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(54) Microfluidic device and method of manufacturing thereof

(57) A microfluidic device and method of manufacturing thereof are disclosed. In one embodiment, the microfluidic device includes a fluidic channel encapsulated in a solid container. Further, one wall of the fluidic channel is formed by an oxide. Furthermore, a surface of the solid container includes a first recess down to the oxide thereby allowing optical inspection of a fluid sample in the fluidic channel via the first recess, through the oxide.

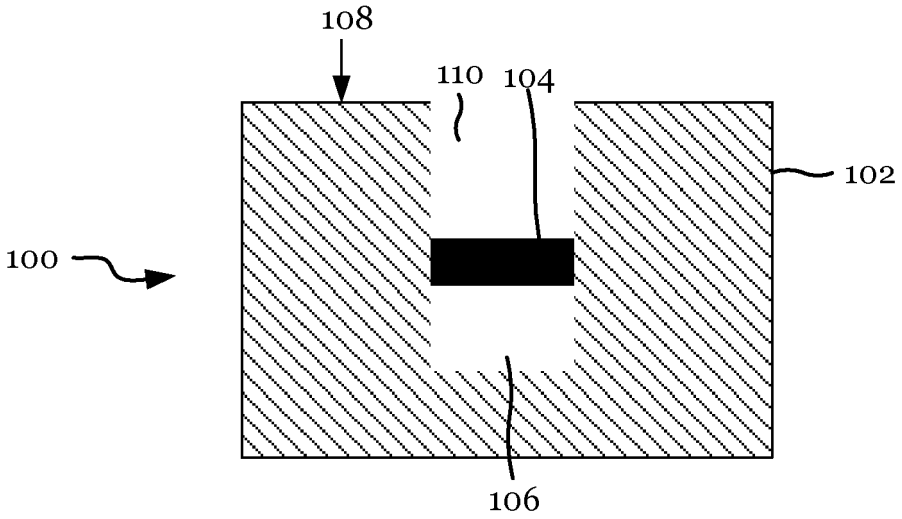

FIG 1A

EP 2 977 606 A1

Description

Field of the Invention

[0001] Embodiments of the present invention relate to microfluidic devices. In particular, embodiments of the present invention relate to the manufacturing of such microfluidic devices.

Background to the Invention

[0002] Micromachining is a technology used to create fluidic channels of microfluidic devices. These microfluidic devices are generally used for lab-on-chip applications having a chemical reaction based detection principle. The fluidic channels are used for parallel analysis of and manipulation of small volumes.

[0003] Generally, a polymer material, e.g. PDMS, may be used for defining the fluidic channels. However, if the detection mechanism is optical (for example, based on fluorescence), the use of the fluidic channels defined in polymer material may become problematic because of their auto-fluorescence and optical properties, such as refractive index, which are difficult to control. Also, the polymer material has limited temperature resistance, poor mechanical properties, poor resistance to certain chemicals and ages with time.

[0004] In fabricating fluidic channels for such lab-on-chip applications, existing techniques provide a substrate having trenches defined in silicon oxide that has lower light absorbance and auto-fluorescence within a wider wavelength range compared to e.g. polymer materials. Further, the existing techniques use anodic bonding of Pyrex (i.e. glass) to seal the topside of the trenches defined in the silicon oxide. However, auto-fluorescence caused by sodium (Na) doping, necessary for this glass. may limit its use for fluorescence based optical detection. Further, the thickness of the top glass wafer must be at least 100 micrometer (μm) to 200μm to prevent breaking.

Summary of the Invention

[0005] A microfluidic device and method of manufacturing thereof are disclosed.

[0006] According to one aspect of the present invention, the microfluidic device includes a fluidic channel encapsulated in a solid container. Further, one wall of the fluidic channel is formed by an oxide. Furthermore, a surface of the solid container includes a first recess exposing the oxide thereby allowing optical inspection of a fluid sample in the fluidic channel underneath the first recess, through the oxide.

[0007] According to another aspect of the present invention, a first substrate having a first oxide layer is provided. The first substrate may be a silicon substrate. Further, a second substrate is provided. The second substrate may be a silicon substrate. Furthermore, a fluidic structure is etched in the second substrate. Moreover, the first substrate is bonded with the second substrate, wherein the first oxide layer is bonded to the second substrate thereby closing the fluidic structure. Also, the first recess is created in the first substrate down to the first oxide layer. In addition, a second recess may be created in the second substrate down to the fluidic structure for supplying or exiting the fluid sample.

Brief Description of the Drawings

[0008]

FIG 1A to **FIG1B** illustrate cross-sectional views of an exemplary microfluidic device including a fluidic channel encapsulated in a solid container, according to an embodiment.

FIG 2A to **FIG 2C** illustrate cross-sectional views of exemplary microfluidic devices depicting various types of fluidic channels, according to different embodiments.

FIG 3A to **FIG 3E** are schematic illustrations of a method of manufacturing a microfluidic device, according to an embodiment.

FIG 4A to **FIG 4E** are schematic illustrations of a method of manufacturing a microfluidic device, according to another embodiment.

FIG 5 illustrates a flow chart of an exemplary method of manufacturing a microfluidic device, according to an embodiment.

Description of the Invention

[0009] A microfluidic device and method of manufacturing thereof are disclosed. In the following detailed description of the embodiments of the present invention, references are made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration specific embodiments in which the present invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the present invention, and it is to be understood that other embodiments may be utilized and that changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present subject matter is defined by the appended claims.

[0010] **FIG 1A** and **FIG 1B** illustrate cross-sectional views of an exemplary microfluidic device **100** including a fluidic channel **10 6** encapsulated in a solid container **10 2,** according to an embodiment. For example, the fluidic channel **106** is a microfluidic channel or a nanofluidic channel. A cross section of the fluidic channel **106** may be rectangular. Referring now to **FIG 1A,** one wall of the

fluidic channel **10 6** is formed by an oxide **104.** Preferably, the oxide **104** is a thermally grown oxide. For example, the thickness of the oxide **104** is in the range of 100 nanometers (nm) to 3 microns (μm). It is an advantage of the invention that the thermally grown oxide is a thin layer which does not disrupt optical signals during inspection of the fluid channel **106** through the thermally grown oxide. It also is an advantage of the invention that the fluidic channel **10**6 can remain closed during optical inspection.

[0011] As shown in **FIG 1A,** a surface **108** of the solid container **102** includes a first recess **110** down to the oxide **104** thereby allowing optical inspection of a fluid sample in the fluidic channel **106** via the first recess **110,** through the oxide **104.** For example, an external optical system can visualize fine details of the fluid sample in the fluidic channel **106** through the thin oxide **104.** The thin oxide **104** significantly increases the numerical aperture of the external optical system monitoring the fluid sample.

[0012] Referring now to **FIG 1B,** the outer surface **10 8** of the solid container **10 2** further includes a second recess **112** down to the fluidic channel **106** for supplying or exiting the fluid sample to and from the fluidic channel.

[0013] Further, the solid container **10 2** is formed by two bonded semiconductor substrates, for example, one semiconductor substrate comprising the fluidic channel **10 6,** e.g. formed in the surface of that semiconductor substrate, and the other semiconductor substrate closing the fluidic channel **10 6.** This assembly is explained in detail with reference to **FIG 2A** to **2C.**

[0014] **FIG 2A to 2C** illustrate cross-sectional views of exemplary microfluidic devices depicting various types of fluidic channels, according to different embodiments. Referring now to **FIG 2A,** the microfluidic device **100** includes a first substrate **202** and a second substrate **204.** Particularly, the solid container **102,** shown in **FIG 1A** and **FIG 1B,** in the microfluidic device **100** is formed by bonding the first substrate **202** to the second substrate **204.** In the example shown in **FIG 2A,** the first substrate **202** comprises a first oxide layer **206** and the second substrate **204** comprises a second oxide layer **208.** Preferably, the first substrate **202** and the second substrate **204** are semiconductor substrates. Preferably, the first oxide layer **206** and, optionally, the second oxide layer **208** are thermally grown on such first substrate **202** and such second substrate **204,** respectively. A preferred example of such thermally grown oxide is silicon dioxide. Alternatively, the first oxide layer **206** and, optionally, the second oxide layer **208** are deposited on such first substrate **202** and such second substrate **204,** respectively

[0015] Furthermore, the second substrate **204** includes the fluidic channel **106.** In this embodiment, the fluidic channel **106** is etched in the second oxide layer **208** of the second substrate **204.** Further, the first substrate **202** and the second substrate **204** are bonded to each other whereby the first oxide layer **206** closes the fluidic channel **106.** This is explained in detail with reference to **FIG 3C.** Furthermore in this embodiment, all the walls of the fluidic channel **10 6** are formed by an oxide, preferably thermally grown oxide.

[0016] Referring now to **FIG 2B,** the microfluidic device **100** includes: the first substrate **202** comprising the first oxide layer **206,** and the second substrate **204.** In this embodiment, the fluidic channel 106 is etched in the second substrate **204.** Further, the first substrate **202** and the second substrate **204** are bonded to each other such that the first oxide layer **206** closes the fluidic channel **10 6.** This is explained in detail with reference to **FIG 4C.**

[0017] Referring now to **FIG 2C,** the first substrate **202** comprises the first oxide layer **206,** and the second substrate **204** comprises the second oxide layer **208.** In this embodiment, the fluidic channel **106** is etched in the second oxide layer **208** and partly in the underlying second substrate **204.** Further, the first substrate **202** and the second substrate **204** are bonded to each other such that the first oxide layer **206** closes the fluidic channel **10 6.**

[0018] In the examples shown in **FIG 2A to 2C,** the first substrate **202** comprises the first recess **110** down to the first oxide layer **206** thereby allowing optical inspection of the fluid sample in the fluidic channel **106** via the first recess **110,** through the first oxide layer **206.** Further, the first substrate **202** or the second substrate **204** can also comprise a second recess **112** down to the fluidic channel **106** for supplying or exiting the fluid sample.

[0019] **FIG 3A to 3E** are schematic illustrations of a method of manufacturing a microfluidic device **100,** according to an embodiment. Referring now to **FIG 3A,** the first substrate **202** comprising the first oxide layer **206** is provided. The first oxide layer **206** is a thermally grown oxide, located on at least a part of the top of a surface of the first substrate **202.** The thickness of the first oxide layer **206** may be in the range of 100nm to 3 μm. Further, the second substrate **204** is provided. In this embodiment, the second substrate **204** comprises the second oxide layer **208.** For example, the second oxide layer **208** may be deposited or thermally grown on a surface of the second substrate **204.** When deposited, the second oxide layer **208** may have a thickness between 20-30 μm. When thermally grown, the second oxide layer **208** may have a thickness between 100 nm and 3μm.

[0020] Referring now to **FIG 3B,** a fluidic structure **210** (i.e., the fluidic channel **106** shown in **FIG 1** and **FIG 2)** is etched in the second substrate **204.** In the example shown in **FIG 3B,** the fluidic structure **210** is etched at least partly into the second oxide layer **208** of the second substrate **204.**

[0021] Referring now to **FIG 3C,** the first substrate **202** and the second substrate **204** are bonded. The first substrate **202** and the second substrate **204** are bonded such that the first oxide layer **206** is bonded to the second substrate **204** thereby closing the fluidic structure **210.** In one example, the first substrate **202** and the second substrate **204** are bonded by activating the first oxide layer **206** and the second oxide layer **208.** In this case, all the walls of the fluidic structure **210** are formed by the

thermally grown oxide. The first and second oxide layers are activated by increasing the number of Si-OH groups on their surface. These groups are highly reactive and when the two surfaces contact each other, permanent Si-O-Si bonds are formed. The activation may comprise an 02, Ar or N2 plasma exposure of the surfaces. The plasma step may be followed by H2O spray on the substrate surface.

[0022] Referring now to **FIG 3D,** the first recess **110** is created in the first substrate **202** down to the first oxide layer **206.** In this embodiment, the first recess **110** is created in a surface of the first substrate **202** opposing the surface of the first substrate **202** comprising the first oxide layer **206.** The first recess **110** allows optical inspection of the fluid sample in the fluidic structure **210** through the first oxide layer **206.** Referring now to **FIG 3E,** the second recess **112** is created in the second substrate **204** down to the fluidic structure **210** for supplying or exiting the fluidic sample therefrom. The second recess **112** is created in a surface of the second substrate **204** opposing the surface of the second substrate **204** comprising the second oxide layer **208.** Alternatively, the second recess **112** may also be created in the first substrate **202** down to the fluidic structure **210.**

[0023] **FIG 4A** to **4E** are schematic illustrations of a method of manufacturing the microfluidic device **100,** according to another embodiment. Referring now to **FIG 4A,** the first substrate **202** comprising the first oxide layer **206** located on at least a part of a surface of the first substrate **202** is provided. Further, the second substrate **204** is provided. Referring now to **FIG 4B,** the fluidic structure **210** is etched in the second substrate **204.**

[0024] Referring now to **FIG 4C,** the first substrate **202** and the second substrate **204** are bonded. The first substrate **202** and the second substrate **204** are bonded such that the first oxide layer **206** is bonded to the second substrate **204** thereby closing the fluidic structure **210.** In one example, the first substrate **202** and the second substrate **204** are bonded by activating both surfaces. For example, the deposited first oxide layer **206** on a first substrate **202** may be activated. A second substrate **204** may have a native oxide layer because of natural oxidation which occurs due to the exposure to air, e.g. exposure of a silicon wafer to air. Thus, that native oxidation layer may also be activated.

[0025] Referring now to **FIG 4D,** the first recess **110** is created in the first substrate **202** down to the first oxide layer **206.** The recess **110** is created in a surface of the first substrate **202** opposing the surface comprising the first oxide layer **206.** The first recess **110** allows optical inspection of the fluid sample in the fluidic structure **210** through the first oxide layer **206.** The dimensions of the first recess are selected thereby allowing optical inspection through the first recess **110.** For example, when an external optical tool is used to perform optical inspection, the dimensions of the first recess **110** are chosen thereby allowing optical inspection using that external optical tool, e.g. a microscope. Referring now to **FIG 4E,** the second recess **112** is created in the second substrate **204** down to the fluidic structure **210** for supplying or exiting the fluidic sample therefrom.

[0026] **FIG 5** illustrates a flow chart **500** of an exemplary CMOS-compatible method of manufacturing a microfluidic device, according to an embodiment.

[0027] At step **502,** a first substrate **202** comprising a first oxide layer **206** is provided. In one embodiment, the first oxide layer **206** is a thermally grown oxide. Further, the first oxide layer **206** can have a thickness in the range of 100nm to 3 μm.

[0028] At step **50 4,** a second substrate **20 4** is provided. This is explained in detail with reference to **FIG 3A** to **FIG 4A.**

[0029] At step **506,** a fluidic structure **210** is etched in the second substrate **204.** In one embodiment, the second substrate **204** comprises a second oxide layer. The fluidic structure **210** is then at least partly etched into the second oxide layer of the second substrate **204.**

[0030] At step **508,** the first substrate **202** and the second substrate **204** are bonded. The first substrate **202** is bonded with the second substrate **204** such that the first oxide layer **206** is bonded to the second substrate **204** thereby closing the fluidic structure **210.** This is explained in detail with reference to **FIG 3C** and **FIG 4C.**

[0031] At step **510,** a first recess **110** is created in the first substrate **202** down to the first oxide layer **206.**

[0032] At step **512,** a second recess **112** is created in the second substrate **204** down to the fluidic structure **210** for supplying or exiting a fluid sample. This is explained in detail with reference to **FIG 3E** and **FIG 4E.** This step **512** is optional. The second recess **112** is dimensioned thereby allowing application of a fluid sample in the fluidic structure **210.** The size of the second recess **112** may be adapted to allow external tools, e.g. pipetting tools, to provide a fluid sample in the fluidic structure **210.**

[0033] Though the **FIG 1** through **FIG 5** are explained with reference to one fluidic channel, the same embodiments are applicable to a microfluidic device with multiple fluidic channels. Also, the different embodiments of the fluidic channel, explained with reference to **FIG 2A** to **FIG 2C,** can be fabricated in any combination in the microfluidic device.

[0034] It should be understood that the embodiments and the accompanying drawings as described above have been described for illustrative purposes and the present invention is limited by the following claims.

Claims

1. A microfluidic device (100) comprising a fluidic channel (106) encapsulated in a solid container (102), wherein one wall of the fluidic channel (106) is formed by an oxide (104),
characterized in that:

a surface (108) of the solid container (102) com-

prises a first recess (110) down to the oxide (104) thereby allowing optical inspection, through the oxide (104), of a fluid sample in the fluidic channel (106) via the first recess (110).

2. The microfluidic device (100) according to claim 1, wherein the oxide (104) is a thermally grown oxide.

3. The microfluidic device (100) according to claim 2, wherein all walls of the fluidic channel (106) are formed by a thermally grown oxide.

4. The microfluidic device (100) according to any of the preceding claims, wherein the thickness of the oxide (104) is in the range of 100 nanometers (nm) to 3 microns (μm).

5. The microfluidic device (100) according to any of the preceding claims, wherein the surface (108) of the solid container (102) further comprises a second recess (112) down to the fluidic channel (106) for supplying or exiting the fluid sample therefrom.

6. The microfluidic device (100) according to any of the preceding claims, wherein the solid container (102) further comprises a first substrate (202) and a second substrate (204), wherein the second substrate (204) comprises the fluidic channel (106), wherein the first substrate (202) closes at least the fluidic channel (106), and wherein the first substrate (202) and the second substrate (204) are bonded with each other.

7. A method of manufacturing a microfluidic device (100), the method comprising:

- providing a first substrate (202) comprising a first oxide layer (206);
- providing a second substrate (204);
- etching a fluidic structure (210) in the second substrate (204);
- bonding the first substrate (202) and the second substrate (204), wherein the first oxide layer (206) is bonded to the second substrate (204) thereby closing the fluidic structure (210); and
- creating a first recess (110) in the first substrate (202) down to the first oxide layer (206).

8. The method according to claim 7, wherein the first oxide layer (206) is a thermally grown oxide.

9. The method according to any of claims 7 to 8, wherein the first oxide layer (206) has a thickness in the range of 100nm to 3 microns (μm).

10. The method according to any of claims 7 to 9, further comprising: creating a second recess (112) in the second substrate (204) down to the fluidic structure (210) for supplying or exiting a fluid sample therefrom.

11. The method according to any of claims 7 to 10, wherein the second substrate (204) comprises a second oxide layer (208), and wherein etching the fluidic structure (210) in the second substrate (204) comprises at least partly etching into the second oxide layer (208) of the second substrate (204).

12. The method according to any of claims 7 to 11, wherein the first substrate (202) and the second substrate (204) are semiconductor substrates.

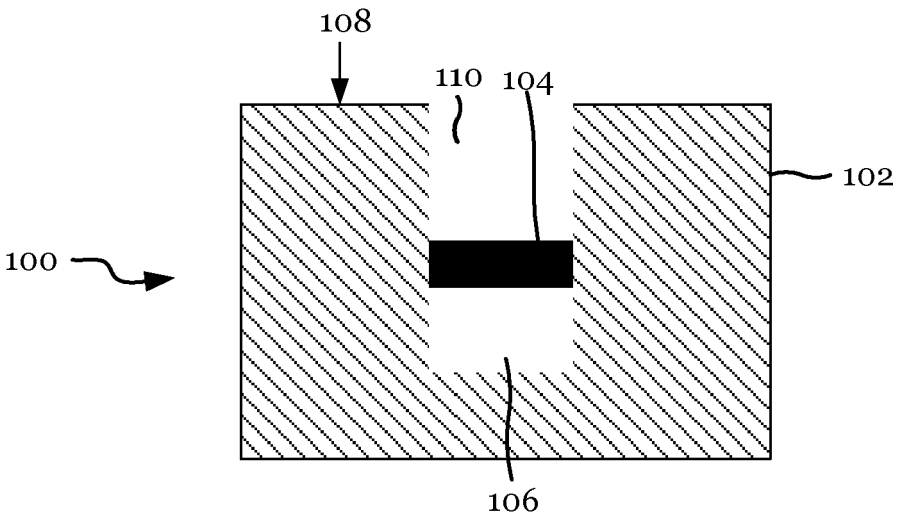

FIG 1A

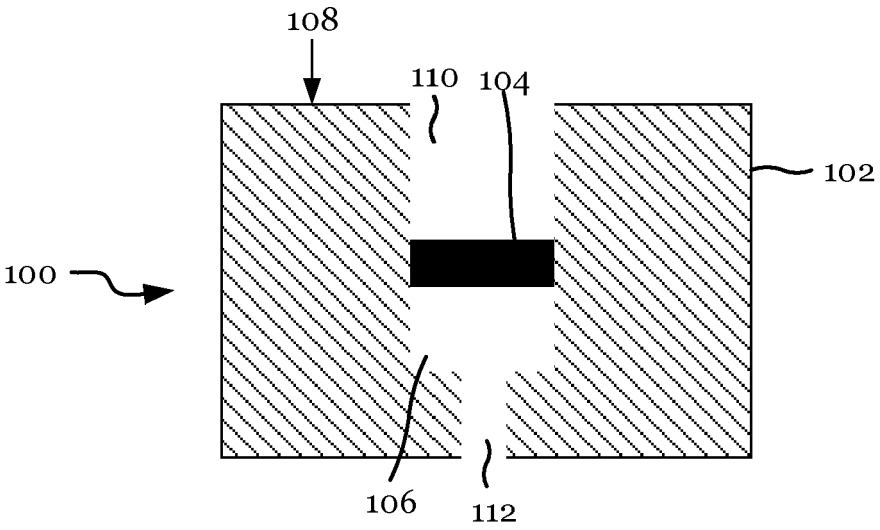

FIG 1B

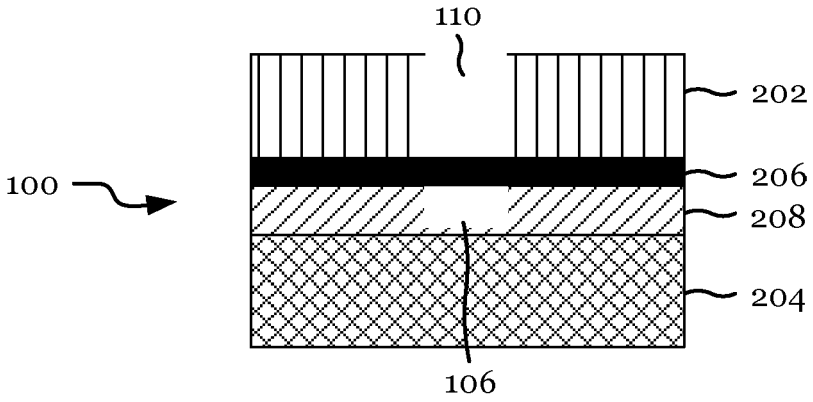

FIG 2A

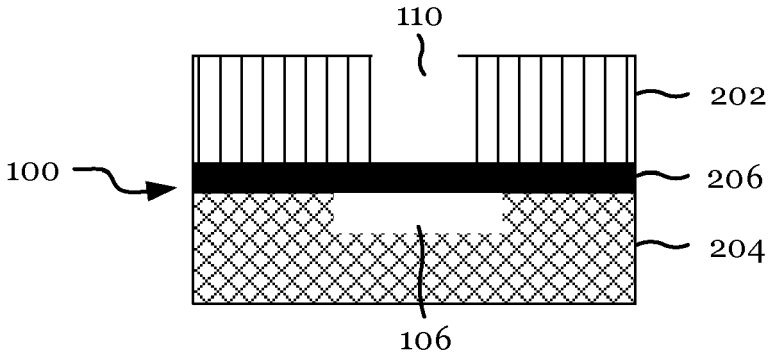

FIG 2B

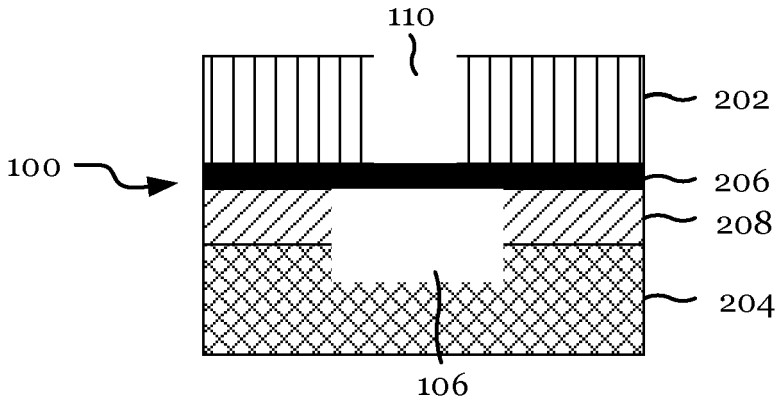

FIG 2C

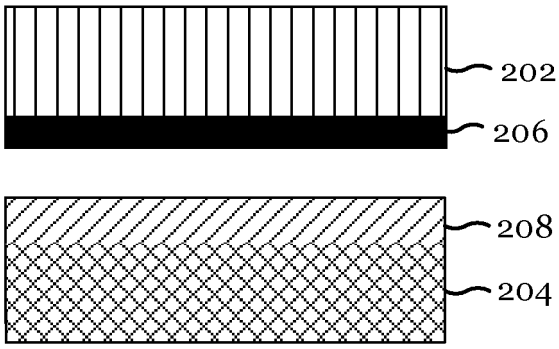

FIG 3A

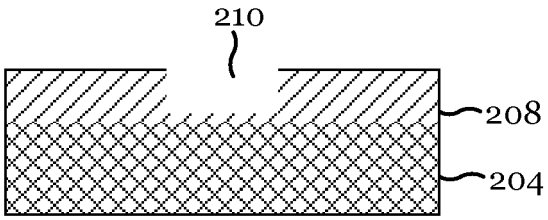

FIG 3B

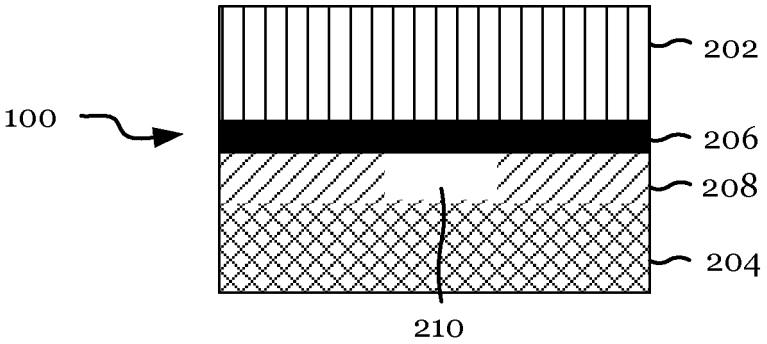

FIG 3C

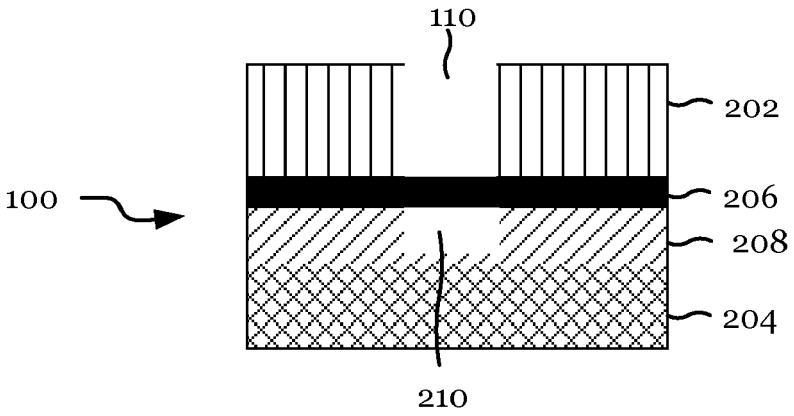

FIG 3D

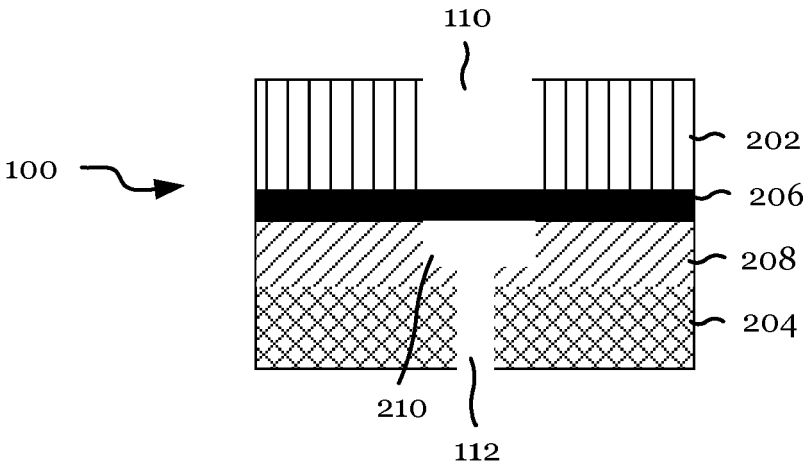

FIG 3E

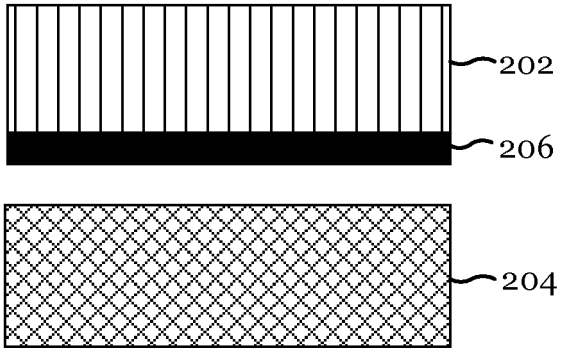

FIG 4A

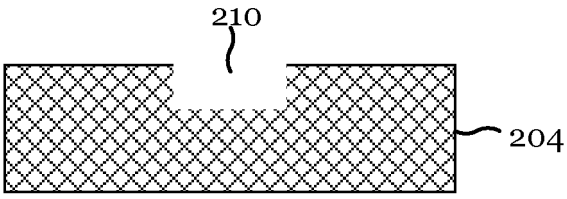

FIG 4B

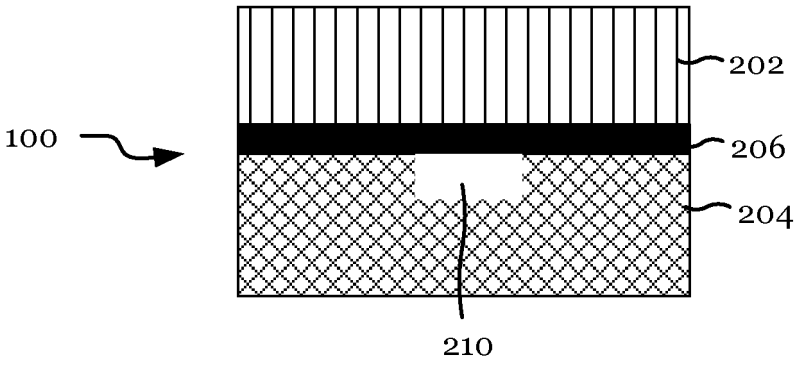

FIG 4C

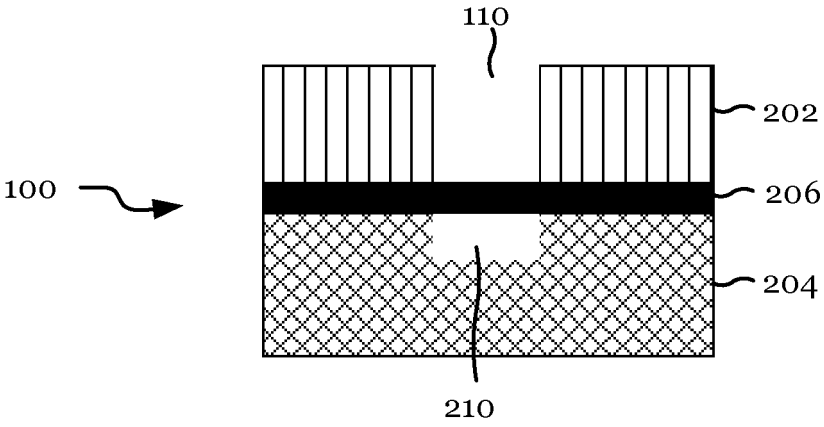

FIG 4D

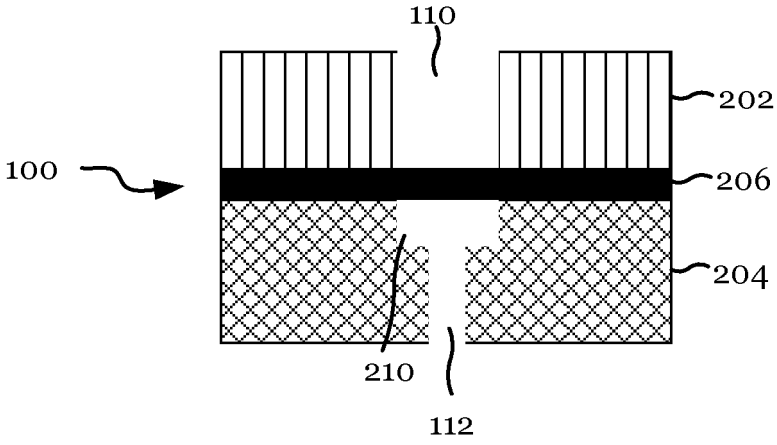

FIG 4E

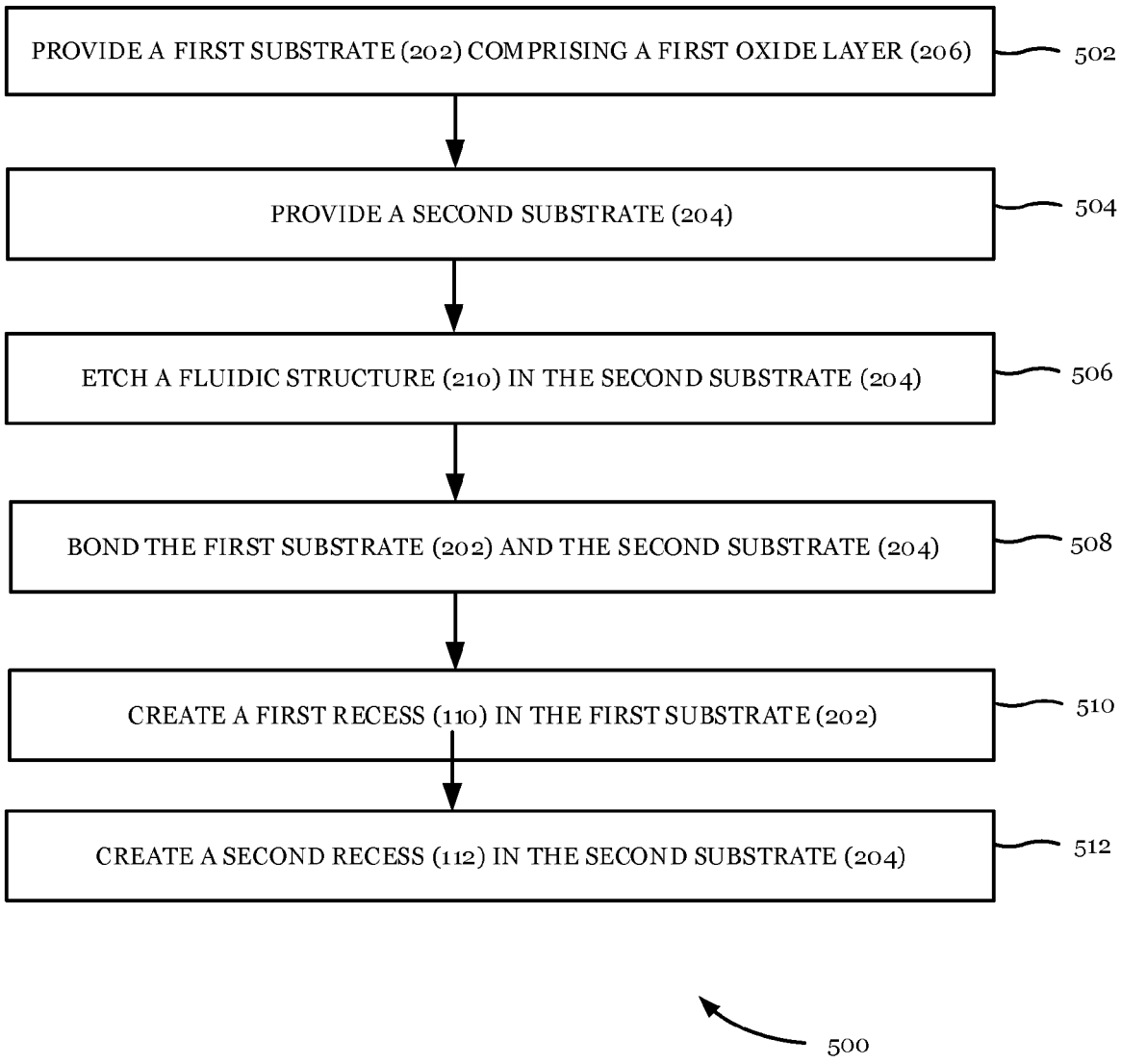
PROVIDE A FIRST SUBSTRATE (202) COMPRISING A FIRST OXIDE LAYER (206)
502
PROVIDE A SECOND SUBSTRATE (204)
504
ETCH A FLUIDIC STRUCTURE (210) IN THE SECOND SUBSTRATE (204)
506
BOND THE FIRST SUBSTRATE (202) AND THE SECOND SUBSTRATE (204)
508
CREATE A FIRST RECESS (110) IN THE FIRST SUBSTRATE (202)
510
CREATE A SECOND RECESS (112) IN THE SECOND SUBSTRATE (204)
512
500

FIG 5

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 14 17 8482

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2010/277722 A1 (AGILENT TECHNOLOGIES INC [US]) 4 November 2010 (2010-11-04) * figures 1-26 * * paragraph [0003] * * paragraph [0046] - paragraph [0047] * * paragraph [0049] * * paragraph [0081] - paragraph [0091] * * paragraph [0103] - paragraph [0106] *	1-12	INV. F04B19/00 F04B43/00 H01L21/00 G01N21/00 B01L3/00 B01L9/00
A	US 2011/241134 A1 (ONO KOICHI [JP] ET AL) 6 October 2011 (2011-10-06) * figures 4,5,7,8 * * paragraph [0036] - paragraph [0043] * * paragraph [0063] * * paragraph [0073] *	1-12	
A	WO 02/28532 A2 (PROTASIS CORP [US]) 11 April 2002 (2002-04-11) * figures 1a,6 * * page 3, line 21 - line 31 * * page 9, line 29 - page 10, line 14 * * page 13, line 31 - page 14, line 12 * * page 15, line 6 - line 9 * * page 27, line 17 - line 32 *	1-12	TECHNICAL FIELDS SEARCHED (IPC) F04B H01L G01N B01L
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Place of search	Date of completion of the search	Examiner
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