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[Continued on next page]

(54) **Title**: 3 AXIS POLYMERIC ACCELEROMETER AND METHOD OF PRODUCTION

(57) **Abstract**: The present invention consists in a thermal accelerometer capable of detecting acceleration in multiple axes. The accelerometer is made of four microinjected polymeric parts (1, 2, 3, 4), which can be two identical top parts and two identical central parts or four different parts, which are assembled with active polymeric membranes (5, 6, 7) to construct the 3-axis acceleration sensing device. The microinjected parts provide mechanical support for the heater and temperature sensors that are placed on the membranes. The device operating gas medium is hermetically sealed by the polymer parts and electrical current applied to the heater causes the air to heat and external acceleration imposes a gradient of temperature sensed by the thermal sensing elements.

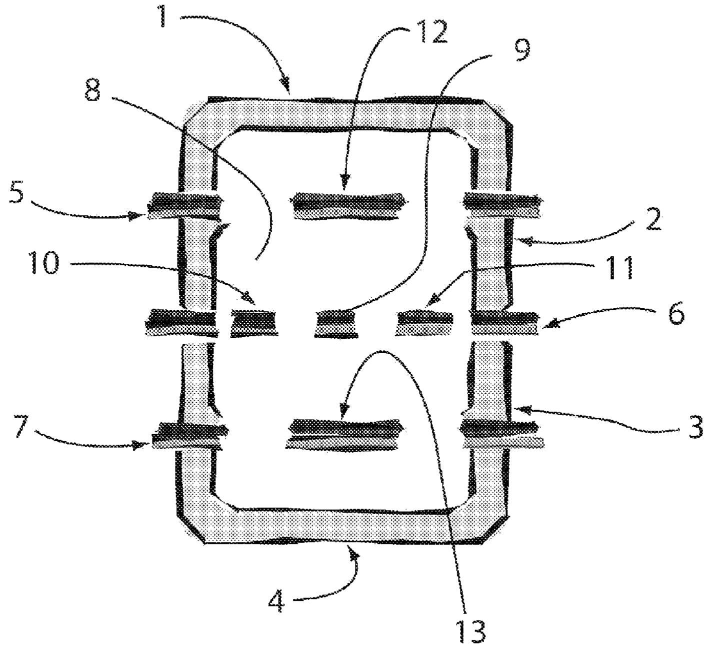

FIG. 1

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DESCRIPTION

"3 AXIS POLYMERIC ACCELEROMETER AND METHOD OF PRODUCTION"

Field of the invention

The present invention relates to the production of micro-fabricated thermal accelerometers capable of detecting acceleration in multiple axes. More particularly, a 3-axis sensing device based on polymers.

State of the art

Thermal accelerometers based in convection heat present several advantages when compared to piezo and capacitive accelerometers and are known to comprise an enclosure in which a central filament is disposed that is connected to a power supply member delivering electricity, and that is located between two sensors for comparing the temperatures. Without acceleration a symmetrical temperature profile is generated with a maximum value at the heater's center location while when acceleration is applied, free convection occurs and the sensors measure a temperature difference. The developed signal is then amplified, conditioned and output as either radiometric or an absolute voltage allowing the characterization of the nature and direction of the applied force.

Patent documents describing innovations related to the method of production and functioning of thermal accelerometers providing up to three axes of acceleration were found. Prior inventions address silicon based devices and therefore, except for the sensing principle, this invention is completely different regarding the method of production, the 3-axis sensing mechanism and materials used. A thermal accelerometer using a silicon substrate with at least one enclosed chamber formed by micromachining and at least one heat element suspended over the cavity in the X-Y plane and a mechanism for detecting heat transfer including a first and second temperature sensing elements disposed on the X and/or Y axes at equal distances from the heater element and with the possibility of integrating a third and a fourth element in the same conditions is described in Patent US 7,392,703 B2. Acceleration in the X and Y directions is given by the temperature sensing elements disposed on the X and Y axes on opposite sides. The accelerometer further includes an amplification circuitry operative capable of receiving signals representing a differential temperature detected by the first and second temperature and producing an output voltage representative of the magnitudes of acceleration along a Z axis perpendicular to the XY plane presenting an increased sensitivity for measuring the acceleration in the Z direction. This circuitry increases the sensitivity to measure the acceleration in the Z direction by being configured to reduce both DC offset and drift input by the internal reference voltage. It is also compatible with CMOS technology and bipolar processes with reduced costs while guaranteeing a high level of reliability.

Patent US 6,182,509 B1 describes two implementations where the first provides an accelerometer mainly constituted by a silicon substrate with a cavity formed by micromachining, a metal heater extending across the open space and a metal pair of temperature sensing elements equidistant and parallel to the heater positioned on opposite sides being both formed by micromachining and coated with silicon dioxide. Electrical current is provided to the heater by a conductor connected to an external source of power and the differential resistance between the temperature sensing elements is measured by a bridge circuit. Heat transfer medium may consist of a fluid or a gas.

A second accelerometer is described presenting some differences from the previous device such as having a heater and temperature sensing elements of polysilicon being the heater made of a metal and polysilicon coated with dielectric silicon dioxide. The device includes a pair of auxiliary heaters as intermediate symmetrically disposed on either side of and spaced from the primary heater. Conductive lines from an external source of power and operative are coupled to provide electrical current to the auxiliary heaters allowing independent changing of current through each auxiliary heater. Instead of two temperatures sensing elements a thermopile of a plurality of thermocouples is arrange linearly as in the previous accelerometer device. The thermopiles are electrically connected in series and with opposite polarity producing an electrical potential proportional to the difference in temperature measured by a coupled differential amplifier. Each thermocouple is made of conductors and semiconductors materials forming a junction physically arranged in a linear pattern between materials generating a plurality of functions.

Another approach for a 3-axis thermal accelerometer was introduced by Tsang et Al. in his research work "MONOLITHICALLY FABRICATED POLYMER MEMS 3-AXIS THERMAL ACCELEROMETERS DESIGNED FOR AUTOMATED WIREBONDER ASSEMBLY" presented at MEMS Conference 2008, Tucson, AZ, USA, January 13-17, pp. 880-883. A surface micromachining like process, with silicon as the supporting substrate, is used for the fabrication of the active elements, the heater and temperature sensors (thermocouples). The fabrication process uses a series of layers, including a supporting mechanical spin-coated photoresist layer, and a release etching process that adds complexity to the process. The accelerometer requires two heaters, one for the XY axis and another one for the Z axis, for full 3-axis measurement as opposed to the single heater requirement presented in this invention. A final external mechanical stimulus is required on the Z-axis heater supporting layer to place it in the vertical position, which strongly limits reproducibility.

Majority of thermal accelerometer patents, US 6,171880 B1, US 6,795,752 B1, US 7,096,734 B2, describe silicon micromachined convective accelerometers with one or more cavities therein in which is included the thermal acceleration sensor and associated signal conditioning circuitry. Silicon presents very good thermal conductivity increasing this way the thermal losses and consequently power consumption and the process to fabricate the accelerometer device is rather slow and expensive for small series. Thermal sensors tend to be based on platinum thermistor with a large thermal capacitance causing a reduction of the sensor bandwidth.

Although previous inventions demonstrate silicon based thermal accelerometers, it would be desirable to have a lower cost thermal accelerometer configured to provide up to three axes of acceleration sensing with high levels of reliability while avoiding thermal losses and with reduced power consumption.

The possibility of producing microsystems both functional and economic is leading polymer micromanufacturing technologies towards new fields of application. The micromolding technology is emerging to a new level of complexity and precision and this challenging technique requires improvements in relation to the conventional mould production techniques, as well as changing the extraction and temperature systems and even the product designing to best suit the new processing demands. Advantages are related to size and weight reduction, better performance, lower consumption, greater design flexibility as well as lower manufacturing costs for large scale productions.

Summary of the invention

One object of the present invention is a 3-axis thermal accelerometer device, which comprises:

- An hermetically sealed enclosure containing a gas (8);
- A top polymeric part (1) and a central external part (2) divided by a top polymeric membrane (5), and a bottom polymeric part (4) and a central external part (3) divided by the bottom polymeric membrane (7), attached by a central membrane (6);
- A heating mean on the center;

- 3 pairs of temperature sensors along X, Y and Z directions.

In a preferential aspect, the 3-axis thermal accelerometer device includes membranes (5 and 7) placed equidistant to the central membrane (6).

In another preferential aspect, the 3-axis thermal accelerometer device includes sensors placed above the membranes (5, 6 and 7) at an equal distance from the heating mean.

In a preferential aspect, the 3-axis thermal accelerometer device includes gas (8) that is hermetically sealed by the polymer parts by means of adhesives, glues or a welding process.

In another preferential aspect, the 3-axis thermal accelerometer device has a central membrane (6) that include the heater and the XY-axis temperature sensors.

In a preferential aspect, the 3-axis thermal accelerometer device presents top and bottom membranes (5 and 7) that include the Z-axis temperature sensor.

In another preferential aspect, the 3-axis thermal accelerometer device includes a sensing system that consists of low-thermal conductive polymeric membranes with active elements.

In a preferential aspect, the 3-axis thermal accelerometer device includes active elements fabricated using metals, polymers or conductive inks by means of deposition methods and/or inkjet printing.

In another preferential aspect, the 3-axis thermal accelerometer device has a distance between the temperature sensors and heater within the interval 100-1500 microns and the total length of the heater is within the interval 1000-3500 microns.

In a preferential aspect, the 3-axis thermal accelerometer device has the polymeric membrane (6) geometry defined by laser cutting, wet etching or dry etching.

In another preferential aspect, the 3-axis thermal accelerometer device includes X temperature sensor (10), Y temperature sensor (14), Z temperature sensor (12) and the heater (9) which are made of metal or semiconductor or conductive polymer or conductive ink.

In a preferential aspect, the 3-axis thermal accelerometer device includes temperature sensors and heater deposited using physical vapor deposition techniques, inkjet printed or spin casted.

In another preferential aspect, the construction of the 3-axis thermal accelerometer device includes lithography techniques used to define the temperature sensor and heater geometry.

In a preferential aspect, the 3-axis thermal accelerometer device has a central membrane (6) assembled by means of adhesives, glues or ultrasound technologies.

In another preferential aspect, the 3-axis thermal accelerometer device has temperature sensors in the Z direction (12 and 13) occupying the largest possible area.

Another aspect of the present invention is the method of production of the 3-axis thermal accelerometer device which comprises the following steps:

- the external parts (1, 2, 3 and 4) are produced by microinjection;
- The membranes (5, 6 and 7) are produced;
- Final assembly process.

In a preferential aspect, the method of production of the 3-axis thermal accelerometer device includes membranes (5, 6 and 7) and external parts (1, 2, 3 and 4) assembled by means of adhesives, glues or any welding process usually applied to polymer parts in an automated or manual process.

General Description of the Invention

The present invention consists in 3-axis thermal accelerometer and the method of production thereof. Current thermal accelerometer devices are manufactured from a silicon substrate micromachined to form one or several cavities. Although simple, this is a non-effective process when it comes to high rates and series of production and silicon presents disadvantages as heat losses diminishing the device efficiency.

Polymer microinjected microparts are used in this invention to produce the structural part of the accelerometer. The microinjection process, based in the injection process, has been widely studied and used to produce pieces in the micron scale with low amounts of material and high level of detail, including true 3D geometries, being simultaneously reliable and economic. This technique does feature a wide range of thermoplastics which present a variety of physical and chemical properties combined with low cost, good processing capability, recyclability among other advantages.

Four microinjected polymeric parts (two identical top parts and two identical central parts or four different parts) are to be assembled with active polymeric membranes (two identical z-axis membranes and a central membrane) to construct the 3-axis acceleration sensing device. The microinjected parts provide mechanical support for the active elements that are placed on the membranes (the heater and the temperature sensors). The invention enables the realization of a 3-axis thermal accelerometer based on polymers. The device operating gas medium is hermetically sealed by the polymer parts by means of adhesives, glues or a welding process and electrical current applied to the heater causes the air to heat and external acceleration imposes a gradient of temperature sensed by the thermal sensing elements.

The use of microinjected parts, with low thermal conductance, improves power consumption and enables novel sensor configurations including 3 sensing acceleration axes. The polymeric membranes support the active temperature sensing elements and their design can compensate for asymmetries during the assembly process: top and bottom membranes can be made larger and with larger sensing area in order to have constant response in case of planar (XY) asymmetries between central and top/bottom membranes. The top and bottom membranes are placed at equidistance from the central membrane to sense acceleration changes on the Z-axes and the central membrane includes the heater and the XY acceleration sensing elements. The low thermal conduction of the polymeric membranes improves the overall power efficiency. The central membrane requires a different design than the top/bottom membranes since both the heater and the XY-axis temperature sensors must be placed in the central membrane while the top/bottom membrane only includes the Z-axis temperature sensor. Since there are no design constraints for the Z-axis temperature sensor, the occupied area of the sensor can be maximized in order to compensate for small asymmetries (between top and bottom membranes and central membrane) that are likely to happen during the assembly process.

Brief description of the drawings

For easy understanding of the present invention we attached figures that represent preferred realizations of the invention which, however, are not intended to limit the object of the present invention.

FIG. 1 represents a 2D cross-section view of the thermal accelerometer device showing the following elements:

- Polymeric external parts (1, 2, 3 and 4);
- Membranes (5, 6, and 7);
- The active elements (9, 10, 11, 12 and 13);
- The enclosed gas medium (8).

FIG. 2 depicts the central membrane (6) with preferred configuration consisting in the central heater (9), X temperature sensors (10 and 11) and Y temperature sensors (14 and 15).

FIG. 3 depicts the top/bottom membrane (5, 7), with preferred configuration with Z temperature sensor (12).

FIG. 4 depicts an illustrative embodiment of the elements of the thermal accelerometer prior to final assembly. The top, central and bottom membranes (5, 6 and 7) are placed between the polymeric external parts (1, 2, 3 and 4), followed by the accelerometer assembly.

Detailed description

The present application describes the method of production of polymeric based 3-axis thermal accelerometers. The invention takes advantage of the potential of polymeric materials diverse properties and uses microinjection technology to have a both reproducible and economic process suitable for high production series. Also, the sensing system consists of low-thermal conductive polymeric membranes with active elements produced by simple fabrication methods. The active elements, heater and temperature sensors, are fabricated using metals, polymers or conductive inks by means of deposition methods and/or inkjet printing.

The method of production of the current invention can be divided in three distinct phases: the microinjection of the external parts, the fabrication of the membranes, and a final assembly process.

FIG. 1 depicts an illustrative 2D plane of the parts of the thermal accelerometer device. When electrical current is applied to the heater (9), the gas medium around it (8) will heat up. In the absence of any external acceleration, the XY temperature sensors (10 and 11) and the Z temperature sensors (12 and 13) placed equidistant to the heater will have zero temperature difference. In the presence of external acceleration, free convection occurs and a temperature difference between the pair of temperature sensors exists (depending on the direction of the external acceleration). The measured temperature difference is proportional to the external acceleration. The distance between the temperature sensors and heater is within the interval 100-1500 microns and the total length of the heater is within the interval 1000-3500 microns. However, other dimensions may be selected depending on the accelerometer desired specifications. The placement of 3 pairs of temperature sensors enables to measure acceleration in 3 axes.

The thermal accelerometer external structure is composed by four polymeric parts (1, 2, 3 and 4) where parts (1 and 4) can be identical (top/bottom) as well as parts (2 and 3) which can also be identical. The fact that the polymeric parts can be made equal in pairs brings advantages such as the use of only two different moldings and simplicity of the assembly process.

The active elements, heater (9), XY temperature sensors (10 and 11) and Z temperature sensors (12 and 13) are placed on top of the polymeric membranes (5, 6 and 7). The Z temperature sensors occupy the largest possible area in manner to compensate asymmetries. After assembling of the parts and membranes, the gas medium cavity (8) gets hermetically sealed.

FIG. 2 shows a detailed view of the central membrane (6). The polymeric membrane (6) geometry can be defined by laser cutting, wet etching or dry etching. The heater (9) is placed at the center and can be made of any kind of metal, such as platinum or aluminum, semiconductor, any kind of conductive polymer, such as polyacetylene, polypyrrole and their copolymers or any kind of conductive inks, such as inks with silver nano-particles. According to the material, the heater can be deposited using physical vapor deposition techniques such as thermal evaporation or electron beam evaporation, inkjet printed or spin casted. Lithography techniques may be used to further define the heater geometry.
The X temperature sensors and the Y temperature sensors (10, 11, 14 and 15) are placed equidistant to the heater and can be made of metal, semiconductor, conductive polymer or conductive ink. Both Pyroelectric and resistive transduction

mechanisms can be used to measure the temperature and depending on the material, the temperature sensors can be deposited using physical vapor deposition techniques, inkjet printed or spin casted. Lithography techniques may be used to further define the temperature sensors geometry.

FIG. 3 shows a detailed view of the top (5) and bottom (7) membrane. Membranes (5 and 7) are placed equidistant to the central membrane (6). The polymeric membrane (5) geometry can be defined by laser cutting, wet etching or dry etching. The Z temperature sensor (12) can be made of metal, semiconductor, conductive polymer or conductive ink. Both pyroelectric and resistive transduction mechanisms can be used to measure the temperature and depending on the material, the temperature sensors can be deposited using physical vapor deposition techniques, inkjet printed or spin casted. Lithography techniques may be used to further define the temperature sensor geometry.

FIG. 4 depicts the final assembly process. Top and bottom equal membranes (5 and 7) are placed between external polymeric parts (1, 2 and 3, 4) and are assembled by means of any kind of adhesives/glues such as epoxy and UV curing adhesives, ultrasound technologies or other welding process usually applied to polymer parts. The central membrane (6) is placed between external polymeric parts (2 and 3) and is assembled by means of adhesives, glues or ultrasound technologies. The order of assembling of the parts (1, 2, 3 and 4), and the membranes (5, 6 and 7) can be arbitrary and should be selected in such a way to minimize the number of required steps. Both manual and automatic assembly can be used.

The preferential examples for the realization of the invention previously demonstrated are intended to be illustrative and not a limitation of the possible geometries. Different geometries may be selected depending on the accelerometer desired specifications.

CLAIMS

1. A 3-axis thermal accelerometer device comprising:
   - An hermetically sealed enclosure containing a gas (8);
   - A top polymeric part (1) and a central external part (2) divided by a top polymeric membrane (5), and a bottom polymeric part (4) and a central external part (3) divided by the bottom polymeric membrane (7), attached by a central membrane (6);
   - A heating mean on the center;
   - 3 pairs of temperature sensors along X, Y and Z directions.

2. A 3-axis thermal accelerometer device according to claim 1, wherein the membranes (5 and 7) are placed equidistant to the central membrane (6).

3. A 3-axis thermal accelerometer device according to previous claims, wherein the sensors are placed above the membranes (5, 6 and 7) at an equal distance from the heating mean.

4. A 3-axis thermal accelerometer device according to previous claims, wherein the gas (8) is hermetically sealed by the polymer parts by means of adhesives, glues or a welding process.

5. A 3-axis thermal accelerometer device according to the previous claims, wherein the central membrane (6) includes the heater and the XY-axis temperature sensors.

6. A 3-axis thermal accelerometer device according to the previous claims, wherein the top and bottom membranes (5 and 7) include the Z-axis temperature sensor.

7. A 3-axis thermal accelerometer device according to the previous claims, wherein the sensing system consists of low-thermal conductive polymeric membranes with active elements.

8. A 3-axis thermal accelerometer device according to the previous claims, wherein the active elements are fabricated using metals, polymers or conductive inks by means of deposition methods and/or inkjet printing.

9. A 3-axis thermal accelerometer device according to the previous claims, wherein the distance between the temperature sensors and heater is within the interval 100-1500 microns and the total length of the heater is within the interval 1000-3500 microns.

10. A 3-axis thermal accelerometer device according to the previous claims, wherein the polymeric membrane (6) geometry is defined by laser cutting, wet etching or dry etching.

11. A 3-axis thermal accelerometer device according to the previous claims, wherein the X temperature sensor (10), the Y temperature sensor (14), the Z temperature sensor (12) and the heater (9) are made of metal or semiconductor or conductive polymer or conductive ink.

12. A 3-axis thermal accelerometer device according to the previous claims, wherein the temperature sensors and heater are deposited using physical vapor deposition techniques, inkjet printed or spin casted.

13. A 3-axis thermal accelerometer device according to the previous claims, wherein lithography techniques are used to define the temperature sensor and heater geometry.

14. A 3-axis thermal accelerometer device according to the previous claims, wherein the central membrane (6) is assembled by means of adhesives, glues or ultrasound technologies.

15. A 3-axis thermal accelerometer device according to the previous claims, wherein the temperature sensors in the Z direction (12 and 13) occupy the largest possible area.

16. Method of production of the 3-axis thermal accelerometer device as described in claim 1 comprising the following steps:
- the external parts (1, 2, 3 and 4) are produced by microinjection;
- The membranes (5, 6 and 7) are produced;
- Final assembly process.

17. Method of production of the 3-axis thermal accelerometer device according to previous claim, wherein the membranes (5, 6 and 7) and the external parts (1, 2, 3 and 4) are assembled by means of adhesives, glues or any welding

process usually applied to polymer parts in an automated or manual process.

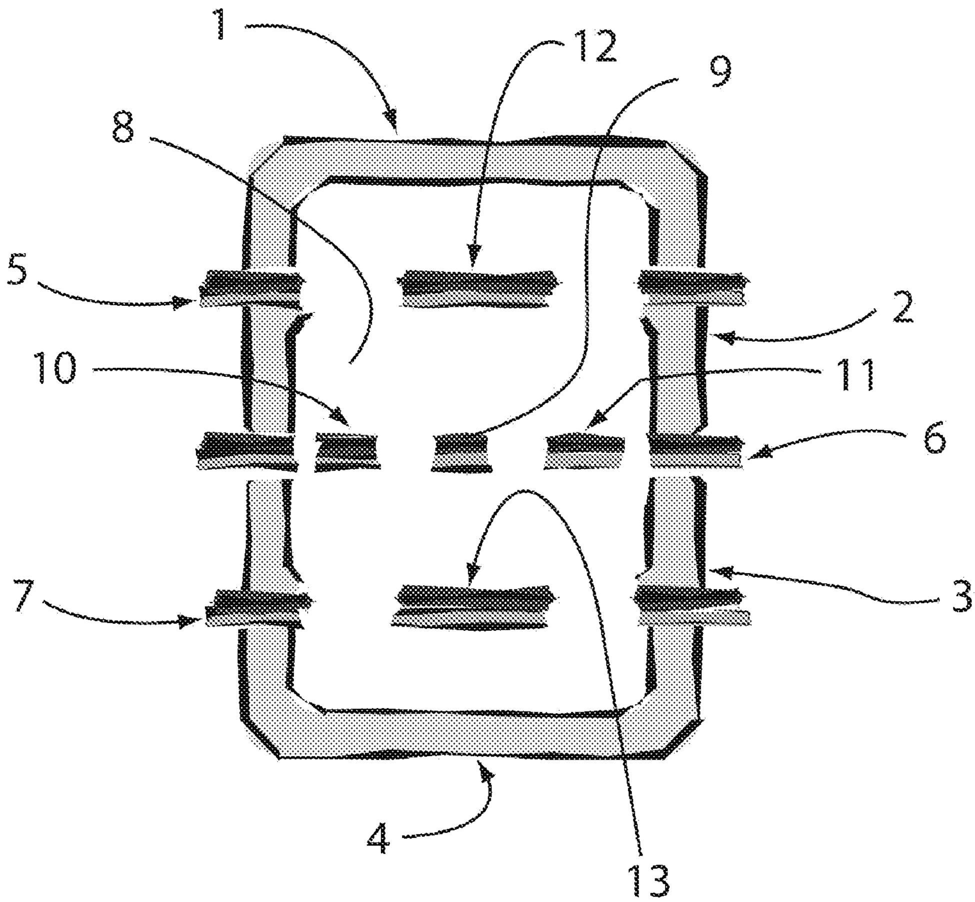

FIG. 1

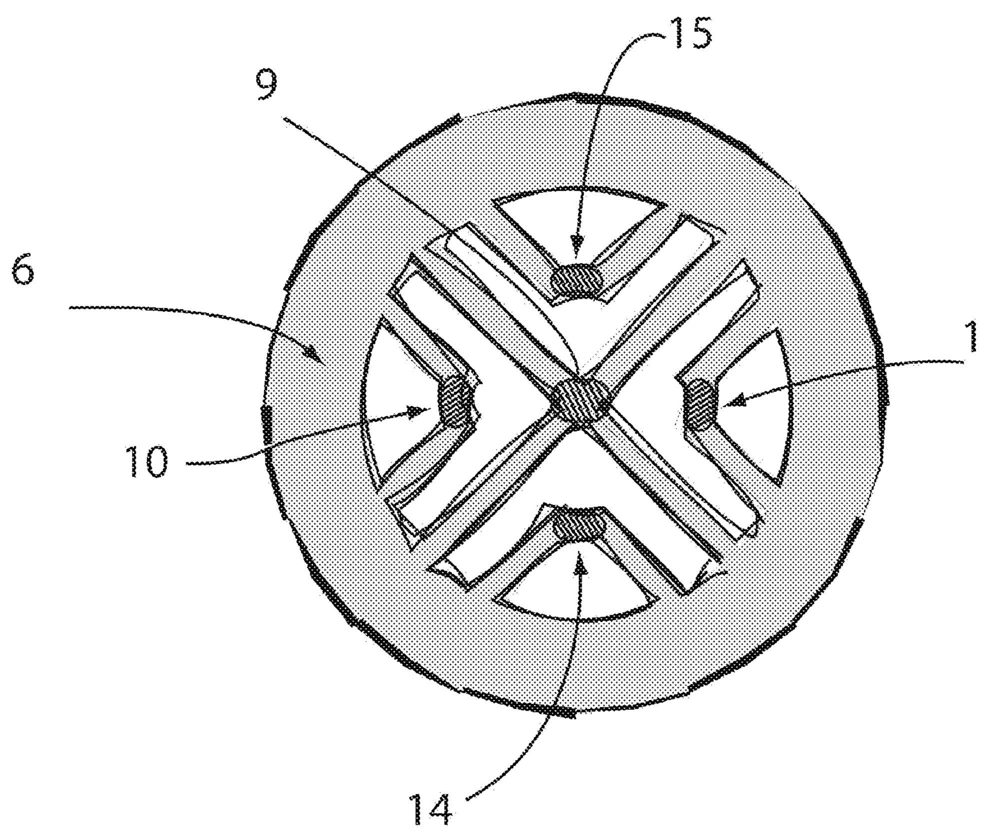

FIG. 2

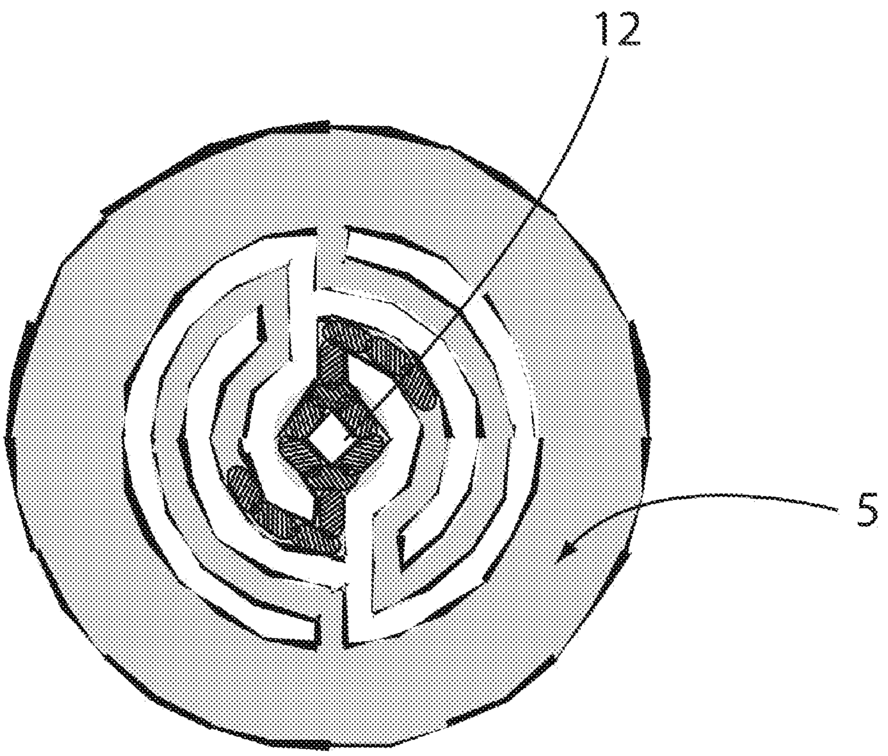

FIG. 3

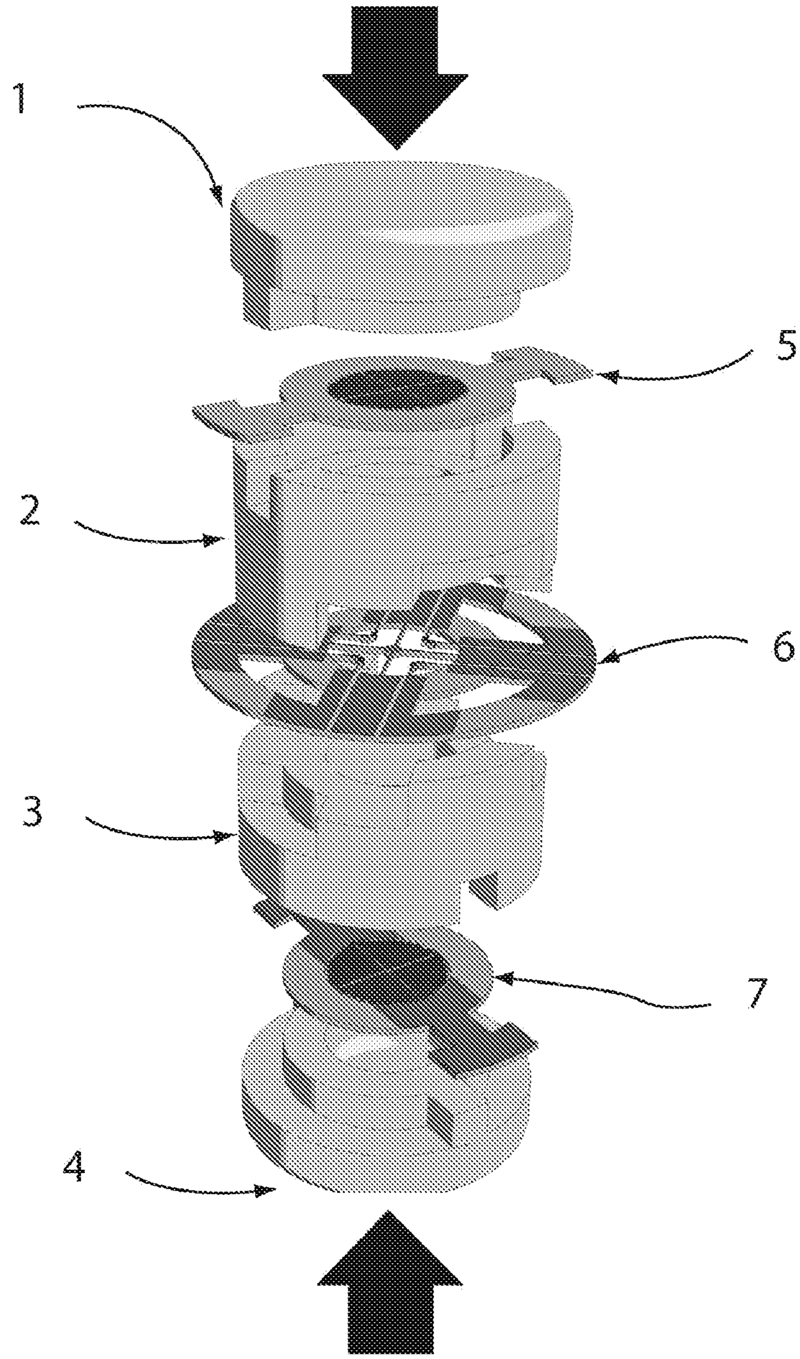

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/053056

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01P15/00 G01P15/18
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)
G01P

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

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X	EP 0 664 456 A1 (HONDA MOTOR CO LTD [JP]) 26 July 1995 (1995-07-26) column 19, line 40 - column 24, line 3; figures 21, 22, 23 -----	1-17
A	US 2007/101813 A1 (HUA YAPING [CN] ET AL) 10 May 2007 (2007-05-10) page 5, paragraph 49 - page 9, paragraph 77; figure 4 -----	1-17
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 October 2012	17/10/2012

Name and mailing address of the ISA/
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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