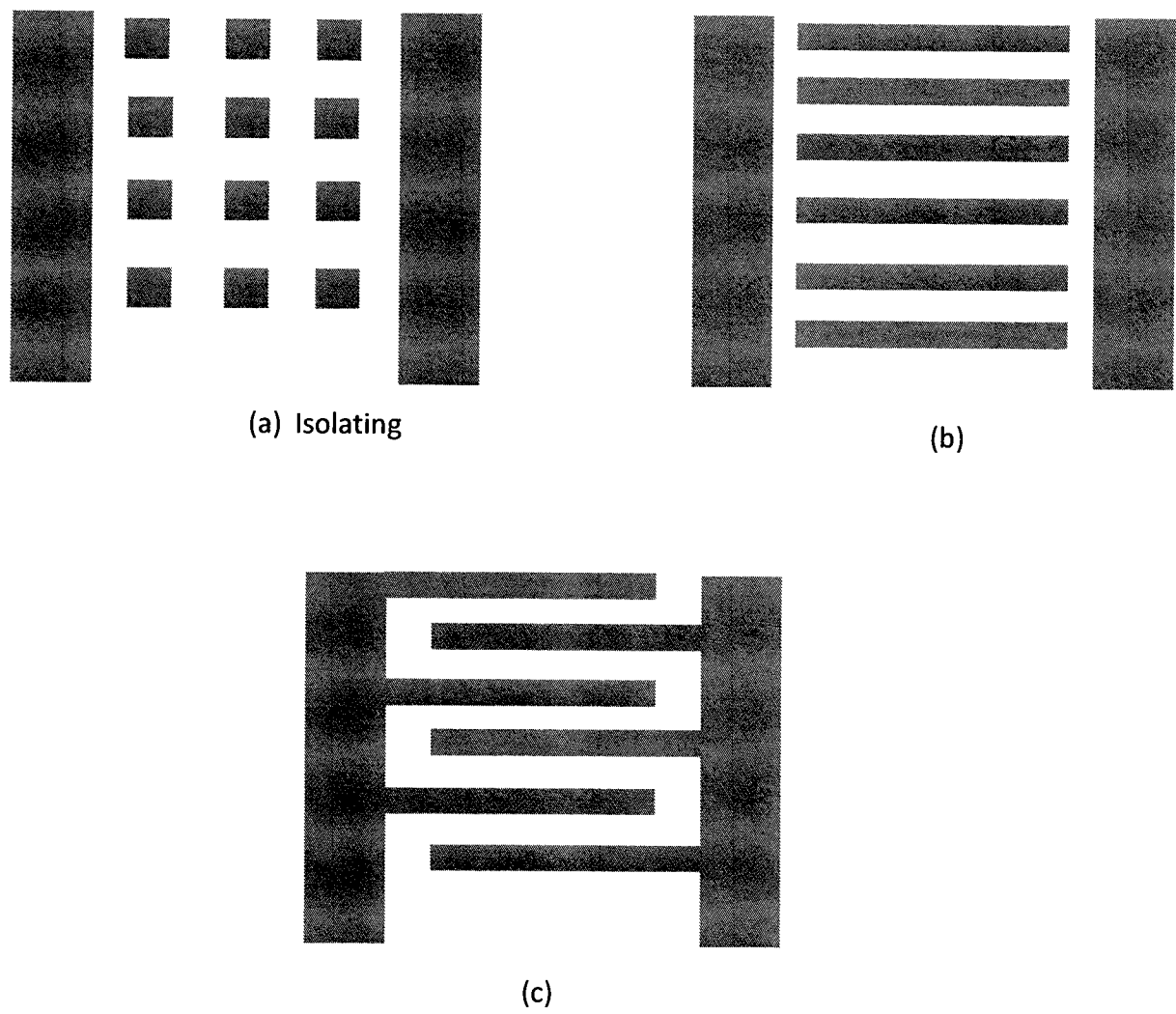


Figure 3

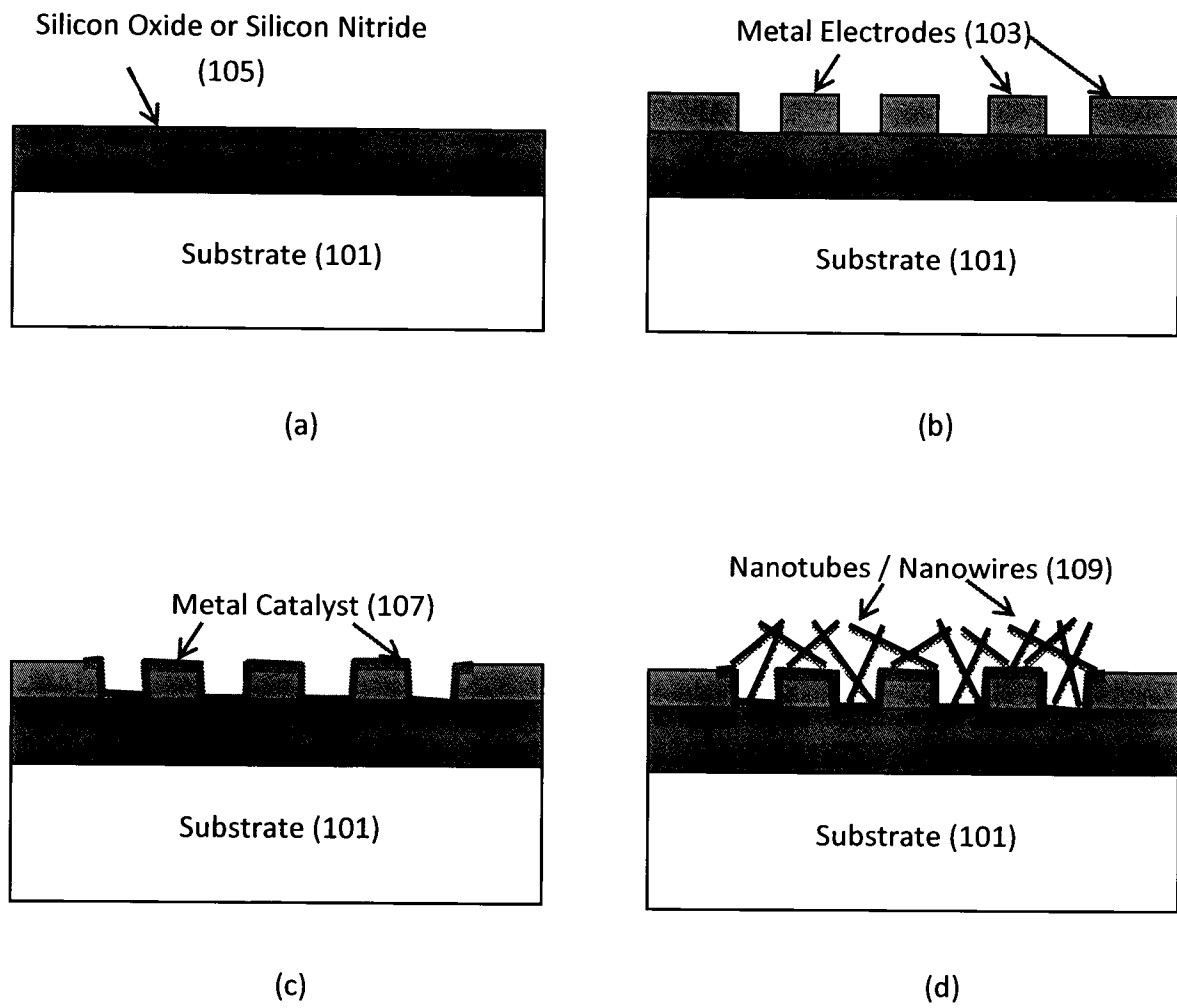


Figure 4

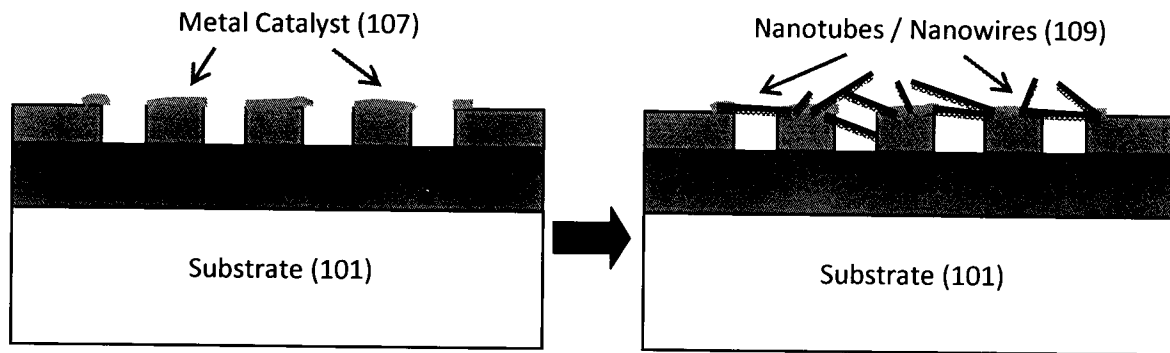


Figure 5

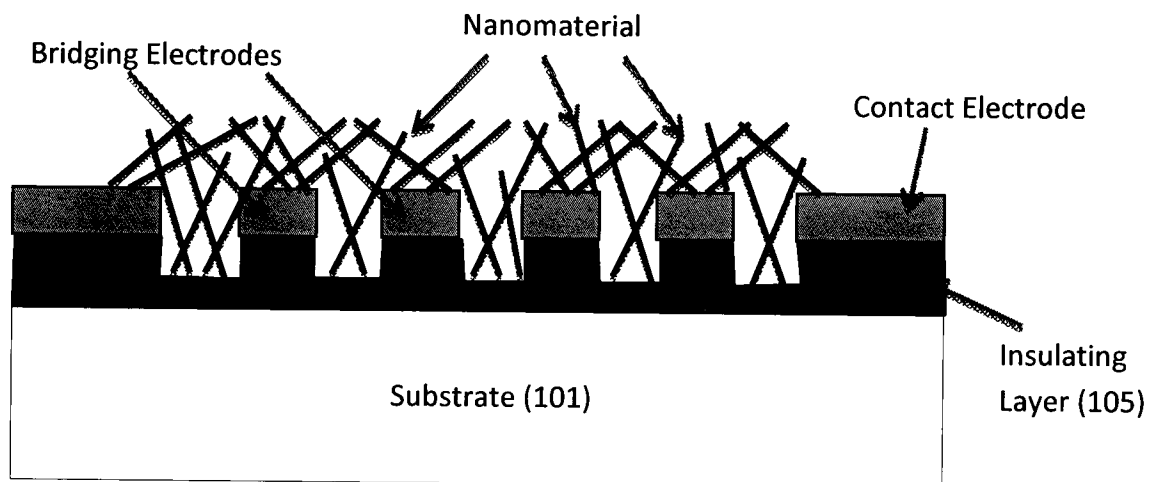


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/MY2013/000225

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N27/12 B82Y15/00
ADD.

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)
G01N B82Y

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)

EPO-Internal, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/153593 A1 (BOURNS INC [US]; UNIV CALIFORNIA [US]; DESHUSSES MARC ARNOLD [US]; MYU) 18 December 2008 (2008-12-18) paragraph [0056] - paragraph [0062]; figures 1,2A,4A-4D	1-7
A	----- PRAHALAD M PARTHANGAL ET AL: "A universal approach to electrically connecting nanowire arrays using nanoparticles-application to a novel gas sensor architecture", NANOTECHNOLOGY, IOP, BRISTOL, GB, vol. 17, no. 15, 14 August 2006 (2006-08-14), pages 3786-3790, XP020103945, ISSN: 0957-4484, DOI: 10.1088/0957-4484/17/15/029 figure 5a ----- -/-	4-7

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

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

2 April 2014

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16/04/2014

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/MY2013/000225

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01/44796 A1 (UNIV LELAND STANFORD JUNIOR [US]) 21 June 2001 (2001-06-21) page 6 - page 7; figures 2,3B -----	1,3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/MY2013/000225

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