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[Continued on next page]

(54) Title: HUMIDITY SENSOR WITH NANOPOROUS POLYIMIDE MEMBRANES AND A METHOD OF FABRICATION THEREOF

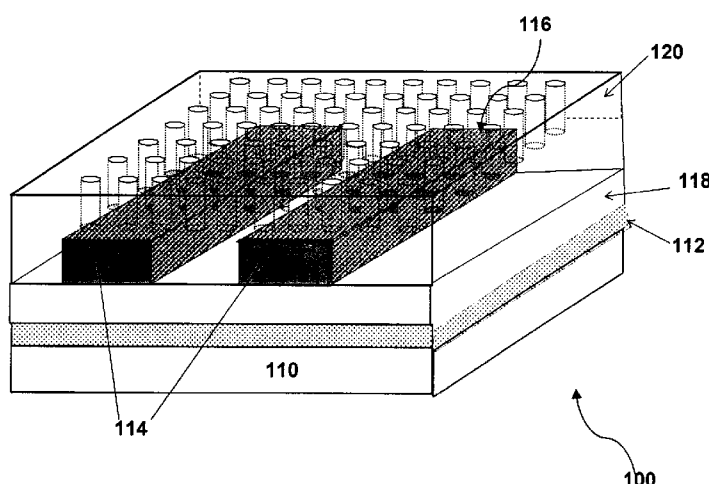


Figure 1

(57) Abstract: The present invention relates to an improved humidity sensor (100) with nanoporous polyimide membrane as the sensing element more particularly, to a humidity sensor and method of fabricating the humidity sensor (100) with polyimide membrane to improve sensor's response to changes in environmental humidity. One of the advantages of the present invention is that it enhances moisture absorption and desorption from the polyimide membrane to improve device response to changes in environmental humidity. Another advantage of the system and method of the present invention is that the formation of nanopores is independent of lithographic resolution. In addition, diameter of the pores can be accurately controlled as they are directly dependent on the diameter of the grown silicon nanowires which in turns is dependent on the thickness of the metal catalyst used.



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HUMIDITY SENSOR WITH NANOPOROUS POLYIMIDE MEMBRANES AND A METHOD OF FABRICATION THEREOF

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FIELD OF THE INVENTION

The present invention relates to an improved humidity sensor with nanoporous polyimide membrane as the sensing element more particularly, to a humidity sensor and method of
10 fabricating the humidity sensor with polyimide membrane to improve sensor's response to changes in environmental humidity.

BACKGROUND OF THE INVENTION

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Measurement of relative humidity by measuring the variation in impedance is the most frequently used, since it is the easiest to implement. In particular, there are two categories of sensors measuring variation in impedance. A first category concerns sensors of a variation in resistance, in which the variation in conductivity of a surface is measured. Sensors of
20 capacitive type can also be distinguished, in which a layer of sensitive dielectric material is provided to absorb surrounding humidity. In said sensor, the layer of dielectric material is located between two electrodes and forms a capacitor. When humidity varies, the quantity of water absorbed by said layer of dielectric material also varies, leading to a change in the dielectric constant of this layer, and to a variation in the capacitance of the capacitor which is
25 measured.

In a humidity sensor of capacitive type, one of the electrodes may be permeable to humidity, to allow the water vapour to migrate into the layer of dielectric material of the capacitor. At present, polyimide based capacitive humidity sensor comprises of interdigital electrodes with
30 planar polyimide membrane as its sensing element. However, moisture absorption and desorption in and out of the polyimide membrane has impacting the device response time particularly if the membrane is thick.

To date, none of these technologies can improve sensitivity, selectivity and response time
35 towards measuring relative humidity polyimide based capacitive humidity sensor. The

present invention provides an improved humidity sensor with nanoporous polyimide membrane as the sensing element more particularly, to a humidity sensor and method of fabricating the humidity sensor with polyimide membrane to improve sensor's response to changes in environmental humidity. The present invention further provides a considerable
5 reduction of materials with even greater efficiency and economically during operation.

SUMMARY OF THE INVENTION

10 The present invention provides a method of fabricating a capacitive humidity sensor having nanoporous polyimide membranes comprising depositing an insulating layer as an electrical isolation layer on a substrate and sandwiched between a plurality of conductive electrodes and the substrate forming a first polyimide sensing membrane by depositing a first polyimide
15 layer on top of the insulating layer, etching the deposited conductive layer on top of the first polyimide sensing membrane to form a plurality of interdigital capacitive electrodes, growing a plurality of silicon nanowires, depositing a second polyimide sensing membrane on top of the conductive electrodes, planarising the silicon nanowires coated with the second polyimide sensing membrane and removing the silicon nanowires to form a plurality of
20 nanopores on the second polyimide sensing membrane.

In one of the embodiment of the present invention, the polyimide sensing membranes are provided to capture a fringing electric field beneath the interdigital capacitive electrodes.

25 In yet another embodiment of the present invention, the silicon nanowires are grown by plasma enhanced chemical vapor deposition via a thin layer of metal catalyst.

In another embodiment of the present invention, the coated silicon nanowires are planarised by a chemical mechanical polishing (CMP) method.

30 In yet another embodiment of the present invention, the silicon nanowires are removed by wet etching with potassium hydroxide solution.

A capacitive humidity sensor comprises a substrate, an insulating layer as an electrical isolation layer is deposited on the substrate and sandwiched between a plurality of
35 conductive electrodes and the substrate; and a plurality of an array of interdigital capacitive

electrodes as sensing elements placed on the insulating layer and sandwiched between a first nanoporous polyimide membrane and a second nanoporous polyimide membrane wherein each nanoporous polyimide membrane changes its dielectric permittivity when different relative humidity levels are detected.

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In another embodiment of the present invention, a depth of the nanoporous of each nanoporous polyimide membrane is 0.5 μm to 5 μm .

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In yet another embodiment of the present invention, a diameter of nanoporous of the polyimide membrane is in the range of 10 nm to 200 nm.

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A capacitive humidity sensor comprises a substrate, an insulating layer as an electrical isolation layer is deposited on the substrate and sandwiched between a plurality of conductive electrodes and the substrate; and a plurality of an array of interdigital capacitive electrodes as sensing elements placed on the insulating layer and below a nanoporous polyimide membrane wherein the nanoporous polyimide membrane changes its dielectric permittivity when different relative humidity levels are detected.

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BRIEF DESCRIPTION OF THE DRAWINGS

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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.

Figure 1 illustrates 3-dimensional view of capacitive humidity sensor with nanoporous polyimide membranes in accordance of the present invention.

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Figure 2 illustrates a flow chart depicts the fabrication of the capacitive humidity sensor and formation of the nanoporous membrane in accordance of the present invention.

Figure 3 illustrates interdigital electrode structure embedded in the capacitive humidity sensor in accordance of the present invention.

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Figure 4 illustrates capacitive humidity sensor formation process flow as in Figure 2 in accordance of the present invention.

Figure 5 illustrates capacitive humidity sensor with single layer nanoporous polyimide on top of the electrode surface in accordance to an alternative embodiment of the present invention.

DETAILED DESCRIPTIONS OF THE INVENTION

The present invention will now be described in detail in connection with specific embodiments with reference to the accompanying drawings.

As used herein the term “nanowire” refers to nanoscale material created in an array pore.

The term does not imply that the aspect ratio of the material need to be high, and in some embodiments, the material to be deposited in an array can have a low aspect ratio.

“Nanowires” can also refer to material that is not necessarily electrically conductive, but is nevertheless useful when present in nanoscale arrays. Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood

by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below

The present invention provides an improved humidity sensor device with nanoporous polyimide membrane as the sensing element. The increased in porosity enhances moisture absorption and desorption from the polyimide membrane to improve device response to changes in environmental humidity.

Figure 1 illustrates a capacitive humidity sensor (100) of the present invention comprises a substrate (110), an insulating layer (112) as an electrical isolation layer is deposited on the substrate and sandwiched between a plurality of conductive electrodes (114) and the substrate (110); and a plurality of an array of interdigital capacitive electrodes (116) as sensing elements placed on the insulating layer (112) and sandwiched between a first nanoporous polyimide membrane (118) and a second nanoporous polyimide membrane

(118) wherein each nanoporous polyimide membrane changes its dielectric permittivity when different relative humidity levels are detected.

In the preferred embodiment, a depth of the nanoporous of each nanoporous polyimide membrane is 0.5 μm to 5 μm while a diameter of nanoporous of the polyimide membrane is in the range of 10 nm to 200 nm. The nanopores in each nanoporous polyimide membrane are provided to improve the adsorption and desorption of water moisture from the polyimide membrane to improve device response to changes in environmental humidity. Dimensions of the nanopores can be accurately controlled with the use of silicon nanowires.

To a person skilled in the art, the formation of nanoporous membrane comprises the growth of vertical silicon nanowires and selective etching of silicon where diameter of the pores is dependent on the diameter of the grown silicon nanowires, which is typically less than 100nm. The conductive electrodes preferably metal electrode materials are required to withstand the silicon nanowire growth temperature of at least 350 $^{\circ}\text{C}$.

Figure 2 illustrates a flow chart depicts the fabrication of the capacitive humidity sensor and formation of the nanoporous membrane in accordance of the present invention. While, Figure 4 illustrates capacitive humidity sensor formation process flow in accordance of the present invention. In operation, a method of fabricating a capacitive humidity sensor having nanoporous polyimide membranes begins with depositing an insulating layer as an electrical isolation layer on a substrate (210; 212) (Figure 4a) and sandwiched between a plurality of conductive electrodes and the substrate. This is followed by forming a first polyimide sensing membrane (214) by depositing a first polyimide layer on top of the insulating layer (Figure 4b). Then, the deposited conductive layer on top of the first polyimide sensing membrane to form a plurality of interdigital capacitive electrodes is etched (216) (Figure 4c). Subsequently, a plurality of silicon nanowires are grown (218). The silicon nanowires are grown by plasma enhanced chemical vapor deposition via a thin layer of metal catalyst (Figure 4d). A second polyimide sensing membrane is deposited on top of the conductive electrodes (220) (Figure 4e) and this is followed by planarising the silicon nanowires coated with the second polyimide sensing membrane (222) (Figure 4f). The coated silicon nanowires are planarised by a chemical mechanical polishing (CMP) method. Finally, the silicon nanowires are removed to form a plurality of nanopores on the second polyimide sensing membrane (224) (Figure 4g). These silicon nanowires are removed by wet etching with potassium hydroxide

solution. The polyimide sensing membranes are provided in the present invention to capture a fringing electric field beneath the interdigital capacitive electrodes.

Interdigitated capacitor has been widely incorporated with dielectric sensing membrane for chemical sensing applications. Typically, the physical structure of the device comprises of a sensing membrane sitting on top of an array of interdigitated fingers. Figure 3 depicts interdigital electrode structure (310) embedded in the capacitive humidity sensor in accordance of the present invention. The sensing mechanism is based on the dielectric properties of membrane material which includes physical, chemical, or structural properties influencing the fringing electric field between the finger electrodes resulting in a change in capacitance. There are extensive applications for nanoporous membranes and not limited to the following highly selective transfer mask, a filter for biochemical, biomedical and material studies; sensing membrane layer; anti-reflection surface for solar cells; and as photonic crystals. At present these nonporous membranes are fabricated using lithographic methods which have resolution and cost imposed limitations; or by using material(s) that is able to change its chemical structure. However, applications for such materials are limited and the processing methods are not compatible with the flow of semiconductor device fabrication.

In the present invention, nanoporous polyimide membrane which less than 100nm in dimension is fabricated by utilizing silicon nanowires and a combination of selective etching methods. The nanoporous polyimide membrane can be fabricated onto silicon, glass, metal or polymer type substrate as long as it can withstand the growth temperature of the silicon nanowires, which is typically above 350 °C. Diameter of the pores can be accurately controlled as they are directly dependent on the diameter of the grown silicon nanowires which in turns is dependent on the thickness of the metal catalyst used. As for the height of the nanopores, there are of high aspect ratio and is dependent on the thickness of the membrane material which typically ranges up to 5µm.

In an alternative embodiment, capacitive humidity sensor with single layer nanoporous polyimide on top of the electrode surface in accordance to an alternative embodiment of the present invention is provided as depicted in Figure 5. The method of fabricating a capacitive humidity sensor having single layer nanoporous polyimide is the same with the present method with the difference in not depositing/forming the bottom polyimide layer.

One of the advantages of the present invention is that it enhances moisture absorption and desorption from the polyimide membrane to improve device response to changes in environmental humidity. Another advantage of the system and method of the present invention is that the formation of nanopores is independent of lithographic resolution. In addition, diameter of the pores can be accurately controlled as they are directly dependent on the diameter of the grown silicon nanowires which in turns is dependent on the thickness of the metal catalyst used.

The foregoing embodiment and advantages are merely exemplary and are not to be construed as limiting the present invention. The description of the embodiments of the present invention is intended to be illustrative and not to limit the scope of the claims and many alternatives, modifications and variations will be apparent to those skilled in the art.

CLAIMS

1. A method of fabricating a capacitive humidity sensor having nanoporous polyimide membranes comprising

depositing an insulating layer as an electrical isolation layer on a substrate and sandwiched between a plurality of conductive electrodes and the substrate (210; 212);

forming a first polyimide sensing membrane by depositing a first polyimide layer on top of the insulating layer (214);

etching the deposited conductive layer on top of the first polyimide sensing membrane to form a plurality of interdigital capacitive electrodes(216);

growing a plurality of silicon nanowires(218);

depositing a second polyimide sensing membrane on top of the conductive electrodes(220);

planarising the silicon nanowires coated with the second polyimide sensing membrane(222); and

removing the silicon nanowires to form a plurality of nanopores on the second polyimide sensing membrane(224).

2. The method as claimed in Claim 1 wherein the polyimide sensing membranes are provided to capture a fringing electric field beneath the interdigital capacitive electrodes.

3. The method as claimed in Claim 1 wherein the silicon nanowires are grown by plasma enhanced chemical vapor deposition via a thin layer of metal catalyst.

4. The method as claimed in Claim 1 wherein the coated silicon nanowires are planarised by a chemical mechanical polishing (CMP) method.

5. The method as claimed in Claim 1 wherein the silicon nanowires are removed by wet etching with potassium hydroxide solution.

6. A capacitive humidity sensor (100) comprises

a substrate (110),

an insulating layer (112) as an electrical isolation layer is deposited on the substrate and sandwiched between a plurality of conductive electrodes (114) and the substrate (110); and

a plurality of an array of interdigital capacitive electrodes (116) as sensing elements placed on the insulating layer (112) and sandwiched between a first nanoporous polyimide membrane (118) and a second nanoporous polyimide membrane (118) wherein each nanoporous polyimide membrane changes its dielectric permittivity when different relative humidity levels are detected.

7. The capacitive humidity sensor as claimed in Claim 6 wherein a depth of the nanoporous of each nanoporous polyimide membrane is 0.5 μm to 5 μm .

8. The capacitive humidity sensor as claimed in Claim 6 wherein a diameter of nanoporous of the polyimide membrane is in the range of 10 nm to 200 nm.

9. A capacitive humidity sensor (100) comprises

a substrate (110),

an insulating layer (112) as an electrical isolation layer is deposited on the substrate and sandwiched between a plurality of conductive electrodes (114) and the substrate (110); and

a plurality of an array of interdigital capacitive electrodes (116) as sensing elements placed on the insulating layer (112) and below a nanoporous polyimide membrane (118) wherein the nanoporous polyimide membrane changes its dielectric permittivity when different relative humidity levels are detected.

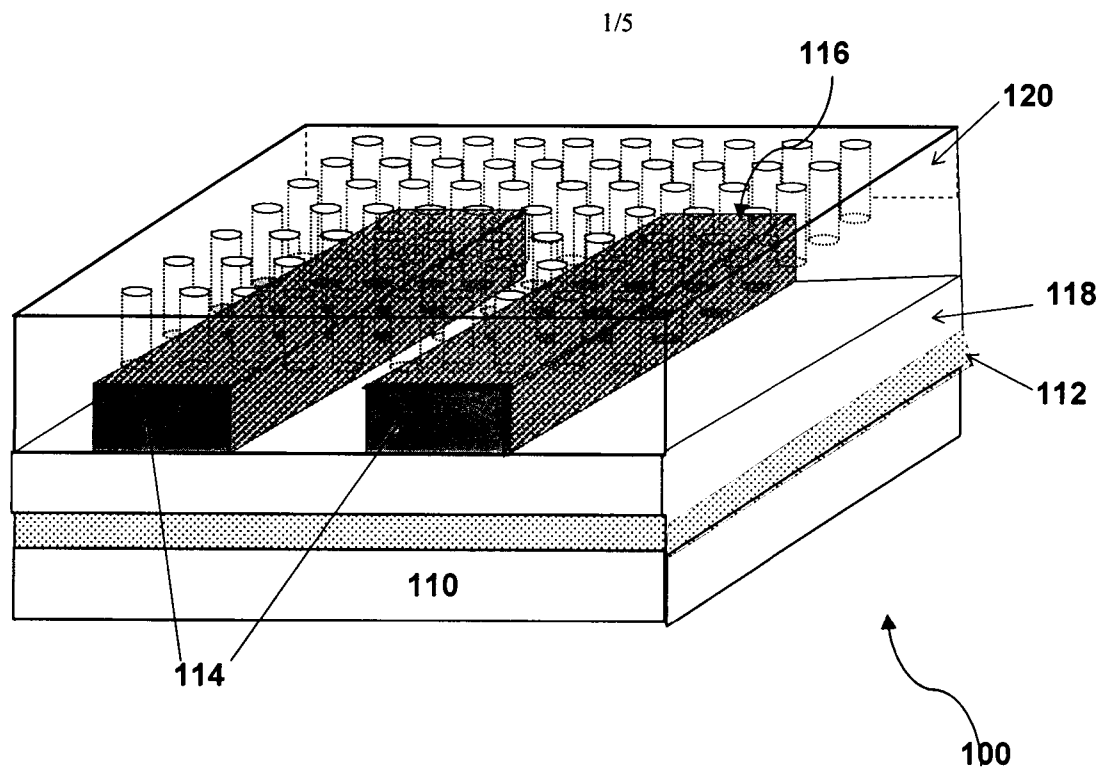
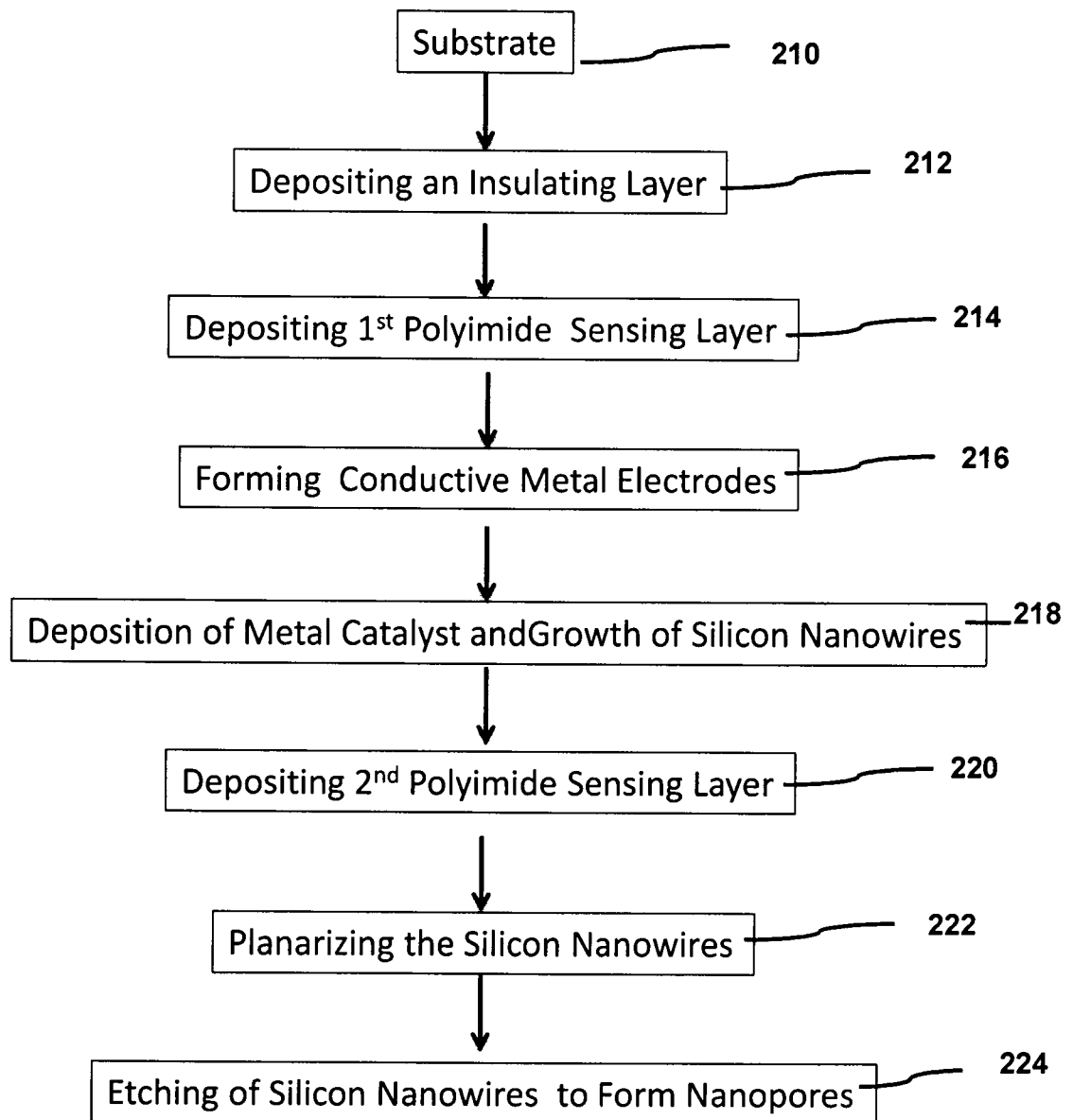


Figure 1

2/5

**Figure 2**

3/5

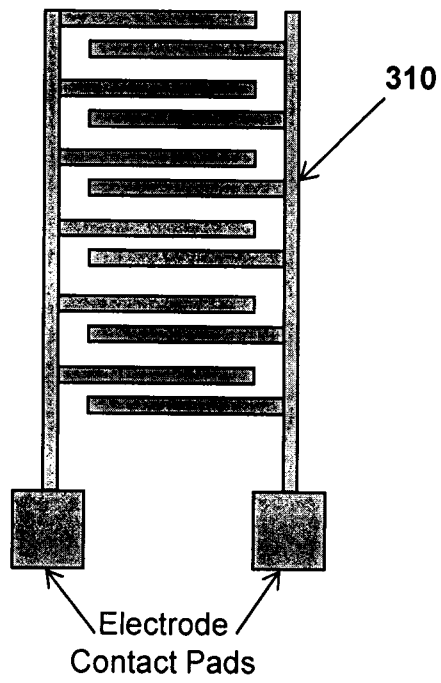


Figure 3

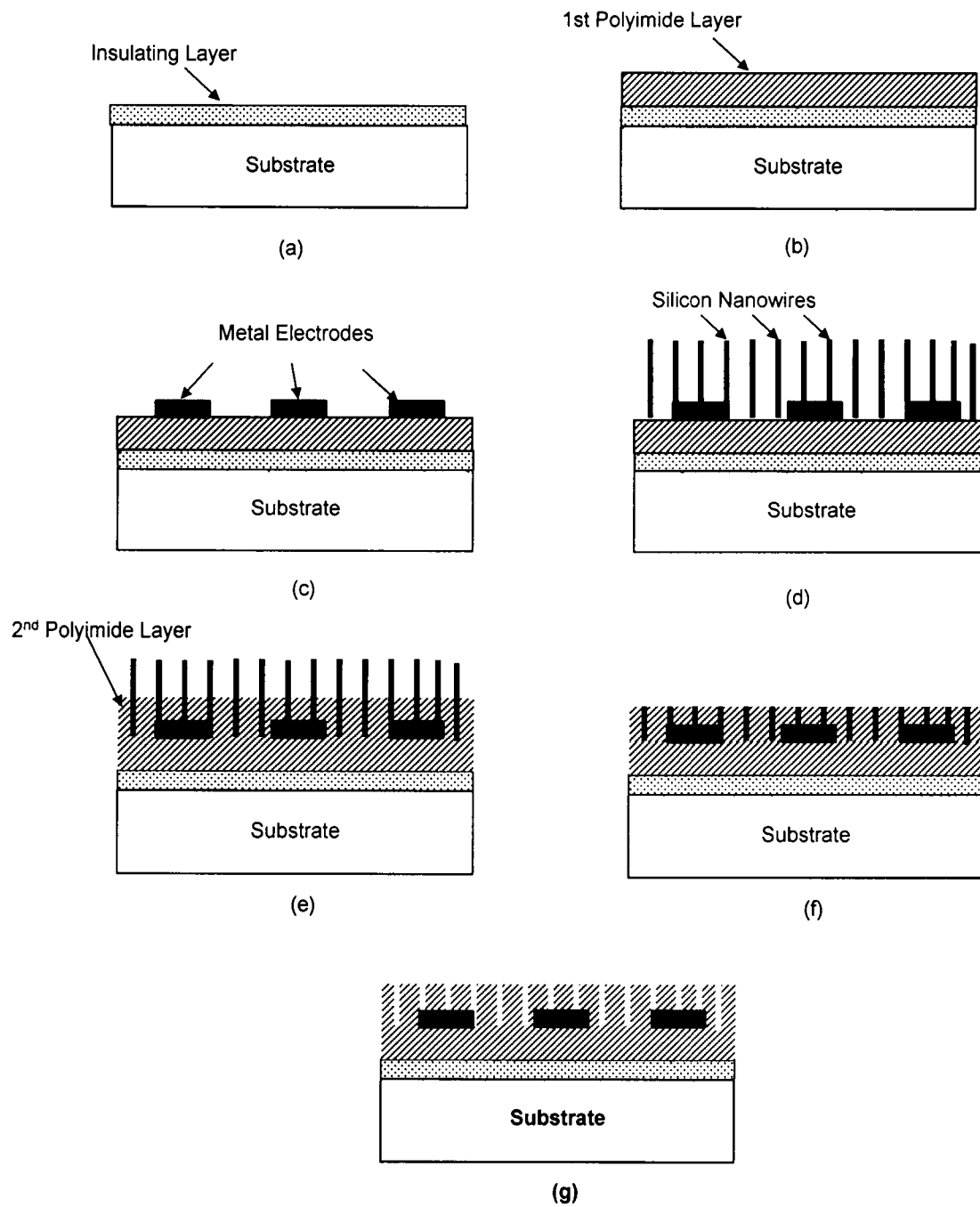


Figure 4

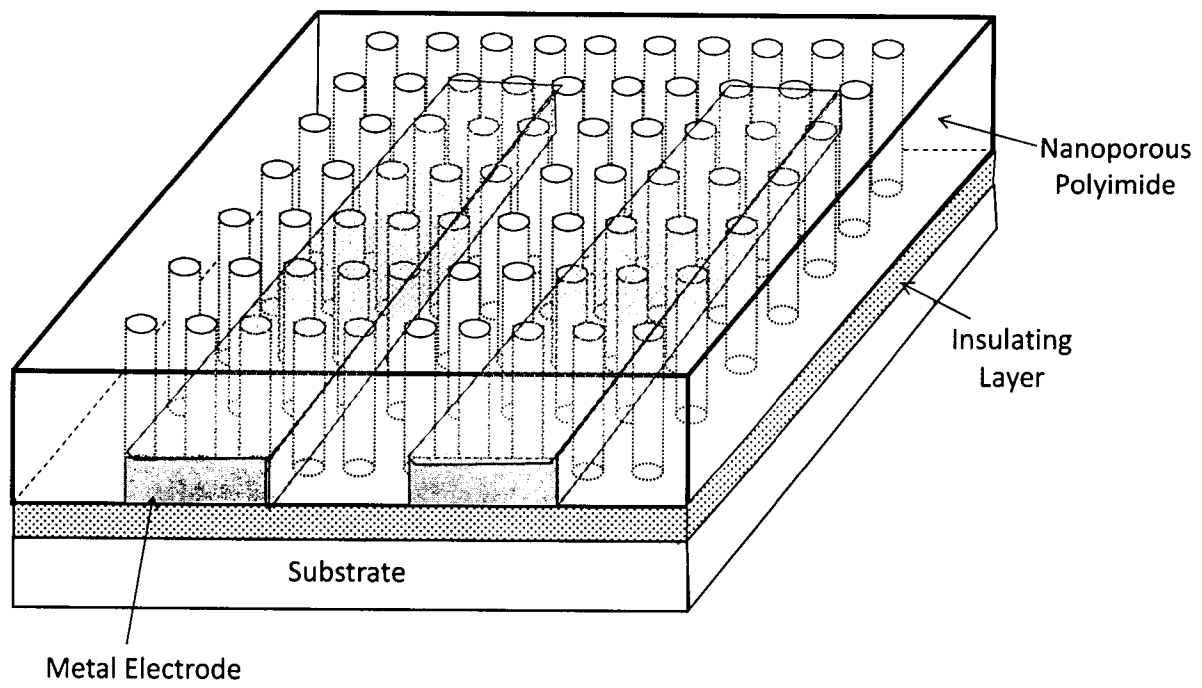


Figure 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/MY2015/000083

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. G01N27/22 (2006.01) i

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)

Int.Cl. G01N27/00-27/24

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2015
 Registered utility model specifications of Japan 1996-2015
 Published registered utility model applications of Japan 1994-2015

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

JSTPlus/JST/580 (JDreamIII)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2009/066992 A2 (MIMOS BERHAD) 2009.05.28, p. 1, lines 6-8, p. 4, lines 8-28, Fig. 1 (No Family)	1-9
Y	WO 2012/064177 A1 (MIMOS BERHAD) 2012.05.18, p. 1, lines 14-18, p. 6, lines 16-23, p. 7, lines 1-16, p. 9, lines 1-4, Figs. 1-4 (No Family)	1-9
Y	US 2013/0095349 A1 (Van Dorn Carolyn Pitcher) 2013.04.18, paragraph [0062] & JP 2013-89283 A & EP 2581906 A2 & KR 10-2013-0040751 A & CN 103295588 A	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“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

“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

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Date of the actual completion of the international search

17.12.2015

Date of mailing of the international search report

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Name and mailing address of the ISA/JP

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/MY2015/000083

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2012/141883 A1 (3M INNOVATIVE PROPERTIES COMPANY) 2012.10.18, p. 3, lines 24-35, p. 4, lines 1-2 & JP 2014-518568 A & US 2015/0109003 A1 & EP 2697643 A & CN 103492872 A & KR 10-2014-0047602 A	1-9
A	WO 2012/067488 A1 (MIMOS BERHAD) 2012.05.24, paragraphs [0048]-[0049], Figs. 1, 5 (No Family)	1-9
A	US 2011/0113893 A1 (Arms Steven W.) 2011.05.19, paragraphs [0032]-[0034], Figs. 2, 3b (No Family)	1-9