

Sensing Apparatus, System and Method

FIELD OF THE INVENTION

5 The present invention relates to the field of sensors, namely, sensing apparatus, systems and methods. In particular, the invention relates to sensors where micro machining is used to manufacture such sensors. In one form, the invention relates to a Micro Electro Mechanical System (MEMS) for sensing. It will be convenient to hereinafter describe the invention in relation
10 to the use of an in-plane decoupled micro machined gyroscope however, it should be appreciated that the present invention is not limited to that use, only.

BACKGROUND OF THE INVENTION

15 A gyroscope for measuring angular velocity is an example of a device that may incorporate micro machining or, in particular, MEMS technology. MEMS is a technology embodying the fabrication of mechanical and electrical elements using semiconductor processing. A gyroscope is a device able to measure an angular velocity by measuring the Coriolis force that occurs when
20 an angular velocity is applied to an object moving at a given velocity. The Coriolis force is proportional to the cross product of the moving velocity and the angular velocity due to an externally acting force. In order for the gyroscope to sense the Coriolis force, the gyroscope requires a mass to be subjected to the external force.

25 Generally, in a gyroscope using MEMS technology, three coordinate axes are established. The first two axes, an X-axis and a Y-axis may be parallel to a surface of the substrate and perpendicular to each other. The third axis, a Z-axis, is normal to the X-Y plane.

 The gyroscope (gyro) is an important inertia sensor for the
30 measurement of the angular motion (rotation and angular rates) between a body-fixed axis and an inertially-fixed axis. Microelectromechanical (MEMS) gyroscopes have increasingly attracted attentions due to their potentially low

cost, small size stemming from mass production of semiconductor industry, and potential applications in many relatively new civilian fields, such as the automobile industry for ride stabilization and rollover detection, robotics, consumer electronics, etc. Generally, it could be said that most of the
5 micromachined gyros that are manufactured use a vibratory design with an electrostatic comb drive and capacitance detection.

Corporations such as Analog Devices Inc., BEI Technologies, Robert Bosch GmbH have already shipped MEMS gyros for automobile applications in recent times. Moreover, in more established markets, MEMS gyros by
10 Honeywell, Boeing for military applications. Samsung, Toyota, MilliSensor Systems and Actuators, Inc. are also active in developing micro machined gyros.

The inventor has identified that due to small size, micro machined gyros face many obstacles, one of which is small sense signals. On the other
15 hand, the inventor considers that many errors may be caused by improper design of gyro structure and electronics and these may contribute to signals that may be greater than sense signals that are being transduced by the apparatus. The inventor has further identified that a troublesome type of improper design is that of coupled gyro design, where drive and sense proof
20 mass and suspension systems are the same resulting in significant cross mode coupling effect if the difference in resonant frequencies of the mechanical microstructure in the drive mode and the sense mode is too small. However, it is desirable to minimize the difference in resonant frequencies between the drive and sense axes in order to maximize the sensitivity of the
25 micro machined gyro. In order to resolve such a dilemma for vibratory gyroscopes in one particular instance, popular design so far has been to decouple the drive and sense systems for the drive and sense mechanisms independently.

Any discussion of documents, devices, acts or knowledge in this
30 specification is included to explain the context of the invention. It should not be taken as an admission that any of the material forms a part of the prior art

base or the common general knowledge in the relevant art in Singapore or elsewhere on or before the priority date of the disclosure and claims herein.

An object of the present invention is to provide a useful alternative to the prior art systems

- 5 A further object of the present invention is to alleviate at least one disadvantage associated with the prior art.

SUMMARY OF THE INVENTION

10 In one aspect the present invention provides a micro machined sensing apparatus comprising:

 a microstructure disposed on a substrate having first and second electrode formations, the microstructure comprising a drive structure and a sense structure, wherein;

15 the drive structure is adapted to be movably connected to the substrate and comprises a third electrode formation operatively associated with the first electrode formation for driving the drive structure, and;

20 the sense structure is adapted to be movably suspended from the substrate and comprises a fourth electrode formation operatively associated with the second electrode formation for sensing a resultant motion of the sense structure and such that the fourth electrode formation is disposed externally with respect to the drive structure.

25 In another aspect the present invention provides in a micro machined sensing system comprising a microstructure apparatus as disclosed herein, a method of detecting a sense signal transduced from a sense structure comprising the step of:

 detecting the sense signal at a point external to the drive structure.

 Other aspects and preferred aspects are disclosed in the specification and / or defined in the appended claims, forming a part of the description of the invention.

30 In essence, the present invention stems from the realization that an extension of the sense electrode formations of a sense structure beyond the confines of a drive structure that surrounds the sense structure, may simplify

the fabrication of a micro machined sensing apparatus and further provide reliability of operation.

The present invention has been found to result in a number of advantages, such as retaining the working principle of previously improved in-
5 plane sensing apparatus. Consequently, no additional masks are required in the fabrication process, for example, to allow for bond pads to pick up output sense signals. Accordingly, a simple fabrication process is provided for.

In a preferred embodiment, the drive and sense structures are mechanically de-coupled such that the drive structure is constrained to be
10 driven so as to oscillate in a y-axis extending in a first plane relative to the microstructure and the sense structure is constrained to movement in an x-axis also extending in the first plane and normal to the y-axis under the influence of a Coriolis force generated by the combination of the driving oscillation of the drive structure and angular motion of the microstructure
15 about a z-axis normal to both x and y axes.

The first plane is preferably parallel to the plane of the microstructure. The sense structure may be disposed internally with respect to the drive structure and further comprises laterally extending electrode support structures for supporting the fourth electrode formation externally with respect
20 to the drive structure. Preferably, the drive structure comprises a frame supported by a drive mode flexure interposing the frame and anchor means fixed to the substrate. Further the sense structure may comprise a proof mass suspended by a sense mode flexure interposing the proof mass and the frame. Preferably, each of the electrode formations comprises interdigitated
25 fingers. It is to be noted that the electrode formations may comprise other structures within the knowledge of the skilled person, for example, single strip conductors or parallel plate conductors. However, the most preferable formation is the interdigitated fingers disclosed herein, which is suited to micromachining processes.

30 In a preferred embodiment the apparatus is fabricated as a micro electro mechanical system (MEMS).

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Further disclosure, objects, advantages and aspects of the present application may be better understood by those skilled in the relevant art by reference to the following description of preferred embodiments taken in conjunction with the accompanying drawings, which are given by way of illustration only, and thus are not limitative of the present invention, and in which:

Figure 1 illustrates a schematic of a prior art in-plane micro machined gyroscope.

Figure 2 illustrates a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

In the example of Figure 1 there is an in-plane gyroscope 10 exemplary of the prior art. These gyroscopes are ordinarily used to measure rotation about an axis perpendicular to the surface of the substrate. However, it should be noted that the present invention may be extended in its application to measure rotation about an axis parallel to the surface of the substrate. Figure 1 illustrates schematically a prior art decoupled in-plane gyroscope 10 the original design of which is that of the present applicant. This design decouples the sense-mode from the drive-mode by nesting a proof mass 1 and its associated springs for mounting (not shown) within the outer frame 2 forming the drive structure and constrains the motion of the proof mass 1 to the x-axis, as indicated. The frame 2 is constrained to move only along the y-axis. This effectively reduces errors coupled into the sense mode structure

from the drive mode structure and allows for independent optimization of the drive and sense mechanical microstructure elements. The microstructure itself may be considered as the frame 2 alone, the frame 2 and its electrode formation 3, the frame 2 and proof mass 1, or the frame 2 and proof mass 1 and the respective electrode formations 3, 4 of each integer. In general, a microstructure as herein disclosed and defined by the appended claims may comprise any structure fabricated by micromachining processes and may accordingly further comprise suspension systems and anchors, for example. Preferably, the designs disclosed herein follow fabrication processes based on that which have been provided by the Cronous foundry in the United States of America. In particular, the surface micromachining processes known as MUMPS (Multi-User MEMS Processes). In a preferred embodiment, the three-layer polysilicon surface micro machining process is the MUMP utilised and may provide for nested electrodes within the frame 2. Bond pads B may also be used to get output signals from nested sense electrodes 4. Large parasitic capacitance may be caused by bond pads B. As with many electronic designs it may be a challenge to accommodate the effects that may be contributed by parasitic capacitance. Moreover, it may be necessary to employ complex driving electronics to suppress or compensate error signals introduced to the apparatus 10.

In accordance with a preferred embodiment of the present invention, reference is now made to Figure 2. Figure 2 shows a schematic view of a preferred form of an electrostatic drive and capacitive sense decoupled in-plane micro machined gyroscope 100. Components appearing in Figure 1 have been given the same reference except where they differ. The microstructure is comprised of the frame 2, which is generally an outer frame to the microstructure, and the proof mass 1, disposed within the bounds of the frame structure 2. As with the structure of Figure 1 the microstructure may take a number of forms. The outer frame 2 is supported by the folded-beam drive mode flexure 5 which serves to connect the outer frame 2 in a movable fashion to the fixed anchors 6 of the substrate S. The drive flexure 5 is disposed interposing the frame 2 and the fixed anchor 6. The proof mass 1 is

suspended by the sense mode flexure 7 to the outer frame 2. Interdigitated fingers 8 on the two shown sides of the outer frame 2 and the rigid substrate S form the drive electrodes to drive the microstructure to vibrate in the direction of the y-axis as shown in figure 2. This is the drive mode. Another
5 set of interdigitated fingers 9a, 9b is shown extending from the proof mass 1 by support structures 11 to the external region of the frame 2. The proof mass 1 and the rigid substrate S comprise the sense electrodes 9a and 9b to detect any movement in the X-axis direction. This is the sense mode. When
10 there is a rotation of the gyroscope 100 about the Z-axis, the combination of rotation and oscillation in the Y-axis generates a Coriolis force which induces the proof mass 1 to move in the X-axis. The Coriolis force or acceleration is then detected by the change in separation between the movable fingers 9a attached to the proof mass 1 at its lateral extremities 11 as shown, and the fixed fingers 9b of the sense electrodes situated externally of the frame 2. It is
15 to be noted that in the embodiment of figure 2, there is no need for bond pads to facilitate extraction of a detected signal which would otherwise have been required if the geometry of the microstructure was that of figure 1. As with the apparatus 10 shown in figure 1, the design of figure 2 has the sense mode decoupled from the drive mode by nesting the proof mass 1 per se, and its
20 associated spring mountings (not shown), within the confining structure of the outer frame 2 and constraining the movement of the proof mass 1 to the X-axis. Correspondingly, the outer frame 2 is constrained to move only along the Y-axis. In this way, mechanical cross talk is effectively eliminated. This design also allows for independent optimization of the drive and sense
25 mechanical microstructure elements.

While this invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification(s). This application is intended to cover any variations, uses or adaptations of the invention following in general, the principles of the invention
30 and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth.

As the present invention may be embodied in several forms without departing from the spirit of the essential characteristics of the invention, it should be understood that the above described embodiments are not to limit the present invention unless otherwise specified, but rather should be
5 construed broadly within the spirit and scope of the invention as defined in the appended claims. Various modifications and equivalent arrangements are intended to be included within the spirit and scope of the invention and appended claims. Therefore, the specific embodiments are to be understood to be illustrative of the many ways in which the principles of the present
10 invention may be practiced. In the following claims, means-plus-function clauses are intended to cover structures as performing the defined function and not only structural equivalents, but also equivalent structures. For example, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas
15 a screw employs a helical surface to secure wooden parts together, in the environment of fastening wooden parts, a nail and a screw are equivalent structures.

“Comprises/comprising” when used in this specification is taken to specify the presence of stated features, integers, steps or components but
20 does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.”

CLAIMS

1. A micro machined sensing apparatus comprising:
a microstructure disposed on a substrate having first and second electrode formations, the microstructure comprising a drive structure and a
5 sense structure, wherein;
the drive structure is adapted to be movably connected to the substrate and comprises a third electrode formation operatively associated with the first electrode formation for driving the drive structure, and;
the sense structure is adapted to be movably suspended from the
10 substrate and comprises a fourth electrode formation operatively associated with the second electrode formation for sensing a resultant motion of the sense structure and such that the fourth electrode formation is disposed externally with respect to the drive structure.
- 15 2. A sensing apparatus as claimed in claim 1 wherein the drive and sense structures are mechanically de-coupled such that the drive structure is constrained to be driven so as to oscillate in a y-axis extending in a first plane relative to the microstructure and the sense structure is constrained to movement in an x-axis also extending in the first plane and normal to the y-
20 axis under the influence of a Coriolis force generated by the combination of the driving oscillation of the drive structure and angular motion of the microstructure about a z-axis normal to both x and y axes.
3. A sensing apparatus as claimed in claim 1 or 2 wherein the first
25 plane is parallel to the plane of the microstructure.
4. A sensing apparatus as claimed in any one of claims 1 to 4 wherein the sense structure is disposed internally with respect to the drive structure and further comprises laterally extending electrode support
30 structures for supporting the fourth electrode formation externally with respect to the drive structure.

5. A sensing apparatus as claimed in any one of claims 1 to 4 wherein the drive structure comprises a frame supported by a drive mode flexure interposing the frame and anchor means fixed to the substrate.

5 6. A sensing apparatus as claimed in claim 5 wherein the sense structure comprises a proof mass suspended by a sense mode flexure interposing the proof mass and the frame.

7. A sensing apparatus as claimed in any one of claims 1 to 6
10 wherein each of the electrode formations comprises interdigitated fingers.

8. A sensing apparatus as claimed in any one of claims 1 to 7 wherein the apparatus is fabricated as a micro electro mechanical system (MEMS).

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9. In a micro machined sensing system comprising a microstructure apparatus as claimed in any one of claims 1 to 8, a method of detecting a sense signal transduced from a sense structure comprising the step of:

20 detecting the sense signal at a point external to the drive structure.

10. Apparatus as claimed in claim 1 substantially as herein described.

25 11. A method as claimed in claim 9 substantially as herein described.