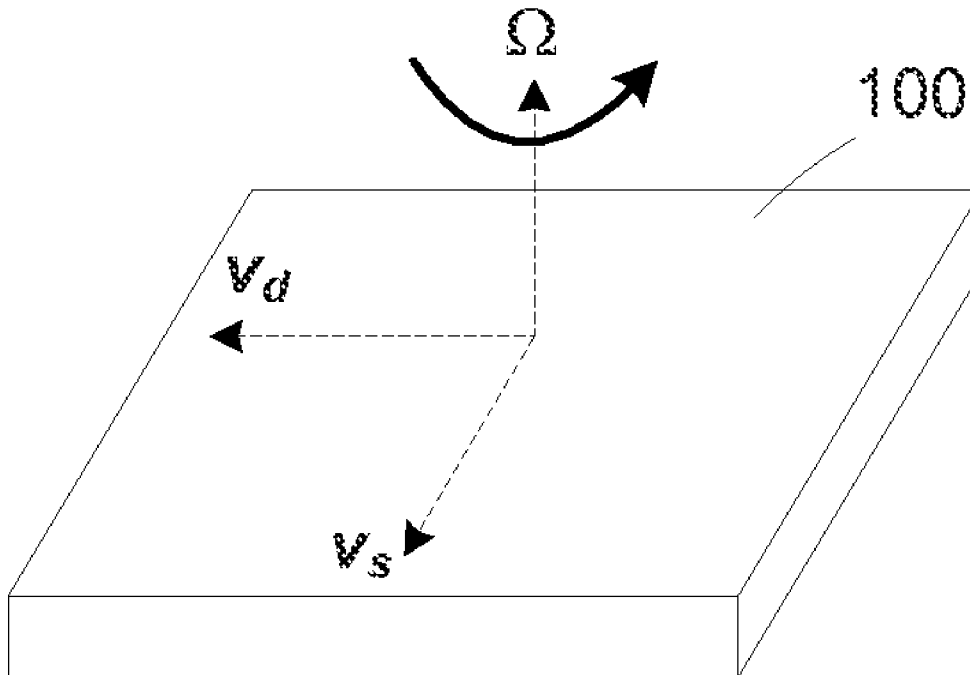




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(19) **United States**(12) **Patent Application Publication**
Zhang et al.(10) **Pub. No.: US 2016/0154020 A1**(43) **Pub. Date: Jun. 2, 2016**(54) **MEMS GYROSCOPE****Publication Classification**(71) Applicant: **InSighTech, LLC**, Los Angeles, CA
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G01R 33/09 (2006.01)(72) Inventors: **Biao Zhang**, Hinsdale, IL (US); **Tao Ju**,
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CPC **G01P 15/105** (2013.01); **G01R 33/093**
(2013.01); **G01R 33/098** (2013.01)(73) Assignee: **INSIGHTECH, LLC**, Los Angeles, CA
(US)(21) Appl. No.: **14/518,712**(57) **ABSTRACT**(22) Filed: **Oct. 20, 2014****Related U.S. Application Data**(63) Continuation of application No. 13/559,625, filed on
Jul. 27, 2012, now abandoned, Continuation of appli-
cation No. 13/854,972, filed on Apr. 2, 2013, now
abandoned.

A MEMS gyroscope is disclosed herein, wherein the MEMS gyroscope comprised a magnetic sensing mechanism and a magnetic source that is formed at the proof-mass, wherein the magnetic sensing mechanism comprises an integrated pickup coil of a fluxgate. A magnetic shield is provided in the vicinity of the magnetic source.



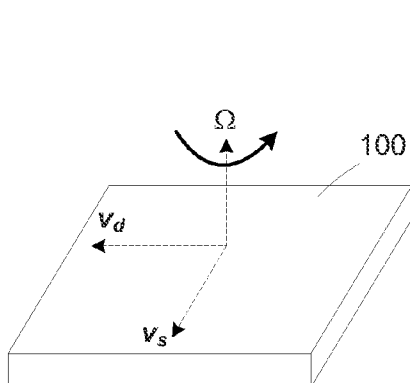


FIG. 1

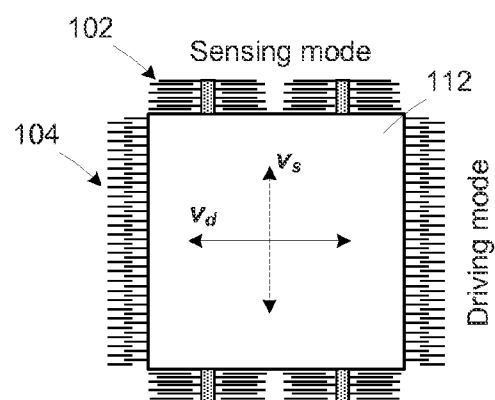


FIG. 2 (Prior art)

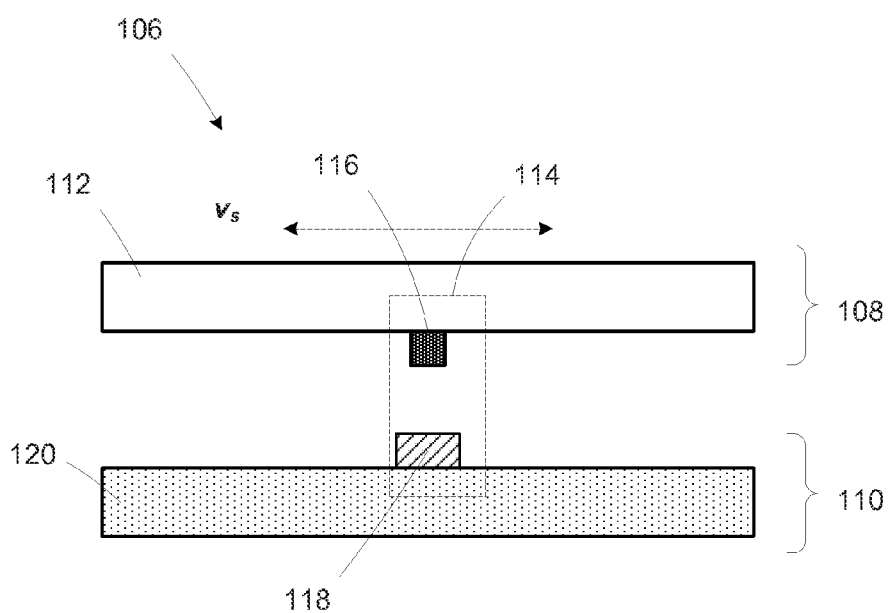


FIG. 3

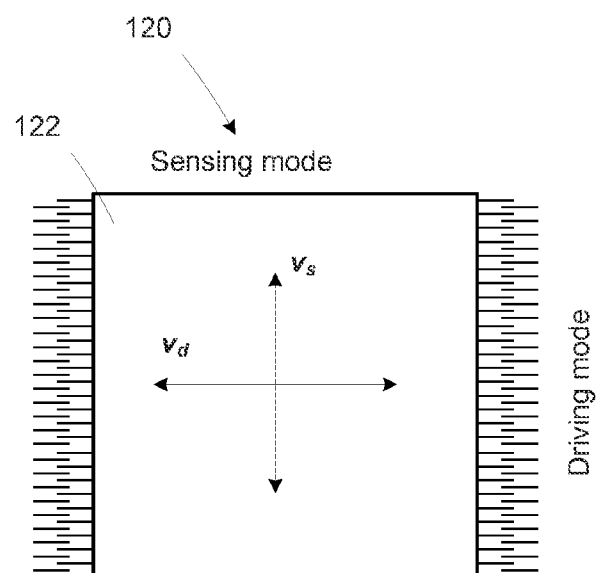


FIG. 4

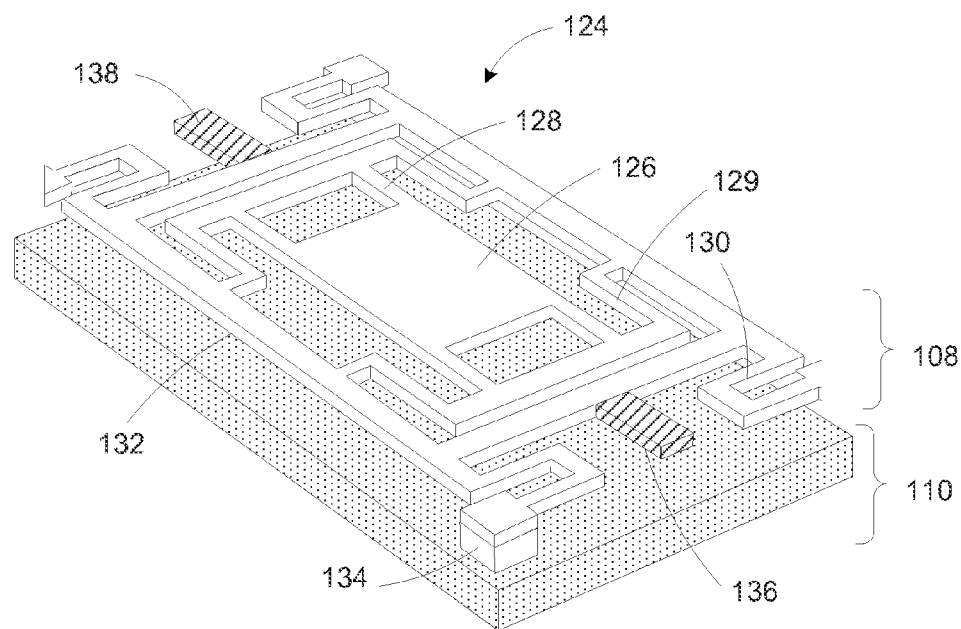


FIG. 5

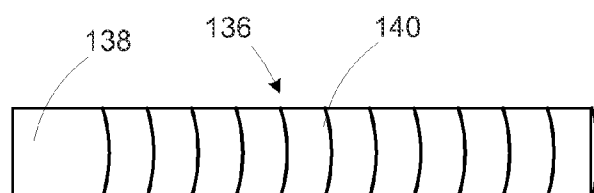


FIG. 6

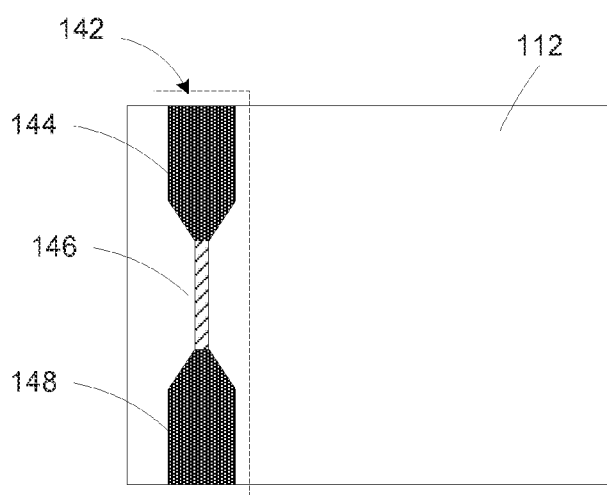


FIG. 7

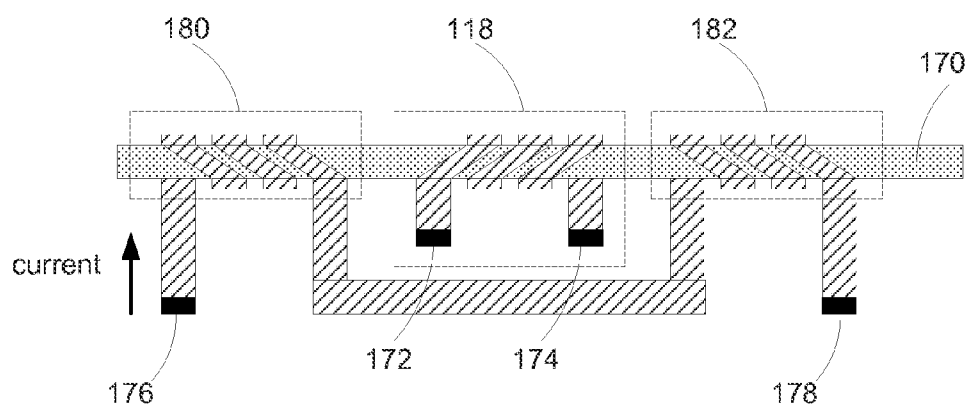


FIG. 8

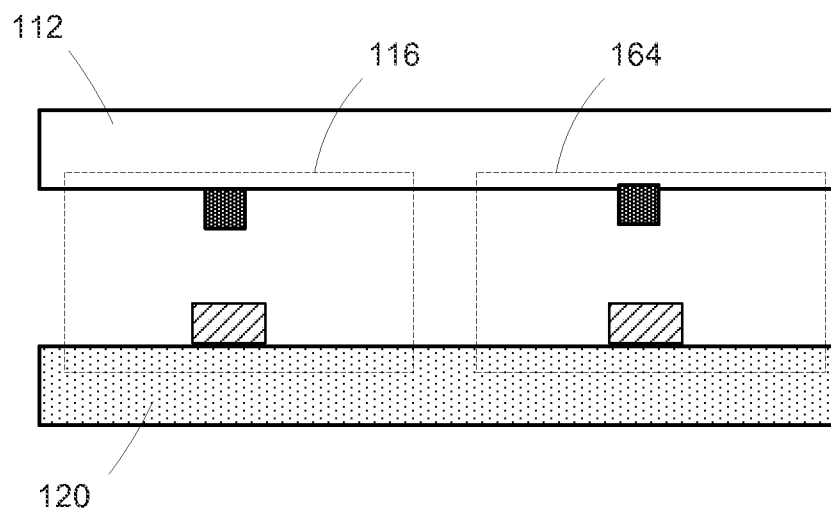


FIG. 9

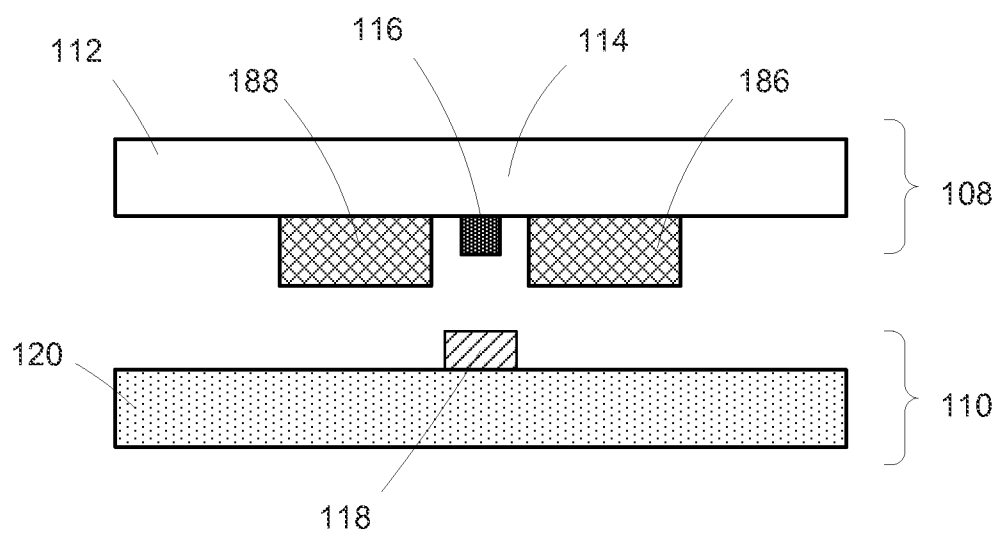


FIG. 10

MEMS GYROSCOPE

CROSS-REFERENCE

[0001] This US utility patent application claims priority from co-pending US utility patent application “A HYBRID MEMS DEVICE,” Ser. No. 13/559,625 filed Jul. 27, 2012, which claims priority from US provisional patent application “A HYBRID MEMS DEVICE,” filed May 31, 2012, Ser. No. 61/653,408 to Biao Zhang and Tao Ju. This US utility patent application also claims priority from co-pending US utility patent application “A MEMS DEVICE,” Ser. No. 13/854,972 filed Apr. 2, 2013 to the same inventor of this US utility patent application, the subject matter of each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD OF THE DISCLOSURE

[0002] The technical field of the examples to be disclosed in the following sections is related generally to the art of operation of microstructures, and, more particularly, to operation of MEMS devices comprising MEMS magnetic sensing structures.

BACKGROUND OF THE DISCLOSURE

[0003] Microstructures, such as microelectromechanical (hereafter MEMS) devices (e.g. accelerometers, DC relay and RF switches, optical cross connects and optical switches, microlenses, reflectors and beam splitters, filters, oscillators and antenna system components, variable capacitors and inductors, switched banks of filters, resonant comb-drives and resonant beams, and micromirror arrays for direct view and projection displays) have many applications in basic signal transduction. For example, a MEMS gyroscope measures angular rate.

[0004] A gyroscope (hereafter “gyro” or “gyroscope”) is based on the Coriolis effect as diagrammatically illustrated in FIG. 1. Proof-mass 100 is moving with velocity V_d . Under external angular velocity Ω , the Coriolis effect causes movement of the proof-mass (100) with velocity V_s . With fixed V_d , the external angular velocity can be measured from V_s . A typical example based on the theory shown in FIG. 1 is capacitive MEMS gyroscope, as diagrammatically illustrated in FIG. 2.

[0005] The MEMS gyro is a typical capacitive MEMS gyro, which has been widely studied. Regardless of various structural variations, the capacitive MEMS gyro in FIG. 2 includes the very basic theory based on which all other variations are built. In this typical structure, capacitive MEMS gyro 102 is comprised of proof-mass 100, driving mode 104, and sensing mode 102. The driving mode (104) causes the proof-mass (100) to move in a predefined direction, and such movement is often in a form of resonance vibration. Under external angular rotation, the proof-mass (100) also moves along the V_s direction with velocity V_s . Such movement of V_s is detected by the capacitor structure of the sensing mode (102). Both of the driving and sensing modes use capacitive structures, whereas the capacitive structure of the driving mode changes the overlaps of the capacitors, and the capacitive structure of the sensing mode changes the gaps of the capacitors.

[0006] Current capacitive MEMS gyros, however, are hard to achieve submicro-g/rHz because the capacitance between sensing electrodes decreases with the miniaturization of the movable structure of the sensing element and the impact of

the stray and parasitic capacitance increase at the same time, even with large and high aspect ratio proof-masses.

[0007] Therefore, what is desired is a MEMS device capable of sensing angular velocities and methods of operating the same.

SUMMARY OF THE DISCLOSURE

[0008] In view of the foregoing, a MEMS gyroscope is disclosed herein, wherein the gyroscope comprises: a first substrate, comprising: a movable portion that is movable in response to an external angular velocity; a magnetic source for generating magnetic field; and a magnetic shield in the vicinity of the magnetic source; a second substrate having a magnetic sensor for detecting the magnetic field from said magnetic source, wherein the magnetic sensor is a pickup coil of a fluxgate.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. 1 diagrammatically illustrates the Coriolis effect in a MEMS structure;

[0010] FIG. 2 is a top view of a typical existing capacitive MEMS gyroscope having a driving mode and a sensing mode, wherein both of the driving and sensing mode utilize capacitance structures;

[0011] FIG. 3 illustrates an exemplary MEMS gyroscope having a magnetic sensing mechanism;

[0012] FIG. 4 illustrates a top view of a portion of an exemplary implementation of the MEMS gyroscope illustrated in FIG. 3, wherein the MEMS gyroscope illustrated in FIG. 4 having a capacitive driving mode and a magnetic sensing mechanism;

[0013] FIG. 5 illustrates a perspective view of a portion of another exemplary implementation of the MEMS gyroscope illustrated in FIG. 3, wherein the MEMS gyroscope illustrated in FIG. 5 having a magnetic driving mechanism for the driving mode and a magnetic sensing mechanism for the sensing mode

[0014] FIG. 6 illustrates an exemplary magnetic driving mechanism of the MEMS gyroscope in FIG. 5;

[0015] FIG. 7 illustrates an exemplary magnetic source of the MEMS gyroscope illustrated in FIG. 3;

[0016] FIG. 8 illustrates an exemplary magnetic sensing mechanism that can be used in the MEMS gyroscope illustrated in FIG. 3;

[0017] FIG. 9 illustrates an exemplary MEMS gyroscope having multiple magnetic sensing mechanisms; and

[0018] FIG. 10 illustrates another exemplary MEMS gyroscope comprising a magnetic field shield for enhancing measurements of the magnetic signal.

DETAILED DESCRIPTION OF SELECTED EXAMPLES

[0019] Disclosed herein is a MEMS gyroscope for sensing an angular velocity, wherein the MEMS gyroscope utilizes a magnetic sensing mechanism. It will be appreciated by those skilled in the art that the following discussion is for demonstration purposes, and should not be interpreted as a limitation. Many other variations within the scope of the following disclosure are also applicable. For example, the MEMS gyroscope and the method disclosed in the following are applicable for use in accelerometers.

[0020] Referring to FIG. 3, an exemplary MEMS gyroscope is illustrated herein. In this example, MEMS gyroscope

106 comprises magnetic sensing mechanism **114** for sensing the target angular velocity through the measurement of proof-mass **112**. Specifically, MEMS gyroscope **106** comprises mass-substrate **108** and sensor substrate **110**. Mass-substrate **108** comprises proof-mass **112** that is capable of responding to an angular velocity. The two substrates (**108** and **110**) are spaced apart, for example, by a pillar (not shown herein for simplicity) such that at least the proof-mass (**112**) is movable in response to an angular velocity under the Coriolis effect. The movement of the proof-mass (**112**) and thus the target angular velocity can be measured by magnetic sensing mechanism **114**.

[0021] The magnetic sensing mechanism (**114**) in this example comprises a magnetic source **116** and magnetic sensor **118**. The magnetic source (**116**) generates a magnetic field, and the magnetic sensor (**118**) detects the magnetic field and/or the magnetic field variations that is generated by the magnetic source (**116**). In the example illustrated herein in FIG. 3, the magnetic source is placed on/in the proof-mass (**112**) and moves with the proof-mass (**112**). The magnetic sensor (**118**) is placed on/in the sensor substrate (**120**) and non-movable relative to the moving proof-mass (**112**) and the magnetic source (**116**). With this configuration, the movement of the proof-mass (**112**) can be measured from the measurement of the magnetic field from the magnetic source (**116**).

[0022] Other than placing the magnetic source on/in the movable proof-mass (**112**), the magnetic source (**116**) can be placed on/in the sensor substrate (**120**); and the magnetic sensor (**118**) can be placed on in the proof-mass (**112**).

[0023] It is also noted that the MEMS gyroscope illustrated in FIG. 3 can also be used as an accelerometer.

[0024] The MEMS gyroscope as discussed above with reference to FIG. 3 can be implemented in many ways, one of which is illustrated in FIG. 4. Referring to FIG. 4, the proof-mass (**120**) is driven by capacitive, such as capacitive comb. The sensing mode, however, is performed using the magnetic sensing mechanism illustrated in FIG. 3. For this reason, capacitive combs can be absent from the proof-mass (**120**).

[0025] Alternatively, the proof-mass can be driven by magnetic force, an example of which is illustrated in FIG. 5. Referring to FIG. 5, the mass substrate (**108**) comprises a movable proof-mass (**126**) that is supported by flexible structures such as flexures **128**, **129**, and **130**. The layout of the flexures enables the proof-mass to move in a plane substantially parallel to the major planes of mass substrate **108**. In particular, the flexures enables the proof-mass to move along the length and the width directions, wherein the length direction can be the driving mode direction and the width direction can be the sensing mode direction of the MEMS gyro device. The proof-mass (**126**) is connected to frame **132** through flexures (**128**, **129**, and **130**). The frame (**132**) is anchored by non-movable structures such as pillar **134**. The mass-substrate (**108**) and sensing substrate **110** are spaced apart by the pillar (**134**). The proof-mass **12** in this example is driving by a magnetic driving mechanism (**136**). Specifically, the proof-mass (**126**) can move (e.g. vibrate) in the driving mode under magnetic force applied by magnetic driving mechanism **136**, which is better illustrated in FIG. 6.

[0026] Referring to FIG. 6, the magnetic driving mechanism **136** comprise a magnet core **138** surrounded by coil **140**. By applying an alternating current through coil **140**, an alternating magnetic field can be generated from the coil **140**. The

alternating magnetic field applies magnetic force to the magnet core **140** so as to move the magnet core. The magnet core thus moves the proof-mass.

[0027] The magnetic source (**114**) of the MEMS gyroscope (**106**) illustrated in FIG. 3 can be implemented in many ways, one of which is illustrated in FIG. 7. Referring to FIG. 7, conductive wire **142** is displaced on/in proof-mass **112**. In one example, conductive wire **142** can be placed on the lower surface of the proof-mass (**112**), wherein the lower surface is facing the magnetic sensors (**118** in FIG. 3) on the sensor substrate (**110**, in FIG. 3). Alternatively, the conductive wire (**142**) can be placed on the top surface of the proof-mass (**112**), i.e. on the opposite side of the proof-mass (**112**) in view of the magnetic sensor (**118**). In another example, the conductive wire (**142**) can be placed inside the proof-mass, e.g. laminated or embedded inside the proof-mass (**112**), which will not be detailed herein as those examples are obvious to those skilled in the art of the related technical field.

[0028] The conductive wire (**142**) can be implemented in many suitable ways, one of which is illustrated in FIG. 7. In this example, the conductive wire (**142**) comprises a center conductive segment **146** and tapered contacts **144** and **148** that extend the central conductive segment to terminals, through the terminals of which current can be driven through the central segment. The conductive wire (**142**) may have other configurations. For example, the contact tapered contacts (**144** and **148**) and the central segment (**146**) maybe U-shaped such that the tapered contacts may be substantially parallel but are substantially perpendicular to the central segment, which is not shown for its obviousness.

[0029] The magnetic sensor (**118**) as shown in FIG. 3 can be a pickup coil of a fluxgate, as illustrated in FIG. 8. Referring to FIG. 8, magnetic sensor **118** is the pickup coil of fluxgate **117**. The fluxgate (**117**) further comprises excitation coils **182** and **180** that are wired around magnetic core **170**. The excitation coils **180** and **182** are wired in the opposite direction to the pickup coil **118** such that the inducted magnetic field from the pickup coil **118** is in the opposite direction to the excitation coils **180** and **182**. The excitation coils are serially connected. Specifically, the output of one excitation coil (e.g. **180**) is connected to the input of the other excitation coil (e.g. **182**). In operation, excitation current can be delivered into the excitation coils through the input **176** of excitation coil **180** and output from the output terminal **178** of excitation coil **182**. The voltage between the terminals **172** and **174** of pickup coil **118** is measured to obtain the magnetic flux change. The motion of the proof-mass can be derived from such magnetic flux change. The fluxgate (**117**) as illustrated in FIG. 8 can be fabricated by using MEMS technology and integrated in the sensor wafer (**110**) as shown in FIG. 3. The derivation of the proof-mass motion from the measured magnetic flux change is not discussed herein because of its obviousness to the person skilled in the art.

[0030] The fluxgate can be implemented in many ways. In one example, the coils can be composed of copper; and the magnetic core can be composed of NiFe and are fabricated on a silicon wafer (i.e. the sensor wafer).

[0031] In some applications, multiple magnetic sensing mechanisms can be provided, an example of which is illustrated in FIG. 10. Referring to FIG. 10, magnetic sensing mechanisms **116** and **164** are provided for detecting the movements of proof-mass **112**. The multiple magnetic sensing mechanisms can be used for detecting the movements of proof-mass **112** in driving mode and sensing mode respec-

tively. Alternatively, the multiple magnetic sensing mechanisms **116** and **164** can be provided for detecting the same modes (e.g. the driving mode and/or the sensing mode).

[0032] In another example, the MEMS gyroscope as discussed above with reference to FIG. **3** can have magnetic field shield so as to increase magnetic field signal measurement, as illustrated in FIG. **10**. Referring to FIG. **10**, magnetic field shields **186** and **188** can be disposed in the vicinity of magnetic field source **116**. The magnetic field shields (**186** and **188**) may be composed of any suitable magnetic materials, such as nickel-iron alloys. The magnetic shields (**186** and **188**) can be formed by magnetic sputtering or other suitable methods, which will not be discussed herein.

[0033] The magnetic field shields (**186** and **188**) can be in any suitable forms. In one example, the magnetic field shields (**186** and **188**) can be formed such that the gap between the shields is larger than the lateral dimension of the underlying magnetic sensor (**118**) so as to provide sufficient space to allow the motion of proof-mass **112**.

[0034] It will be appreciated by those of skilled in the art that a new and useful MEMS gyroscope has been described herein. In view of the many possible embodiments, however, it should be recognized that the embodiments described herein with respect to the drawing figures are meant to be illustrative only and should not be taken as limiting the scope of what is claimed. Those of skill in the art will recognize that the illustrated embodiments can be modified in arrangement and detail. Therefore, the devices and methods as described herein contemplate all such embodiments as may come

within the scope of the following claims and equivalents thereof. In the claims, only elements denoted by the words “means for” are intended to be interpreted as means plus function claims under 35 U.S.C. §112, the sixth paragraph.

We claim:

1. A MEMS gyroscope, comprising:
a first substrate, comprising:
a movable portion that is movable in response to an external angular velocity;
a magnetic source for generating magnetic field; and
a magnetic shield in the vicinity of the magnetic source;
a second substrate having a magnetic sensor for detecting the magnetic field from said magnetic source, wherein the magnetic sensor is a pickup coil of a fluxgate.
2. The MEMS gyroscope of claim **1**, wherein the magnetic source comprises a conducting wire.
3. The MEMS gyroscope of claim **1**, wherein the magnetic source comprises a magnetic nanoparticle.
4. The MEMS gyroscope of claim **2**, wherein the magnetic sensor comprises a giant-magnetic-resistor.
5. The MEMS gyroscope of claim **2**, wherein the magnetic sensors comprises a spin-valve structure.
6. The MEMS gyroscope of claim **2**, wherein the magnetic sensors comprises a tunnel-magnetic-resistor.
7. The MEMS gyroscope of claim **2**, wherein the magnetic sensors comprises a magnetic pickup coil that is an element of a fluxgate.

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