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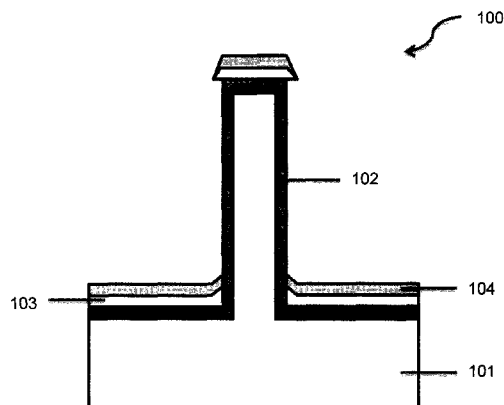
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(54) Title: METAL ELECTRODE WITH HIGH ASPECT RATIO STRUCTURES AND METHOD OF FABRICATING THE SAME



(57) Abstract: Described herein is a metal electrode (100) having at least one high aspect ratio structure. The metal electrode (100) comprises a silicon layer (101) having the high aspect ratio structure, an oxide layer (102) on top of the silicon layer (101), an adhesive layer (103) on top of the oxide layer (102), and a metal layer (104) on top of the adhesive layer (103). The thickness of the metal layer (104) is at least 15 times lesser than the height of the high aspect ratio structure. Due to this particular feature, the metal layer (104) is deposited on top of the adhesive layer (103) in a self-aligned manner, taking the shape of the high aspect ratio structure, and disconnected at the wall of the high aspect ratio structure. Further, the metal electrode (100) can be modified accordingly to suit different applications. Also described herein is a method for fabricating the aforementioned metal electrode (100).

FIGURE 1



MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
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METAL ELECTRODE WITH HIGH ASPECT RATIO STRUCTURES AND METHOD OF FABRICATING THE SAME

5 TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to an electrode and a method of fabricating the same, and more particularly to a metal electrode having at least one high aspect ratio structure and a method of fabricating the same.

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BACKGROUND OF THE INVENTION

Conductive metal electrode with at least one microstructure or nanostructure, which is also known as microelectrode array, has many applications. For instances, it can be used as sensors for sensing and measuring electrical
15 conductivity, pressure, and others, or used in energy storage devices as supercapacitors.

The method of fabricating the aforesaid metal electrode normally involves a process called patterning that is performed on thin layers of material to create
20 structures or features on the said thin layers of material. One of the more common and conventional methods of patterning include photolithography followed by plasma etching or wet chemical etching. Nonetheless, there are several disadvantages concerning this particular method, where it has been found that thin layers of metal, especially noble metal such as platinum, gold,
25 and silver are hard to be patterned. Moreover, as the plasma etching and the wet chemical etching typically require the use of high power plasma and heated acid, respectively, it is difficult to find a suitable masking material that is able to withstand such harsh treatment or environment.

30 Alternatively, 'lift-off' method can be employed for patterning these thin layers of noble metal. In general, this particular method involves a first step of depositing a photoresist layer on top of a substrate, which is subsequently patterned. Thereafter, a thin noble metal layer is blanket-deposited all over the substrate,

covering the whole surface of the photoresist layer and areas in which the photoresist has been cleared or patterned. Consequently, the rest of the photoresist layer, including the thin noble metal layer that is covering it, is removed with solvent, leaving only the thin noble metal layer that is directly deposited on the substrate. Nevertheless, the 'lift-off' method suffers from several limitations, which are listed as below:

- a) The maximum thickness of the metal layer that can be 'lift-off' when using a single resist must be at least 5 times thinner than the thickness of the said resist.
- b) 'Ear' feature on the patterned metal layer after the 'lift-off' due to low resist aspect ratio. This is undesirable because it will influence device performance and its fragility is a source of contamination to downstream processes.
- c) Lithographic resolution is significantly reduced when using very thick resist, which is undesirable for fabricating metal electrode having structures or patterns of nano-dimensions.
- d) Thick resist is difficult to be 'lift-off', and is often performed under undesirable conditions (e.g. heated condition, sonication) that may cause damage to the patterned or structured metal electrode.
- e) 'Lift-off' of thick resist usually generates a lot of unwanted residues, which is considered as a source of contamination to downstream processes.
- f) Bi-layer type resist requires tightly controlled process during curing, exposure, and developing stages to ensure a desired undercut is achieved.
- g) High temperature curing process is required to cure thick polymer such as polyimide, when it is used in replacement of typical resist.

In view of the above, it therefore has become an aim of the present invention to solve the above-mentioned technical issues and disadvantages by introducing a metal electrode having at least one high aspect ratio structure, which does not require its metal layer to be patterned via the conventional methods as discussed above. It is also an aim of the present invention to teach a method of fabricating the metal electrode of the present invention.

SUMMARY OF THE INVENTION

The first core aspect of the present invention is directed to a metal electrode having at least one high aspect ratio structure, which can be used as sensors for sensing and measuring electrical conductivity, gas, pressure, and others, or used in energy storage devices as supercapacitors.

The said metal electrode comprises a silicon layer having the high aspect ratio structure, an oxide layer on top of the silicon layer, an adhesive layer on top of the oxide layer, and a metal layer on top of the adhesive layer. The thickness of the metal layer is at least 15 times lesser than the height of the high aspect ratio structure. Due to this unique feature, the metal layer is deposited on top of the adhesive layer in a self-aligned manner, taking the shape of the high aspect ratio structure, and disconnected at the wall of the high aspect ratio structure. In other words, the metal electrode of the present invention does not require its metal layer to be patterned via the conventional methods as identified in the above section.

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In an embodiment of the present invention relating to the above-mentioned metal electrode, the aforesaid oxide layer is silicon dioxide.

In another embodiment of the present invention relating to the above-mentioned metal electrode, the adhesive layer is titanium, tantalum, or titanium nitride.

In a further embodiment of the present invention relating to the above-mentioned metal electrode, the metal layer is platinum, gold, silver, rhodium, or iridium.

Additionally, the aforesaid metal electrode can be modified to suit different applications. In an embodiment of the present invention, the aforesaid metal electrode can be modified to further comprise an encapsulation layer of oxide, nitride, polyimide, or glass when the said metal electrode is intended to be used in a wet condition. The said encapsulation layer includes an opening at the most top part of the high aspect ratio structure, exposing the metal layer at the most top part of the high aspect ratio structure.

10 The second core aspect of the present invention is directed to a method of fabricating a metal electrode having at least one high aspect ratio structure, which can be used as sensors for sensing and measuring electrical conductivity, gas, pressure, and others, or used in energy storage devices as supercapacitors. The said method does not involve patterning the metal layer of the said metal
15 electrode via the conventional methods as identified in the above section.

The said method comprises a first step of forming the high aspect ratio structure on a silicon layer via plasma etching or deep reactive ion etching, a second step of forming an oxide layer on top of the etched silicon layer via wet or dry thermal
20 oxidation, a third step of depositing an adhesive layer on top of the oxide layer, and a fourth step of depositing a metal layer having a thickness of at least 15 times lesser than the height of the high aspect ratio structure on top of the adhesive layer via physical vapor deposition. This particular fourth step causes the metal layer to be deposited on top of the adhesive layer in a self-aligned
25 manner, taking the shape of the high aspect ratio structure, and disconnected at the wall of the high aspect ratio structure.

In an embodiment of the present invention relating to the above-mentioned method, the aforesaid oxide layer is silicon dioxide.

30

In another embodiment of the present invention relating to the above-mentioned method, the adhesive layer is titanium, tantalum, or titanium nitride.

In a further embodiment of the present invention relating to the above-mentioned method, the metal layer is platinum, gold, silver, rhodium, or iridium.

5 Additionally, the aforesaid method can be modified in order to fabricate a metal electrode having at least one high aspect ratio structure that suits different applications. In an embodiment of the present invention, the aforesaid method can be modified to further comprise a fifth step of depositing an encapsulation layer of oxide, nitride, polyimide, or glass on top of the metal layer when the fabricated metal electrode is intended to be used in a wet condition. The said
10 encapsulation layer includes an opening at the most top part of the high aspect ratio structure, exposing the metal layer at the most top part of the high aspect ratio structure.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 illustrates the metal electrode of the present invention having at least one high aspect ratio structure;

Figure 2 illustrates the silicon layer having at least one high aspect ratio structure;

20

Figure 3 illustrates the oxide layer on top of the silicon layer;

Figure 4 illustrates the adhesive layer on top of the oxide layer; and

25 Figure 5 illustrates the metal electrode of the present invention having at least one high aspect ratio structure comprising an encapsulation layer.

DETAILED DESCRIPTION OF THE INVENTION

30 The above mentioned and other features and objects of this invention will become more apparent and better understood by reference to the following detailed description. It should be understood that the detailed description made known below is not intended to be exhaustive or limit the invention to the precise

disclosed form as the invention may assume various alternative forms. On the contrary, the detailed description covers all the relevant modifications and alterations made to the present invention, unless the claims expressly state otherwise.

5

The present invention introduces herein two main aspects. The first one being a metal electrode (100) having at least one high aspect ratio structure, which can be used as sensors for sensing and measuring electrical conductivity, gas, pressure, and others, or used in energy storage devices as supercapacitors, whereas the second one being a method of fabricating the said metal electrode (100).

We now refer to Figure 1, where the first main aspect is now being discussed in details. In essence, the metal electrode (100) comprises a silicon layer (101) having the high aspect ratio structure, an oxide layer (102) on top of the silicon layer (101), an adhesive layer (103) on top of the oxide layer (102), and a metal layer (104) on top of the adhesive layer (103).

One of the main technical features in relation to the first aspect of the present invention is the relationship between the thickness of the metal layer (104) and the height of the high aspect ratio structure. Specifically, the thickness of the metal layer (104) must be at least 15 times lesser than the height of the high aspect ratio structure. Due to this technical feature, the metal layer (104), during the deposition process, is deposited on top of the adhesive layer (103) in a self-aligned manner, taking the shape of the high aspect ratio structure, and disconnected at the wall of the high aspect ratio structure. As such, the metal electrode (100) of the present invention is a fully functional metal electrode just like any other known metal electrodes in the market. The only difference is that the known metal electrodes in the market are fabricated by having their metal layers to be patterned via the conventional methods as mentioned in the background section, which are prone to many known disadvantages. This is not the case for the metal electrode (100) of the present invention as the metal

layer (104) is not patterned or structured, it is the silicon layer (101) that is patterned or structured.

Referring to the oxide layer (102), it (102) is of silicon dioxide, or the like. The
5 oxide layer (102) isolates the adhesive layer (103) from the silicon layer (101).

Referring to the adhesive layer (103), it (103) is of titanium, tantalum, titanium
nitride, or the like. The adhesive layer (103) promotes excellent bonding between
the oxide layer (102) and the metal layer (104).

10

Referring to the metal layer (104), it (104) is of platinum, gold, silver, rhodium,
iridium, or the like.

The metal electrode (100) of the present invention can be modified so that it (100)
15 may be suitable to be used in different applications. For one example, the metal
electrode (100) of the present invention is modified to have an additional
encapsulation layer (105) deposited on top of the metal layer (104). The
encapsulation layer (105) can be of oxide, nitride, polyimide, glass, or the like,
and includes an opening at the most top part of the high aspect ratio structure,
20 exposing the metal layer (104) at the most top part of the high aspect ratio
structure. This specific modification allows the metal electrode (100) to be used
in wet condition. The said metal electrode (100) having the aforesaid
modification is illustrated in Figure 5.

25 We now refer to Figure 1, Figure 2, Figure 3, and Figure 4, where the second
main aspect is now being discussed in details. In essence, the method of
fabricating a metal electrode (100) having at least one high aspect ratio structure
comprises a first step of providing a silicon layer (101), and having the said
silicon layer (101) to be patterned or etched in order to form the high aspect ratio
30 structure (as shown in Figure 2). The etching can be done via plasma etching or
deep reactive ion etching. Subsequently, an oxide layer (102) with uniform
thickness is formed on top of the silicon layer (101) (as shown in Figure 3). This
can be accomplished by having the silicon layer (101) to undergo either a wet

thermal oxidation or a dry thermal oxidation. Soon after the formation of the oxide layer (102), an adhesive layer (103) is deposited on top of the oxide layer (102) to promote bonding between the oxide layer (102) and the next layer, which is a metal layer (104) (as shown in Figure 4). The metal layer (104) with a thickness of at least 15 times lesser than the height of the high aspect ratio structure is deposited on top of the adhesive layer (103) (as shown in Figure 1). This particular step can be achieved via physical vapor deposition such as electron beam physical vapor deposition. Due to the specific requirement on thickness of the metal layer (104) and the deposition method used to deposit the metal layer (104), the metal layer (104) is deposited on top of the adhesive layer (103) in a self-aligned manner, taking the shape of the high aspect ratio structure. Also, due to the same reasons, the metal layer (104) is disconnected at the wall of the high aspect ratio structure, causing the metal electrode (100) of the present invention to be of electrically open circuit type.

15

Referring to the oxide layer (102), it (102) is of silicon dioxide, or the like. The oxide layer (102) isolates the adhesive layer (103) from the silicon layer (101).

Referring to the adhesive layer (103), it (103) is of titanium, tantalum, titanium nitride, or the like. The adhesive layer (103) promotes excellent bonding between the oxide layer (102) and the metal layer (104).

20

Referring to the metal layer (104), it (104) is of platinum, gold, silver, rhodium, iridium, or the like.

25

The method of the present invention can be modified so that it fabricates a metal electrode (100) having at least one high aspect ratio structure that may be suitable to be used in different applications. For one example, the method of the present invention is modified to have an additional step of depositing an encapsulation layer (105) on top of the metal layer (104). The encapsulation layer (105) can be of oxide, nitride, polyimide, glass, or the like, and includes an opening at the most top part of the high aspect ratio structure, exposing the metal layer (104) at the most top part of the high aspect ratio structure. This

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specific modification to the method results in a metal electrode (100) that can be used in wet condition. The said metal electrode (100) fabricated from the aforesaid modified method is illustrated in Figure 5.

CLAIMS

- 1) A metal electrode (100) having at least one high aspect ratio structure, the metal electrode (100) comprises:
- 5 a) a silicon layer (101) having the high aspect ratio structure;
b) an oxide layer (102);
c) an adhesive layer (103); and
d) a metal layer (104);
wherein the thickness of the metal layer (104) is at least 15 times lesser
10 than the height of the high aspect ratio structure;
wherein the metal layer (104) is disconnected at the wall of the high aspect ratio structure.
- 2) A metal electrode (100) in accordance with claim 1 further comprises an
15 encapsulation layer (105) of oxide, nitride, polyimide, or glass, the encapsulation layer (105) having an opening at the most top part of the high aspect ratio structure, exposing the metal layer (104) at the most top part of the high aspect ratio structure.
- 3) A metal electrode (100) in accordance with claim 1, where the oxide layer (102) is silicon dioxide.
- 4) A metal electrode (100) in accordance with claim 1, where the adhesive layer (103) is titanium, tantalum, or titanium nitride.
- 25 5) A metal electrode (100) in accordance with claim 1, wherein the metal layer (104) is platinum, gold, silver, rhodium, or iridium.
- 6) A method of fabricating a metal electrode (100) having at least one high
30 aspect ratio structure, the method comprises the steps of:
a) forming the high aspect ratio structure on a silicon layer (101) via plasma etching or deep reactive ion etching;
b) forming an oxide layer (102) on top of the silicon layer (101) via wet or dry thermal oxidation;

- 5 c) depositing an adhesive layer (103) on top of the oxide layer (102);
 and
 d) depositing a metal layer (104) with a thickness of at least 15 times
 less than the height of the high aspect ratio structure on top of
 the adhesive layer (103) via physical vapor deposition, causing the
 metal layer (104) to be deposited in a self-aligned manner, taking
 the shape of the high aspect ratio structure, and disconnected at
 the wall of the high aspect ratio structure.
- 10 7) A method in accordance with claim 6 further comprises the step of
 depositing an encapsulation layer (105) of oxide, nitride, polyimide, or
 glass on top of the metal layer, the encapsulation layer (105) having an
 opening at the most top part of the high aspect ratio structure, exposing
 the metal layer (104) at the most top part of the high aspect ratio structure.
- 15 8) A method in accordance with claim 6, wherein the oxide layer (102) is
 silicon dioxide.
- 9) A method in accordance with claim 6, where the adhesive layer (103) is
20 titanium, tantalum, or titanium nitride.
- 10) A method in accordance with claim 6, wherein the metal layer (104) is
 platinum, gold, silver, rhodium, or iridium.

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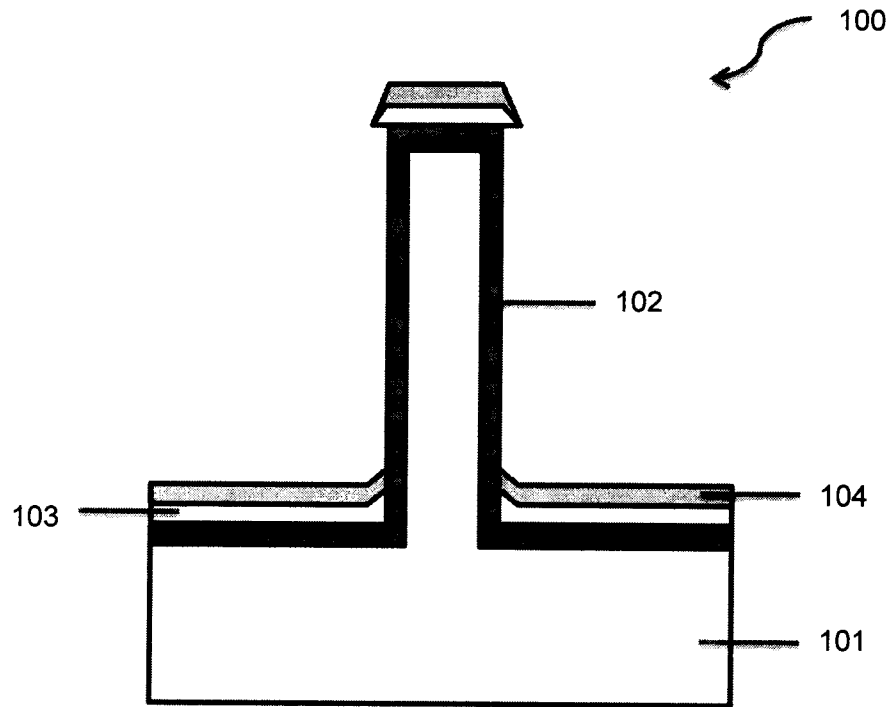


FIGURE 1

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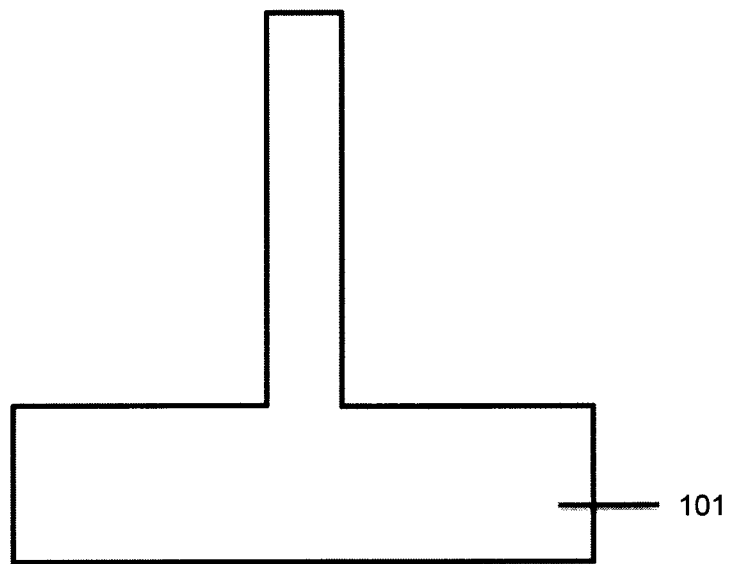


FIGURE 2

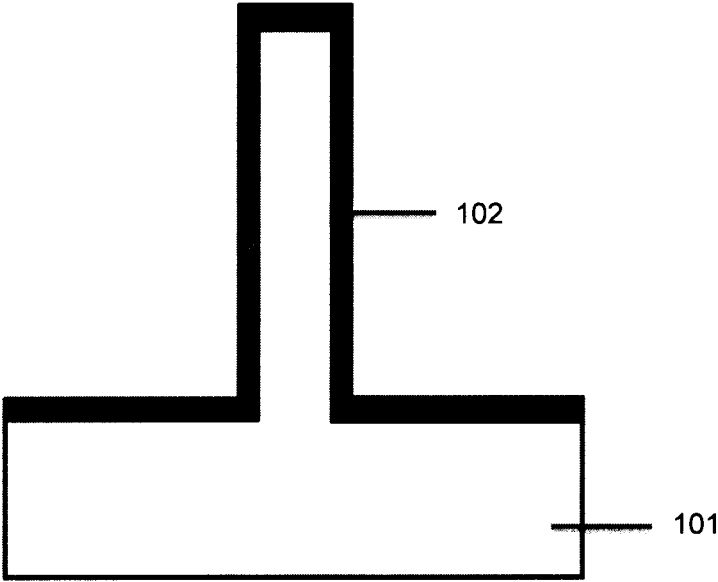


FIGURE 3

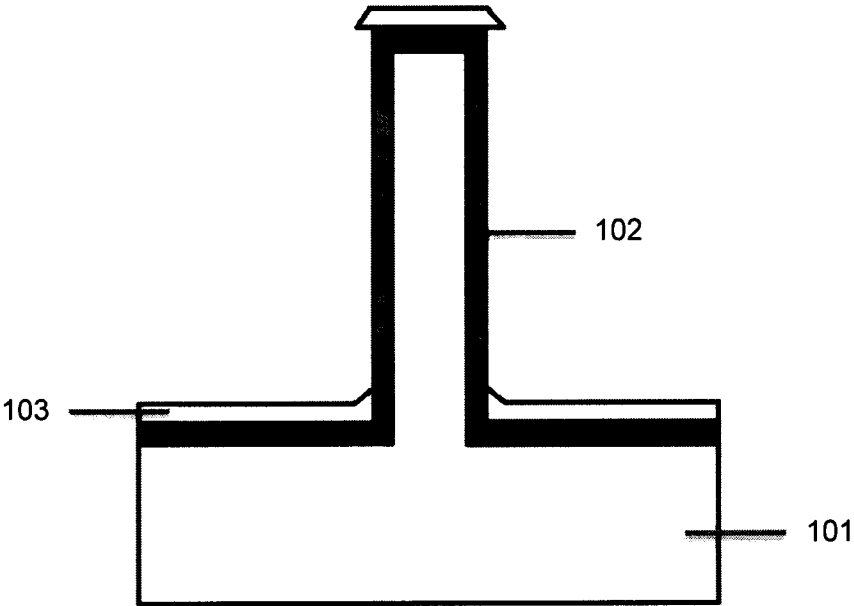


FIGURE 4

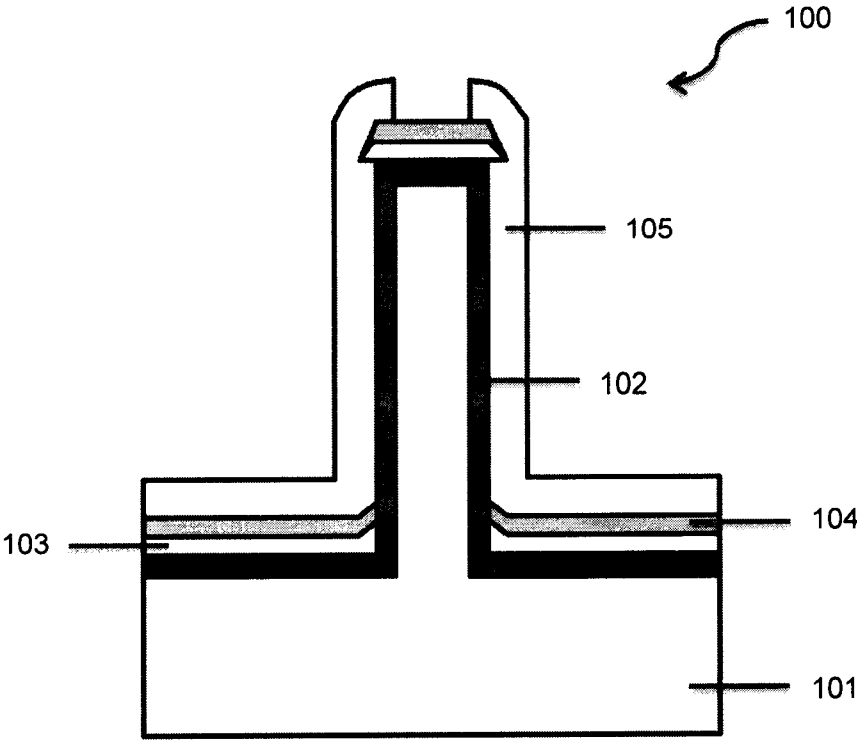


FIGURE 5

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N27/07 G01N27/22 G01N27/30 H01L21/027 H01L29/786
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 H01L

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, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 191 510 A (HUFFMAN MARIA [US]) 2 March 1993 (1993-03-02) the whole document -----	1-10
A	US 2012/025299 A1 (KO SOO-BYUNG [KR]) 2 February 2012 (2012-02-02) the whole document -----	1-10
A	BIEN D C S ET AL: "Formation of silicon nanostructures with a combination of spacer technology and deep reactive ion etching", NANOSCALE RESEARCH LETTERS 2012 SPRINGER NEW YORK USA, vol. 7, 2012, XP002729677, DOI: 10.1186/1556-276X-7-288 the whole document -----	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report		Publication date		Patent family member(s)		Publication date
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