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(54) Title: A PIEZORESISTIVE ACCELEROMETER

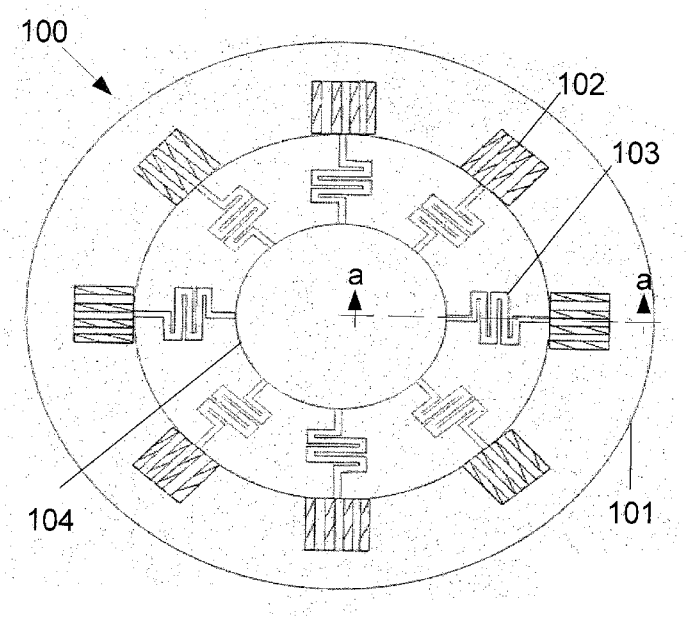


Figure 1

(57) Abstract: Disclosed is a force-balanced piezoresistive 3-axis accelerometer. An exemplary accelerometer (100) comprises a proof mass (104) which is coupled to a plurality of meanders (103), which further couple to a plurality of anchor pads (102) that extends out from each meander (103). The proof mass (104), meanders (103) and anchor pads (102) are integrally fabricated multilayer construct which comprises a base silicon layer (201), insulator 1 (202), insulator 2 (204), metal 1 (203) and metal 2 (205) arranged in an intermittent fashion and fabricated through CMOS compatible fabrication process. Piezoresistive sensing means is used in detecting acceleration in three degree of freedoms or directions in which piezoresistors (206) embedded within the multilayer construct are used to sense the movement of proof mass (104) and meanders (103) upon external force which exerted on the proof mass (104). Electrical signals upon the sensing are then generated and processed by electrical circuitry to provide DC biasing on respective anchor pads (102) to produce x-, y- and z-direction acceleration data in terms of magnitude and direction. The accelerometer is also designed with self-test capability in which the meanders (103) perform self-test by bending at least one meander while keeping other meanders stationary and measuring z-displacement. The resulting accelerometer has the potential for low power consumption due to DC biasing, low cost and high-accuracy operation over wide temperature range due to additional Wheatstone bridge circuit embedded within the multilayer construct.

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A PIEZORESISTIVE ACCELEROMETER

FIELD OF INVENTION

The present invention relates to an accelerometer. In more particular, the present invention relates to the operation of an accelerometer from detection via the piezoresistance to force-balancing the proof mass which makes use of DC power only, thus reducing power consumption.

BACKGROUND OF THE INVENTION

An accelerometer is a device that measures acceleration of motion of an object or structure. Accelerometers can be used to measure vibration on vehicles, machines, buildings, process control systems and safety installations. They can also be used to measure seismic activity, inclination, machine vibration, dynamic distance and speed with or without the influence of gravity. Typical types of accelerometer include mechanical accelerometer, capacitive accelerometer, piezoelectric accelerometer, magnetic accelerometer, thermal accelerometer and etc. In general, accelerometer works based on the principle of Newton second law of motion, or mathematically, F = ma in which acceleration can usually be known or found with the knowledge of force and mass.

In a conventional accelerometer, the inertial force produced by the vibration deflects the proof mass from its equilibrium position, and thus its displacement or deflection is then converted into an electric signal. The electrical signal is further processed by electrical circuitries to provide acceleration data. This principle of measurement is currently applied for short-period seismometers only. Long-period or broadband seismometers are built according to the force-balanced principle. It means that the inertial force is balanced by an electrically generated force so that the motion of proof mass is controlled and adjusted to the minimal level. The amount of electrical energy used to generate feedback force is processed and provide acceleration data. With this

working principle, the acceleration is directly converted into an electrical signal instead of depending on the precision of the mechanical suspension within the accelerometer system. Most current force-balanced accelerometers require capacitive plates to both detect and provide force-feedback signal. This requires consistent biasing for measuring the signal i.e. for modulating and demodulating.

Most of the patented technologies apply capacitive force balancing method to balance the proof mass and also involve AC biasing in their applications. Patent No. US2009/0280594A1 relates to a 3-axis force-balanced accelerometer in which it applies capacitive sensing means to derive electrical signals caused by forces exerted on the proof mass, and the electrical signals in terms of AC biasing are processed by the processing electronics to produce x-, y- and z- direction acceleration data. Incorporating a piezoresistive sensing using simple CMOS compatible fabrication process eliminates this biasing requirement because sensing is done through directly measuring the current produced using DC biasing. However, none of the patented technologies disclose an accelerometer which is made by fully applying piezoresistive detection for force balancing in three orthogonal axes and also applies DC biasing for meander driving. As the significance of an innovative accelerometer has been increasingly increased, there is a need for incorporating innovative means into the manufacture of the accelerometer.

SUMMARY OF INVENTION

The present invention extends the technology of the force-balanced 3-axis accelerometer design to lower power consumption design required in wide applications. The present invention describes the operating principle which involves detecting the proof mass movement by using piezoresistors on meanders and anchor pads through Wheatstone bridge circuits (WBS). The signals are then fed back to a controller circuit to provide DC biasing on metal lines to keep the proof mass stationary. The amount of DC biasing on respective pad finally gives both the magnitude and direction of acceleration which is readable by the users.

One object of the present invention is to provide an accelerometer that consumes low power by applying DC biasing in the controller circuit.

Another object of the present invention is to provide an accelerometer that is compatible with the CMOS fabrication process, which is less costly to fabricate.

Still another object is to provide an accelerometer that is force-balanced through adjustable physical length by DC biasing.

Yet another object is to provide an accelerometer having an integrated readout circuit.

Still another object is to provide an accelerometer with no damping problem since proof mass is controlled in static position.

A further object is to provide an accelerometer capable of measuring acceleration simultaneously along three orthogonal axes of a Cartesian coordinate system.

A still further object is to provide an accelerometer having wide input range.

Another object is to provide an accelerometer having wide adjustable bandwidth.

Yet another object is to provide an accelerometer having adjustable sensitivity.

Still another object is to provide an accelerometer which is highly linear with less signal distortion and having higher accuracy.

A further object is to provide an accelerometer having high resolution.

A still further object is to provide an accelerometer having minimized stress through the spring design.

At least one of the preceding objects is met, in whole or in part, by the present invention, in which one of the embodiment of the present invention is an

accelerometer (100) comprising a support (101) fabricated with a centrally located hollow; a plurality of anchor pads (102) located on the support surrounding the hollow space; a meander (103) extends out from each anchor pad (102) towards the hollow and being suspended within the hollow; a proof mass (104) connected to the anchor pads (102) through meanders (103) that the proof mass (104) is displaceable in relative to the anchor pads (102) when subjected to an external force and able to resume its original position once the external force is removed; wherein the anchor pads (102), meanders (103) and proof mass are integrally fabricated multilayer construct which includes a plurality of metals and insulator layers arranged in an intermittent fashion with the bottommost layer is the insulator layer followed by a base silicon layer (201) characterized in that piezoresistors (206) are disposed within multilayer construct at the meanders and/or anchor pads and connected to at least one metal layer to generate an electrical signal upon displacement of the proof mass (104) in relative to the anchor pads (102).

In order to allow accelerometer to operate at low power and able to detect accelerations in all three orthogonal axes, one preferred embodiment of the present invention includes embedment of three types of motion piezoresistors (206), i.e. lateral, vertical and axial motion piezoresistor within the multilayer construct. Displacement of the proof mass (104) in various directions is detected by the piezoresistors (206) within the multilayer construct at the anchor pads (102) and electrical signals in terms of DC biasing are generated upon the displacement of the proof mass (104) in the controller circuit to provide feedback force to hold the proof mass (104) stationary.

In order to optimize sensitivity of acceleration detection in all three orthogonal axes, in another embodiment, meanders (103) are designed at the minimum in terms of its structure and amount.

In other aspect of the present invention, a means for compensating temperature effect is used in which immobile Wheatstone resistors are embedded within base silicon layer (201) in the multilayer construct at each of the anchor pads (102).

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the present invention will be more fully understood when considered with respect to the following detailed descriptions, appended claims and accompanying drawings wherein:

Figure 1 is a top view of a force-balanced piezoresistive 3-axis accelerometer;

Figure 2 is a cross-sectional view taken along line a-a of Figure 1, showing the inner layer materials of present invention; and

Figure 3 shows a block diagram showing operational principle of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

It should be noted that the following detailed description is directed to a force-balanced piezoresistive 3-axis accelerometer and is not limited to any particular size or configuration of the accelerometer but in fact a multitude of sizes and configurations within the general scope of the following description.

The present invention involves an accelerometer (100) comprising a support (101) fabricated with a centrally located hollow; a plurality of anchor pads (102) located on the support surrounding the hollow space; a meander (103) extends out from each anchor pad (102) towards the hollow and being suspended within the hollow; a proof mass (104) connected to the anchor pads (102) through meanders (103) that the proof mass (104) is displaceable in relative to the anchor pads (102) when subjected to an external force and able to resume its original position once the external force is removed; wherein the anchor pads (102), meanders (103) and proof mass are integrally fabricated multilayer construct which includes a plurality of metals and insulator layers arranged in an intermittent fashion with the bottommost layer is the insulator layer followed by a base silicon layer (201) characterized in that

piezoresistors (206) are disposed within multilayer construct at the meanders and/or anchor pads and connected to at least one metal layer to generate an electrical signal upon displacement of the proof mass (104) in relative to the anchor pads (102).

With reference to Figure 1, the support (101) in the present invention is a PCB i.e. printed circuit board which is fabricated round in shape with a centrally located hollow that provides substrate to anchor the entire accelerometer (100) structure and interconnections to external components such as electrical power supply. In other words, the support (101), PCB is used to offer mechanical support for the proof mass (104) while at the same time serving as a connection platform to establish connection to electronic components using conductive pathways, tracks or signal traces etched from copper sheets laminated onto a non-conductive substrate. Preferably, a total amount of eight anchor pads (102) are uniformly located on the support (101) surrounding the hollow space of the support (101). A resilient meander (103) extends out from each of the anchor pads (102) towards the center of the hollow and being connected to the proof mass (104) which disposed at the center of the hollow. Possible embodiments with varied number of anchor pads (102) and meanders (103) of the should also be cleared to those skilled in the arts. For example, six or less anchors pads and meanders may be used in one of the embodiments as well. However, it is important to be noted herein the amount of anchor pads (102) and meanders (103) is eight owing to its optimum design in terms of sensitivity and accuracy of the acceleration data over other amounts.

In a preferred embodiment, the structures of the resilient meanders (103) are designed at the minimum in order to provide sensitivity of accelerometer (100) in all three orthogonal axes.

In order to detect acceleration in all three orthogonal axes, the proof mass (104), which is made to be displaceable in relative to the anchor pads (102) in three degree of freedoms, i.e. x-, y- and z- directions when subjected to an external force or inertial force during force action and it is able to resume its original position once the force is removed or balanced by an electrically generated force which exerts on the proof mass (104), through the detection of various directional displacement of the proof mass (104) in terms of electrical signals generated, and through the processing

electrical circuitries which process the electrical signals and provide feedback to the controller circuit in terms of balancing forces to hold the proof mass (104) stationary. Processing of the electrical signals allows determination of acceleration components along x-, y-, and z- axes of the proof mass (104) in the accelerometer (100) system.

Further embodiment, the proof mass (104) is made to be round in shape. However, it is not intention of the inventors to rule out other possible forms or shapes applicable onto the proof mass (104) in the present invention such as rectangular, square, polygonal, oval and so forth. It is important to be noted herein that the proof mass (104) preferably possess a shape allowing for more uniform balancing among the meanders (103) upon the movement of the proof mass (104) in various directions.

Referring now to Figure 2, which is a cross-sectional view taken along line a-a of Figure 1, it is seen that there are multilayered materials within the exemplary force-balance piezoresistive 3-axis accelerometer (100). The anchor pads (102), meanders (103) and proof mass (104) excluding the support (101) are integrally fabricated multilayer construct through CMOS compatible fabrication process which includes a plurality of metal and insulator layers which are arranged in such a way that the bottommost layer is the base silicon layer (201), followed by upper layer of insulator 1 (202), metal 1 (203), insulator 2 (204) and the uppermost layer, metal 2 (205). The metals and insulators used within the multilayer construct can be found in most integrated circuits, as they can be aluminum, silicon dioxide and silicon nitride, for instance.

In an advantageous embodiment, piezoresistors (206) are disposed within the multilayer construct in which consisting of three types of motion piezoresistors, i.e. lateral, vertical and axial piezoresistors to detect the displacement of proof mass (104) along three independent orthogonal axes, effectively. Lateral motion piezoresistor is embedded within the silicon base layer (201) in the meander (103) to measure displacement along x-axis. Vertical motion piezoresistor is also embedded within the silicon layer (201) in the meander (103) to measure displacement along y-axis but it is further extended to the anchor pad (102) so as to reduce overall cross sensitivity in the x-y plane. Axial motion piezoresistor is embedded within silicon base layer (201) in

the anchor pad (102) to measure displacement along z-axis. All three types of motion piezoresistors (206) as described function simultaneously when the proof mass (104) is subjected to any external force or inertial force. However, it is not intention of the inventors to rule out other possible arrangement of the piezoresistors (206) in the present invention. It is important to be noted herein that the piezoresistors (206) preferably possess an arrangement allowing more sensitive, accurate and precise acceleration data over all three orthogonal directions.

In a particular embodiment, Wheatstone bridge circuit in the present invention, although not shown in Figure 2, is embedded within the anchor pad (102) in the base silicon layer (201) and connected to the metal 1 (203) which further connected to metal 2 (205). Such Wheatstone bridge circuit arrangement within the multilayer construct helps to provide temperature compensation to allow for operations at wider temperature range. In other words, the accelerometer system can be operated at even higher temperature with the embedment of Wheatstone bridge circuit within the multilayer construct. It should be clear to those skilled in the art that these concepts and techniques are generally known. Variation in configuration, types of material and dimensions including thickness of the material, for example in order to meet certain technical requirements should also be clear to those skilled in the arts.

Further embodiment in the present invention preferably has gaps in between metal layers at each anchor pad (102), although not shown specifically in Figure 2. Reasons of adding gaps in between metals in each metal layer at the anchor pad (102) is to provide a unique path for the bottom layer, metal 1 (203) connected to the uppermost layer, metal 2 (205) as it is necessary that the force feedback signal to be fed to each anchor pad (102) through different metal lines from the signal readout where the metal lines are formed as a result of adding gaps in between metals in each metal layer.

Figure 3 illustrates the operational principle for acceleration detection in the form of block diagram (300). With regard to the accelerometer (100) shown in Figure 1 and Figure 2, acceleration causes movement in the proof mass (104) and meanders (103) that such movement temporarily deforms the piezoresistors and generates an electrical

signal thereof. Strength of the electrical signal generated is proportional to the level of deformation or the movement of proof mass (104). Electrical signals are generated upon the detection of movement of the proof mass (104) and meanders (103) through a bridge readout detection circuit (301). The signals are then fed back to a meander control circuit (302) to provide DC biasing on metal lines within the metal layers to keep the proof mass (102) stationary. The amount of DC biasing on respective anchor pad (104) gives both magnitude and direction of acceleration which is readable by the users.

The present disclosure includes as contained in the appended claims, as well as that of the foregoing description. Although this invention has been described in its preferred form with a degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangements of parts may be resorted to without departing from the scope of the invention.

CLAIMS

1. An accelerometer (100) comprising:
   a support (101) fabricated with a centrally located hollow;
   a plurality of anchor pads (102) located on the support surrounding the hollow space;
   a meander (103) extends out from each anchor pad (102) towards the hollow and being suspended within the hollow;
   a proof mass (104) connected to the anchor pads (102) through meanders (103) that the proof mass (104) is displaceable in relative to the anchor pads (102) when subjected to an external force and able to resume its original position once the external force is removed;
   wherein the anchor pads (102), meanders (103) and proof mass are integrally fabricated multilayer construct which includes a plurality of metals and insulator layers arranged in an intermittent fashion with the bottommost layer is the insulator layer followed by a base silicon layer (201) characterized in that piezoresistors (206) are disposed within multilayer construct at the meanders and/or anchor pads and connected to at least one metal layer to generate an electrical signal upon displacement of the proof mass (104) in relative to the anchor pads (102).

2. An accelerometer of claim 1, further comprising a Wheatstone resistor arrangement within the multilayer construct at each of the anchor pads (102) to provide temperature compensation effect.

3. An accelerometer of claim 1 or 2, wherein the meanders (103) are designed at the minimum to provide sensitivity of the accelerometer (100) in all three directions.

4. An accelerometer of claim 1 or 2, wherein the uppermost layer of the construct is a metal layer (205).

5. An accelerometer of claim 1 or 2, wherein the proof mass (104) is round in

shape.

6. An accelerometer of claim 1 or 2, wherein the piezoresistor (206) is positioned on a location within the multilayer construct that a mechanical force is exerted on it upon vertical movement of the proof mass (104).

7. An accelerometer of claim 1 or 2, wherein the piezoresistor (206) is positioned on a location within the multilayer construct that a mechanical force is exerted on it upon lateral movement of the proof mass (104).

8. An accelerometer of claim 1 or 2, wherein the piezoresistor (206) is positioned on a location within the multilayer construct that a mechanical force is exerted on it upon axial movement of the proof mass (104).

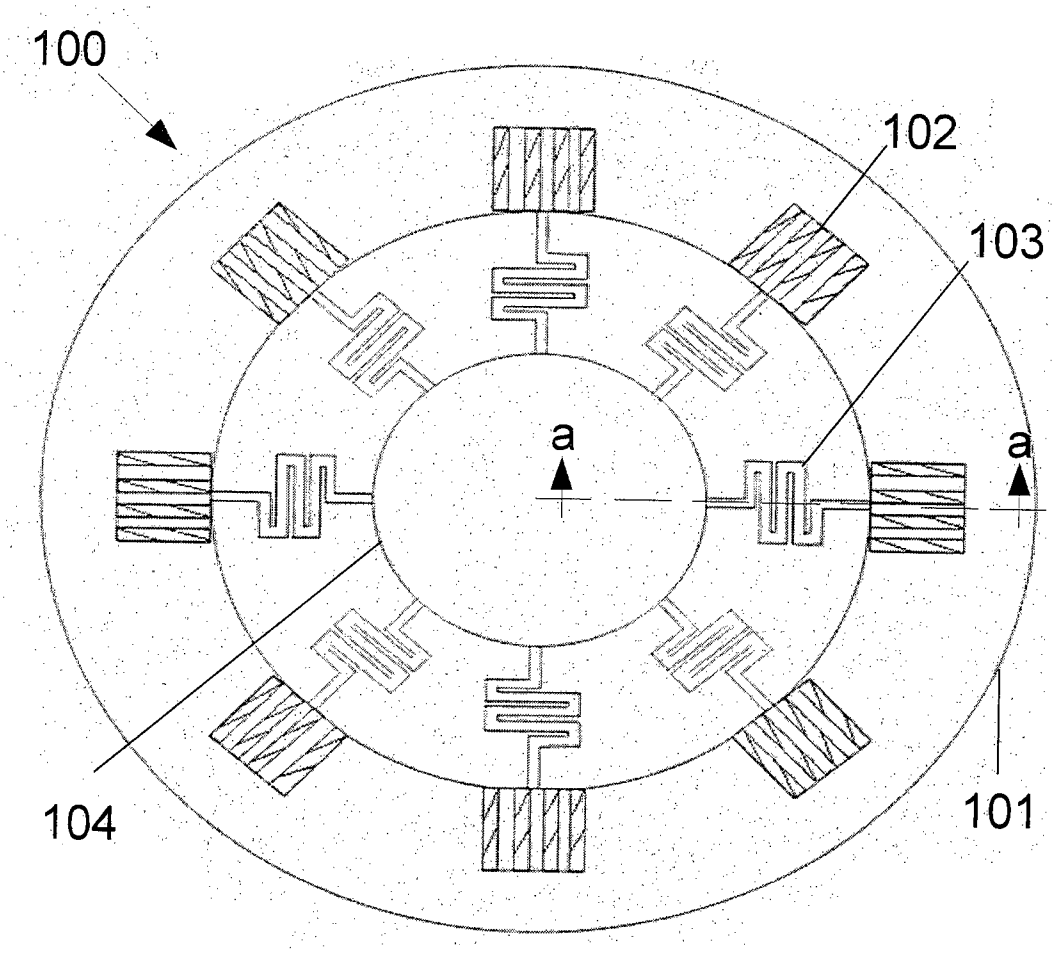


Figure 1

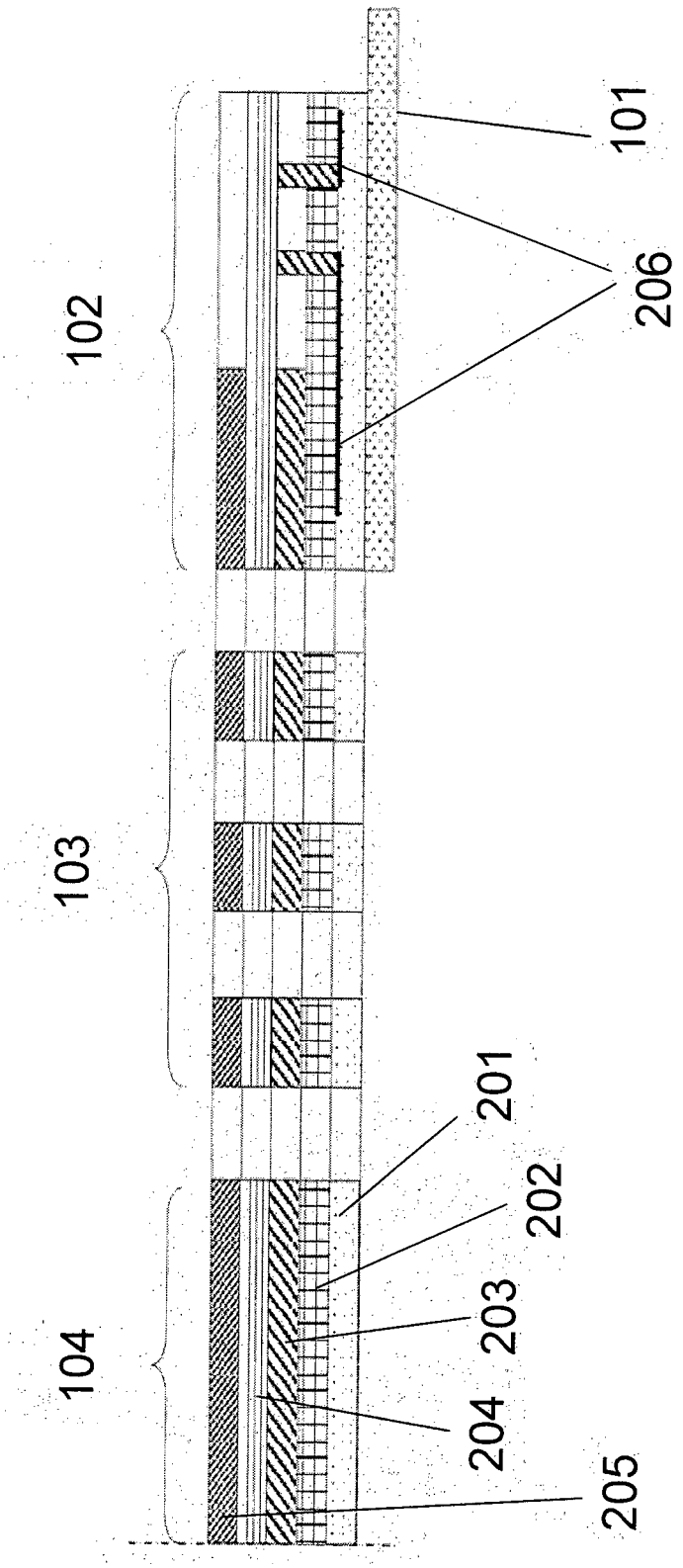


Figure 2

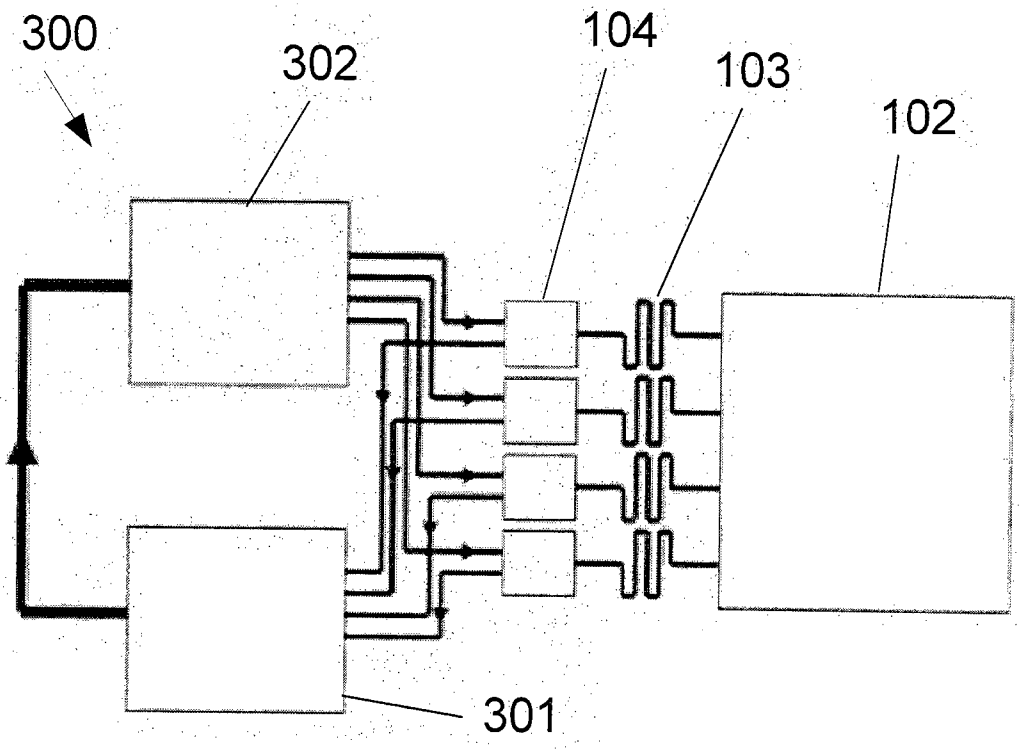


Figure 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/MY2012/000140

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01P15/08 G01P15/12 B81C1/00
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 B81C B81B

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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Y	US 2010/218607 A1 (KAZAMA ATSUSHI [JP] ET AL) 2 September 2010 (2010-09-02) paragraph [0122] - paragraph [0123] paragraph [0126] paragraph [0129] - paragraph [0130] figures 1,3,6	1-4,6-8
Y	WO 2010/145907 A2 (BAOLAB MICROSYSTEMS SL [ES]; TAYYIB SABIR [GB]; LLAMAS MOROTE MARC ANT) 23 December 2010 (2010-12-23) page 13, line 27 - page 14, line 28 page 23, line 16 - line 30 page 28, line 13 - line 23 figures 1,14	1-4,6-8

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

[X] 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

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"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
31 October 2012	12/11/2012

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	Robinson, Mark

INTERNATIONAL SEARCH REPORT

International application No
PCT/MY2012/000140

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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