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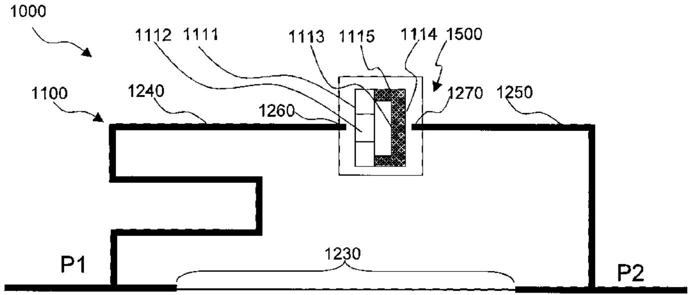

FIG. 1A

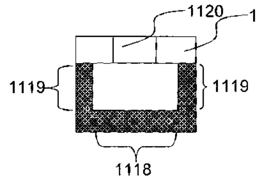

FIG. 1B

(57) **Abstract**: The present invention discloses a flow-rate sensor adapted to measure the differential pressure between an inlet and an outlet of a main channel. In embodiments, the flow-rate sensor comprises a sensor channel, wherein the sensor channel comprises an upstream channel, a downstream channel and a sensor die employing a pressure-sensitive membrane having an upstream side and downstream face communicating with the upstream channel and the downstream channel of said sensor channel. In embodiments, thes main channel comprises an inlet channel, a flow-restriction channel and an outlet channel which are operatively connected to each other in series. The sensor channel is operatively connected in parallel to the main channel at an upstream junction and downstream junction such that the pressure-sensitive membrane is subjected to differential pressure between an upstream location and a downstream location with respect to the flow-restriction channel. Additional and alternative embodiments are disclosed and claimed.

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FLOW-RATE SENSOR AND METHOD FOR MANUFACTURING THEREOF

FIELD OF THE INVENTION

[0001] The present invention relates to the field of flow-rate measurement and more specifically, to the field of flow-rate sensors that are operational based on the measurement of differential pressure.

BACKGROUND OF THE INVENTION

[0002] Commercially available flow-rate sensor to measure very low fluid flow-rates of, e.g., below 100µl/s, may be based on thermal dispersion mass flow measurement as used employed in hot wire anemometer or other thermal flow-rate sensors; on differential pressure; or on the concept of inertia as employed in association with a mass flow meter or coriolis flow meter.

[0003] Fully integrated thermal flow-rate sensors are offered by various companies as exemplified and listed below:

[0004] Bronkhorst:

http://www.bronkhorst.com/en/products/liquid_flow_meters_&_controllers/

http://www.bronkhorst.com/files/published_articles/thermal.pdf

[0005] Honeywell:

http://sensing.honeywell.com/index.cfm?ci_id=140301&la_id=1&pr_id=106049

[0006] Upchurch:

http://www.upchurch.com/Products/specsheet.asp?vSpecSheet=799&vFrom=L

[0007] Sierra Instruments:

http://www.sierrainstruments.com/products/digital.html

[0008] Sensirion:

http://www.sensirion.com/en/02_liquid_flow_sensors/00_liquid_flow_sensor.htm

[0009] HSG-IMIT: http://www.hsg-imit.de/fileadmin/gfx/pdfs/0801_AB_24_Thermische_Stroemungssensoren_d_e.pdf

[0010] Further, coriolis flow sensors are offered by Bronkhorst and Honeywell: http://www.bronkhorst.com/en/products/liquid_flow_meters_&_controllers/cori-flow/ http://hpsweb.honeywell.com/Cultures/en-US/Products/Instrumentation/flow/coriolis/default.htm

[0011] Flow-rate sensors that are based on the measurement of differential pressure (hereinafter: differential flow-rate sensor) are offered by Cole Parmer and Seyonic

http://www.coleparmer.co.uk/catalog/product_index.asp?cls=1766

http://www.seyonic.com/prodflowsensor.php

[0012] Differential flow-rate sensors have a significantly faster response time than thermal flow-rate sensors and Coriolis flow-rate sensors. On the other hand differential flow-rate sensors measure volume flow instead of mass flow. Examples of differential flow-sensors are outlined herein below.

[0013] US patent 5'945'605 to Francis et al. discloses a non-invasive sensor assembly device that includes a pedestal mounted sensor die for stress isolation of the sensor die from external stresses, a substrate and die porting configuration to limit exposure of the sensor assembly to only the interior of the sensor die and a connecting tube to provide significant isolation of the sensor assembly and its constituent parts from the fluid stream, and an inert coating conformally deposited on the inside surfaces of the die, pedestal, and connecting tube that are in contact with the fluid media to thereby provide complete isolation of the sensor assembly from the media. The pedestal is fabricated on the substrate by screening multiple layers of conductive ink on the substrate, flashing off the solvents, and firing the substrate to burn off the binders to provide a boss of sufficient height such that the sensor die, once mounted on the boss, is substantially isolated from the substrate and, therefore, from included stresses that might otherwise have been transferred to the die from the substrate. The contact area of the boss with the die is optimally selected to provide maximum stress isolation and sufficient mounting strength. A through hole in the substrate and through the longitudinal center of the boss is in cooperative coaxial alignment with a fluid entry port in the die to permit measurement of the physical characteristic of interest within the interior of the die.

[0013] US patent 6'150'681 to Allen discloses a monolithic, integrated circuit sensor combining both a differential pressure sensor and a flow sensor on the same silicon chip. The integrated circuit has a diaphragm with a number of piezo-resistive elements placed on it in the normal manner for a pressure sensor. In addition, a channel is provided between the spaces on the two sides of the diaphragm. The channel has a cross-section which is a fraction of the size of the diaphragm. In one embodiment, the channel is a hole in the diaphragm. In another embodiment, the channel is an etched groove in the frame supporting the diaphragm.

[0014] US patent 5'959'213 to Ikeda et al. discloses a semiconductor differential pressure measuring device comprising two measurement diaphragms and two detection sensors provided in a semiconductor substrate using micromachining techniques, and a computing circuit which computes the differences between the two sensor outputs, wherein a communicating hole is provided for applying pressure to each diaphragm so that the diaphragms operate in opposite phases by differential pressure, and two detecting sensors are provided on each diaphragm for detecting displacement or strain of each diaphragm caused by the differential pressure applied to the respective diaphragm, whereby detecting the differences in displacement or strain cancels the static pressure error and temperature error so that the invention has excellent temperature and static pressure characteristics, and whereby the computing circuit comprises a bridge using the two detecting sensors, which substantially reduces the cost of the device.

[0015] US patent 4'565'096 to Knecht et al. discloses a transducer having a first and second sensing diaphragm configured such that a first pressure P1 is applied to the first diaphragm and a second pressure P2 is applied to the second diaphragm and wherein both diaphragms are formed on the same substantially flat face of a diaphragm wafer. The transducer is configured such that each diaphragm responsive to P1 or P2 respectively also affects a fluid in a closed common fluid cavity such that the deflection of the diaphragm is representative of the pressure differential (P1-P2).

[0016] US patent 5'969'591 to Fung discloses a single-sided differential pressure sensing chip having a cavity formed in the top surface of a substrate, a deformable diaphragm spanning the cavity, and a pressure passage connecting the top surface of the substrate with the cavity, and a method of making the same. A first fluid pressure applied to the top surface of the substrate in the vicinity of the diaphragm exerts a force on the top surface of the diaphragm, and a second fluid pressure applied to the top surface of the substrate near the pressure passage exerts a force on the bottom surface of the diaphragm. The diaphragm deflects in response to the forces exerted upon it, and a sensing element detects the flexing of the diaphragm. The pressure sensing chip can be contained within a housing structure formed of a carrier and a cap. The housing structure forms a first pressure chamber that communicates with the top surface of the diaphragm and a second pressure chamber that communicates with the bottom surface of the diaphragm through the pressure passage. The cap can include a first opening for connecting a first fluid pressure with the first chamber, and a second opening for connecting a second fluid pressure with the second chamber.

[0017] US patent 6'898'981 to Boillat e al. discloses a device for measuring pressure in two points of a fluid flow, comprising: a frame consisting of two plates comprising each two planar surfaces, one outer and the other inner and wherein one of the plates is perforated with recess closed by the other plate to form an assembly of two chambers comprising two planar walls parallel to the surfaces of the frame and a side wall forming its periphery and a fluidic restriction channel connecting the two chambers with each other, and means for supplying a measurement of the pressure in each of the chambers. In order to improve the accuracy of the measurement, the side wall of the chambers is perpendicular to its two planar walls and is configured such that the chambers are spindle-shaped.

DESCRIPTION OF THE FIGURES

[0018] These and further features and advantages of the invention will become more clearly understood in the light of the ensuing description of a some embodiments thereof, given by way of example only, with reference to the accompanying figures (FIGs), wherein:

[0019] **FIG. 1** is a schematic channel layout illustration of a flow-rate sensor, according to an embodiment of the invention;

[0020] **FIG. 2** is a schematic cross-sectional front view illustration of the flow-rate sensor, according to the embodiment of **FIG. 1**;

[0021] **FIG. 3** is a schematic cross-sectional side view illustration of the flow-rate sensor, according to the embodiment of **FIG. 1**;

[0022] **FIG. 4** is a schematic top view illustration of a base substrate, according to the embodiment of **FIG. 1**;

[0023] **FIG. 5** is a schematic top view illustration of an intermediate substrate, according to the embodiment of **FIG. 1**;

[0024] **FIG. 6** is a schematic isometric illustration of the flow-rate sensor, according to an embodiment of the invention;

[0025] **FIG. 7** is a schematic detailed isometric cross-sectional illustration of a sensor die of the flow-rate sensor, according to the embodiment of **FIG. 6**;

[0026] **FIG. 8** is a schematic detailed top view illustration of the courses of a flow-restriction channel, an upstream channel and a downstream channel, according to the embodiment of **FIG. 6**;

[0027] **FIG. 9** is a schematic channel-layout illustration of a flow-rate sensor, according to an alternative embodiment of the invention;

[0028] **FIG. 10** is a schematic detailed isometric illustration of the courses of a flow-restriction channel, an upstream channel and a downstream channel, according to an embodiment of the invention;

[0029] **FIG. 11** is a schematic isometric detailed cross-sectional illustration of a sensor die, according to the embodiment of **FIG. 10**;

[0030] **FIG. 12** is a schematic detailed top view illustration of the courses of a flow-restriction channel, an upstream channel and a downstream channel, according to the embodiment of **FIG. 10;**

[0031] **FIG. 13** is a schematic channel-layout illustration indicating gas traps in the flow-rate sensor of **FIG. 6**;

[0032] **FIG. 14** is a schematic channel-layout illustration of a flow-rate sensor employing a plurality of sensor dies in parallel, according to an embodiment of the invention;

[0033] **FIG. 15A** is a schematic top view illustration of base substrate, according to the embodiment of **FIG. 14**; and

[0034] **FIG. 15B** is a schematic top view illustration of an intermediate substrate, according to the embodiment of **FIG. 14**.

DESCRIPTION OF THE INVENTION

[0035] Positional terms such as "upper", "lower" "right", "left", "bottom", “below”, "lowered", "low", "top", “above”, "elevated", "high", "vertical" and "horizontal" as well as grammatical variations thereof as may be used herein do not necessarily indicate that, for example, a "bottom" component is below a "top" component, or that a component that is “below” is indeed “below” another component or that a component that is “above” is indeed “above” another component as such directions, components or both may be flipped, rotated, moved in space, placed in a diagonal orientation or position, placed horizontally or vertically, or similarly modified. Accordingly, it will be appreciated that the terms "bottom", “below”, "top" and “above” may be used herein for exemplary purposes only, to illustrate the relative positioning or placement of certain components, to indicate a first and a second component or to do both.

[0036] It should further be noted that the term “vertically” and “horizontally” as used herein also encompass the meaning of the terms “at least approximately vertically” and “at least approximately horizontally”, respectively.

[0037] Summary of the invention:

[0038] Embodiments of the present invention disclose a flow-rate sensor comprising a sensor channel and a main channel. Sensor channel comprises a sensor die configured, e.g., as known in the art, employing a pressure-sensitive membrane having an upstream side and downstream face communicating with an upstream channel and a downstream channel of the sensor channel. The pressure-sensitive membrane comprises piezo-resistive material and is thus be electrically responsive to mechanical deflections. More specifically, mechanical deflections of the piezo-resistive membrane may result in a corresponding change in the electrical resistance.

[0039] The main channel comprises an inlet channel, a flow-restriction channel and an outlet channel, which are operatively connected to each other in series. The cross-sectional area of the flow-restriction channel is smaller compared to the cross-sectional area of inlet channel and outlet channel. The cross-sectional area of inlet channel may be at least approximately equal ot the cross-sectional area of the outlet channel. The sensor channel is operatively connected in parallel to the main channel at an upstream junction and downstream junction, wherein the upstream junction is located upstream of the fluid-restriction channel, and the downstream junction is located downstream of the fluid-restriction channel.

[0040] The sensor die is configured such that when being operatively coupled in parallel with a flow-restriction channel, the upstream face is subjected to pressure which is present at a location upstream (hereinafter: upstream location) of the flow-restriction channel, whilst the downstream face is subjected to pressure which is present at a location downstream (hereinafter: downstream location) of the flow-restriction channel. A potential deflection of the pressure-resistive membrane thus corresponds to the differences in absolute pressure **P1** and **P2** (hereinafter: differential pressure) between an upstream location and a downstream location. It should be noted that the differential pressure (**P1**-**P2**) to which the pressure-sensitive membrane may be subjected to may be significantly lower than the system pressure to which two membranes may be subjected to for measuring the differential pressure based on the deflection of each of the two membranes.

[0041] The flow-rate sensor comprises at least one substrate comprising at least some of the sensor channel and the main channel.

[0042] The flow-rate sensor according to embodiments of the invention may be adapted to measure differential pressure ranging, for example, from 1 mbar to 100 mbar, and thus the corresponding flow-rate.

[0043] The response time to changes in the flow rate of the flow-rate sensor according to embodiments of the invention may be, for example, maximal 1 ms, and for example have a value of 0.5 ms.

[0044] According to embodiments of the invention, the flow-rate sensor comprises electric conductors such that an electronic readout module is mechanically and operatively coupleable with the electric conductors for readout of the electrical resistance change due to the deflection of the pressure-sensitive membrane.

[0045] According to embodiments of the invention, the flow-rate sensor is configured such that the pressure-sensitive membrane remains unaffected to sudden changes in absolute pressure, but is only affected by the changes in the differential pressure, which is proportional to the flow rate through the flow-restriction channel according to the law of Hagen-Poiseuille.

[0046] Detailed description of the invention

[0047] Reference is now made to **FIG. 1A** and to **FIG. 1B**. According to embodiments of the invention, flow-rate sensor **1000** comprises an inlet **1211** to an inlet channel **1210** leading to a flow-restriction channel **1230**, which leads to an outlet channel **1220** having an outlet **1221**. Both inlet channel **1210** and outlet channel **1220** have as cross-sectional area being larger than the cross-sectional area of flow-restriction channel **1230**. Accordingly, flow-restriction channel **1230** constitutes a narrowing section between inlet **1211** and outlet **1221** causing a pressure drop of fluid (not shown) flowing from inlet **1211** to outlet **1221** from **P1** to **P2**, wherein **P1** is the pressure of the fluid upstream of fluid-restriction channel **1230** and **P2** is the pressure of the fluid downstream of fluid-restriction channel **1230**. The drop in the pressure (**P2-P1**) is at least approximately proportional to the fluid's volume flow or flow-rate. The proportionality may be expressed by the Hagen-Poisseuilles law.

[0048] Flow-rate sensor **1000** further comprises a sensor channel **1100** which communicates in parallel with flow-restriction channel **1230** via inlet channel **1210** and outlet channel **1220** such to share inlet **1211** and outlet **1221**. More specifically, sensor channel **1100** comprises an upstream channel **1240** which communicates upstream of flow-restriction channel **1230**, at an upstream junction **1241**, with inlet channel **1210**. Further, sensor channel **1100** comprises a downstream channel **1250** which communicates with outlet channel **1220** at a downstream junction **1251**. It should be noted that to simplify the discussion that follows, a possible drop in pressure of fluid in inlet channel **1210**, outlet channel **1220**, upstream channel **1240** and downstream channel **1250** may be considered as negligible, at least in comparison to the drop in pressure of fluid between upstream channel **1210** and downstream channel **1220** caused by flow-restriction channel **1230**.

[0049] Sensor channel **1100** additionally includes a sensor die **1500**, e.g., as known in the art, comprising a pressure-sensitive membrane **1115**, which may be U-shaped such to have a diaphragm **1118** connected to legs **1119**, which are coupled to a membrane substrate **1111** comprising a fluid opening **1112**. Upstream channel **1240** operatively communicates via an upstream outlet **1260** with an upstream face **1113** of pressure-sensitive membrane **1115**. Similarly, downstream channel **1250** operatively communicates via a downstream outlet **1270** with a downstream face **1114** of pressure-sensitive membrane **1115**.

[0050] According to embodiments of the invention, flow-restriction channel **1230**, upstream channel **1240** and downstream channel **1250** are manufactured in at least one substrate layer, as outlined herein below in greater detail.

[0051] Further reference is now made to **FIG. 2** and **FIG. 3**. According to embodiments of the invention, flow-rate sensor **1000** comprises a base substrate **2100**, whereon an intermediate substrate **2200** is provided. In embodiments of the invention, flow-rate sensor **1000** moreover may comprise a circuit substrate **2300** including or constituting a circuit board having an electrical circuit and/or comprising electric connections and/or electric components such as, for example, an amplifier or amplifier circuit. According to embodiments of the invention, circuit substrate **2300** may for example comprise electric vias **2355** terminating in electric connections. Intermediate substrate **2200** may be sandwiched between circuit substrate **2300** and base substrate **2100**. To simplify the discussion that follows, circuit substrate **2300** comprising or constituting the circuit board is hereinafter referred to as "circuit board **2300**". Circuit board **2300** may have a concavity **2310** adapted to house therein in a sealed manner sensor die **1500** and may be mechanically coupled, e.g., adhesively, with intermediate substrate **2200**. Accordingly, circuit board **2300** may constitute a part of a housing of flow-rate sensor **1000**.

[0052] The course of inlet channel **1210**, outlet channel **1220**, flow-restriction channel **1230**, upstream channel **1240** and downstream channel **1250** in flow-rate sensor **1000** is outlined hereinafter. It should however be noted that the described course is for exemplary purposes only and that it may be vary in respective embodiments of the invention.

[0054] According to embodiments of the invention, inlet channel **1210** may first run horizontally from its inlet **1211** and then vertically in circuit board **2300** via intermediate substrate **2200** to base substrate **2100**. In base substrate **2100**, inlet channel **1210** may run horizontally such to pass upstream junction **1241** and to lead into flow-restriction **1230**. Flow restriction **1230** may run horizontally in base substrate **2100** and lead into outlet channel **1220** prior to passing downstream junction **1251**. Outlet channel **1220**, after passing downstream junction **1251** may further run horizontally in base substrate **2100** and then vertically from base substrate **2200** via intermediate substrate **2200** to circuit board **2300**. In circuit board **2300**, outlet channel **1220** may run horizontally and terminate in its outlet **1221**.

[0055] Additional reference is now made to **FIG. 4**. According to embodiments of the invention, upstream channel **1240** may depart horizontally from upstream junction **1241** and run within base substrate **2100** until it vertically emerges into intermediate substrate **2200** to terminate in concavity **2310** such to communicate with upstream face **1113** of pressure-sensitive membrane **1115**. Similarly, downstream channel **1250** may depart horizontally from downstream junction **1251** and run within base substrate **2100** until downstream channel **1250** vertically emerges out of intermediate substrate **2200** such to communicate with downstream face **1114** of pressure sensitive membrane **1115**.

[0056] According to some embodiments of the invention, a flow-rate sensor such as, for example, flow-rate sensor **1000** may be designed to prevent or at least to reduce the risk of contamination and/or clogging flow in flow-restriction channel **1230**, since any change in the geometry of flow-restriction channel **1230** may cause a corresponding change of the pressure drop between an upstream location and a downstream location such as, for example, upstream junction **1241** and downstream junction **1251**. As a consequence, the flow-rate and thus the corresponding measurement thereof may be altered. Further, performed calibration of flow-rate sensor **1000** may be distorted. Therefore, according to some embodiments of the invention, the section of inlet channel **1210** and outlet channel **1220** integrated in intermediate substrate **2200** may comprise a plurality of parallel channels **1231** which may act as a backup to one another to reduce the risk that particles enter flow-restriction channel **1230** and clog within the latter the flow of fluid. Additionally or alternatively, a filter structure (not shown) may be included, e.g., in base substrate **2100**, wherein the filter structured may be employed such to reduce the risk of clogging of flow-restriction channel **1230**.

[0057] According to some embodiments of the invention, circuit board **2300** may comprise fluidic connections. For example, at least some of the horizontal portion of inlet channel **1210** and outlet channel **1220** in circuit board **2300** may be embodied by fluidic connections such as, for example, an inlet tube **2361** and an outlet tube **2362**, respectively, and/or by any other suitable fluidic connection such as, for example, threaded holes.

[0058] Additional reference is now made to **FIG. 5**. According to embodiments of the invention, flow-rate sensor **1000** comprises a plurality of membrane connections **2351** and circuit connections **2352** provided between intermediate substrate **2200** and circuit board **2300**. More specifically, membrane connections **2351** are provided between pressure-sensitive membrane **1115** and intermediate substrate **2200**, and further to make a seal between concavity **2310** and intermediate substrate **2200** to guide fluid to upstream face **1113** of pressure-sensitive membrane **1115**.

[0058] According to embodiments of the invention, pressure-sensitive membrane **1115** is flipped such that its diaphragm **1118** is electrically coupled to membrane connections **2351**. Thusly configured, flow-rate sensor **1000** obviates the need of employing wirebonds that would otherwise be required for electrically coupling pressure-sensitive membrane **1115** with electric vias **2355**.

[0059] According to embodiments of the invention, circuit connections **2352** may be aligned with and positioned between respective electrical vias **2355** of circuit board **2300** and intermediate substrate **2200**. As is schematically illustrated in **FIG. 5**, circuit connections **2352** are electrically coupled via electric conducts **2356** with respective membrane connections **2351**. Consequently, electric vias **2355** are electrically coupled with pressure-sensitive membrane **1115**.

[0060] According to some embodiments of the invention, electric vias **2355** may electrically communicate with integrated circuitry, and/or electronic components such as, for example, transistors, electric conducts and/or interconnections provided and/or embedded in circuit board **2300**.

[0061] According to embodiments of the invention, the number of electric conducts **2356** employed connecting between membrane connections **2351** and circuit connections **2352** enables for example the connection to a Wheatstone bridge which may be implemented on sensor die **1500**.

[0062] According to embodiments of the invention, flow-rate sensor **1000** may comprise additional conductive connections and/or conducts (not shown) to enable the implementation of an integrated temperature sensor such as, for example, thermocouples, thermistors, resistance temperature detectors (RTDs) etc. Membrane connections **2351** and/or circuit connections **2352** may have a relatively low modulus of elasticity of, e.g. < 10 MPa.

[0063] According to embodiments of the invention, flow-rate sensor **1000** may further include seals **2360** between intermediate substrate **2200** and circuit board **2300** to make a seal between intermediate substrate **2200** and concavity **2310**. Similar to membrane connections **2351** and/or circuit connections **2352**, seals **2360** may be made of a material having a relatively low modulus of elasticity of, e.g., < 10 MPa. The relatively low modulus of elasticity of seals **2360** and/or membrane connections **2351** and/or circuit connections **2352** are chosen such to limit the mechanical stress between intermediate substrate **2200** and circuit board **2300** that might develop due to their possible difference in coefficient of thermal expansion.

[0064] According to embodiments of the invention, flow-rate sensor **1000** may include an electronic readout **2400** adapted to measure a change in electrical resistance due to the deflection of pressure-sensitive membrane **1115**. Electronic readout **2400** may be electrically coupleable with pressure-sensitive membrane **1115**, e.g., by placing electronic readout **2400** on circuit board **2300** such that electronic readout **2400** operatively communicates with electrical vias **2355**. Electronic readout **2400** may be adapted, for example, to amplify signals corresponding to change in electrical resistance in response to the mechanical deflections of pressure-sensitive membrane **1115**, and/or to perform analog-to-digital conversion and/or to calibrate flow-rate sensor **1000** based on the measured differential pressure and temperature. Electronic readout **2400** may be mechanically coupled e.g., soldered, with circuit board **2300**.

[0065] It should be noted that in some embodiments of the invention, at least some of the functions that may be performed by electronic readout **2400** may additionally or alternatively performed by elements of circuit board **2300**. For example, amplification may be performed by elements embedded in circuit board **2300**. As a consequence, in some embodiments of the invention, flow-rate sensor **1000** may be operational without the employment of electronic readout **2400**.

[0066] According to some embodiments of the invention, flow-rate sensor **1000** may be circuit board-less, i.e., flow-rate sensor **1000** may not include circuit board **2300**. Instead, a change in the resistance of pressure-sensitive membrane **1115** may be measured simply by applying a voltage between circuit connections **2352**, e.g., with or without performing amplification of the measured change in resistance. Further, a tube or hose (not shown) may be operatively coupled with fluid opening **1112** and thus with upstream face **1113** of pressure-sensitive membrane **1115**.

[0067] Referring to **FIG. 6**, a schematic isometric illustration of flow-rate sensor **1000** is depicted; referring to **FIG. 7** a schematic isometric detailed cross-sectional illustration of sensor die **1500** is depicted; and referring to **FIG. 8**, a schematic top view illustration of courses of flow-restriction channel **1230**, upstream channel **1240** and downstream channel **1250** is depicted.

[0068] According to embodiments of the invention, the length of a first course of fluid flow measured from a location upstream of upstream junction **1241** until upstream face **1113** as well as the length of a second course of fluid flow measured from said location to downstream face **1114** is at least approximately equal. As a consequence, changes in the absolute pressure at the upstream location are conveyed to upstream face **1113** and downstream face **1114** by an at least approximately equal delay. Therefore, upstream face **1113** and downstream face **1114** are subjected to changes in absolute pressure att least approximately at the same time, thus preventing deflections of pressure-sensitive membrane **1115** corresponding to changes in absolute pressure only at the upstream location or the downstream location. Correspondingly, pressure-sensitive membrane **1115** is unaffected by sudden changes in the absolute pressure that might occur at the upstream location and/or at the downstream location, but may thus only affected by the changes in the differential pressure between the upstream and downstream location and thus less prone to damage. More specifically, pressure-sensitive membrane **1115** may be subjected to at any given time to **P1-P2** and not to **P1** or **P2** alone. It should be noted that the term “any given time” also encompasses the term “substantially at any given time”.

[0069] As is schematically illustrated in **FIG. 1**, **FIG. 2**, **FIG. 3, FIG. 4, FIG. 5** and **FIG. 6**, upstream outlet **1260** and downstream outlet **1270** communicate with opposite sides of diaphragm **1118**. However, as is outlined herein below, with reference to **FIG. 9**, **FIG. 10**, **FIG. 11** and **FIG. 12**, a flow-rate sensor **9000** according to an embodiment of the invention may employ a single-sided differential pressure die, for example, as disclosed in US patent 5’969’591. For example, flow-rate sensor **9000** may employ a sensor die **9500** comprising a housing **1116** wherein upstream outlet **1260** (of an upstream channel **9240**) and downstream outlet **1270** of a downstream channel **9250** terminate with respect to diaphragm **1118** at the same side. Sensor die **9500** further comprises a seal **1280**, which diverts fluid exiting upstream outlet **1260** towards upstream face **1113** and fluid exiting downstream outlet **1270** towards downstream face **1114**, thereby subjecting different sections of diaphragm **1118** at the same side with respective upstream pressure **P1** and downstream pressure **P2**. Consequently, the deflection of diaphragm **1118** corresponds to the differential pressure **P1-P2**.

[0070] Reference is now made to **FIG. 13**. According to embodiments of the invention, flow-rate sensor **1000** may be adapted to measure the flow-rate of a fluid which may be, e.g., a liquid **1295**. In that case, gas pockets **1290** may be trapped between sensor die **1500** and inlet channel **1210** and outlet channel **1220**. The appearance of gas pockets **1290** may be utilized to protect sensor die **1500** from liquid **1295**, which may be aggressive (e.g., highly acidic or basic) such to have the potential to damage sensor die **1500**. Clearly, the phenomenon of gas pockets **1290** may be utilized when merely measuring pressure of liquid **1295**, instead of measuring the flow-rate of the latter.

[0071] According to embodiments of the invention, upstream channel **1240** and downstream channel **1250** may have a length such that borders **1293** between liquid **1295** and gas **1290** appear at locations that are between upstream junction **1241** and sensor die **1500**, as well as between downstream junction **1251** and sensor die **1500**, respectively.

[0072] According to embodiments of the invention, flow-rate sensor **1000** may be configured such that the volume of gas is such that still ensures a responsiveness of, e.g., maximal 1 ms. For example, the volume of the gas surrounding sensor die **1500** may be as small as possible.

[0073] Reference is now made to **FIG. 14**, and **FIG. 15A**. According to embodiments of the invention, a plurality of sensor dies **1500** may be integrated into a flow-rate sensor **14000**, which may be configured such that each one measures a corresponding differential pressure. More specifically, flow-rate sensor **14000** may comprise sensor dies **1500A** and **1500B** that are operatively connected to each other in parallel. Sensor die **1500A** may communicate with upstream channel **14240A** and with downstream channel **14250A** and be connected in parallel to flow-restriction channel **14230** through inlet channel **14210** and outlet channel **14220**. Sensor die **1500B** communicates with downstream channel **14250B** which is connected in parallel to upstream channel **14240A**. In addition, sensor die **1500B** communicates with inlet channel **14210B** and outlet channel **14220B**. Thusly configured, the system pressure to which sensor die **1500A** is subjected to corresponds to **P1-P2**, wherein **P1** may be the pressure upstream of flow-restriction channel **14230** and **P2** the pressure downstream of flow-restriction channel **14230**. The system pressure to which sensor die **1500B** may be subjected to corresponds to **P0-P1**, wherein **P0** is the pressure in inlet channel **14210B**. As a consequence, flow-rate sensor **14000** may be adapted to measure relative high absolute pressure of e.g., 10 bar, with sensor die **1500B**; and a relative low differential pressure corresponding to a flow rate of, e.g., less than 100 µl/seconds,.

[0074] It should be noted that the length of a first course of fluid flow measured from a location upstream of upstream junction **1241** until upstream face **14113**, as well as the length of a second course of fluid flow measured from said location to downstream face **14114** may be at least approximately equal.

[0075] Reference is now made to **FIG. 15B**. Flow-rate sensor **14000** includes membrane connectors **2351**, readout connections **2352**, electric conducts **2356** and electric vias (not shown) such to enable the readout of **P0-P1** and **P1-P2** by electronic readout **2400**.

[0076] Manufacturing methods of a flow-rate sensor according to an embodiment of the invention such as, for example, flow-rate sensor **1000**, may include the following steps: providing base substrate **2100**; providing inlet channel **1210**, providing outlet channel **1220** providing flow-restriction channel **1230**, upstream channel **1240** and downstream channel **1250** in base substrate **2100**. Further, the method may include providing intermediate substrate **2200**; and providing therein inlet channel **1210**, outlet channel **1220**, upstream channel **1240** and downstream channel **1250**. The method may additionally include providing membrane connections **2351**, circuit connections **2352**; and seals **2360** on intermediate substrate **2200**. The method may also include the step of providing intermediate substrate **2200** onto base substrate **2100** to provide a cover for base-sections of inlet channel **1210,** outlet channel **1220,** flow-restriction channel **1230;** upstream channel **1240** and downstream channel **1250** and such that intermediate-sections of the channels communicate with base-sections of the channels, as is for example schematically illustrated in **FIG. 2, FIG. 3** and **FIG.4**.

[0077] In addition, the method may include providing electric vias **2355**, sensor die **1500** and circuit-board sections of flow-restriction channel **1230** into circuit board **2300**; and providing circuit board **2300** on intermediate substrate **2200** such that intermediate-sections of the channels communicate with circuit-board sections of the channels and such that sensor die **1500** communicates with electric vias **2355**.

[0078] According to embodiments of the invention, upstream channel **1240** and downstream channel **1250** may be provided into base substrate **2100** and/or intermediate substrate **2200**, e.g., as known in the art, for example, by employing an etching process like, for example, wet etching and/or Deep Reactive Ion Etching (DRIE) and/or sand blasting; and/or by employing photostructurable glass, epoxy or polysiloxane and/or a structured tape between base substrate **2100** and intermediate substrate **2200**. Structures provided in the photostructurable epoxy (SU-8), polysiloxane and/or the structured tape enables the direct manufacturing of upstream channel **1240** and downstream channel **1250** in an etching-less process, which is a process that obviates the need of employing any additional etching processes.

[0079] It should be noted that the sequence of the above-mentioned steps for manufacturing a flow-rate sensor according to an embodiment of the invention should not be construed as limiting and that the order of the steps may be interchanged and ordered in any others suitable way. It should further be noted that at least some of the above-mentioned steps may be performed in a plurality of steps or consolidated into a fewer steps, e.g., as known in the art.

[0080] According to some embodiments of the invention, base substrate **2100** and/or intermediate substrate **2200** may be made for example, of silicon or glass, or any other suitable material. According to embodiments of the invention the piezo-sensitive material of pressure-sensitive membrane **1115** and the material of circuit board **2300** may be chosen such that the coefficient of thermal expansion is at least approximately equal. According to embodiments of the invention, circuit board **2300** may be made, of a material suitable for implementing a printed circuit board (PCB), (e.g. woven glass with epoxy), e.g., as known in the art.

CLAIMS

1. A flow-rate sensor adapted to measure the differential pressure between an inlet and an outlet of a main channel,

   characterized by

   comprising a sensor channel, wherein said sensor channel comprises an upstream channel, a downstream channel and a sensor die employing a pressure-sensitive membrane having an upstream side and downstream face communicating with said upstream channel and said downstream channel of said sensor channel;

   wherein said main channel comprises an inlet channel, a flow-restriction channel and an outlet channel which are operatively connected to each other in series, and

   wherein said sensor channel is operatively connected in parallel to said main channel at an upstream junction and downstream junction such that said pressure-sensitive membrane is subjected to differential pressure between an upstream location and a downstream location with respect to said flow-restriction channel.

2. The flow-rate sensor of claim 1, wherein said flow-restriction channel has a cross-sectional area that is smaller compared to the cross-sectional area of said inlet channel and said outlet channel.

3. The flow-rate sensor according to any of the preceding claims, wherein said inlet channel and said outlet channel have an at least approximately equal cross-sectional area.

4. The flow-rate sensor according to any of the preceding claims comprising at least one substrate integrating at least some of said sensor channel and said main channel.

5. The flow-rate sensor of according to any of the preceding claims, **characterized in that**

   the length of a first course of fluid flow measured from a location upstream of said upstream junction until upstream face as well as the length of a second course of fluid flow measured from said location is at least approximately equal such that changes in the absolute pressure at said location are conveyed to said upstream face and said downstream face by an at least approximately equal delay.

6. The flow-rate sensor according to any of the preceding claims, **characterized in that**

   said upstream face and said downstream face are on opposite sides of the diaphgram of said pressure-sensitive membrane.

7. The flow-rate sensor according to any of the preceding claims, **characterized in that**

   said upstream face and said downstream face are on the same side of the diaphgram of said pressure-sensitive membrane.

8. The flow-rate sensor according to any of the preceding claims **characterized by** comprising an electronic readout which is electrically coupled with said pressure-sensitive membrane.

9. The flow-rate sensor according to any of the preceding claims, **characterized by** comprising electrical conductors, membrane connections and electronic readout connections that are operative with said pressure-sensitive membrane.

10. The flow-rate sensor according to any of the preceding claims,

characterized in that

said base substrate and said intermediate substrate are made of material consisting of the following group: silicon, and glass

11. A manufacturing method for manufacturing the flow-rate sensor according to any of the preceding claims **characterized by**:

providing said sensor channel and said main channel in said at least one substrate;

providing seals, membrane connections, circuit connections and electric conducts on an intermediate substrate of said at least one substrate.

12. The manufacturing method according to claim 11, **characterized in that**

providing said upstream channel and said downstream channel is accomplished by at least one of the following methods: etching, sand blasting, by photostructurable glass, polysiloxane or epoxy (SU-8); and by a structured tape.

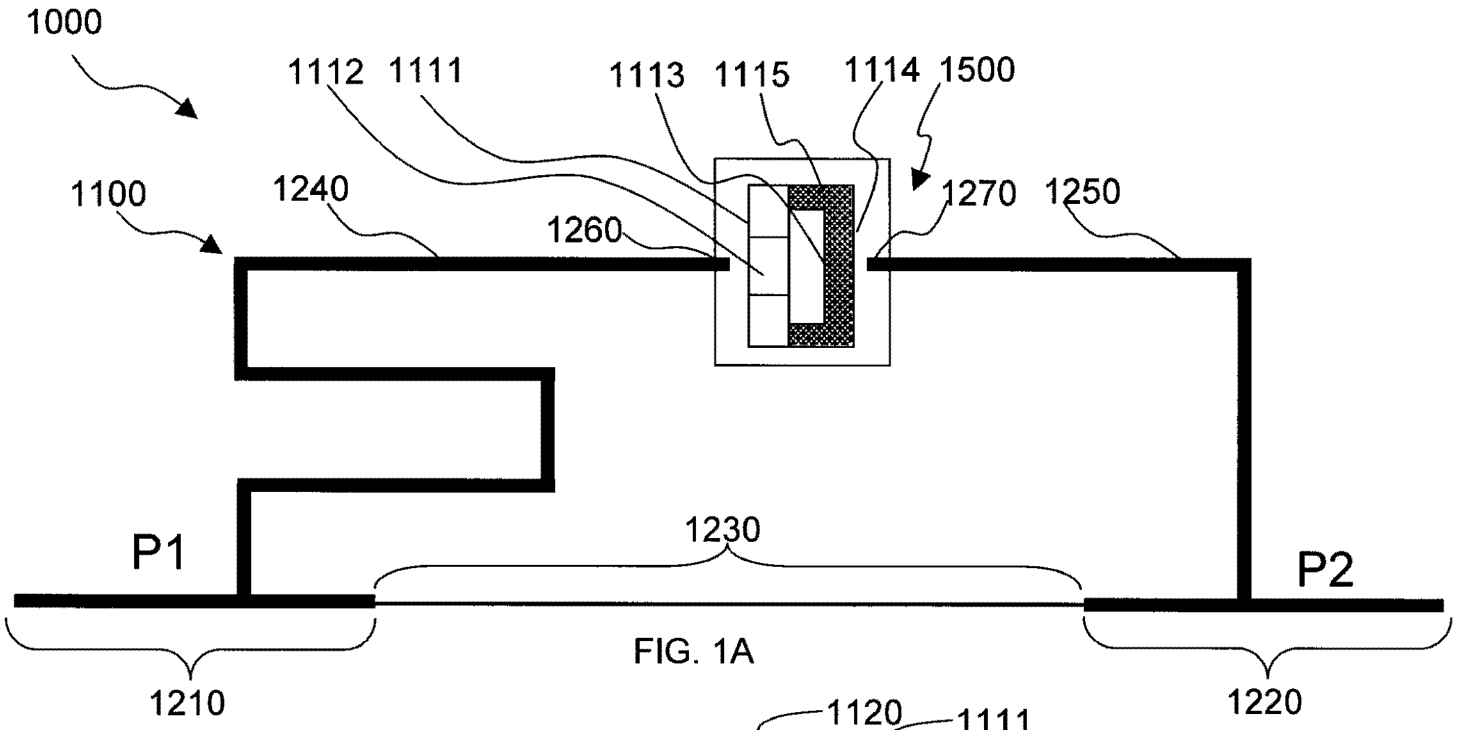

1000
1100
1240
1112
1111
1260
1113
1115
1114
1500
1270
1250
P1
1230
P2
1210
1220

FIG. 1A

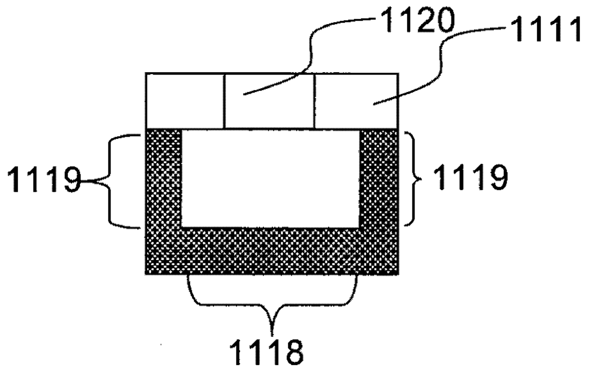
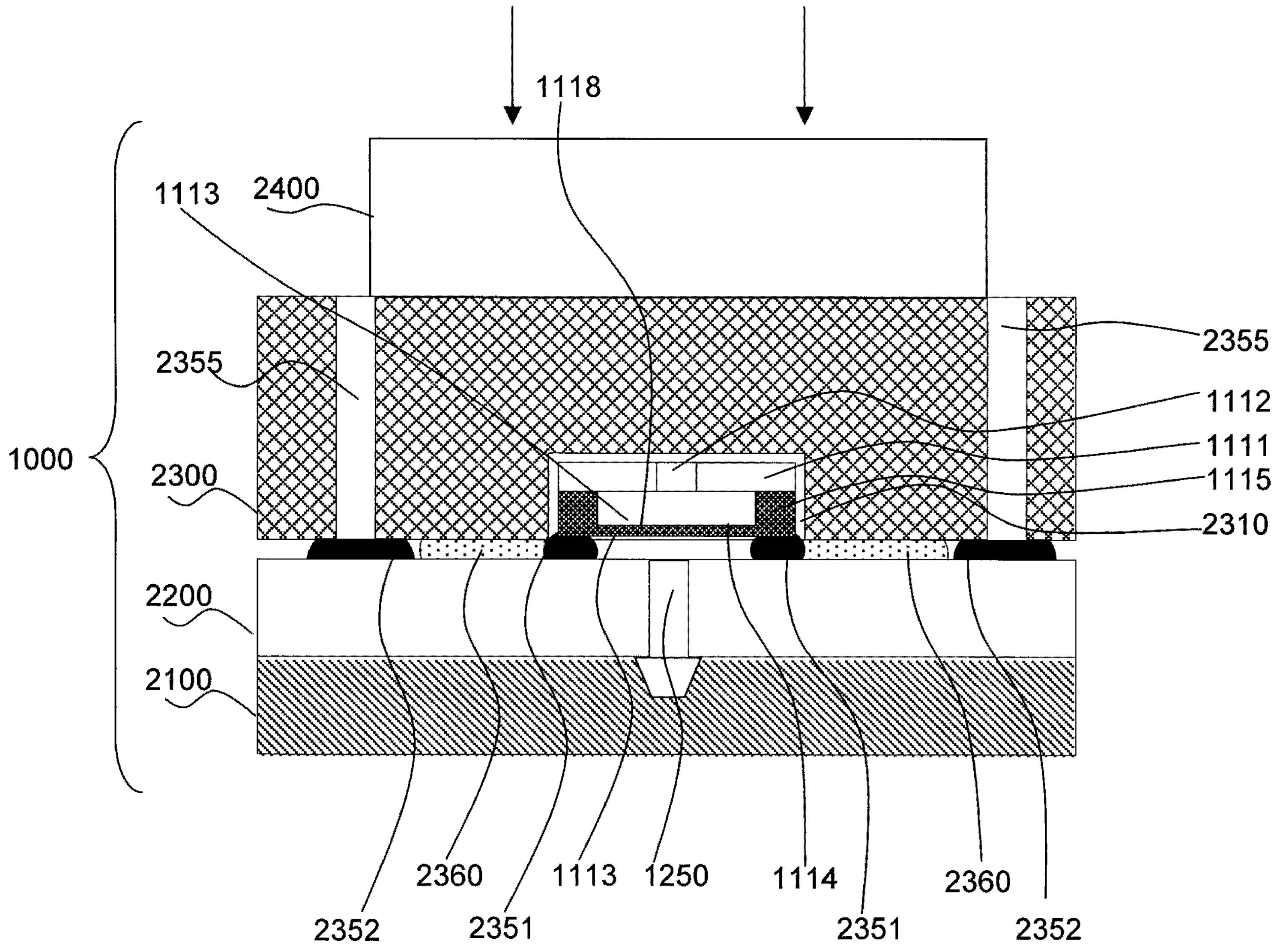

1120
1111
1119
1119
1118

FIG. 1B


1118
1113
2400
2355
2355
1112
1111
1115
2310
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2300
2200
2100
2352
2360
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1250
1114
2351
2360
2352

FIG. 2

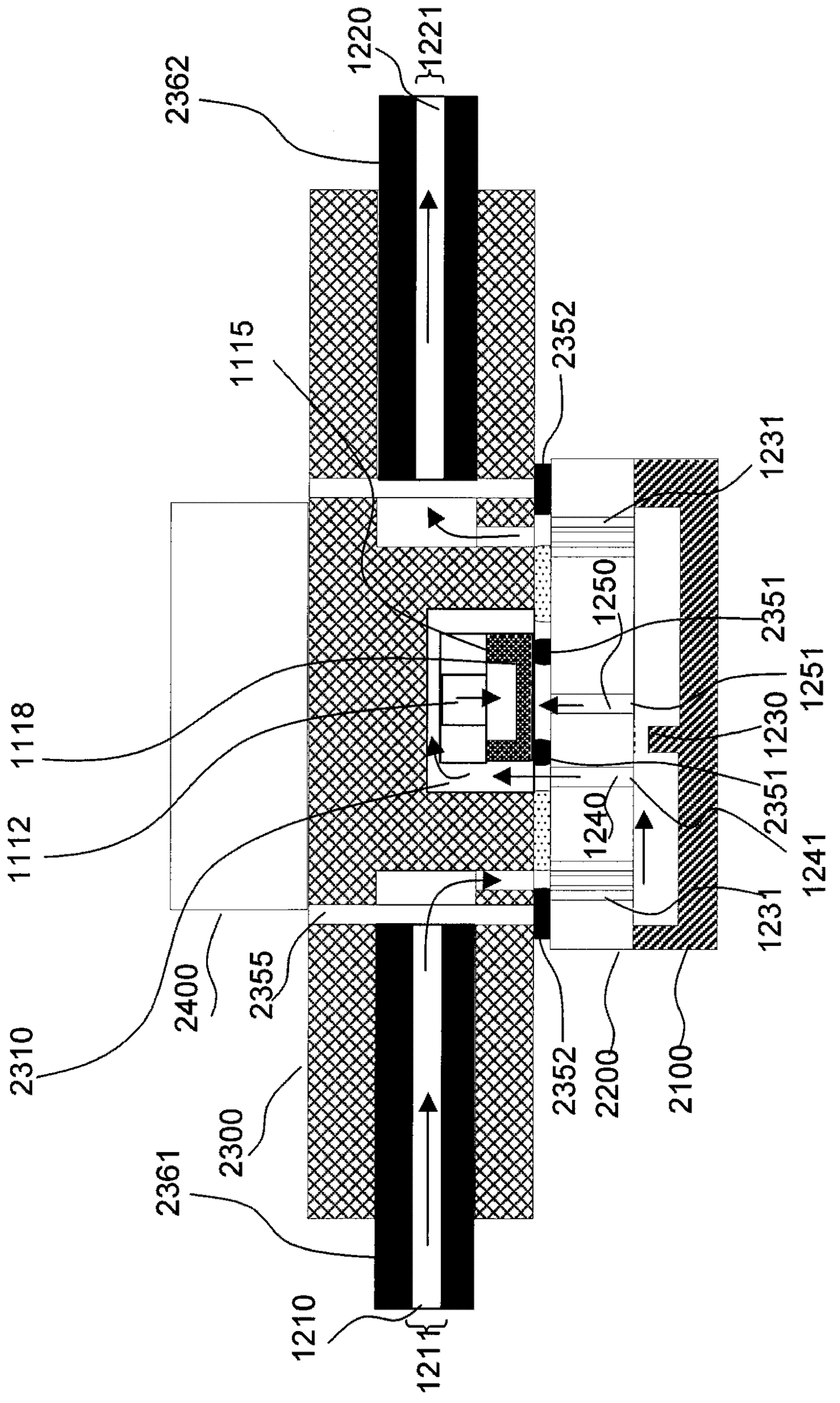
2362
1220
1221
1115
2352
1231
1250
2351
1251
1230
2351
1241
1240
1231
1118
1112
2310
2400
2355
2352
2200
2100
2300
2361
1210
1211

FIG. 3

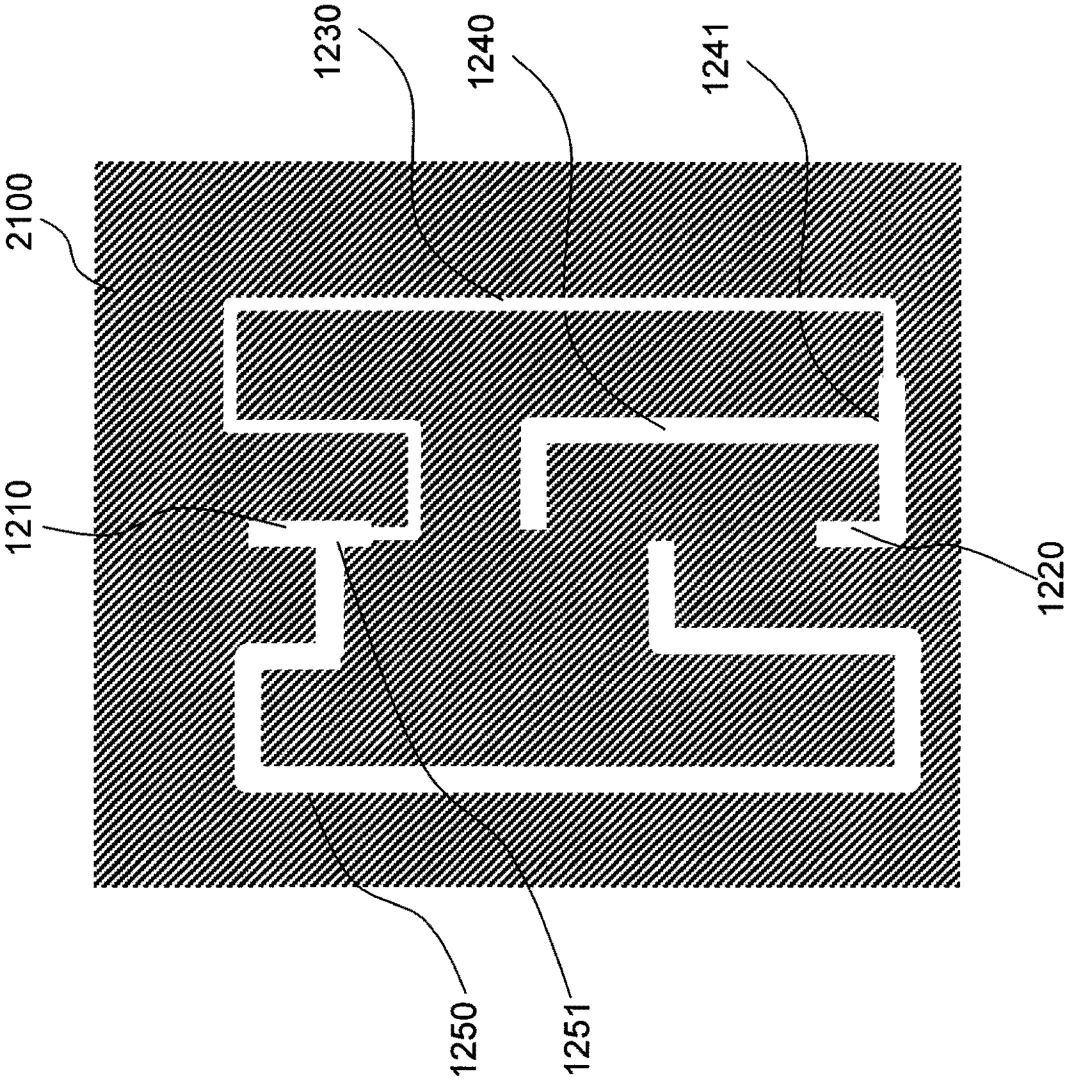

FIG. 4

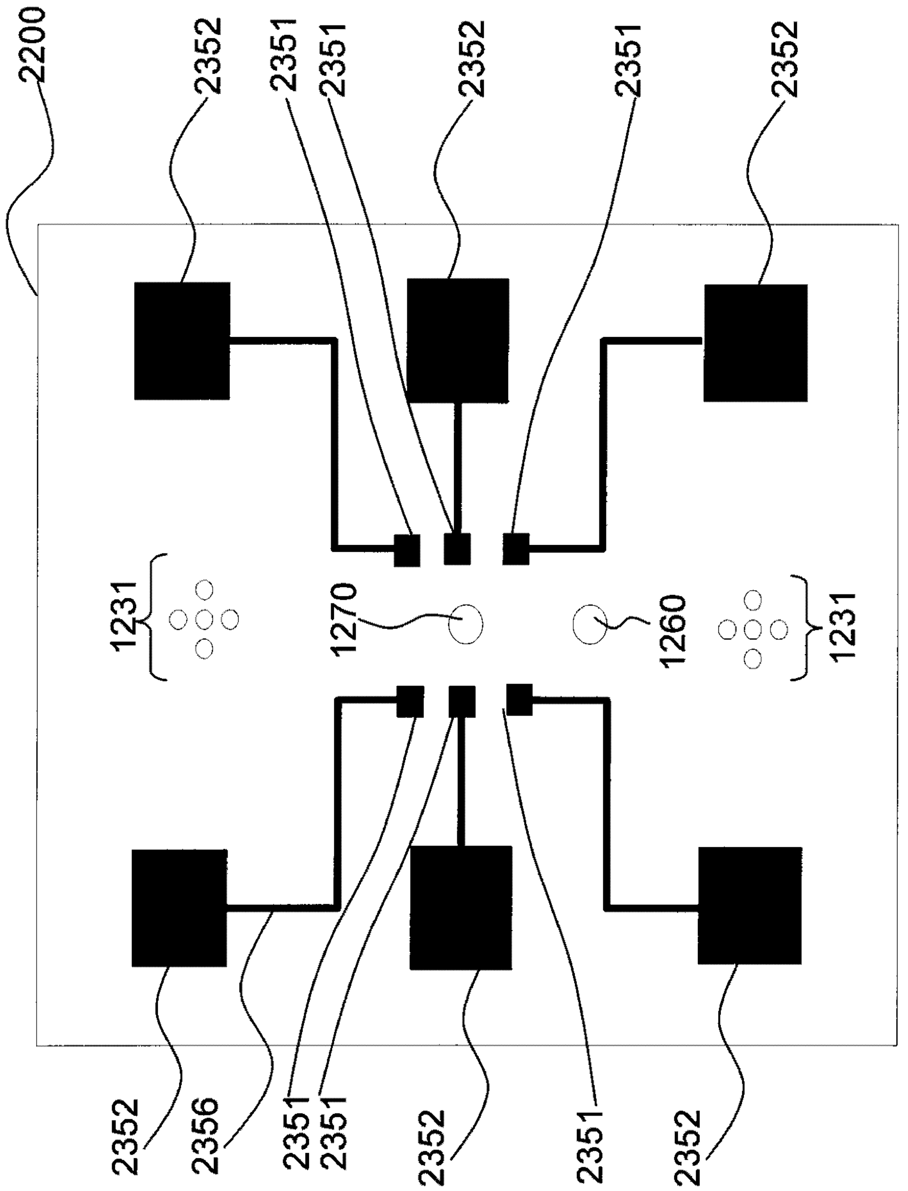
2200
2352
2351
2351
2352
2351
2352
1231
1270
1260
1231
2352
2356
2351
2351
2352
2351
2352

FIG. 5

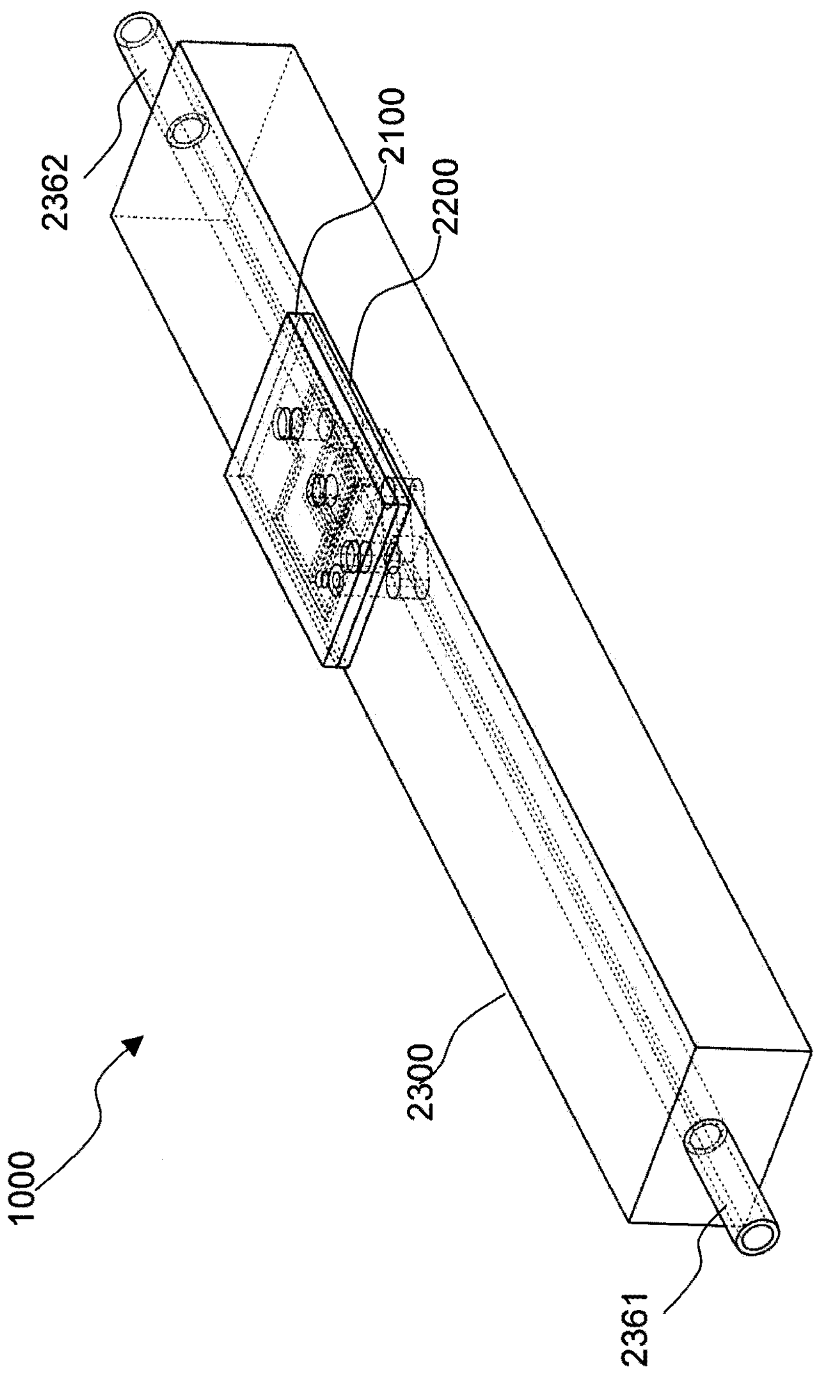

FIG. 6

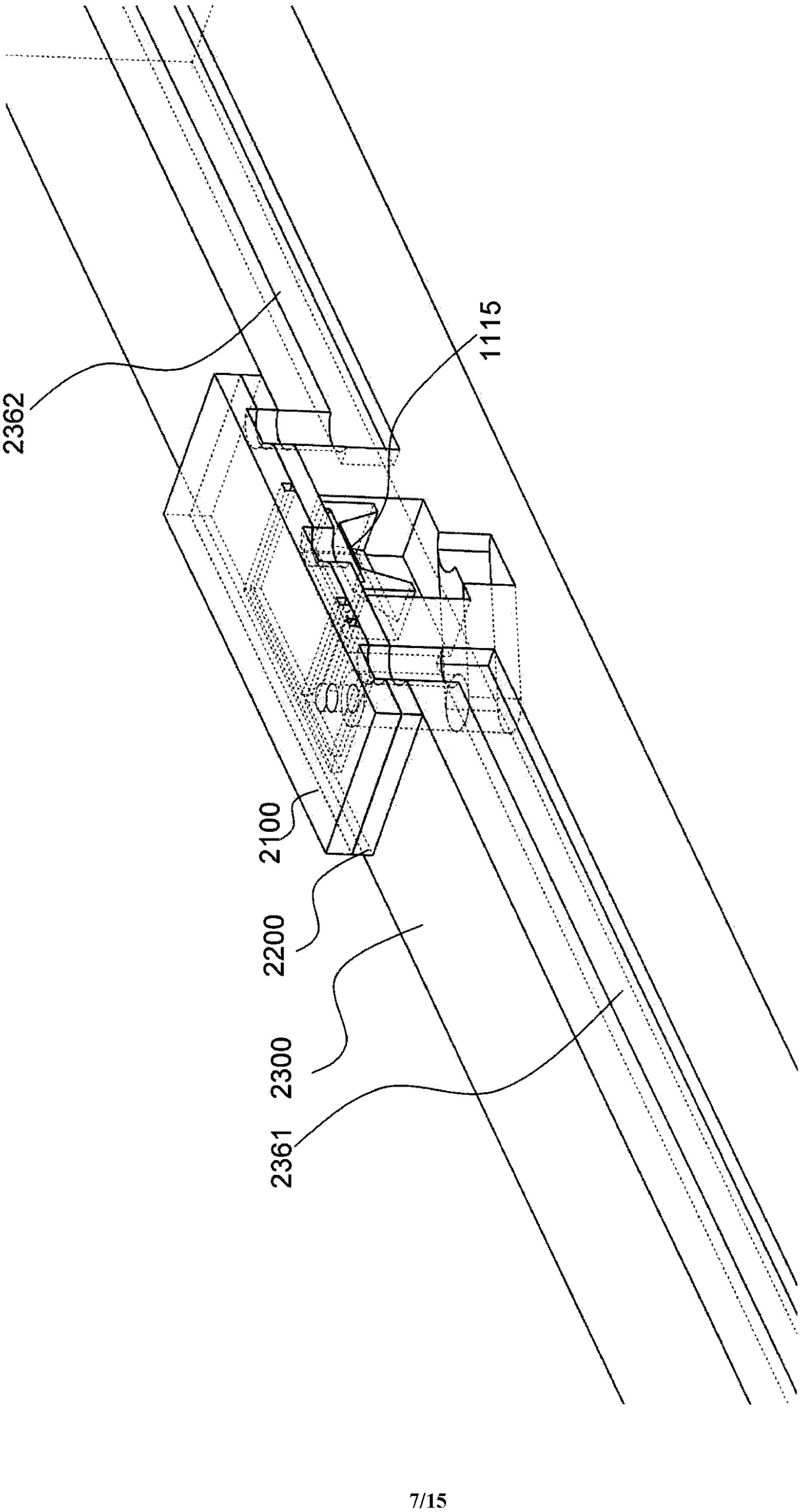

FIG. 7

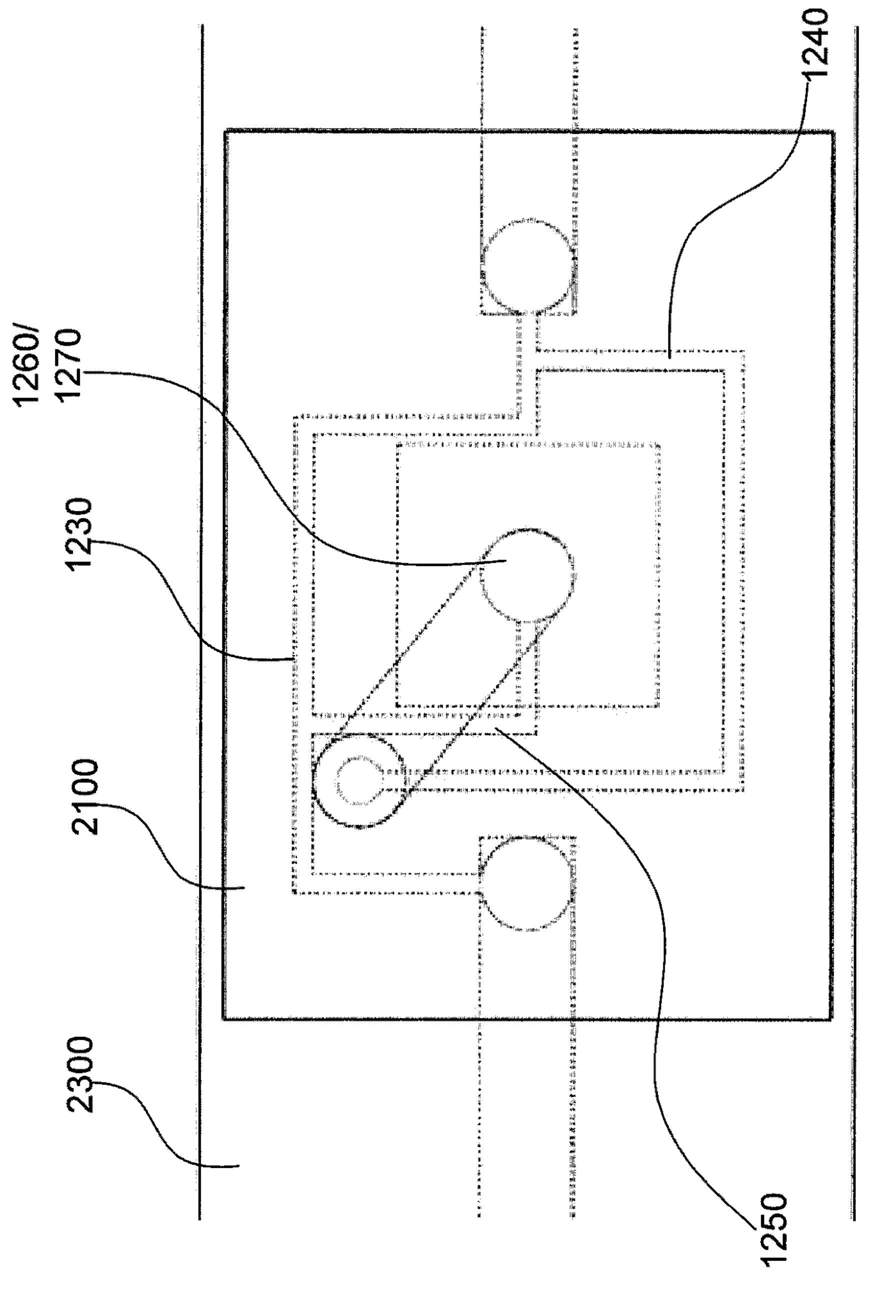

FIG. 8

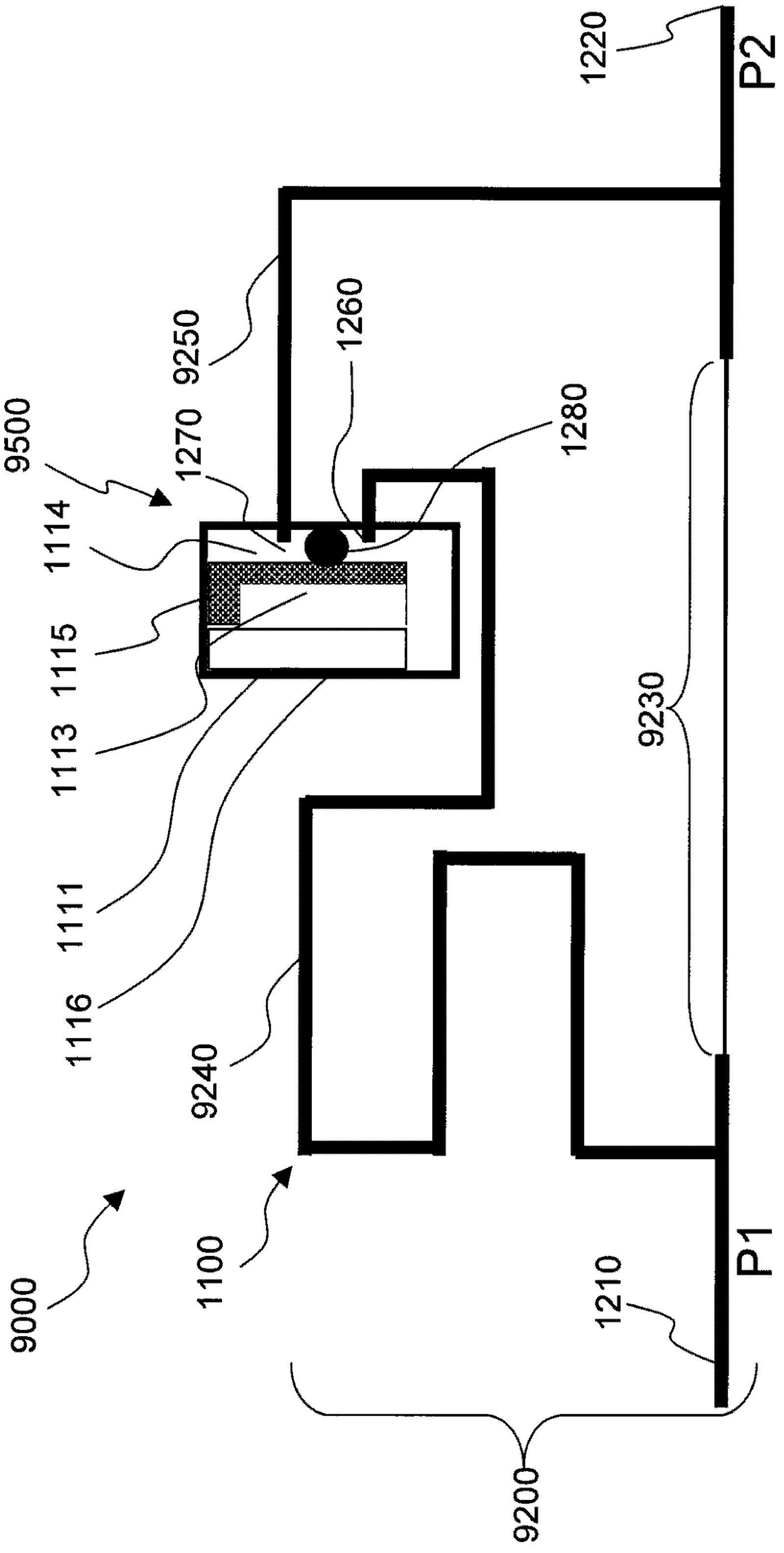
9000
1100
9200
1210
P1
9240
1116
1111
1113
1115
1114
9500
1270
9250
1260
1280
9230
1220
P2

FIG. 9

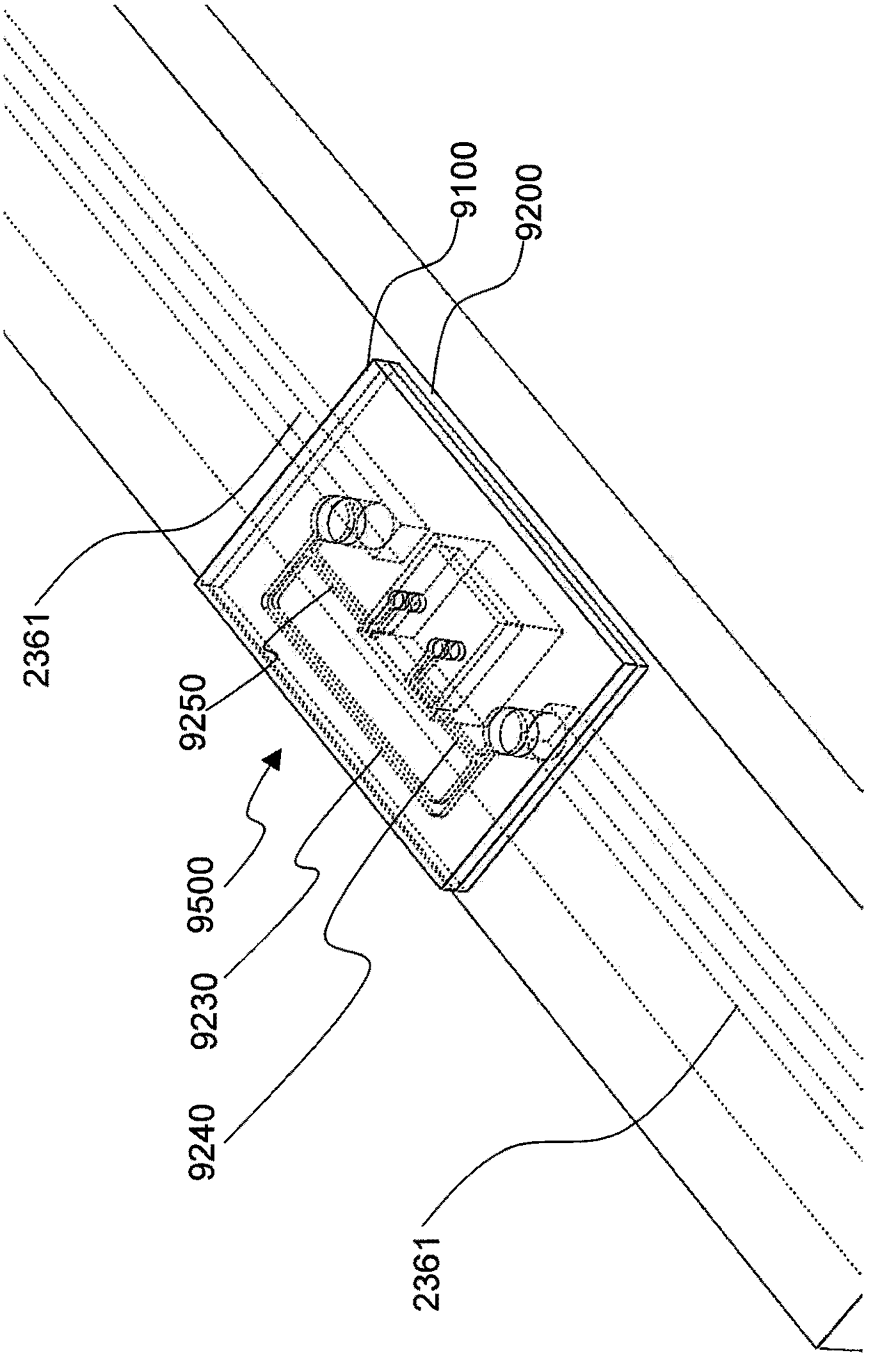

FIG. 10

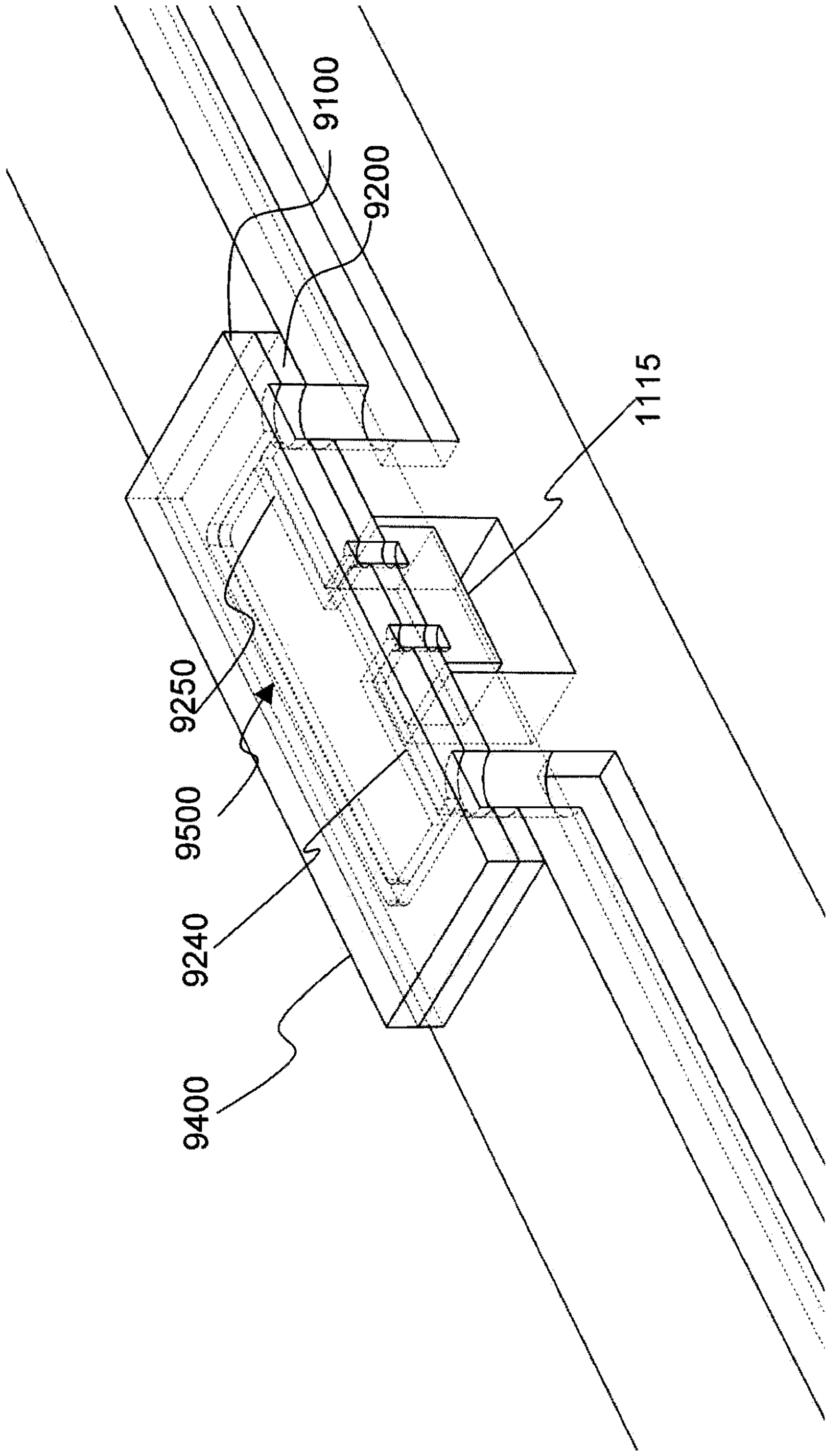

FIG. 11

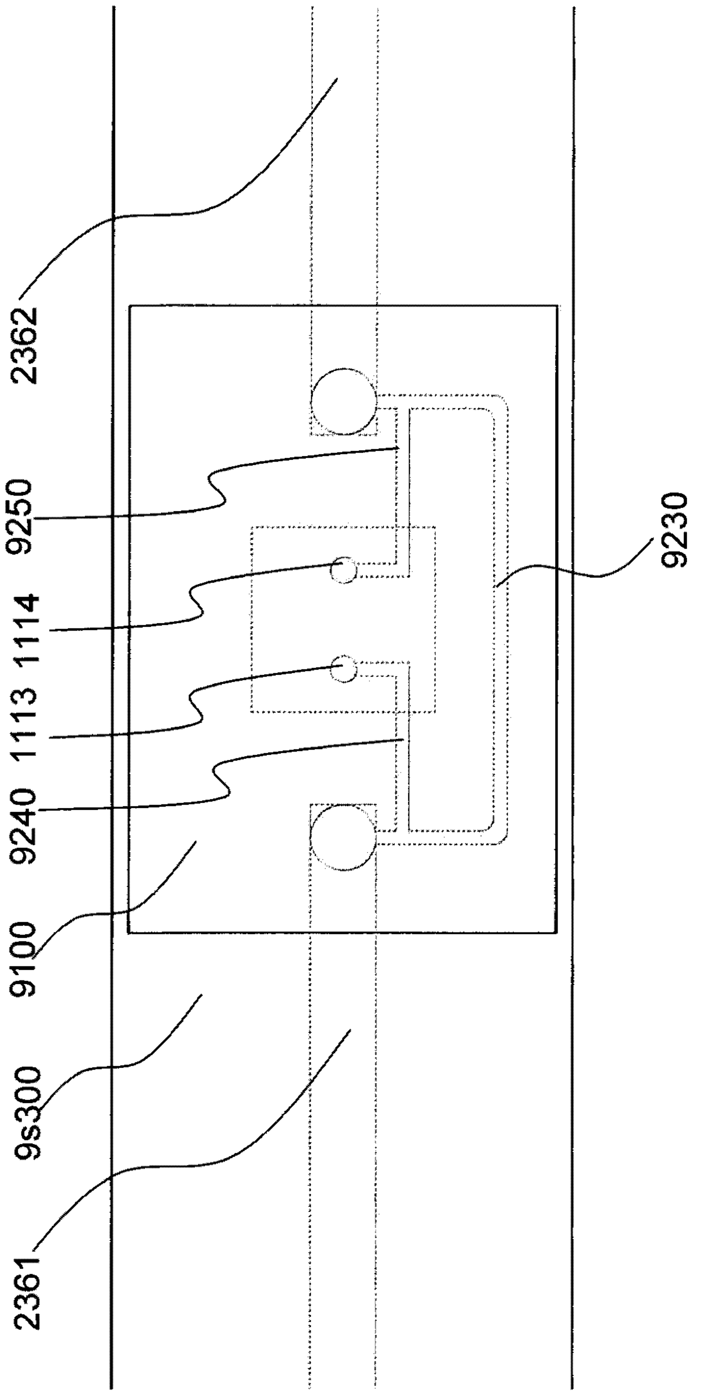

FIG. 12

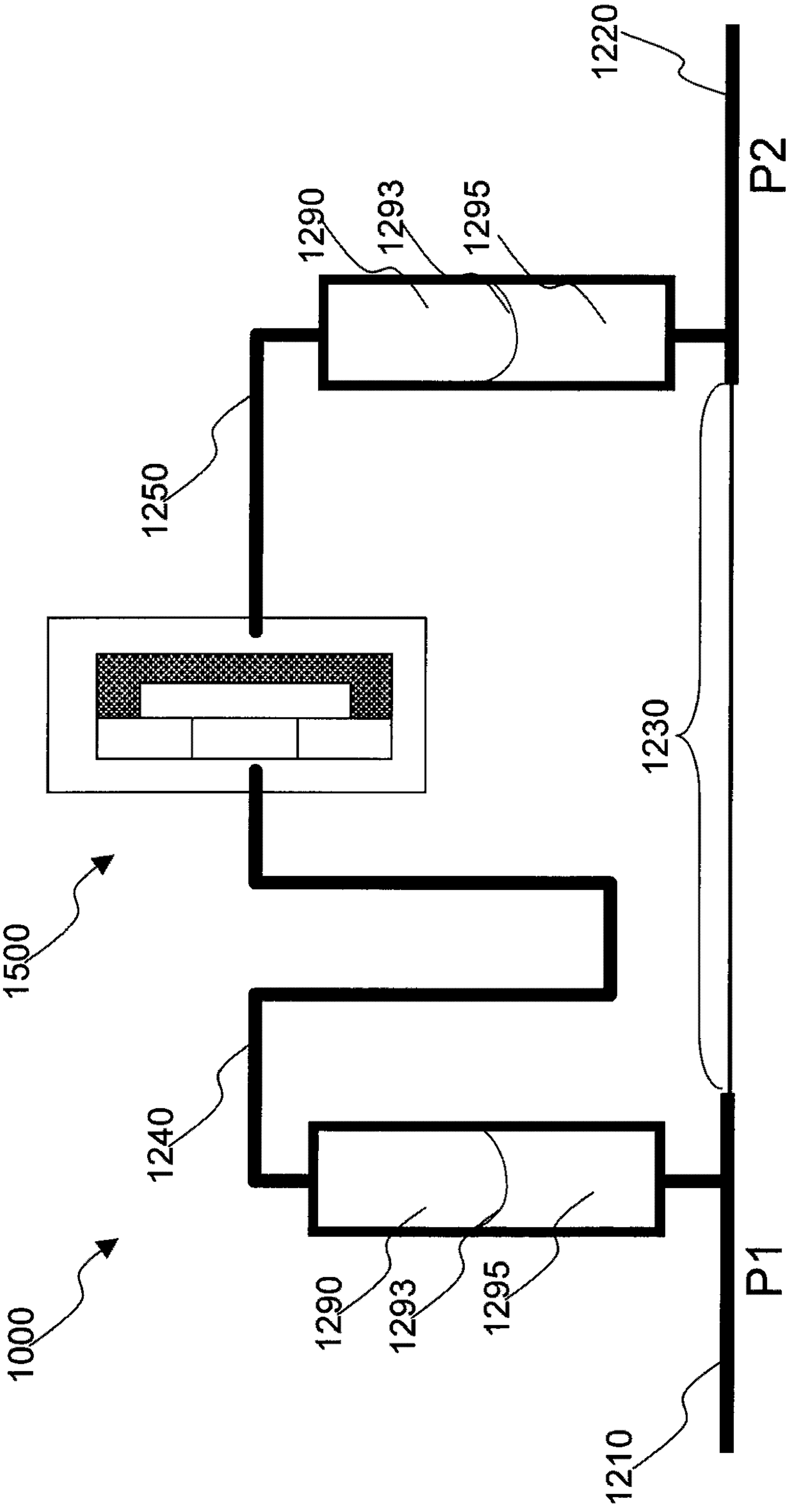
1000
1500
1240
1250
1290
1293
1295
1290
1293
1295
1230
1210
1220
P1
P2

FIG. 13

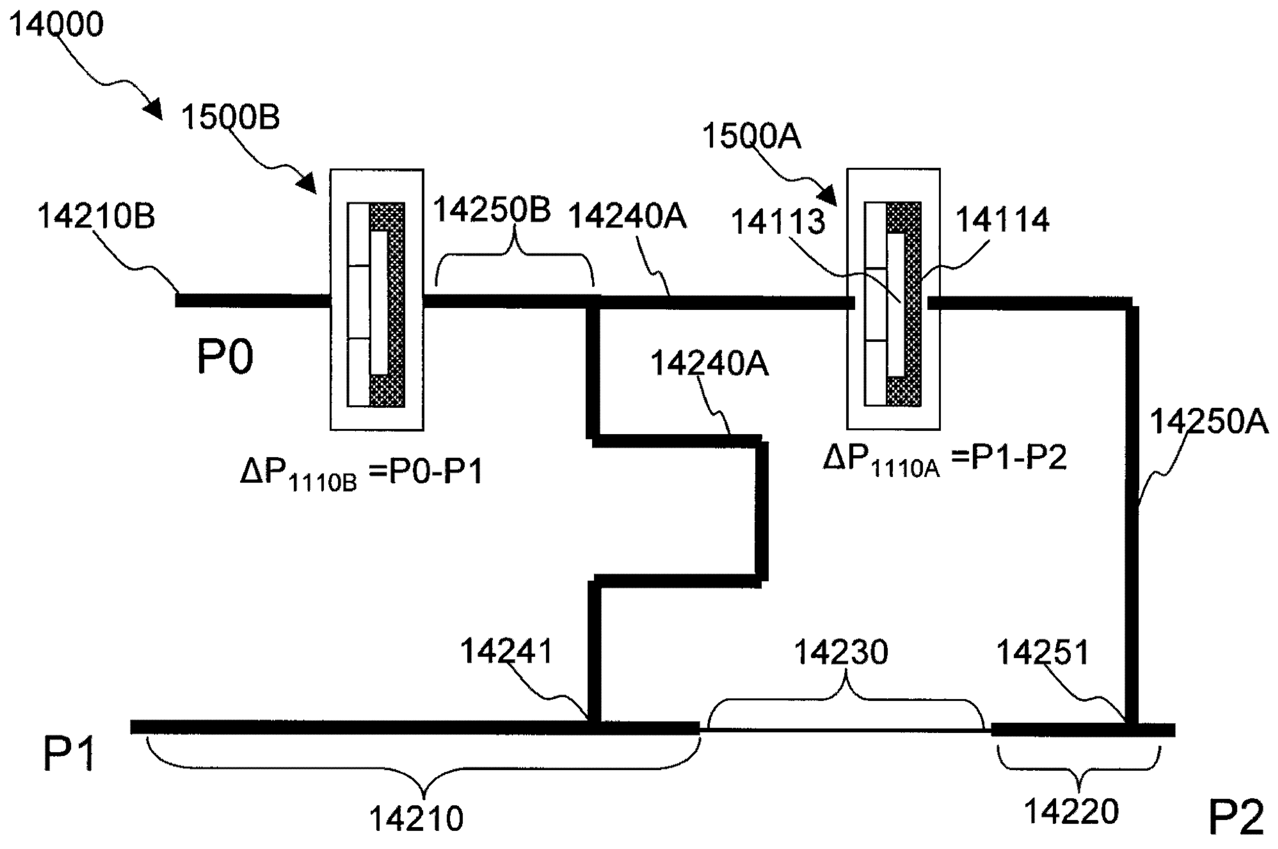
14000
1500B
1500A
14210B
14250B
14240A
14113
14114
P0
14240A
14250A
ΔP_{1110B} =P0-P1
ΔP_{1110A} =P1-P2
14241
14230
14251
P1
14210
14220
P2

FIG. 14

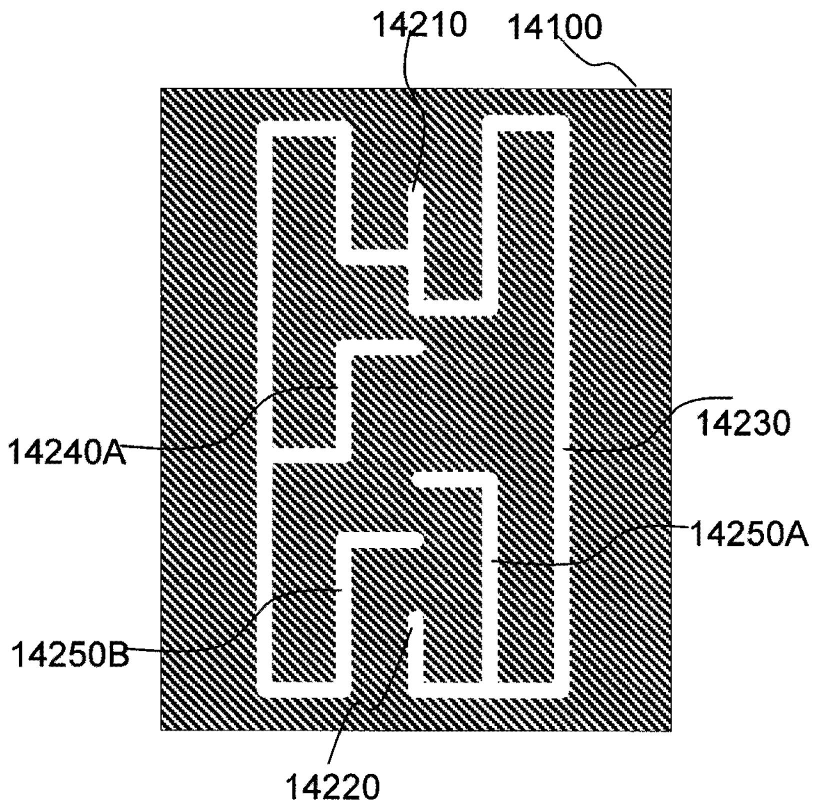

FIG. 15A

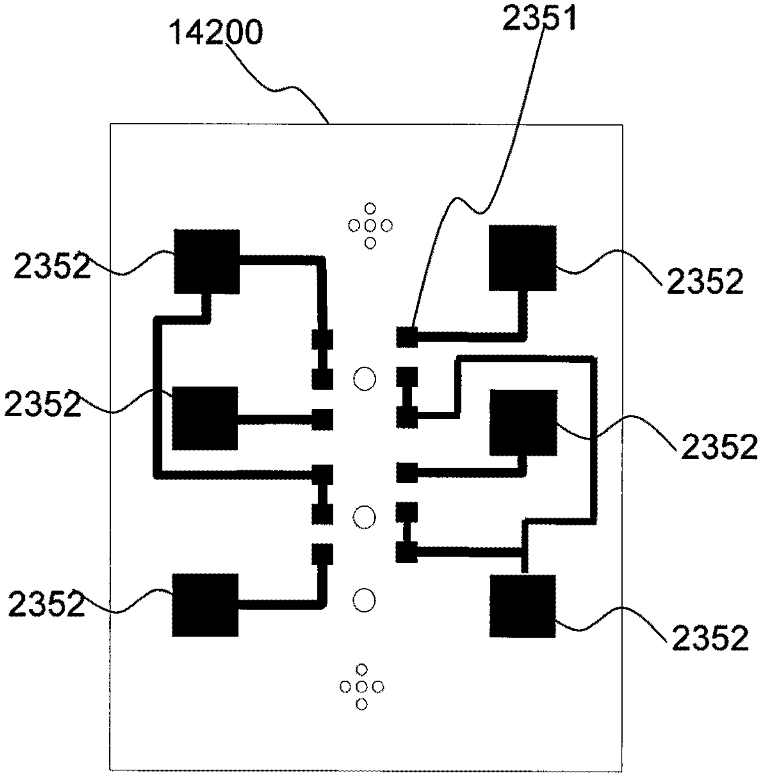

FIG. 15B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/053940

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01F1/38
ADD. G01F15/10

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)
G01F

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 756 899 A (UGAI SEIICHI [JP] ET AL) 26 May 1998 (1998-05-26) column 13, line 32 - line 62 figures 1,21	1-4,6, 8-12 7
X	DE 390 953 C (ERICH ROUCKA) 26 February 1924 (1924-02-26) figure 1	1-3,5-6
Y	US 5 969 591 A (FUNG CLIFFORD D [US]) 19 October 1999 (1999-10-19) cited in the application abstract; figures 1,2	7

-/--

☒ 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
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"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
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"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.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 July 2009	16/07/2009

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL – 2280 HV Rijswijk
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Fax: (+31–70) 340–3016

Authorized officer

Kloppenburg, Martin

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/053940

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 150 681 A (ALLEN HENRY V [US]) 21 November 2000 (2000-11-21) cited in the application column 1, line 41 - line 56 figure 1	1,4, 10-12
A	US 6 263 741 B1 (WOIAS PETER [DE]) 24 July 2001 (2001-07-24) abstract; figures	1,4, 10-12

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2009/053940

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			EP	0943076 A1	22-09-1999