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(71) Applicant: **BERKIN B.V.** [NL/NL]; Nijverheidsstraat 1A, 7261 AK Ruurlo (NL).

(72) Inventors: **LOTTERS, Joost Conrad;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL). **GROENESTEIJN, Jarno;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL). **STEENWELLE, Ruud Johannes Antonius;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL). **WIEGERINK, Remco John;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL). **ALVERINGH, Dennis;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL). **MA, Kechun;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL). **ZENG, Yaxiang;** c/o Berkin B.V., Nijverheidsstraat 1A, 7261 AK Ruurlo (NL).

(74) Agent: **LGEMEEN OCTROOI- EN MERKENBUREAU B.V.;** P.O. Box 645, 5600 AP Eindhoven (NL).

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(54) Title: CORIOLIS FLOW SENSOR

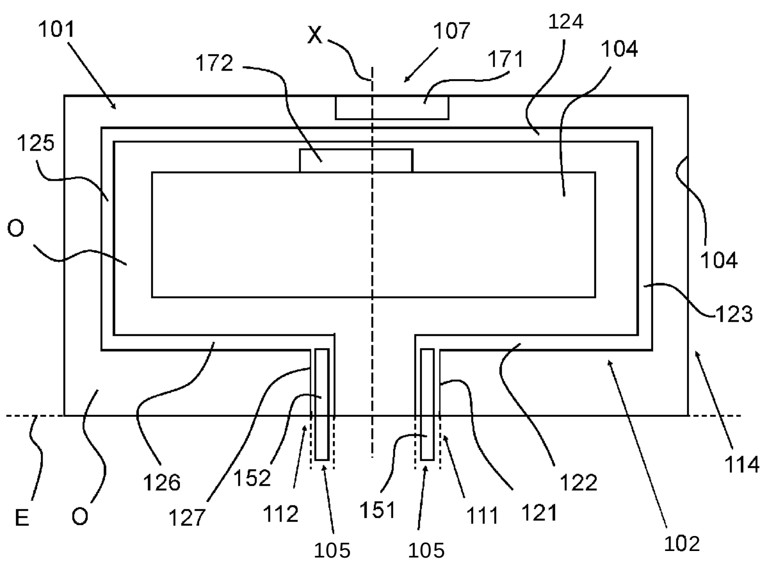

Fig. 3

(57) **Abstract:** The invention relates to a Coriolis flow sensor, comprising at least a Coriolis-tube with at least two ends being fixed in a tube fixation means, wherein the flow sensor comprises excitation means for causing the tube to oscillate, as well as detection means for detecting at least a measure of displacements of parts of the tube during operation. According to the invention, the detection means comprise two detection elements that are positioned on both sides of the Coriolis tube, wherein the detection elements partly overlap each other.

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Title: Coriolis flow sensor

Description

The invention relates to a Coriolis flow sensor, comprising at least a Coriolis-tube with at least two ends being fixed in a tube fixation means, wherein the flow sensor comprises excitation means for causing the tube to oscillate, as well as detection means for detecting at least a measure of displacements of parts of the tube during operation.

Integrated micro fluidic systems have generated interest in various fields such as medical and micro chemical technology. Accurate flow measurement of small flows is a very important component in these technologies. Coriolis flow sensing is a preferred choice for flow measurement because of its ability to directly measure mass flow regardless of fluid properties.

A Coriolis flow sensor having a loop-shaped Coriolis tube is known from EP 1 719 982 A1. Various types of loop-shaped Coriolis tubes are described therein, both of the single loop type and of the (continuous) double loop type. The present invention relates to any of these types, but is not restricted thereto.

A Coriolis flow sensor (also indicated as flow sensor of the Coriolis type) comprises at least one vibrating tube, often denoted Coriolis tube, flow tube, or sensing tube. This tube or these tubes is or are fastened at both ends to the housing of the instrument. These tube ends serve at the same time as feed and discharge ducts for the liquid or gas flow to be measured.

Besides the flow tube (or tubes), a Coriolis flow sensor normally comprises two further subsystems, i.e. one for excitation and one for detection. The excitation system (exciter) is arranged for bringing the tube into vibration. For this purpose, one or several forces or torques are applied to portions of the tube. The detection system is arranged for detecting at least a measure of the displacements of one or several points of the tube as a function of time.

As a fluid flows in the vibrating tube, it induces Coriolis forces, proportional to the mass-flow, which affect the tube motion and change the mode shape. Measuring the tube displacement using the detection system, the amplitude of the secondary vibration can be detected relative to the actuation amplitude, which allows for mass-flow measurements.

The vibration of the tube generated by the exciter takes place at a more or less fixed frequency which varies slightly as a function, amongst others, of the density of the medium flowing through the tube. The vibration frequency is almost always a natural frequency of the tube so that a maximum amplitude can be achieved with a minimum energy input.

Micro Coriolis flow sensors previously reported are driven by either electrostatic force or Lorentz force. However, electrostatic actuation requires high voltage while Lorentz actuation results in relatively large power consumption and Joule heating of the sensor tube and the required strong external magnets cause packaging issues.

It is an object of the present invention to provide an improved Coriolis flow sensor that eliminates or reduces the drawbacks of the prior art, in particular with respect to the high voltage required for the electrostatic actuation, and/or with respect to the external magnets required for the Lorentz force solution.

To this end, the invention provides a Coriolis flow sensor comprising a Coriolis tube having at least two outer ends that are fixed in tube fixation means, wherein said flow sensor comprises excitation means for oscillating said Coriolis tube about an excitation-axis, as well as detection means for detecting, in use, at least a measure for movements of part of the tube.

According to the invention, the excitation means comprise a piezo material. The invention allows a micro Coriolis mass flow sensor that is actuated by piezo material, in an embodiment an integrated lead zirconate titanate (PZT) thin film actuator. The piezo material may be applied to the Coriolis tube, and an applied actuation voltage will make the piezo material shrink or expand, which may be used to impart the desired motion to the Coriolis tube. The use of the piezo material allows low voltage, low power actuation compared to current actuation methods. With this, the object of the invention is achieved.

In an embodiment, the sensor comprises a single Coriolis tube.

In an embodiment, the excitation means exist solely of the piezo material, such that no further means for exciting the Coriolis tube are necessary. This way, no electrostatic force or Lorentz force is necessary. The piezo material may comprise one or more piezo actuators.

In an embodiment, the piezo material has been processed in the Coriolis tube. The piezo material may form part of the outer jacket of the Coriolis tube. The piezo material may extend in particular mainly parallel to the longitudinal axis of the Coriolis tube. This provides for a compact solution. In an embodiment, the piezo material has been processed on the tube fixation means as well. By providing piezo material on the tube fixation means and the Coriolis tube, it is possible to move the Coriolis tube with respect to the tube fixation means. The skilled person will understand though that also providing piezo material on the tube fixation means is not necessary for obtaining the advantages of the present invention.

It should be noted that US 2015/1 14137 A 1 and WO 2009/102763 A 1 disclose Coriolis-type flow sensors. However, the piezo material is not integrated nor processed in the Coriolis tube.

In an embodiment, the Coriolis tube comprises two tube outer end parts that preferably extend substantially parallel to each other, wherein said piezo material is provided on said tube outer end parts over a length thereof. By providing said piezo material on said tube outer end parts, a reliable and accurate Coriolis excitation is possible.

In an embodiment, said piezo material comprises lead zirconate titanate.

In an embodiment, the piezo material, or piezo actuator, is a thin film layer provided on or in the Coriolis tube. In an embodiment, the thin film layer is provided on a part of the outer jacket of the Coriolis tube, and extends mainly parallel to the longitudinal axis of the Coriolis tube. This way, the thin film layer is relatively easy to apply during manufacturing of the Coriolis flow sensor.

In an embodiment, the flow meter comprises an electrode that is integrated into the piezo material. The electrode may comprise two interdigitated electrodes, which provides for an effective way for actuating the piezo material.

In an embodiment, the detection means comprise capacitive sensor elements.

In an embodiment, the piezo material is provided on one side of the Coriolis tube. The Coriolis tube may substantially define a plane, and said Coriolis tube then has a first side when viewed in a first direction perpendicular to said plane, and a second side when viewed in a second direction perpendicular to said plane, wherein said second direction is opposite to said first direction. In an embodiment, the piezo material is only provided on said first side of said Coriolis tube, and the second side of said Coriolis tube is free from piezo material. The piezo material may be provided on both tube outer end parts over a length thereof.

In an embodiment, said flow meter comprises a system chip with a substrate having an opening therein, wherein the Coriolis tube is freely suspended in said opening, and wherein the substrate forms the tube fixation means as the two outer ends of the Coriolis tube are fixed in said substrate. Said piezo material may then be provided on the Coriolis tube and on the substrate, meaning that a piezo actuator may connect the substrate to the Coriolis tube. This way, a micro Coriolis chip having integrated piezo excitation is obtained. The integration of piezo material into said system chip is beneficial, since this provides an effective solution to the aforementioned problems with high voltage, and/or large power consumption and Joule heating of the sensor tube and the required strong external magnets.

In an embodiment, the substrate is made of silicon, and/or the Coriolis tube is made of silicon nitride.

In an embodiment, the detection means comprise the piezo material. This may be the piezo material that is already used in the excitation means, or this may be further piezo material next to the piezo material that is already used in the excitation means. In an embodiment, the excitation means thus comprise a piezo material, and the detection means comprise said piezo material as well. In an alternative embodiment, said excitation means comprise a piezo material, and the detection means comprise a further piezo material. Said piezo material and/or said further piezo material may comprise one or more piezo actuators.

Another aspect of the invention concerns a fluid dosing system comprising a pump or valve for dispensing a fluid and an aforementioned flow sensor configured for operating the pump or valve to control the dose of fluid dispensed by the pump or valve.

Another aspect of the invention relates to a fluid flow control system comprising a control valve for controlling fluid flow in a fluid line and an aforementioned flow sensor configured for operating the control valve to control the fluid flow in the fluid line.

The invention will be explained in more detail below, by way of example, with reference to the drawing in which:

Fig. 1 : is a diagrammatic elevation of an embodiment of a prior art flowmeter with a system chip and a Coriolis flow sensor;

Fig. 2a-2c : show schematic views of operation of the Coriolis flow sensor of Fig. 1;

Fig. 3 : shows a first embodiment of a Coriolis flow sensor according to the invention;

Fig. 4 : shows a second embodiment of a Coriolis flow sensor according to the invention;

Fig. 5 : shows a detail of a Coriolis flow sensor according to a further embodiment of the invention.

Corresponding components have been given the same reference numerals as much as possible in the Figures.

Figures 1 and 2 are brief descriptions of a prior art flow meter of the Coriolis type as described in EP2078936 B1. The reference to these figures is used to clarify the general build of these types of flowmeters, and the method of operation.

Fig. 1a shows a system chip 17 comprising a monocrystalline silicon substrate 1 in which an opening 4 has been etched. The system chip 17 in this example has a Coriolis flow sensor with a Coriolis tube 3 of silicon nitride which is freely suspended in the opening 4. An absolute pressure sensor 2, such as a Pirani pressure sensor, may be integrated in or on the substrate 1. The Coriolis tube has a loop shape, in this case a rectangular loop shape. Other loop shapes, such as triangular, trapezoidal, or U-shaped, are also possible, and may be used in the Coriolis flow sensor according to the invention as well.

The system chip 17 is (monolithically) assembled with two mutually opposed permanent magnets 9, 9' which are arranged on a carrier 5, for example a PCB (printed circuit board) of ceramic or synthetic resin material with copper tracks thereon. The substrate is manufactured from a <1,0,0> Si wafer mounted on the carrier 5. The electrical connections between the system chip 17 and the carrier 5 are provided by so-termed bonding wires arranged in groups 6, 7, and 8. The bonding wires 6 (from and to the sensor chip) serve for conditioning the chip temperature / c.q. temperature control. A local temperature sensor and an (ambient) pressure sensor 2 may be present, if so desired.

The pressure sensor 2, if present, measures the absolute pressure. This is important because the quality factor of the tube's vibration depends inter alia on the air pressure.

The bonding wires 7 serve for bringing the freely suspended tube 3 into vibration. The bonding wires 8 serve for controlling the read-out elements for the freely suspended tube.

The freely suspended tube 3 together with the rod magnets 9, 9', a current conductor (wire) 10 on the tube 3, and capacitive sensor elements 11 on the tube and 12 on the system chip 17 forms a so-termed Coriolis flowmeter, which is further clarified in Figs. 2a to 2c. A body of soft magnetic material may optionally be provided between the rod magnets 9 and 9' in a location within the loop so as to enhance the efficiency of the magnet arrangement.

A housing may be provided around the entire assembly for protection; this is not shown.

Fig. 2a shows a U-shaped Coriolis tube 3 that was made by MST technology, that is freely suspended, and that is partly embedded in the silicon substrate where it merges into inlet and outlet channels present in the substrate and issuing at the side of the substrate 1 opposite to the freely suspended portion 3. The applied magnetic field 31 is indicated by arrows B, and the current passed through the conductor 10 on the tube 3 for generating the Lorentz forces is referenced 32.

During operation, a medium enters at 21 and exits at 2T. The mass flow of a medium is the mass that passes through a cross-section of the tube per second. If the mass is a self-contained quantity, the mass flow through the U-tube of Fig. 2a must be the same everywhere (otherwise mass will accumulate somewhere, or mass disappears somewhere).

Therefore, the mass flow Q has the same (constant) modulus (or vector 'length') everywhere in the tube 3. However, mass flow Q points in the positive x-direction in tube portion 22 and in the negative x-direction in tube portion 26.

The following methods exist for realizing and applying a Coriolis mass flowmeter with the U-tube 3 of Fig. 2a:

- a torque mode is generated through Lorentz excitation, i.e. a torsional movement (cf. Fig. 2b);
- heat is generated in the conductor pattern 10 through thermal excitation,

which leads to a flapping mode (cf. Fig. 2c).

Method 1, Fig. 2b:

The U-tube is actuated (vibrated) about an axis of rotation 29 (= the x-axis), which in the case of a mass flow leads to a Coriolis force in that location where the distance to the axis of rotation changes, which is at tube portion 24. This Coriolis force on tube portion 24 causes the U-tube 3 to rotate about an axis of rotation 30 (= the y-axis), leading to a translatory movement of the tube portion 24. This (vibratory) actuation movement is referenced 34 in Fig. 2b. The resulting Coriolis-induced rotation about the y-axis is proportional to the mass flow and results in a z-movement 35 of the tube portion 24. The tube portion 24 performs both movements simultaneously, i.e. the actuating torsional vibration 34 and the flapping movement 35 (proportional to the mass flow).

Method 2, Fig. 2c:

The tube is flapped, or actuated (vibrated) about the axis of rotation 30 (= y-axis); this in the case of a mass flow again leads to a Coriolis force in that location where the distance to the axis of rotation changes, which is at tube portion 22 (upward) and tube portion 26 (downward) this time, causing a rotation of the tube portion 24. The (vibratory) actuation movement of the tube portion 24 in the z-direction is referenced 36 in Fig. 2c. The resulting Coriolis-induced rotation about the x-axis 29 is proportional to the mass flow and results in the rotational x-movement 37 of the tube portion 24. Again, the tube portion 24 performs both movements simultaneously, i.e. the actuating flapping vibration 36 and the torsional vibration 37 that is proportional to the mass flow.

Reference numeral 11 (11', 11") in the previous Figures indicates means (projections or tags of SiN) at or on the connecting part between the legs of the U-shaped tube 3. These form capacitances together with their counterpart means (projections or tags) 12 (12', 12") at the substrate side. This renders it possible to detect the movements of the tube in a capacitive manner. One, two, or three such pairs of tags, for example, may be used.

As can be seen in Fig. 1, the magnets 9, 9' are relatively bulky compared to the Coriolis tube, and these magnets cause packaging issues.

Fig. 3 shows a Coriolis flow sensor 101 according to a first embodiment of the invention, which reduces one or more drawbacks of the prior art as described above. It is noted that the reference signs used in Fig. 3 are not related to any of the reference signs of the prior art embodiments as described with respect to Fig. 1 and Fig. 2.

In the embodiment of fig. 3, the flow sensor 101 comprises a system chip 114 with a substrate 104 in which an opening O has been etched, similar to the system of Fig. 1. The system chip 114 has a Coriolis flow sensor with a Coriolis tube 102 of silicon nitride which is freely suspended in the opening O. The Coriolis tube 102 has at least two outer ends 111, 112 that are fixed in tube fixation means 104, which fixation means in the embodiment shown is formed by the substrate 104. The flow sensor 101 comprises excitation means 105 for oscillating said Coriolis tube 102 about an excitation axis E or an excitation axis X. The flow sensor 101 also comprises detection means 107 for detecting, in use, at least a measure for movements of part of the Coriolis tube 102. According to the invention, the excitation means 105 comprise a piezo material 151, 152 that is provided on the Coriolis tube 102 and on the substrate 104. In this embodiment, the piezo material is provided on one side of the Coriolis tube 102.

The Coriolis tube 102 comprises two tube outer end parts 121, 127 that preferably extend substantially parallel to each other, and said piezo material 151, 152 is provided on said tube outer end parts 121, 127 over a length thereof. Said piezo material may comprise lead zirconate titanate, and may be a thin film layer provided on or in the Coriolis tube 102.

By providing piezo material 151, 152 on the Coriolis tube 102 and on the substrate 104, it is possible to activate the piezo material. By applying an actuation voltage, the piezo material, for example a PZT thin film, may shrink or expand, bending the Coriolis tube 102 in the upward or downward direction, respectively. This way the Coriolis tube may be activated according to one of the modes as described with respect to Fig. 2b or Fig. 2c. Preferably, the Coriolis tube is brought into swing motion (Fig. 2c) by means of the piezo material. The resulting twist motion will be superimposed on the swing motion. It will have the same frequency, but because the Coriolis forces are proportional to the angular velocity of the actuation mode there will be 90 degrees phase shift. As a result, instead of measuring the ratio between the vibration amplitudes of the Coriolis (twist) mode and actuation (swing) mode, one can obtain a signal proportional to the mass flow by measuring the phase shift between two points at opposite sides of the twist mode axis. To this end, the detection means 107 comprise two detection elements 171 and 172, which are provided on opposite sides of the most outer Coriolis tube part 124, and each of which is positioned with an offset with respect to the central axis X. It is noted that the offset of the detection elements 171, 172 is generally the same, but in a different direction, which is clearly visible in Fig. 3. Here, the detection elements 171, 172 are shown schematically, but they may be embodied the same as the capacitive detection elements 11, 12 as shown in Fig. 1 and 2. Alternative detection means, for example using laser vibrometer means, may be used as well.

Due to the use of piezo material, no electrostatic force or Lorentz force is required for driving the Coriolis tube. Thus, no high voltage is required, the external magnets are not required anymore. In all, the use of piezo material leads to low voltage and low power actuation compared to previous actuation methods.

In the embodiment shown, the piezo material 151, 152 has been processed in the Coriolis tube 102, which may be done by depositing the integrated thin film actuators on top of silicon-rich silicon nitride (SiRN) fluidic microchannels by pulsed laser deposition (PLD).

Now turning to Fig. 4, an alternative embodiment is shown, in which the piezo material is used as the detection means as well. For reasons of conciseness, the same reference signs are used as in Fig. 3 with the addition of 100. For example, the flow sensor 101 as denoted in Fig. 3, is denoted flow sensor 201 in Fig. 4.

In Fig. 4, the flow sensor 201 comprises detection means 207 that comprise the piezo material 251, 252. The voltage of the pair of piezo actuators 205 may be used to determine the angular twist of the Coriolis tube, with which the actual flow may be determined. This provides for a very compact solution.

In an embodiment additional thin film silicon nitride bridges containing piezo material may be added between Coriolis tube part 224 and the substrate 204 to measure the movement (not shown). In this case, excitation is based on piezo material, and detection is based on additional piezo material.

According to an aspect the piezo material 151, 152 may be used solely for detection purposes, i.e. in combination with Lorentz actuation or Joule heating. It is noted that according to this aspect, a flow sensor of the Coriolis type is provided, comprising a Coriolis tube having at least two outer ends that are fixed in tube fixation means, wherein said flow sensor comprises excitation means for oscillating said Coriolis tube about an excitation axis, as well as detection means for detecting, in use, at least a measure for movements of part of the Coriolis tube. According to this aspect, the detection means comprise a piezo material. The piezo material may be embodied in any way as described herein in view of the excitation means.

Now turning to Fig. 5, a detail is shown of the outer ends 311, 312 of the Coriolis tube 302, in a further embodiment of the flow sensor according to the invention. Here, the piezo actuators 305 comprise a piezo material 351, 352, each of which is provided with interdigitated electrodes 331, 332 and 333, 334, respectively. The interdigitated electrodes may be made of a Platinum material. These interdigitated platinum electrodes 331, 332; 333, 334 may be patterned on top of the PZT layer. The electrode width and the distance between the electrodes are both 5 pm. The entire actuator is 60 pm wide and 820 pm in length.

In the embodiment shown, additional wiring 341 is running over the sensor tube 302. For this, thin silicon nitride bridges (not shown) next to the tube suspension S may be used. Thus, the flow sensor may comprise, in an embodiment, PZT thin film actuators and thin silicon nitride bridges containing wires, for example four parallel gold wires 341, that can be used for capacitive readout and conventional Lorentz force actuation of the Coriolis tube 102. It is noted however, that the additional wiring and capacitive readout structures are not required for employing the invention.

Fabrication of the device according to the invention may be based on the process described in J. Groenesteijn, M.J. de Boer, J.C. Loiters, and R.J. Wiegerink, “A versatile technology platform for microfluidic handling systems, part I: fabrication and functionalization”, *Microfluidic Nanofluidics,* vol 21, no 7, pp 1-14, 2017, and has some additional steps to integrate the PZT actuators. The process is somewhat similar to the production of a micromachined Coriolis flow sensor as described EP2078936 B1 in particular with respect to Fig. 4a to 4j, and Fig. 5.

First, a 500 nm thick layer of SiRN and a 50 nm thick layer of chromium are deposited on a silicon wafer. The chromium acts as a hard mask for SiRN patterning. After SiRN has been patterned with slits of 5 by 2 pm, the silicon is isotropically etched through the slits to form the tube shape.

Next, the chromium layer is removed and a layer of silicon dioxide is deposited. Then fluidic inlets are etched from the backside of the wafer using deep reactive ion etching, stopping on the silicon dioxide layer. Subsequently the silicon dioxide layer is selectively removed.

Next, another layer of SiRN is deposited by LPCVD to form the channel wall and close the slits in the first SiRN layer. Next, the PZT layer is deposited using an LaNi03 (LNO) seed layer. A Ti/Pt layer is deposited on the top of the PZT layer to form the interdigitated electrodes.

The thicknesses of the LNO/PZT/Ti/Pt layers are 15nm/1 .4pm/20nm/100nm, respectively. The PLD deposition process has been described in M. D. Nguyen et al., “Characterization of epitaxial Pb(Zr,Ti)0 3 thin films deposited by pulsed laser deposition on silicon cantilevers,” J. Micromechanics Microengineering, vol. 20, no. 8, p. 85022, 2010.

Next, the platinum electrodes and the PZT layer are patterned using ion beam etching and reactive ion etching, respectively. Next, a gold layer with chromium adhesion layer is deposited and patterned to form the additional wiring on the tube and the electrodes for capacitive readout.

Finally, the suspended microfluidic channel is released by etching openings in the SiRN layer followed by isotropic etching of silicon through these openings.

Materials and dimensions described in the foregoing are for illustration purposes only. The desired protection is determined by the appended claims.

CLAIMS

1. Flow sensor (101) of the Coriolis type, comprising a Coriolis tube (102) having at least two outer ends (111, 112) that are fixed in tube fixation means (104), wherein said flow sensor (101) comprises excitation means (105) for oscillating said Coriolis tube (102) about an excitation-axis (E), as well as detection means (107) for detecting, in use, at least a measure for movements of part of the Coriolis tube (102), characterized in that the excitation means (105) comprise a piezo material (151, 152), wherein the piezo material (151, 152) has been processed in or integrated in the Coriolis tube (102).

2. Flow sensor according to claim 1, wherein the sensor comprises a single Coriolis tube (102).

3. Flow sensor according to claim 1 or 2, wherein the Coriolis tube (102) comprises two tube outer end parts (121, 127), wherein said piezo material (151, 152) is provided on said tube outer end parts (121, 127) over a length thereof.

4. Flow sensor according to claim 3, wherein the two outer end parts (121, 127) extend substantially parallel to each other.

5. Flow sensor according to any one of the previous claims, wherein said piezo material (151, 152) comprises lead zirconate titanate.

6. Flow sensor according to any one of the previous claims, wherein the piezo material (151, 152) is a thin film layer provided on or in the Coriolis tube (102).

7. Flow sensor according to any one of the previous claims, wherein the flow meter (101) comprises an electrode (331, 332) that is integrated into the piezo material.

8. Flow sensor according to any one of the previous claims, wherein the detection means (107) comprise capacitive sensor elements (171, 172).

9. Flow sensor according to any one of the previous claims, wherein the piezo material (151, 152) is provided on one side of the Coriolis tube (102).

10. Flow sensor according to any one of the previous claims, comprising a system chip (114) with a substrate (104) having an opening (O) therein, wherein the Coriolis tube (102) is freely suspended in said opening (O), and wherein the substrate forms the tube fixation means (104) as the two outer ends of the Coriolis tube (111, 112) are fixed in said substrate.

11. Flow sensor according to claim 10, wherein the substrate (104) is made of silicon, and/or the Coriolis tube is made of silicon nitride.

12. Flow sensor according to any one of the previous claims, wherein the detection means (207) comprise the piezo material (251 , 252).

13. Fluid dosing system comprising a pump or valve for dispensing a fluid and a flow sensor (101) according to any one of the preceding claims configured for operating the pump or valve to control the dose of fluid dispensed by the pump or valve.

14. Fluid flow control system comprising a control valve for controlling fluid flow in a fluid line and a flow sensor (101) according to any one of the preceding claims 1 - 12 configured for operating the control valve to control the fluid flow in the fluid line.

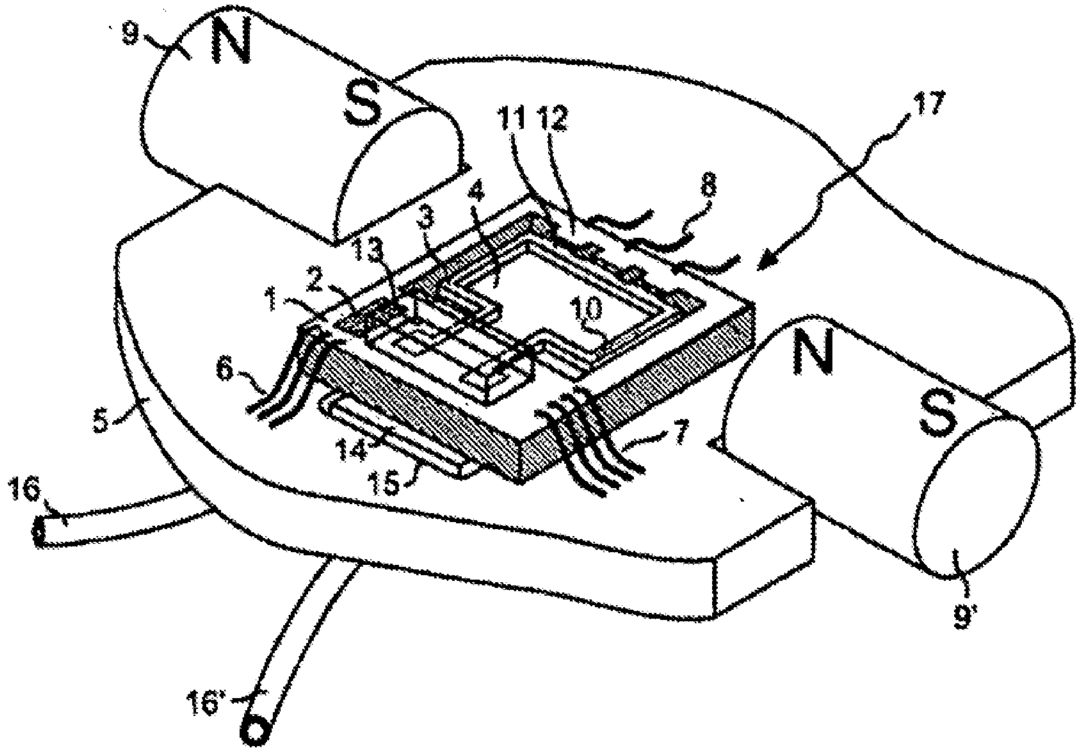

Fig. 1

PRIOR ART

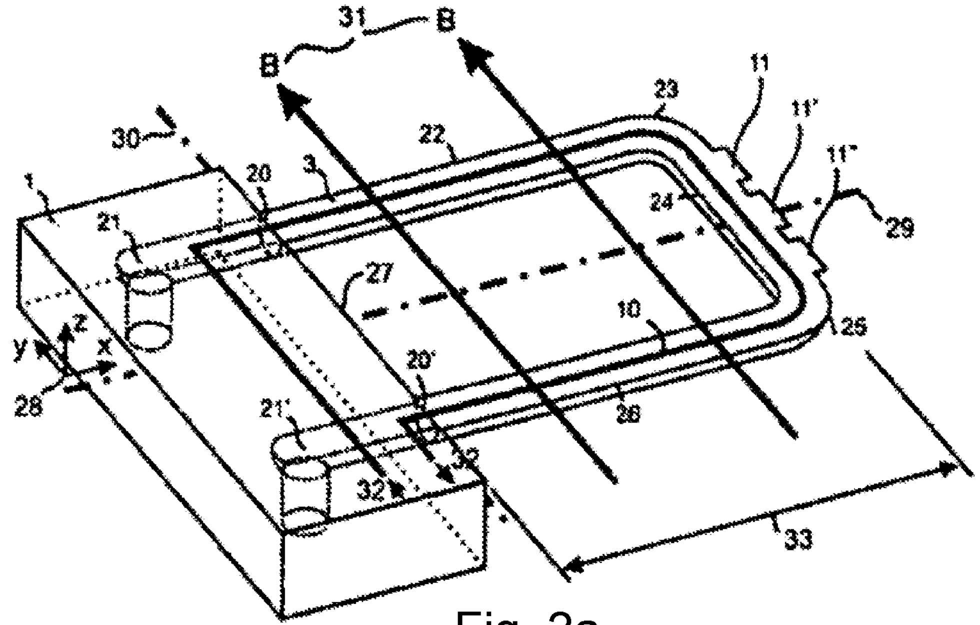

Fig. 2a

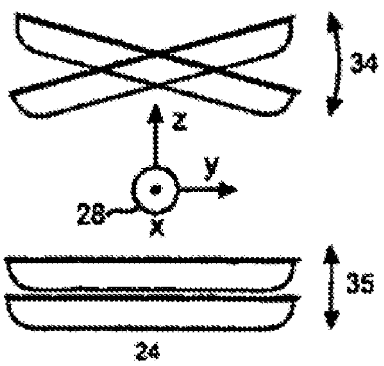

Fig. 2b

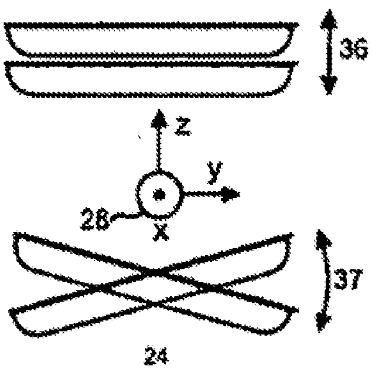

Fig. 2c

PRIOR ART

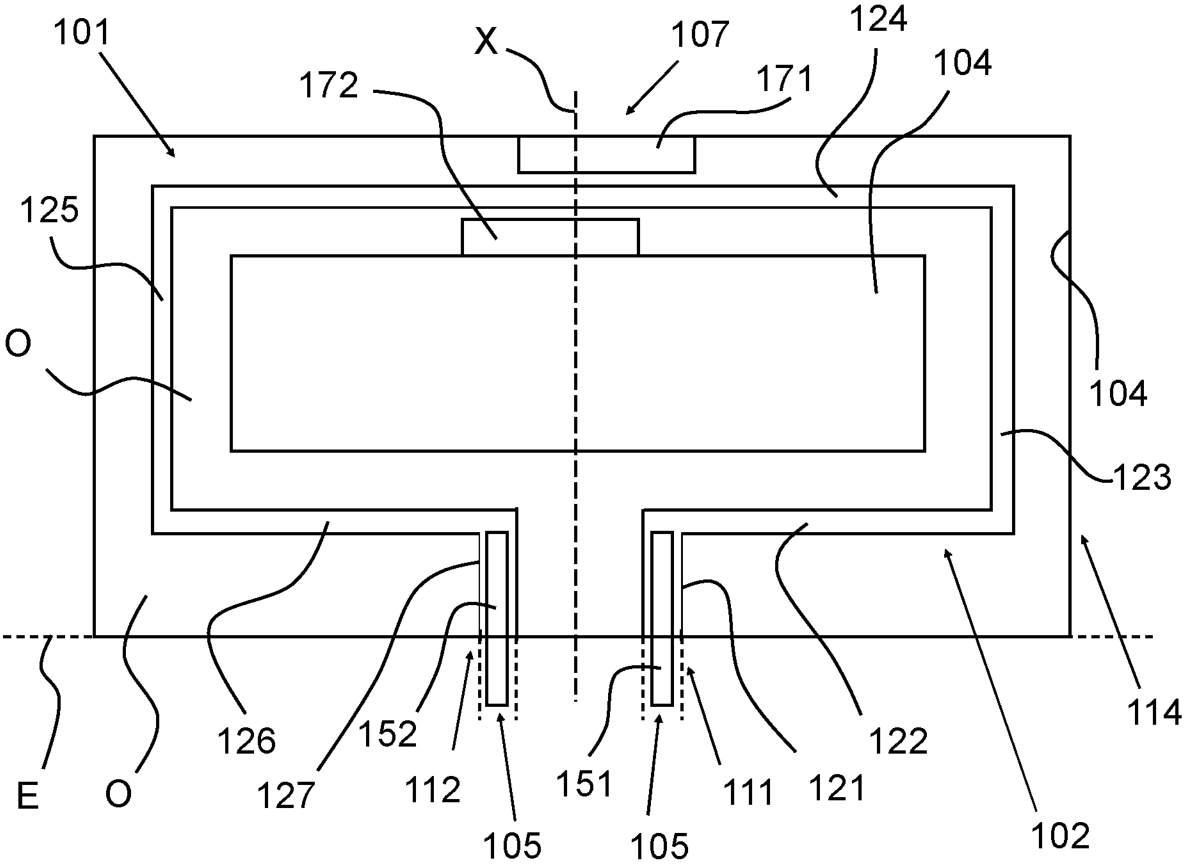
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Fig. 3

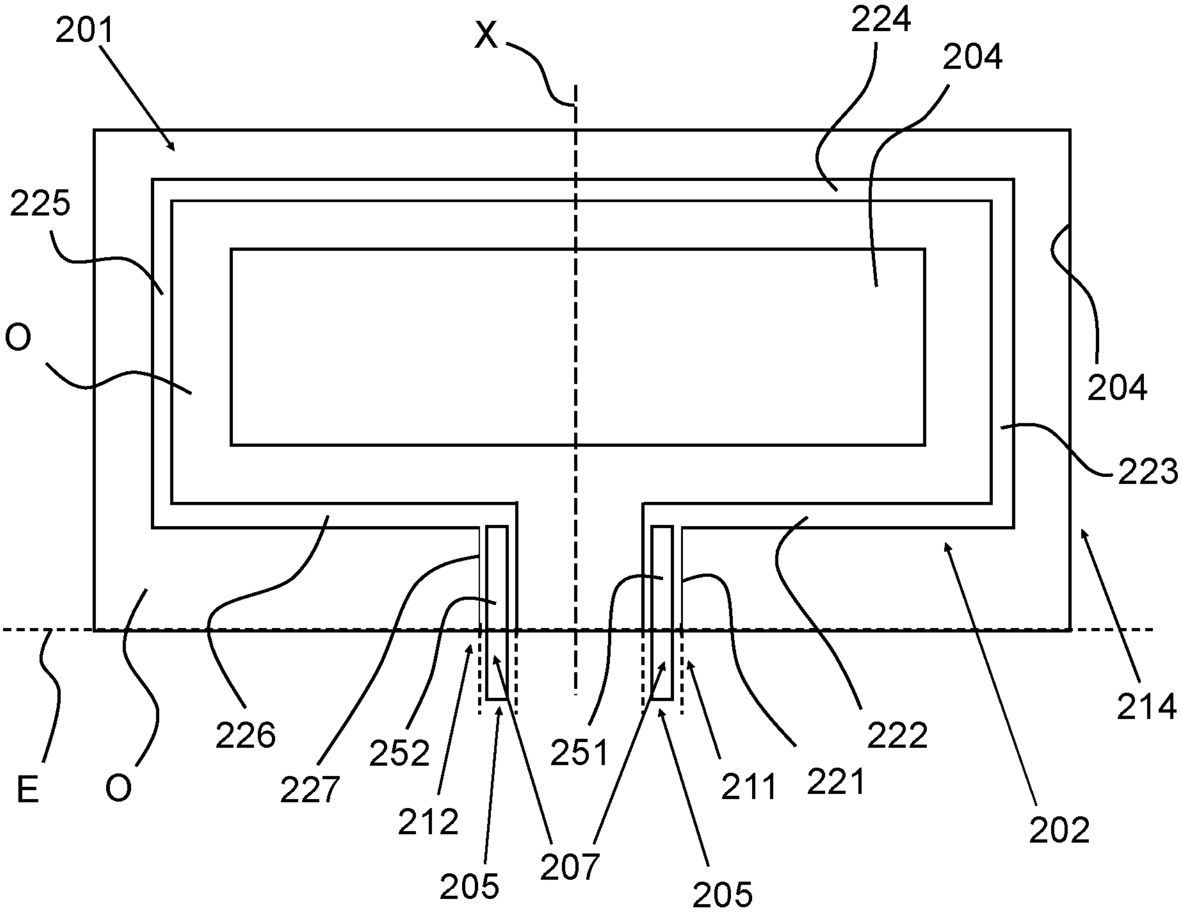
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Fig. 4

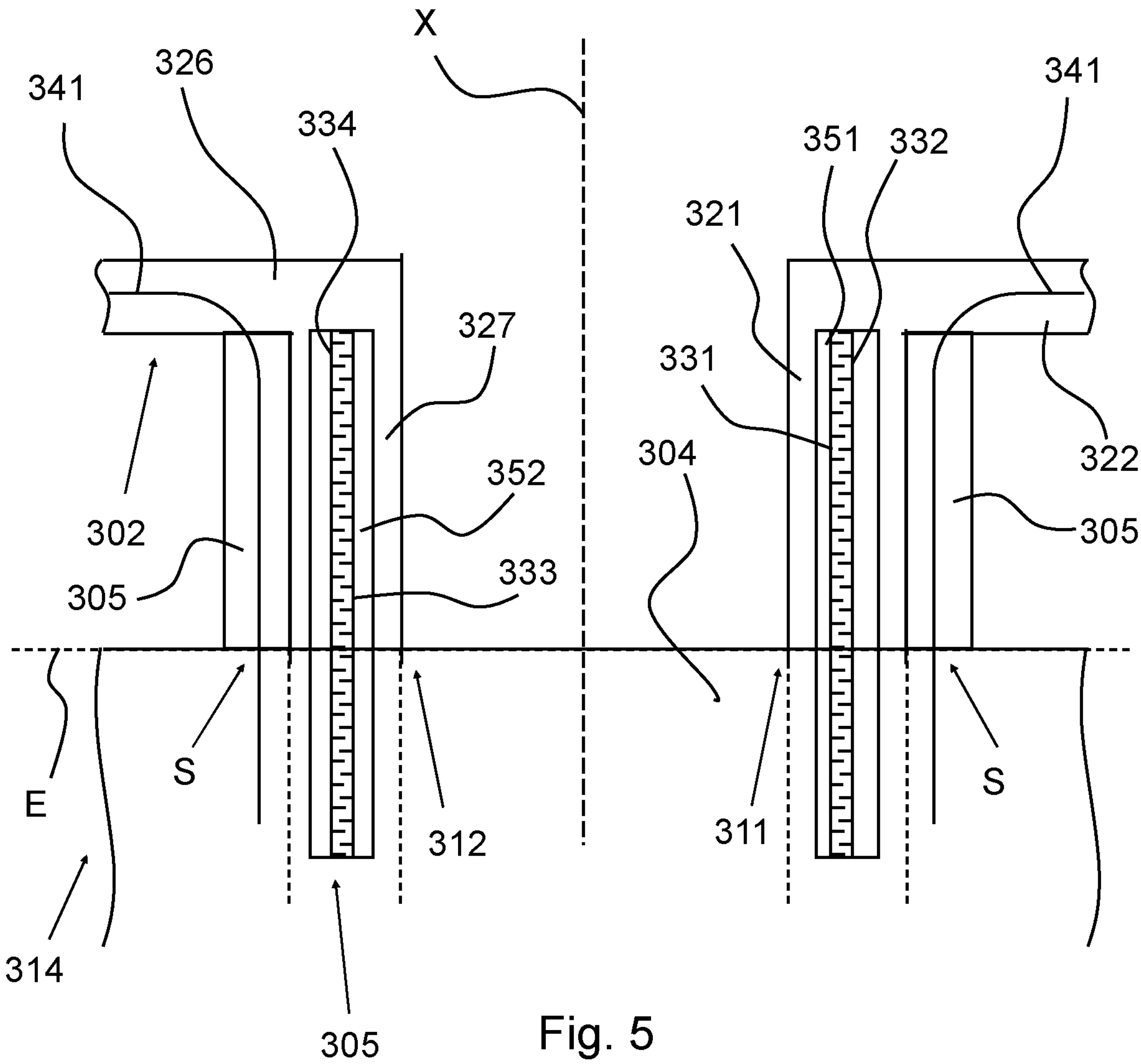
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Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2019/050021

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01F1/84
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)
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 practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/114137 A1 (PUTTY MICHAEL WILLIAM [US] ET AL) 30 April 2015 (2015-04-30) paragraph [0045]; figures 6A,6B -----	1-14
A	NGUYEN M D ET AL: "Characterization of epitaxial Pb(Zr,Ti)O3 thin films deposited by pulsed laser deposition on silicon cantilevers;Characterization of epitaxial Pb(Zr,Ti)O3 thin films deposited by pulsed laser deposition on silicon cantilevers", JOURNAL OF MICROMECHANICS & MICROENGINEERING, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 20, no. 8, 12 July 2010 (2010-07-12), page 85022, XP020196061, ISSN: 0960-1317, DOI: 10.1088/0960-1317/20/8/085022 the whole document -----	5

-/--

[X] Further documents are listed in the continuation of Box C.

[3] See patent family annex.

* Special categories of cited documents :

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"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 May 2019	21/06/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Quertemont, Eric

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 078 936 A1 (BERKIN BV [NL]) 15 July 2009 (2009-07-15) cited in the application paragraph [0025] -----	1-14

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/NL2019/050021

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015114137 A1	30-04-2015	EP 3063509 A1	07-09-2016
		US 2015114137 A1	30-04-2015
		WO 2015066045 A1	07-05-2015
EP 2078936 A1	15-07-2009	AT 498117 T	15-02-2011
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		NL 1034905 C2	14-07-2009
		US 2009308177 A1	17-12-2009